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Inspiratory Muscle Training and Its Potential Benefits on Athlete Performance

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Abstract

Inspiratory Muscle Training (IMT) has garnered significant interest for its potential to enhance athletic performance by targeting the strength and endurance of respiratory muscles. This systematic review examines the impact of IMT on athletes across various disciplines, highlighting both the benefits and limitations observed in the literature. Evidence suggests that IMT can improve respiratory muscle strength, delay fatigue, and increase exercise tolerance, particularly in endurance sports. Positive effects include enhanced time-trial performance in cyclists and improved submaximal performance in rowers. However, the impact on overall aerobic capacity remains inconsistent, with some studies reporting negligible improvements. The review underscores the necessity for further research to refine IMT protocols and better understand its effectiveness across different sports and athlete levels. Overall, while IMT shows promise, its application should be tailored to specific athletic needs and combined with other training methods for optimal results.

Keywords: *Inspiratory Muscle Training, Athletic Performance, Respiratory Muscle Strength, Exercise Tolerance, Endurance Sports.*

INTRODUCTION

Maximizing athlete performance necessitates the continuous review and optimization of training methods. In recent years, Inspiratory Muscle Training (IMT) has garnered attention as a novel training method to enhance athletic performance (Fernández-Lázaro et al., 2021). IMT consists of specific exercises aimed at increasing the strength and endurance of the respiratory muscles, and it is believed to positively impact athletes' performance capacity (Yi, 2023; Hartz et al., 2018). The primary goal of inspiratory muscle training is to strengthen muscles involved in respiration, such as the diaphragm and intercostal muscles. Strengthening and increasing the endurance of these muscles enable athletes to breathe more effectively and efficiently (Ando et al., 2020). Consequently, performance improvements can be observed, particularly in endurance sports. The fundamental principle of IMT is to apply resistance to these muscles to enhance their strength and endurance (Sheel et al., 2001).

Research on IMT has examined its effects on athlete performance and reported positive results. A study by Romer et al. (2002) demonstrated that IMT improved exercise performance and reduced the sensation of fatigue in endurance athletes. These findings suggest that training respiratory muscles can optimize oxygen consumption during exercise, thereby enhancing overall performance. The potential benefits of IMT on athlete performance can be explained through physiological mechanisms. Strengthening the respiratory muscles can elevate the ventilatory threshold, thereby increasing tolerance to higher exercise intensities (Inbar et al., 2000). Additionally, making the respiratory muscles more resistant to fatigue can allow for more efficient distribution of blood flow among the muscles during exercise. This can facilitate the delivery of more oxygen and nutrients to the muscles, aiding in the maintenance of performance (Archiza et al., 2018; Johnson et al., 2007).

The literature on the effects of inspiratory muscle training (IMT) on athletes has yet to reach a full consensus, with some studies reporting significant results while others indicate limited benefits or ineffectiveness. For instance, Romer et al. (2002) found that IMT did not contribute to performance improvement in cyclists. Their

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study indicated that although inspiratory muscle function improved with IMT after 20- and 40-km time trials, this improvement did not directly translate to performance gains.

Conversely, another study reported that IMT improved 25-km cycling time-trial performance and increased anaerobic work capacity. The study observed a 2.66% improvement in time-trial performance in the IMT group, whereas no change was observed in the placebo group (Johnson et al., 2007). These conflicting results underscore the need for more extensive and comprehensive studies to evaluate the effects of IMT. Future research could fill the gaps in the literature by examining the impacts of different IMT modes, intensities, and durations, thereby helping to identify the most effective training strategies for athletes.

In conclusion, inspiratory muscle training stands out as a method with the potential to enhance athlete performance. However, more research is needed to fully understand the effects of IMT and determine in which sports and under what conditions this method is most effective. This mini systematic review aims to comprehensively evaluate the potential benefits of IMT on athlete performance by reviewing current literature.

METHODS

Research Model and Design

In this study, a mini systematic review methodology was employed. We analyzed articles related to inspiratory muscle training (IMT) that specifically focus on athletes, sourced from the Scopus database. Only articles published in journals were included, as they undergo a rigorous scientific review process, ensuring the reliability of the data. Our search identified 554 studies in the Scopus database that included the topic of inspiratory muscle training. Out of these, 51 studies focused on athletes (recreational, amateur, elite). Articles published up to June 15, 2024, were included in our analysis.

Study Criteria

The participants in the included studies were athletes at recreational, amateur, or elite levels. Studies involving healthy or diseased non-athlete participants were excluded. Two researchers reviewed the titles and contents of the studies to determine eligibility based on the inclusion criteria. In cases of disagreement between the researchers, a third researcher was involved in the evaluation (Knoll et al., 2018).

Quality Assessment

The methodological quality assessment was conducted independently by two reviewers using the PEDro scale (HajGhanbari et al., 2013). The PEDro scale consists of 11 items:

Eligibility criteria were specified.

Subjects were randomly allocated to groups.

Allocation was concealed.

The groups were similar at baseline regarding the most important prognostic indicators.

There was blinding of all subjects.

There was blinding of all therapists who administered the therapy.

There was blinding of all assessors who measured at least one key outcome.

Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups.

All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by "intention to treat".

The results of between-group statistical comparisons are reported for at least one key outcome.

The study provides both point measures and measures of variability for at least one key outcome.

Studies with a PEDro score higher than 5 were considered high quality; those with a score of 5 or 4 were considered moderate quality, and studies with a score of 3 or lower were considered low quality (Maher et al., 2013; Bhogal et al., 2005)

Data Extraction

Data were extracted by two independent reviewers using standardized forms that included information on citation details, study objectives, participant descriptions (demographic information, inclusion criteria, and type of sport), intervention descriptions (including group comparisons), outcomes related to sports performance and respiratory muscle performance, measurement units, timing, and the statistical significance of the data. Any disagreements regarding data extraction were discussed and resolved by the two reviewers; if unresolved, a third party was included in the discussion until consensus was reached (HajGhanbari et al., 2013).

RESULTS

Methodological Quality of the Studies

As indicated in Table 1, the PEDro scores of the top 20 IMT studies in the Scopus database, ranked by citations, ranged from 5 to 9. Only one study met the standards of item 6 on the PEDro quality scale, making it the most frequently unmet criterion (24 studies). Other common shortcomings in the studies included: lack of concealed allocation (22 studies), no blinding of all assessors who measured at least one key outcome (22 studies), failure to analyze data for at least one key outcome by "intention to treat" when not all subjects received the allocated treatment or control condition (12 studies), and lack of blinding of all subjects (5 studies). Agreement was achieved between the two reviewers during the quality assessment process.

Tablo 1. PEDro Quality Assessment.

Author, year	1	2	3	4	5	6	7	8	9	10	11	Total	Cite
Volianitis et al., 2001	Yes	1	0	1	1	0	0	1	1	1	1	7	226
Romer et al., 2002	Yes	1	1	1	1	0	1	1	1	1	1	9	139
Romer et al., 2002	Yes	1	1	1	1	0	1	1	1	1	1	9	109
Kilding et al., 2010	Yes	1	0	1	1	0	0	1	1	1	1	7	97
Romer et al., 2002	Yes	1	0	1	1	0	0	1	1	1	1	7	88
Johnson et al., 2007	Yes	1	0	1	1	0	0	1	1	1	1	7	72
Inbar et al., 2000	Yes	1	0	1	1	0	0	1	1	1	1	7	72
Mickleborough et al., 2008	Yes	1	0	1	0	0	0	1	0	1	1	5	71
Williams et al., 2002	Yes	1	0	1	1	0	0	1	0	1	1	6	57
Archiza et al., 2018	Yes	1	1	1	1	1	1	1	0	1	1	9	40
Goosey-Tolfrey et al., 2014	Yes	1	0	1	1	0	0	1	1	1	1	7	39
Tong et al., 2008	Yes	1	0	1	1	0	0	1	0	1	1	6	38
Lomax et al., 2011	Yes	1	0	1	0	0	0	1	0	1	1	5	31
Hartz et al., 2018	Yes	1	0	1	1	0	0	1	0	1	1	6	26
Segizbaeva et al., 2015	Yes	1	0	1	0	0	0	1	0	1	1	5	23
Klusiewicz et al., 2008	Yes	1	0	1	0	0	0	1	0	1	1	5	20
Guy et al., 2014	Yes	1	0	1	1	0	0	1	0	1	1	6	20
M. Abreu et al., 2019	Yes	1	0	1	0	0	0	1	0	1	1	5	19
Okrzymowska et al., 2019	Yes	1	0	1	0	0	0	1	0	1	1	5	12
Turner et al., 2016	Yes	1	0	1	1	0	0	1	0	1	1	6	12

Description of PEDro Categories: 1 = eligibility criteria were specified; 2 = subjects were randomly allocated to groups; 3 = allocation was concealed; 4 = the groups were similar at baseline regarding the most important prognostic indicators; 5 = blinding of all subjects; 6 = blinding of all therapists who administered the therapy; 7 = blinding of all assessors who measured at least 1 key outcome; 8 = measures of 1 key outcome were obtained from .85% of subjects initially allocated to groups; 9 = all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least 1 key outcome was analysed by "intention to treat"; 10 = the results of between-group statistical comparisons are reported for at least 1 key outcome; 11 = the study provides both point measures and measures of variability for at least 1 key outcome.

RELEVANT LITERATURE

Effects of Inspiratory Muscle Training

Inspiratory muscle training (IMT) is a training method aimed at increasing the strength and endurance of the respiratory muscles. Various studies have reported that this method enhances the functionality of respiratory muscles in athletes, but its effects on aerobic capacity and endurance performance are contradictory (Williams et al., 2002; Inbar et al., 2000).

Williams et al. (2002) found that IMT significantly increased the strength and endurance of respiratory muscles. The study observed significant increases in participants' maximal inspiratory pressure (PImax) values and respiratory muscle endurance. PImax is an indicator used to measure the strength of respiratory muscles, with higher PImax values indicating stronger respiratory muscles (Mills et al., 2014). However, these improvements were not translated to VO2max or endurance exercise capacity. VO2max represents the maximum oxygen consumption capacity of the body during exercise and is an important indicator of endurance performance. The study by Williams et al. showed that while IMT enhanced the functionality of respiratory muscles, it had limited effects on overall performance during high-intensity exercises. This finding suggests that although strengthening the respiratory muscles can reduce respiratory muscle fatigue during exercise, it may not be sufficient on its own to improve overall aerobic capacity and endurance performance (Williams et al., 2002).

Inbar et al. (2000) reported that IMT increased the strength and endurance of respiratory muscles in trained endurance athletes, but these improvements had no significant effect on aerobic capacity or arterial oxygen desaturation. Arterial oxygen desaturation refers to the decrease in blood oxygen levels and indicates whether sufficient oxygen is being supplied to the muscles during intense exercise (Harms et al., 2000). This study showed that although IMT improves the performance of respiratory muscles, it did not lead to significant improvements in overall athlete performance. This suggests that strengthening the respiratory muscles may help athletes endure longer by reducing respiratory muscle fatigue during exercise, but it does not directly affect overall aerobic performance.

Another study by Romer et al. (2002) indicated that IMT improved time-trial performance and anaerobic work capacity in cyclists, but had no effect on critical power. Anaerobic work capacity refers to the ability to generate energy during short, high-intensity exercises, and higher anaerobic capacity enhances athletes' ability to sustain higher-intensity exercises. This study suggests that IMT has positive effects on anaerobic performance but is limited in enhancing aerobic capacity.

Fatigue of Respiratory Muscles and Its Impact on Performance

Fatigue of respiratory muscles during exercise can be a performance-limiting factor, especially in endurance sports. Respiratory muscle fatigue can hinder the delivery of adequate oxygen to the muscles during exercise, negatively impacting overall performance (Katayama & Amann, 2012). Johnson et al. (1996) noted that respiratory muscle fatigue could reduce exercise tolerance, possibly due to decreased blood flow to the respiratory muscles. When blood flow to the respiratory muscles is reduced during exercise, their oxygen demand cannot be met, resulting in fatigue. This fatigue becomes more pronounced when respiratory muscles are not sufficiently strong, potentially limiting athletes' performance.

IMT has been implemented to reduce respiratory muscle fatigue and enhance performance, with some studies showing positive results. Boutellier et al. (1992) reported that IMT increased endurance on a bicycle ergometer. This study indicated that strengthening the respiratory muscles through IMT reduced fatigue during exercise, thereby increasing endurance. Participants were able to exercise longer and at higher intensities following IMT. This effect was attributed to the reduction in respiratory muscle fatigue. However, other studies, such as those by Morgan et al. (1987), found that IMT had no significant effect on endurance exercise capacity in moderately trained cyclists. This study observed that while IMT increased the strength of respiratory muscles, these improvements did not translate to endurance performance. It is suggested that in moderately trained cyclists, the respiratory muscles might already be sufficiently strong, and therefore, IMT does not provide additional benefits.

To better understand the impact of reducing respiratory muscle fatigue on performance, it is important to consider other studies. Romer et al. (2002) showed that IMT improved repeated sprint performance and reduced respiratory muscle fatigue. This study highlighted that strengthening the respiratory muscles positively affects performance during high-intensity, repeated exercises. Mills et al. (2013) reported that IMT increased performance in cyclists by reducing respiratory muscle fatigue during exercise. The study noted that IMT delayed fatigue by increasing the oxidative capacity of respiratory muscles, thus improving exercise performance. Participants who underwent IMT felt respiratory muscle fatigue later, allowing them to exercise longer.

Overall, the current literature indicates that IMT is effective in reducing respiratory muscle fatigue and enhancing exercise performance. However, it should be noted that these effects may vary depending on the athletes' training levels and the type of exercise. Using IMT in conjunction with other training methods might be a more effective strategy for optimizing athletes' performance.

Mechanisms of IMT

IMT enhances the performance of respiratory muscles through two primary mechanisms:

Increased Endurance of Respiratory Muscles: IMT can increase the oxidative capacity of respiratory muscles, delaying the onset of metabolic acidosis and reducing lactate accumulation during intense exercise. Increased oxidative capacity allows respiratory muscles to produce energy more efficiently, delaying muscle fatigue. As oxygen consumption increases and lactate accumulation decreases, muscle fatigue is prevented. Through this effect, IMT can contribute to the respiratory muscles working at high performance for longer durations (McConnell & Romer, 2004). Studies have shown that IMT increases the endurance of respiratory muscles, resulting in less fatigue during exercise. Boutellier et al. (1992) reported that IMT increased endurance on a bicycle ergometer, allowing participants to exercise for longer durations due to increased respiratory muscle endurance.

Reduction in Perception of Dyspnea: IMT can reduce the perception of dyspnea (shortness of breath) during respiration. Dyspnea is an uncomfortable sensation of breathing that occurs due to inadequacy or overworking of the respiratory muscles during exercise. By increasing the strength and endurance of respiratory muscles, IMT reduces the strain on these muscles, thereby decreasing the perception of dyspnea (Sheel et al., 2001). A reduction in the perception of dyspnea allows athletes to breathe more comfortably during exercise, enhancing their performance. Romer et al. (2002) demonstrated that IMT improved repeated sprint performance and reduced respiratory muscle fatigue. This study indicated that strengthening the respiratory muscles could have performance-enhancing effects during high-intensity, repeated exercises.

By increasing the performance of respiratory muscles through these two primary mechanisms, IMT allows athletes to maintain high performance for longer durations during exercise and enhance overall endurance. These mechanisms suggest that IMT is an effective method for optimizing athletes' performance.

Impact of IMT on Athlete Performance

Research on the performance-enhancing effects of IMT in endurance athletes presents mixed findings. The effects of IMT on athletes have been evaluated through various physiological mechanisms, such as the strengthening of respiratory muscles, increased endurance, and reduced shortness of breath.

Williams et al. (2002) reported that while IMT increased the strength of respiratory muscles, it did not significantly contribute to endurance performance. The study observed significant increases in participants' maximal inspiratory pressure (PImax) values and respiratory muscle endurance, but these improvements did not translate to VO2max or endurance exercise capacity. VO2max, an indicator of aerobic capacity, measures an individual's maximum oxygen consumption capacity. The study by Williams et al. showed that while IMT enhanced the functionality of respiratory muscles, it had limited effects on overall endurance performance.

In contrast, a study by Volianitis et al. (2001) found that IMT improved submaximal performance and reduced the perception of dyspnea in rowers. Submaximal performance refers to the performance level that an athlete can sustain continuously below their maximum capacity. The study by Volianitis et al. indicated that IMT could increase submaximal performance in rowers by reducing respiratory muscle fatigue. These findings suggest that IMT might have performance-enhancing effects, particularly in submaximal exercises in endurance athletes.

Effects of IMT in Different Sports

Soccer: Guy et al. (2014) showed that IMT improved respiratory functions and overall performance in professional female soccer players. The study reported significant improvements in VO2max values and anaerobic capacity tests. Anaerobic capacity refers to the ability to generate energy during high-intensity exercises, enhancing athletes' ability to sustain short, high-intensity activities.

Swimming: Wells et al. (2005) noted that IMT improved swimming performance and increased the endurance of respiratory muscles in swimmers. The study demonstrated that by increasing the strength of respiratory muscles, IMT improved swimming performance. Strengthening the respiratory muscles allows swimmers to use less energy during respiration, redirecting this energy to other muscle groups.

Cycling: Johnson et al. (2007) reported that IMT improved time-trial performance and anaerobic work capacity in cyclists but had no effect on critical power. Critical power represents the maximum sustainable power output of an athlete. The performance-enhancing effects of IMT in cycling are associated with the strengthening of respiratory muscles and the reduction of their fatigue.

Wheelchair Basketball: Goosey-Tolfrey et al. (2010) investigated the effects of IMT on respiratory functions and repeated sprint performance in wheelchair basketball players. The study showed that IMT significantly increased respiratory muscle strength and maximal expiratory pressure. However, these improvements did not translate to repeated sprint performance. This suggests that while IMT strengthens the respiratory muscles and increases their endurance, it may not be sufficient on its own to enhance overall aerobic capacity and endurance performance.

Elite Rowing: Klusiewicz et al. (2008) demonstrated that IMT improved performance by increasing the strength and endurance of respiratory muscles in elite rowers. The effects of IMT were examined over 11 weeks, showing significant increases in maximal PImax values. This data confirms that the principle of increased inspiratory resistance is effective in methodically increasing the strength of inspiratory muscles in well-trained athletes. Moreover, the muscle strength gained from IMT was maintained even after the termination of IMT, suggesting that IMT enhances the strength of respiratory muscles, thereby improving performance.

Effects of IMT in Various Athletes and Exercise Types

Rugby: Nunes Júnior et al. (2018) reported that IMT improved high-intensity exercise performance in rugby players. The study showed that IMT enhanced the anaerobic capacity and overall performance of rugby players, indicating that the strength and endurance of respiratory muscles directly impact performance in high-intensity sports like rugby.

Skiing: Klusiewicz et al. (2019) demonstrated that IMT improved the physiological responses to exercise in skiers. Significant improvements were observed in exercise performance indicators such as test duration, work output, and peak power, although no significant changes were observed in other respiratory variables such as maximum oxygen consumption (VO2max) and respiratory efficiency. Sports like skiing, which involve high altitudes and cold weather, emphasize the importance of respiratory muscle efficiency, suggesting that IMT could be a potential tool for enhancing performance under challenging environmental conditions.

Athletics: Chang et al. (2021) reported that IMT improved sports performance in 800-meter runners. The study showed that IMT enhanced the strength and endurance of respiratory muscles, allowing runners to perform at higher levels. The research suggests that IMT can enhance performance not only in endurance exercises but also in middle-distance running that requires effective utilization of both aerobic and anaerobic systems.

Elite Athletes: Enright et al. (2000) demonstrated that incremental IMT increased the strength and endurance of respiratory muscles in elite athletes. The study showed that IMT improved the performance of respiratory muscles and overall sports performance in elite athletes.

CONCLUSION

Inspiratory muscle training (IMT) emerges as an effective method with the potential to enhance athlete performance. IMT aims to improve athletes' performance by increasing the strength and endurance of respiratory muscles. The fundamental physiological mechanisms of IMT include increasing the oxidative capacity of respiratory muscles and reducing the perception of dyspnea. These mechanisms allow respiratory muscles to work more efficiently, delaying muscle fatigue during exercise and enhancing athletes' performance.

Studies have shown positive effects of IMT in various sports and athlete levels, including soccer, swimming, cycling, wheelchair basketball, rowing, rugby, skiing, and athletics. However, some conflicting findings in the literature on the effects of IMT on athlete performance suggest the need for more comprehensive studies to evaluate the effects of IMT.

In conclusion, IMT is a method with the potential to enhance athlete performance, effectively increasing the strength and endurance of respiratory muscles. However, more research is needed to fully understand the effects of IMT on overall endurance performance. It is suggested that IMT be used in conjunction with other training methods to optimize athletes' performance. This mini systematic review provides a significant contribution to the existing literature by evaluating the potential benefits of IMT on athlete performance.

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