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ABSTRACT

Since traditional sport-specific training or exercise programs do not create enough stimulus to improve the function of the respiratory muscles, the rationale to introduce respiratory muscle training (RMT) emerged. RMT is associated with improved endurance performance and pulmonary function, and it reduced respiratory fatigue, perceived exertion, or breathlessness. The purpose of this article is to provide coaches with tools to select the appropriate form of RMT in the context of the athletes' needs, using appropriate methods, techniques, devices, and testing protocols. The video abstract is presented in Supplemental Digital Content as SDC 1.

INTRODUCTION

The evidence of the importance of respiratory muscle function in endurance performance emerged during the past decades (10,67,83). However, it appears that the traditional sport-specific training programs do not create enough stimulus to significantly improve the function of the respiratory muscles (12,18), providing the rationale to introduce respiratory muscle training (RMT) The research findings from 50 years ago already indicated that it was possible to enhance the strength and endurance of respiratory muscles in healthy individuals through targeted training (43). However, the effectiveness of RMT has been much debated for decades (50,60). The long-term lack of scientific consensus on RMT may be attributed to the methodological differences in identifying small, worthwhile performance changes between sports and clinical settings. Although <1% differences in athletic performance are decisive for winning medals (14), clinical measures of performance are considered worthwhile based on changes larger than 10% (63).

Moreover, it was suggested that methodological factors such as inappropriate training prescriptions, improper testing measures, lack of sham–control groups, insufficient control over RMT implementation, and small sample sizes have critically influenced the results obtained from RMT studies (52). Finally, identifying respiratory muscle fatigue was elusive during cardiopulmonary exercise testing. Popular laboratory tests usually do not elicit significant fatigue in respiratory muscles due to their limited length and insufficient duration of high-intensity effort (68), whereas longer and more specific time trials are less widespread. Therefore, many scientists did not investigate respiratory muscle function in the context of performance limitation. However, state-of-the-art literature reviews concluded that RMT improves performance during intermittent incremental tests, constant load tests, and time trials,

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improves respiratory muscle endurance and strength, reduces perceived exertion or breathlessness, and reduces respiratory fatigue during exercise in hypoxia (3,25,32). The data indicate an ergogenic effect of RMT in endurance performance, among other benefits (31). Despite this, RMT appears unpopular among strength and conditioning coaches, and it is often not included in the research analyzing their work (21,85). The purpose of this applied article is to provide coaches with tools to select the appropriate form of RMT in the context of the athlete's performance goals.

PHYSIOLOGICAL BACKGROUND

In healthy and untrained young adults, there is compelling evidence suggesting that the respiratory system, including the airways, pulmonary vasculature, lung parenchyma, respiratory muscles, and neural ventilatory control system, is designed remarkably well to deliver an efficient and stable response to exercise, regardless of the intensity and duration. Surprisingly, the respiratory muscles of highly trained endurance athletes stand out as a prominent example of being "underbuilt" (16).

The respiratory muscles can be categorized into 3 groups: the diaphragm, the rib cage muscles, and the abdominal muscles. Inspiratory muscles are the muscles responsible for the expansion of the lungs during inhalation, facilitating air intake into the respiratory system. The primary inspiratory muscle is the diaphragm. Expiratory muscles contract during exhalation, helping to compress the abdominal contents and increase pressure in the thoracic cavity, which facilitates the expulsion of air from the lungs. The main expiratory muscles are the abdominal muscles, including the rectus abdominis, external obliques, and internal obliques. In contrast to rest, the expiratory muscles actively participate in breathing during exercise. The rib cage muscles, including the intercostals, parasternals, scalene, and neck muscles, play a role in inspiration and expiration (2). During exercise, the elevated requirements for ventilation result in an augmented demand for the respiratory muscles.

When exercising at $\dot{V}O_2$max, respiratory muscles require 15–20% of total oxygen consumption and blood flow in highly trained endurance athletes and only 8–10% in untrained subjects (1,27,48). Therefore, exercise-induced load on respiratory muscles may be greater in the athletic population. These variations could be attributed to differences in other physiological systems, which may restrict exercise capacity in untrained individuals before placing a significant load on the respiratory muscles. Moreover, near-infrared spectroscopy monitoring provided evidence indicating that oxygen transport to the respiratory muscles fell short of meeting metabolic requirements, resulting in respiratory muscle deoxygenation during high-intensity exercise (42). This suggests that the metabolic demand exceeds the capacity of the respiratory muscles during intense exercise in trained athletes, which leads to significant respiratory muscle fatigue (79). Typical scenarios that cause performance-limiting respiratory muscle fatigue include long-duration endurance efforts, exercise with intensity exceeding 85% of $\dot{V}O_2$max or shorter maximum exercise bouts, for example, a 200-meter swimming race or a 6-minute time trial in rowers (35,45,83).

The performance benefits associated with RMT stem from enhanced mechanical efficiency and fatigue resistance in respiratory muscles. This, in turn, helps to delay or reduce the impact of the sympathetically mediated respiratory metaboreflex (31). The practical implications of the respiratory metaboreflex are based on the discovery that increased fatigue and the buildup of metabolites in respiratory muscles cause a decrease in blood flow to skeletal muscles and a redirection of blood flow to the respiratory muscles (71). Consequently, vasoconstriction in the active limbs during exercise results in heightened local fatigue and performance limitations (17). Because of the improved RMT status, RMT is expected to limit the negative influence of exercise-induced fatigue, thereby mitigating its systemic effects.

METHODS AND EQUIPMENT

There is a great variety of RMT methods and devices. The 3 following methods have been proven to provide substantial benefits in sports settings: inspiratory pressure threshold loading (IPTL), tapered flow resistive loading (TFRL), and voluntary isocapnic hyperpnea (VIH) (32). TFRL and IPTL are associated with improving respiratory muscle strength, whereas VIH is more associated with improving respiratory muscle endurance (31,52).

IPTL and TFRL use breathing trainers that provide resistance during inspiration and allow for expiration without additional resistance (80). In most IPTL protocols, individuals are instructed to perform full vital capacity inspirations from the residual volume, against a resistance corresponding to 50–80% of maximal inspiratory pressure. Differences between IPTL and TFRL relate to the characteristics of the resistance. During IPTL, the training load is constant and evolves from lower pressure and high airflow at lower lung volumes into higher pressure and low airflow stimulus at high lung volumes. Because of the pressure–flow relationship of the respiratory muscles (in consequence, the inspiration with "full lungs" requires more muscle strength than the inspiration with "empty lungs"); at some point, the resistance exceeds the capacity to generate inspiratory pressure.

Consequently, further shortening of respiratory muscles is not possible, and the ability to achieve full volume expansion during inspiration is limited (41). During TFRL, the external resistance is gradually reduced during inspiration, which provides intermediate pressure and intermediate flow over the complete range of a full vital capacity inspiration (41). VIH uses devices with partial rebreathing circuits and requires paced, vigorous ventilation with an inspiratory focus for up to 40 minutes. No or little external resistance is provided, and the training stimulus is based on intentional hyperventilation with intensity from 60 to 90% of maximal

Figure 1. IPTL training with POWERbreathe Plus Medium device.

voluntary ventilation (49). Figure 1 presents ITPL training, and Figure 2 presents VIH training.

Products such as POWERbreathe, Threshold IMT, and SpiroTiger (recently released as Idiag) are the most commonly used in sports science and physiotherapy research. They have been on the market for more than 2 decades and are regularly used during RMT, as well as world-class athletes. More recently, alternatives have appeared on the market, among which Airofit and Isocapnic Breath Way Better became widely used. The list of the products mentioned above along with individual characteristics is presented in Table 1.

TRAINING PROTOCOLS

Recommended RMT protocols vary depending on the population, method, and purpose of training. Each device described in Table 1 allows the creation of different training protocols based on variables known from strength and conditioning programming. RMT can be used independently of specific training sessions or complement them. Additional breathing exercises are often used between efforts or after completing a training set. Both RMT sessions and discipline-specific training protocols that combine RMT with sport-specific work have been reported to be effective (49). Some solutions are based on the intuition and experience of coaches, whereas others are based on peer-reviewed research and have been thoroughly investigated in terms of effectiveness. An example of the latter is the POWERbreathe Protocol, which involves 30 quick and forceful ITPL or TFRL maneuvers from functional residual capacity, twice daily for 5–6 days per week. Scientifically based VIH training is usually based on 3–5 sessions per week, from 15 to 40 minutes each. Protocols from published studies presenting a significant positive influence of RMT on performance in endurance sports are summarized in Table 2.

The function and structure of respiratory muscles are similar to other striated muscles, both cardiac and skeletal (75). It would be reasonable to expect that training protocols derived from sports training will also be effective in RMT. General training principles, such as progressive overload, periodization, training specificity, and reversibility (66), must be considered. To apply the progressive overload, frequency, intensity, or duration must be gradually increased to provide the necessary adaptation stimulus. The timing of adaptation development related to RMT is not comprehensively described, but the available literature suggests that the protocols above lead to a plateau in strength and power or endurance improvement between 6 and 9 weeks of training (66). After this period, the stimulus should be changed and a greater or different training load should be applied. Therefore, the periodization of RMT might include changing the training method, for example, from VIH to IPTL, every 8 weeks or alternating periods based on a lower number of repetitions and high resistance with periods based

Figure 2. VIH training with Isocapnic BWB device.

Table 1
Individual characteristics of RMT devices, prices as of January 06, 2024

Training equipment	Method	Inspiratory resistance range cmH2O at (1 L/s)	Expiratory resistance range cmH2O at (1 L/s)	Price (USD)	Electronic device/ mechanical device
POWERbreathe K4	TFRL	5–200	Not available	675	E
POWERbreathe Plus Medium	IPTL	23–186	Not available	65	M
Philips Threshold IMT	IPTL	9–41	Not available	26	M
Airofit PRO 2.0	IPTL/other	10–250	10–200	349	E
Airofit active	IPTL/other	20–140	30–200	79	M
SpiroTiger Idiag P100	VIH	Voluntary	Voluntary	1,639	E
SpiroTiger GO	VIH	Voluntary	Voluntary	985	E
BreathWayBetter	VIH	Voluntary	Voluntary	149	M

E = electronic; IPTL = inspiratory pressure threshold loading; M = mechanical; TFRL = tapered flow resistive loading; VIH = voluntary isocapnic hyperpnoea.

on a higher number of repetitions and lower resistance. The specificity principle at the micro level is based on adjusting the stimulus to the desired training response. At the macro level, it requires awareness of the sport-specific needs. RMT may be strength or endurance oriented and may be performed at different times of the day, at different temperatures, with additional weights such as a backpack, with resistance bands to limit chest movements, in a sport-specific body position, or with sport-specific equipment.

For example, track cyclists may perform RMT on the bike in individually adjusted time trial positions, speed skaters may use low skating positions and 10–15°C temperature as required in competition ice rinks, rowers may employ challenging crouch positions as part of the progressive overload, ski mountaineers may perform RMT with loaded backpacks, and the like. The respiratory muscles follow a similar pattern of force-generation ability decline during a detraining period, as do limb muscles (61). Therefore, 2–4-week periods without RMT should not result in significant drops in functional gains (56). A significant loss of RMT gains was observed 8–12 weeks after the cessation of an RMT training program. Hence, much of the detraining

Table 2
Summary of protocols resulting in a significant, positive influence of RMT on performance in endurance sports.

Reference	Sport	RMT method	RMT protocol	Intervention length in wk
Volianitis et al., 2001	Rowing	ITPL	30 inspirations, twice a day, 7 d a week	4–11
Holm et al., 2004 Sonetti et al., 2001 McMahon et al., 2002	Cycling	VIH	30 min per session, 5 sessions per week	4–6
Johnson et al., 2007 Romer et al., 2002	Cycling	ITPL	30 inspirations, twice a day, 7 d a week	6
Kilding et al., 2010	Swimming	ITPL	30 inspirations, twice a day, 7 d a week	6
Okrzymowska et al., 2019	Swimming	ITPL	30 inspirations, twice a day, 5 d a week	8
Wylegala et al., 2007	Swimming	ITPL	30 min (60 inspirations), 5 d a week	4
Leddy et al., 2007	Running	VIH	30 min per session, 5 sessions per week	4
Mickleborough et al., 2010	Running	TFRL	36 inspirations, 3 sessions per week	6

IPTL = inspiratory pressure threshold loading; RMT = respiratory muscle training; TFRL = tapered flow resistive loading; VIH = voluntary isocapnic hyperpnea.

takes place between week 4 and week 8 without RMT. However, athletes still demonstrate positive adaptation many weeks after discontinuing RMT, with improved pulmonary parameters compared with their pre-RMT values (38,66). Notably, excessive overloading of the respiratory muscles can lead to overreaching or overtraining, affecting either specific muscles or the body as a whole.

THE RATIONALE OF RESPIRATORY MUSCLE TRAINING IN VARIOUS APPLICATIONS

The benefits above of RMT such as improved performance, increased respiratory muscle endurance and strength, reduced perceived exertion or breathlessness, and decreased respiratory fatigue during exercise are helpful in all endurance activities. Generally, individuals with lower fitness levels tend to derive greater benefits from RMT than well-trained endurance athletes, and the extent of improvement tends to be significantly larger during longer exercise durations (32). However, the rationale for incorporating RMT may be additionally sport, environment, and population dependent.

ROWING

Competitive rowing is widely recognized as one of the most physically demanding disciplines, placing significant physiological demands on athletes (24). Because of whole-body involvement in rowing, blood variables reach extreme values at race intensity: pH under 7.0, bicarbonate under 10.0 mmol/L, adrenaline 19 nmol/L, and noradrenaline 74 nmol/L (57,70). Despite the constrained body position, male rowers can achieve a ventilation of well more than 200 L · min-1 at race pace. Moreover, highly trained rowers have an exceptionally large vital lung capacity, that is, exhibiting values over 7 L compared with the 5.5 L expected for body size in male rowers (84). Thus, the respiratory muscles are under extreme load.

The respiratory muscles of rowers face specific requirements due to concurrent breathing demand, the need to maintain core stability, and transmitting force during different phases of the stroke (83). The accessory and primary inspiratory muscles play a crucial role in all 3 abovementioned functions and therefore are especially prone to fatigue (25). During the initial catch phase, breathing can be hindered due to the need to stabilize the thorax. The crouch position compresses the abdomen, obstructs the diaphragm, and makes breathing more challenging (78). During the release phase of the rowing stroke, both breathing and postural control are important to maintain the required body position.

Interestingly, based on the timing of peak flow and minimum volume, ventilation is more constrained in the finish position compared with the catch position, suggesting that mechanisms other than the cramped position also play a role in ventilatory impairment in rowing. Recent studies suggest that the periodic cocontraction of the diaphragm and abdominal muscles at the end of a stroke, along with the subsequent temporary rise in abdominal pressure, may be responsible for momentary dysfunction of the diaphragm (76). Moreover, multiple studies have demonstrated that rowers of different experience levels and sex synchronize their breathing patterns to multiples of the stroke rate, ranging from a 1:1 ratio to a 3:1 ratio (47,78). The phenomenon of locomotion and ventilation coupling, known as entrainment, is associated with additional demand on respiratory muscles (83), possibly due to involuntary respiratory muscle contractions that occur during breath holding (59,87). RMT is proven to enhance time trial performance in elite rowers due to reduced respiratory muscle fatigue, diminished perception of dyspnea, and improved pulmonary function (38,83). According to the literature, only 4–6 weeks of RMT significantly improved respiratory muscle strength (23,38). Even larger improvements occurred during programs lasting 11 weeks, ranging from 34 ± 19% to 45.3 ± 29.7% (38,83). Notably, rowers with higher inspiratory muscle strength at baseline observed a smaller effect of RMT (38). Significant rowing performance improvements after RMT program were noted during 6-minute time trials (increase in distance by 3.5 ± 1.2% versus 1.6 ± 1.0%), as well as 5000 m time trials (decrease in time by 3.1 ± 0.8% versus 0.9 ± 0.6%) compared with the placebo group (23,83). The differences may seem small, yet they can be decisive in high-performance settings. A 2% improvement (difference between RMT and placebo) results in 40 m or five skiff lengths during a classic 2000-m rowing regatta (32). According to the literature, inspiratory training is a preferred RMT form in rowing, contrary to expiratory or combined inspiratory/expiratory training, which improves the pulmonary function, but not the rowing performance (20,23). Moreover, the data suggest that incorporating an IPTL-based respiratory warm-up protocol may enhance subsequent maximal rowing performance compared with solely relying on a specific rowing warm-up (82). However, not all studies confirm the positive influence of inspiratory muscle training on rowing performance (65).

CYCLING

The RMT methods mentioned above have been widely investigated in endurance cyclists. Both VIH and IPTL are effective in numerous studies, across diverse populations (29,36,53,67,77). Interestingly, most cycling-related studies investigated the influence of VIH, as training demands match the performance requirements of competitive cycling. Moreover, studies based on a more aggressive progression of respiratory training load might exhibit greater RMT-related benefits (25).

Even short periods of RMT, for example, 4–6 weeks, may improve respiratory muscle strength and dynamic function in well-trained cyclists (19,67). Consequently, improvements in sustainable ventilatory capacity in the range of 12–16% were observed (19,29,43). However, such improvements do not always translate into better cycling performance (19). Nevertheless, studies comparing time trial performances between RMT groups and placebo/sham-training groups report differences from 2.1 to 4.75% in favor of RMT groups after an intervention lasting 5–6 weeks (29,67,77). Not all such improvements were statistically significant (77), so further research is required for confirmation. Reported post-RMT improvements translate to a difference of more than 1 km in a typical 40-km time trial race, constituting a large time difference in high-performance settings (14). It is worth mentioning that the positive influence of RMT increases with time trial length (67). Carrying out prolonged laboratory tests poses many practical difficulties, which limits the possibilities of investigating the impact of RMT on efforts lasting several hours, known from competitive cycling. However, based on the observed trends, we may speculate that RMT may be particularly useful in cycling, compared with sports of shorter duration. Moreover, RMT enhances the efficiency of respiratory and locomotor coupling and allows respiratory muscles to operate more comfortably in a time trial position when using aero bars (49).

SWIMMING

In studies conducted to date, respiratory muscle fatigue in swimming was the highest among all the investigated sports (45). Single race-pace effort resulted in a decline of inspiratory muscle strength from 17 to 21%, depending on the stroke (46). Therefore, because of the tournament nature of the swimming competition (eliminations, semifinals, finals) and a large number of races during typical events, the training status of respiratory muscles is highly important. Naturally, competitive swimming presents specific challenges for breathing muscles: athletes need to overcome the resistance of the water during exhalation and have limited time to perform an inspiration. In addition, respiratory chest movements have to physically overpower the hydrostatic pressure (46). Moreover, lower breathing frequency leads to increased respiratory fatigue (33). Speculatively, it may be caused by the cocontraction of the diaphragm and abdominal muscles, as in rowing entrainment (76). Because the centrally governed respiratory rhythm continues with intentional breath holding, the voluntary “holding the chest at a chosen volume” requires increased diaphragm activity (59), contributing to respiratory muscle fatigue.

RMT has been studied in pool swimmers, divers, and finswimmers. Improvement in specific performances such as time trial results, maximal apnea time, and increased surface and underwater times to exhaustion were observed (37,62,81,88). However, the response to RMT in swimmers seems to be dependent on training dose and training status with larger improvements in less trained individuals and athletes with a smaller training load (74). In competitive swimming, RMT was associated with improvements ranging from 1.2 to 7.3% for 50-, 100-, and 200-m performances compared with control groups (37,89). Interestingly, well-trained swimmers and divers are among the rare athletic able-bodied subgroups that usually did not show a significant increase in respiratory muscle strength or pulmonary function after RMT (25,54). Rigorous swim training programs have already been established to improve the abovementioned parameters (11,13), and the addition of RMT does not enhance respiratory adaptation to a greater extent in well-trained swimmers. Therefore, the underlying mechanisms of RMT-related improvement in their swimming performance should be looked at elsewhere. It was observed that respiratory muscle fatigue of 17% negatively affects stroke characteristics (44).

Moreover, the elicited influence of respiratory metaboreflex is associated with respiratory muscle fatigue of 19%, resulting in increased limb muscle fatigue (51). These magnitudes of respiratory muscle fatigue align with the respiratory muscle fatigue values (17–21%) measured after single efforts at race-pace intensity. Because RMT attenuates respiratory muscle fatigue and delays the respiratory metaboreflex (32), it may mitigate the negative effects on performance associated with both phenomena. Interestingly, swimmers with disabilities who underwent RMT experienced a comprehensive improvement in pulmonary function, respiratory muscle strength, and a complete elimination of existing lung ventilation disorders (58). We found only 1 study investigating RMT’s influence on long-distance swimming performance (3000-m swimming test) (22). Notably, in many aspects, the results of the study were contradictory to the research above, as RMT increased inspiratory muscle strength. Although not statistically significant, swim performance in elite swimmers improved (−1.5% reduction in time), despite no improvement in lactate clearance.

TRIATHLON

The positive effects of RMT in triathlon result from the abovementioned applications of RMT in swimming and cycling. However, triathlon-specific challenges elicit an additional need for multisport athletes to implement RMT. Neoprene wet suits are frequently used in triathlons due to their potential to enhance swimming performance and facilitate thermoregulation. An undesirable side effect is excessive resistance to the breathing movements of the chest and abdomen, which requires additional work from the respiratory muscles and leads to faster fatigue (49). Moreover, it was reported that the same intensity cycle-run effort leads to higher respiratory fatigue than running effort only.

Furthermore, the preceding cycling activity resulted in sustained respiratory muscle fatigue, which was neither reversed nor exacerbated by the subsequent running bout (7). Interestingly, it was observed that lower respiratory fatigue was exhibited by elite triathletes compared with their national and regional ranked counterparts, without performing additional RMT (9). These findings suggest that particular ventilatory adaptations occur due to cycle-run efforts during triathlon training and racing, at least partially compensating for increased respiratory demand through appropriate triathlon training (55). With the growing number of triathlon competitions held in a tournament or multiday system, it is worth noting that respiratory muscle fatigue after a single triathlon race can last more than 24 hours (8). Therefore, the improved respiratory muscle function may be particularly useful in triathletes racing multiple times during the same event.

HYPOXIA

Athletes must overcome the demands of exercise and the physiological challenges posed by the environment. In recent years, there has been a growing interest in investigating the use of RMT as a potential method for reducing the negative effects of hyperventilation-induced respiratory muscle fatigue in athletes who employ hypoxic training methods (3). This interest has arisen due to concerns regarding the potential for prolonged exercise in hypoxic conditions to result in respiratory muscle fatigue, which can adversely impact athletic performance. As a result, researchers have been exploring the applicability of RMT to mitigate these effects (28). A recent review based on 7 independent studies reported that RMT protocols ranging from 4 to 8 weeks led to several benefits when exercising in hypoxia (3). The results showed that RMT decreased respiratory muscle fatigue, improved tolerance and clearance of anaerobic metabolites, delayed respiratory muscle metaboreflex activation, and improved maintenance of oxygen saturation and blood flow to locomotor muscles.

Moreover, improvements in pulmonary function were achieved, which helped individuals adapt to hypoxia and reduce the impact of respiratory stress during the acclimatization stage compared with the placebo/sham groups. Overall, RMT positively affected respiratory efficiency and breathing patterns, reduced dyspneic perceptions, and improved physical performance in hypoxic conditions. As a result, it is recommended to use RMT as a preexposure tool to strengthen respiratory muscles and minimize the negative effects of hyperventilation caused by hypoxia (3). However, living and training at altitude are associated with enhanced stress, possibly increased frequency of infections, and a higher risk of overtraining symptoms (69). Moreover, winter sports athletes face the dual challenges of high-altitude hypoxia and cold, which may be experienced repeatedly during training or competition (72). Therefore, when training at altitude, adding an extra training load (such as RMT) to regular training should proceed with great caution.

GENDER DIFFERENCES

According to literature, the respiratory system may limit athletic performance in women more than in men (4), providing an additional rationale for RMT. Women typically exhibit smaller lung size, smaller diffusion surface area, lower maximal expiratory flow rates, and narrower airway diameter, compared with men of the same height and age. Therefore, women demonstrate increased work of breathing, higher airway hyperresponsiveness, expiratory flow limitation, and potentially greater exercise-induced arterial hypoxemia compared with men (26,73).

Interestingly, a few studies that report the largest RMT-associated improvements or observe high respiratory muscle fatigue investigated female or predominantly female populations (20,45,83). In rowing, it can be attributed to higher lung compliance and lower elastic recoil with subsequent flow-limiting pressure, as observed in female rowers, compared with male rowers (6). Some studies report a positive impact of RMT on female participants but not on male participants (86) or report a larger positive impact on female participants, compared with male participants (29,64). Moreover, there are differences in RMT-induced training load and stress between the sexes. Larger acute changes in blood gasometry and cardiac indices, as well as more frequent pain symptoms in response to RMT, were found in female athletes compared with male athletes (39). However, to our knowledge, the differences in influence of RMT between the sexes remain understudied.

TESTING RECOMMENDATIONS

Training interventions should begin with a clearly defined starting point, and RMT is no exception. Before commencing the RMT protocol, it is recommended to assess the athlete's respiratory muscle strength and endurance, as well as their pulmonary function (40). This information will help to tailor the RMT program to the individual athlete's needs and abilities. However, in most countries, spirometry is regarded as a medical examination subject to specific regulations. These regulations often restrict performing pulmonary function testing to specialized medical professionals. It is important to comply with these regulations to ensure the proper and safe administration of spirometry tests. In the sports environment, it is a common practice to evaluate respiratory muscle strength and endurance using built-in tests from advanced POWERbreathe and Airofit devices. For example, Kowalski and Klusiewicz (40) rely on K-Series POWERbreathe trainers and the S--Index Test to measure inspiratory muscle strength. Based on the results provided by other researchers, we recommend performing the test with 8 forceful and dynamic inspiratory maneuvers from residual volume to full inspiratory capacity, in a standing position, after a respiratory warm-up consisting of 5–10 inspiratory maneuvers (40). The test result is presented with the S-Index score (cmH_2O) and peak inspiratory flow (L/s). The S-Index test is considered a reliable measure of respiratory muscle strength and has a strong correlation and good agreement with traditional spirometry parameters, such as maximal inspiratory pressure (5). Throughout the assessment, the athlete and the coach or practitioner may observe breathing characteristics in real-time on a computer or tablet screen (Figure 3).

Field assessment of respiratory muscle endurance or inspiratory fatigue may include performing the S-Index test before and after engaging in specific exercises. Analyzing the difference between the 2 test results can provide valuable information about the extent of respiratory muscle fatigue and, indirectly, respiratory muscle endurance. There is no consensus on the definition of inspiratory muscle fatigue as a percentage of a drop in measured values. However, statistically significant mean decreases from baseline or thresholds of 10–15% in function are often used (34).

PROGRAMMING RECOMMENDATIONS

One of the basic rules of training programming is focusing on movement quality before increasing load and working on performance and skills that use movement patterns free from dysfunction or limitation. This rule also applies to RMT and developing an efficient breathing technique should precede applying moderate or heavy training load. Although specific breathing techniques are often favored, the scientific literature remains inconclusive regarding preferred respiratory techniques and the effectiveness of nasal or diaphragmatic breathing during exercise (15). Nevertheless, some researchers suggest that any deviation from diaphragmatic breathing has the potential to be "dysfunctional." Diaphragmatic breathing has been shown to reduce stress levels, as evidenced by physiological biomarkers and self-reported psychological assessments (30). Given the benefits, we suggest starting RMT programs by teaching diaphragmatic breathing patterns, increasing thoracic mobility, and focusing on flawless execution, rather than achieving measurable training targets. Although many athletes enjoy practicing their sport, a comparatively smaller subset of athletes enjoys the demanding process of RMT. To maintain high motivation and commitment, we recommend periodically reminding athletes about the benefits associated with RMT. During the first few weeks of the program, we suggest regular supervision of RMT sessions to ensure optimal technique and motivate athletes.

The available scientific literature does not discuss the potential risks of injury or overuse associated with RMT. Acute negative effects, such as mild headache or dizziness, may occur in some athletes (39). However, based on the authors' experience, RMT is a safe form of activity, assuming that it is executed according to equipment manufacturers' guidelines. Of note, RMT may be especially useful to injured athletes or individuals returning to training from injury or disability to maintain or restore necessary respiratory capacity. In addition, the low entry barriers and affordability of basic breathing trainers make RMT accessible for athletes. RMT is not time consuming, and even advanced athletes can benefit from programs that take just a few minutes a day or can be incorporated into recovery intervals during

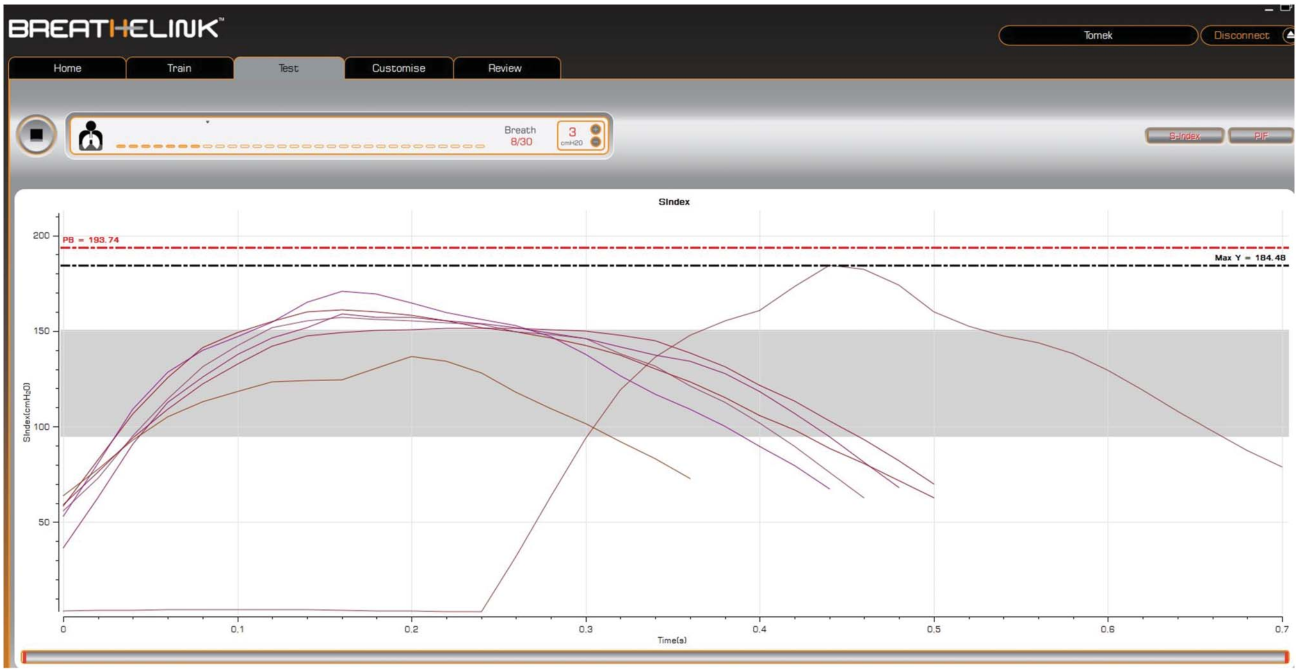

Figure 3. S-Index test results are presented on screen in real time.

sport-specific or strength and conditioning training sessions.

PRACTICAL APPLICATION

- Traditional sport-specific training or exercise programs do not create enough stimulus to improve the function of the respiratory muscles, providing the additional rationale to introduce RMT.
- RMT may improve athletic performance, respiratory muscle endurance, and strength and reduce perceived exertion, breathlessness, and respiratory fatigue during exercise in normoxia and hypoxia.
- A wide range of training devices, methods, and protocols for RMT may be implemented in endurance sports, depending on the athlete's training status and performance demands. Popular RMT protocols include performing 30 inspiratory maneuvers twice a day, 5 days a week, with Powerbreathe resistance-based trainers or 20–40 minutes of vigorous ventilation with Isocapnic BWB devices.
- Focusing on movement quality before increasing load is a basic rule in resistance exercise programming. Similarly, it applies to RMT, and developing an efficient breathing technique should precede applying moderate or heavy training loads.
- The function and structure of respiratory muscles are similar to other striated muscles; therefore, general training principles such as progressive overload, periodization, training specificity, and reversibility may be successfully applied.

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