RESPIRATORY MUSCLE FATIGUE
RESPIRATORY MUSCLE TRAINING

• During heavy exercise, breathing frequency rises to 40 to 50 breaths per minute. Tidal volume is 3 to 4 litres. This gives a minute volume of 120 to 160 litres.

• For Olympic class male endurance athletes, tidal volume can be as high as 5 litres resulting in a minute ventilation of 200 to 250 litres.

• McConnell. A. Breathe Strong. Perform Better.
RESPIRATORY MUSCLE TRAINING

• During intense exercise, the demands on proper functioning of the respiratory system are markedly increased. Research has shown that the respiratory system often “lags behind,” while cardiovascular function and skeletal muscle improve with aerobic training (Bye et al., 1983; Wagner, 2005).

RESPIRATORY MUSCLE TRAINING

• The lungs do not respond to physical training. Training does not increase lung volumes, improve lung function or enhance the ability of the lungs to transfer oxygen to the blood. (Wagner 2005)

• McConnell. A. Breathe Strong. Perform Better.
Accumulating evidence over the past 25 years indicates a substantial role of the healthy respiratory system in limiting high-intensity endurance exercise in humans.

Markus Amann, Pulmonary System Limitations to Endurance Exercise Performance in Humans. Exp Physiol. 2012 March; 97(3): 311–318
RESPIRATORY MUSCLE FATIGUE

• There is strong evidence that the diaphragm and other respiratory muscles may become exhausted during both short term, high intensity exercise (Bye et al) and more prolonged exercise such as marathon running (Loke et al)

• Tim Noakes. The Lore of Running.
The ventilatory response during heavy exercise, which is often accompanied and impaired by expiratory flow limitations and dynamic hyperinflation (Johnson et al., 1992), requires substantial increases in both inspiratory and expiratory muscle work, often leading to respiratory muscle fatigue.

Markus Amann, Pulmonary System Limitations to Endurance Exercise Performance in Humans. Exp Physiol. 2012 March; 97(3): 311–318
RESPIRATORY MUSCLE TRAINING

• As the respiratory muscles fatigue they require an increasing amount of blood flow and oxygen in order to continue. As fatigue sets in, the respiratory muscles are thought to potentially monopolize the blood flow needed for the locomotor muscles.

• The Effects of Inspiratory Muscle Training on Anaerobic Power in Trained Cyclists By Courtenay McFadden Accepted in Partial Completion of the Requirements for the Degree Master of Science
RESPIRATORY MUSCLE FATIGUE

• Fatiguing respiratory muscle work associated with strenuous exercise elicits sympathetically-mediated vasoconstriction in limb-muscle vasculature which compromises leg blood flow.

RESPIRATORY MUSCLE FATIGUE

- This sequence facilitates locomotor muscle fatigue and limits endurance exercise performance.

- Markus Amann, Pulmonary System Limitations to Endurance Exercise Performance in Humans. Exp Physiol. 2012 March; 97(3): 311–318
Prior fatigue of the inspiratory muscles accelerates the development of fatigue in the plantar flexors (ankle) via a reflex change in limb blood flow (McConnell and Lomax 2006).

RESPIRATORY MUSCLE FATIGUE

• There are several lines of evidence suggesting that the diaphragm should be the most important muscle to target during IMT.

• Studies suggest that more than 50% of healthy humans with varying fitness levels develop diaphragmatic fatigue after bouts of high-intensity constant work rate

  • *Diaphragm Recruitment Increases during a Bout of Targeted Inspiratory Muscle Training.* [Medicine & Science in Sports & Exercise](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5009697/) · 2016 Jun;48(6):1179-86
RESPIRATORY MUSCLE FATIGUE

- Fatigue is measured by two different methods: measuring diaphragm twitches during exercise; and testing maximal inspiratory pressure post exercise and comparing it to pre-exercise (Johnson, Babcock, Suman, & Dempsey, 1993; Romer, McConnell, & Jones, 2002).

The Effects of Inspiratory Muscle Training on Anaerobic Power in Trained Cyclists By Courtenay McFadden Accepted in Partial Completion of the Requirements for the Degree Master of Science
FACTORS CAUSING FATIGUE

• The factors that may modulate ventilatory muscle fatigue during exercise are controversial.

FACTORS CAUSING FATIGUE

- If the work of inhalation was decreased, leg blood flow increased by 4.3%.
- If the work of inhalation was increased, leg blood flow decreased by 7%.
- Researchers showed that the trigger for limb vasoconstriction was a reflex originating within the inspiratory muscles which they called the ‘inspiratory muscle metaboreflex’

*McConnell. A. Breathe Strong, Perform Better*
FACTORS CAUSING FATIGUE

• Metaboreflex- when muscles work very hard, metabolic by products such as lactic acid accumulate within them. These metabolites stimulate receptors inside the muscles that send signals to the brain to trigger a reflex shutdown of circulation, including the blood supply to the locomotor muscles.

• McConnell. A. Breathe Strong, Perform Better
FACTORS CAUSING FATIGUE

• Restricting blood flow restricts the supply of oxygen and impairs the removal of exercise metabolites from exercising muscles. As a result, muscles fatigue more quickly and exercise performance is impaired.

• McConnell. A. Breathe Strong, Perform Better
FACTORS CAUSING FATIGUE- HYPOXIA

- The greater amount of diaphragmatic fatigue in hypoxia at lower leg work rates, suggests that when ventilatory muscle load is similar between normoxia and hypoxia, hypoxia exaggerates diaphragmatic fatigue.

FACTORS CAUSING FATIGUE- HYPERCAPNIA

• 14 healthy subjects performed two cycling tests (at 60% of maximal aerobic power for 16 min).

• One group breathing spontaneously (mean minute ventilation (V'E) 67.9 L x min(-1))

• One group hypoventilating voluntarily (mean V'E 53.8 L x min(-1)).

FACTORS CAUSING FATIGUE- HYPERCAPNIA

• As compared with spontaneous breathing (SB), voluntary hypoventilation (VHV) significantly increased mean carbon dioxide tension in arterial blood (Pa,CO2) (51 mmHg versus 41 mmHg) and significantly decreased arterial pH (7.28 versus 7.34).

FACTORS CAUSING FATIGUE- HYPERCAPNIA

• After 10 min of SB test, (twitch mouth pressure response) was unchanged compared to the baseline value (19.1 versus 18.5 cmH2O)

VHV test: it fell significantly as compared to baseline (17.1 versus 18.5 cmH2O)

The results of this study suggest that exposure to hypercapnia may impair respiratory muscle function.

FACTORS CAUSING FATIGUE- HYPERCAPNIA

- Controlled-frequency breathing (CFB) induces hypercapnia (partial pressure of carbon dioxide in arterial blood, PaCO2, > 45 mmHg) rather than hypoxia (Dicker et al., 1980).

- Hypercapnia may fatigue working muscles more quickly, as metabolite clearance cannot keep pace with CO2 production (Babcock et al., 1996; Jonville et al., 2002).

TECHNIQUES OF RMT
TECHNIQUES OF RMT

• Inspiratory muscle resistance training employs resistance training principles and is confined primarily to the inspiratory muscles.

TECHNIQUES OF RMT

• Voluntary isocapnic hyperpnea (VIH) requires individuals to maintain high levels of ventilation for up to 30 min. To prevent hypocapnia, subjects may simply re-breathe through a dead space.

• Physically demanding

• Exhausting
TECHNIQUES OF RMT

• Inspiratory flow resistive loading (IRFL) requires individuals to inspire via a variable diameter orifice whereby, for a given flow, the smaller the orifice the greater the resistive load.

• Studies show increases in inspiratory muscle strength from 18-54%
TECHNIQUES OF RMT

• Pressure threshold loading (IPTL) requires individuals to produce a negative pressure sufficient to overcome a threshold load and thereby initiate inspiration.

• Breathing in- air is only released if you breathe with enough effort to release the valve. The breathing muscles work harder as they move up and down. 30 breaths twice a day.

• Eg: PowerBreathe.
RESPIRATORY MUSCLE TRAINING
The mechanisms by which respiratory muscle training improves exercise performance are unclear. May include:

- Direct effect on respiratory muscle fatigue.
- Indirect effects upon improving blood flow distribution to limb locomotor muscles in heavy exercise.
- Direct and indirect effect upon the intensity with which both respiratory and peripheral efforts are perceived.

RESPIRATORY MUSCLE TRAINING

• To stimulate any muscle to undergo adaptation, the muscle must be overloaded. This means forcing it to do something that it is not accustomed to. Most aerobic training is within the comfort of working muscles. High intensity training would be best- but cannot be sustained long enough to provide an effective overload.

• McConnell A. Breathe Strong, Perform Better.
BREATH HOLD TRAINING
BREATH HOLD TRAINING

- The "extradiaphragmatic" shift in inspiratory muscle recruitment may reflect an extreme loading response to breathing against a heavy elastance (i.e., closed glottis). In addition, the relative intensity of diaphragmatic and inspiratory rib cage muscle contractions approaches potentially "fatiguing" levels by the break point of maximal breath holding.

BREATH HOLD TRAINING

• Limiting the frequency of breaths during swimming may impose more intense stressors on the athlete; this practice has been shown to produce higher levels of inspiratory muscle fatigue without affecting swimming performance (Jakovljevic & McConnell, 2009).

Swimmers are often cited as the exception to Wagner’s hypothesis that exercise does not “grow the lungs” (Wagner, 2005), with early studies showing that competitive swimmers consistently have larger lung volumes than predicted, even when controlling for body size (Clanton et al., 1987).

BREATH HOLD TRAINING

• Controlled frequency breathing (CFB) is a common swim training modality involving holding one's breath for about 7 to 10 strokes before taking another breath.

It is possible that CFB might mimic the effects of RMT. This practice is often used by land-based athletes and is shown to be effective in improving several pulmonary function parameters that might translate into enhanced exercise performance.

BREATH HOLD TRAINING

• Limiting breath frequency during swimming further stresses the respiratory system through hypercapnia and mechanical loading and may lead to appreciable improvements in respiratory muscle strength.

BREATH HOLD TRAINING

• 20 competitive college swimmers were randomly divided into either the CFB group that breathed every 7 to 10 strokes, or a control group that breathed every 3-4 strokes. Pooled results demonstrated a 12% decrease in MIP (maximum inspiratory mouth pressure) at 46s post-race. The training intervention included 5-6 weeks

BREATH HOLD TRAINING

• After four weeks of training, only the CFB group prevented a decline in MIP values pre to 46 s post-race. CFB training appears to prevent inspiratory muscle fatigue yet no difference was found in performance outcomes.

BREATH HOLD TRAINING

• Eighteen subjects (10 men), were randomized to either CFB or stroke-matched (SM) condition. Subjects completed 12 training sessions, in which CFB subjects took two breaths per length and SM subjects took seven.

BREATH HOLD TRAINING

• Post-training, maximum expiratory pressure improved by 11% (15) for all 18 subjects (P < 0.05) while maximum inspiratory pressure was unchanged.

BREATH HOLD TRAINING

- Swimmers, who were subjected to the hypercapnic-hypoxic regimen, had significantly improved strength of their inspiratory muscles in comparison to swimmers in the control group.

• Experimental group have improved the inspiratory muscle strength values (MIP) for 14.9% and the expiratory muscle strength values (MEP) for 1.9% in relation to the control group.

• Dajana KARAULA 1, Jan HOMOLAK 2, Goran LEKO. Effects of hypercapnic-hypoxic training on respiratory muscle strength and front crawl stroke performance among elite swimmers. Turkish Journal of Sport and Exercise. Year: 2016 - Volume: 18 - Issue: 1 - Pages: 17-24
• Voluntary holding of breath may have resulted in involuntary contractions of intercostal muscles during the hypercapnic-hypoxic practice. It is also assumed that above mentioned contraction occurrence has resulted in hypertrophy of intercostal muscles.

• Dajana KARaulA 1, Jan HOMOLAK 2, Goran LEKO. Effects of hypercapnic-hypoxic training on respiratory muscle strength and front crawl stroke performance among elite swimmers. Turkish Journal of Sport and Exercise. Year: 2016 - Volume: 18 - Issue: 1 - Pages: 17-24
BREATH HOLD TRAINING

• Such practice may have enlarged diaphragm thickness which plays an important role in respiratory system and sports performance.

• Dajana KARAULA 1, Jan HOMOLAK 2, Goran LEKO. Effects of hypercapnic-hypoxic training on respiratory muscle strength and front crawl stroke performance among elite swimmers. Turkish Journal of Sport and Exercise. Year: 2016 - Volume: 18 - Issue: 1 - Pages: 17-24
BREATH HOLD TRAINING

- The moment at which the reflex to increase the frequency of unintentional diaphragm contractions kicks in is dependent on the level of anoxia and blood CO2 concentration (Whitelaw et al., 1981).

- Journal of Human Kinetics volume 32/2012, 197-210
BREATH HOLD TRAINING

• Long-term, specialized training also cause an increase in the respiratory system’s functional parameters, which in consequence delays respiratory muscle-fatigue during prolonged breath-hold diving (Nygren-Bonnier et al., 2007).

• Journal of Human Kinetics volume 32/2012, 197-210
BREATH HOLD TRAINING

• 3-month apnea training program, the forced expiratory volume in 1 s was higher (4.85 ± 0.78 vs. 4.94 ± 0.81 L, p < 0.05), with concomitant increases in the maximal oxygen uptake, arterial oxygen saturation, and respiratory compensation point values during an incremental test.

BENEFITS OF RMT
BENEFITS OF RMT

• Respiratory muscle training (RMT) yields improvements in exercise performance in both healthy young adults (McConnell and Romer 2004)

BENEFITS OF RMT

• Respiratory muscle training improves recovery time during high intensity, intermittent exercise in repetitive sprint athletes.

BENEFITS OF RMT

• Evidence that improvements in constant-power and cycling time-trial performance following IMT in cyclists may be explained, in part, by an increase in anaerobic work capacity.

BENEFITS OF RMT

• Further, a 4 week period of IMT increases the intensity of inspiratory muscle work required to elicit changes in limb blood flow and plantar flexor fatigue.