



Year: 2012

Effect of respiratory muscle training on exercise performance in healthy individuals: a systematic review and meta-analysis

Illi, Sabine K ; Held, Ulrike ; Frank, Irène ; Spengler, Christina M

Abstract: **OBJECTIVES:** Two distinct types of specific respiratory muscle training (RMT), i.e. respiratory muscle strength (resistive/threshold) and endurance (hyperpnoea) training, have been established to improve the endurance performance of healthy individuals. We performed a systematic review and meta-analysis in order to determine the factors that affect the change in endurance performance after RMT in healthy subjects. **DATA SOURCES:** A computerized search was performed without language restriction in MEDLINE, EMBASE and CINAHL and references of original studies and reviews were searched for further relevant studies. **REVIEW METHODS:** RMT studies with healthy individuals assessing changes in endurance exercise performance by maximal tests (constant load, time trial, intermittent incremental, conventional [non-intermittent] incremental) were screened and abstracted by two independent investigators. A multiple linear regression model was used to identify effects of subjects' fitness, type of RMT (inspiratory or combined inspiratory/expiratory muscle strength training, respiratory muscle endurance training), type of exercise test, test duration and type of sport (rowing, running, swimming, cycling) on changes in performance after RMT. In addition, a meta-analysis was performed to determine the effect of RMT on endurance performance in those studies providing the necessary data. **RESULTS:** The multiple linear regression analysis including 46 original studies revealed that less fit subjects benefit more from RMT than highly trained athletes (6.0% per $10 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ decrease in maximal oxygen uptake, 95% confidence interval [CI] 1.8, 10.2%; $p = 0.005$) and that improvements do not differ significantly between inspiratory muscle strength and respiratory muscle endurance training ($p = 0.208$), while combined inspiratory and expiratory muscle strength training seems to be superior in improving performance, although based on only 6 studies (+12.8% compared with inspiratory muscle strength training, 95% CI 3.6, 22.0%; $p = 0.006$). Furthermore, constant load tests (+16%, 95% CI 10.2, 22.9%) and intermittent incremental tests (+18.5%, 95% CI 10.8, 26.3%) detect changes in endurance performance better than conventional incremental tests (both $p < 0.001$) with no difference between time trials and conventional incremental tests ($p = 0.286$). With increasing test duration, improvements in performance are greater (+0.4% per minute test duration, 95% CI 0.1, 0.6%; $p = 0.011$) and the type of sport does not influence the magnitude of improvements (all $p > 0.05$). The meta-analysis, performed on eight controlled trials revealed a significant improvement in performance after RMT, which was detected by constant load tests, time trials and intermittent incremental tests, but not by conventional incremental tests. **CONCLUSION:** RMT improves endurance exercise performance in healthy individuals with greater improvements in less fit individuals and in sports of longer durations. The two most common types of RMT (inspiratory muscle strength and respiratory muscle endurance training) do not differ significantly in their effect, while combined inspiratory/expiratory strength training might be superior. Improvements are similar between different types of sports. Changes in performance can be detected by constant load tests, time trials and intermittent incremental tests only. Thus, all types of RMT can be used to improve exercise performance in healthy subjects but care must be taken regarding the test used to investigate the improvements.

DOI: <https://doi.org/10.2165/11631670-000000000-00000>

Posted at the Zurich Open Repository and Archive, University of Zurich
ZORA URL: <https://doi.org/10.5167/uzh-76634>
Journal Article
Accepted Version

Originally published at:

Illi, Sabine K; Held, Ulrike; Frank, Irène; Spengler, Christina M (2012). Effect of respiratory muscle training on exercise performance in healthy individuals: a systematic review and meta-analysis. *Sports Medicine*, 42(8):707-724.

DOI: <https://doi.org/10.2165/11631670-000000000-00000>

**Effect of respiratory muscle training on exercise performance in healthy individuals:
A systematic review and meta-analysis**

Sabine K. Illi^{1,2}, Ulrike Held³, Irène Frank^{1,2}, and Christina M. Spengler^{1,2}

*¹Exercise Physiology, Institute of Human Movement Sciences, ETH Zurich,
Winterthurerstrasse 190, 8057 Zurich, Switzerland*

*²Institute of Physiology and Center for Integrative Human Physiology (ZIHP), University of
Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland*

*³Horten Center for Patient-Oriented Research and Knowledge Transfer, University of Zurich,
8091 Zurich, Switzerland*

Running title: Respiratory muscle training in healthy individuals

Word count: 6171

This article has been reproduced with permission from Adis, a Wolters Kluwer business (see Illi SK, Held U, Frank I, Spengler CM. Effect of respiratory muscle training on exercise performance in healthy individuals: A systematic review and meta-analysis. Sports Medicine 2012; 42 (8): for the final published version). © Adis Data Information BV 2012. All rights reserved.

Acknowledgements

We thank Christoph Brändle and Dr. Alexander Akhmedov for translating the potentially relevant Japanese and Russian papers, respectively, Dr. Ruth Briggs for English editing, as well as the Swiss Federal Office of Sport (grant no. 11-11) and the Swiss National Science Foundation (grant no. 3200B0-116777) for providing financial support.

There are no conflicts of interest to declare.

Name and address for correspondence:

Christina M. Spengler

University and ETH Zurich

Exercise Physiology

Institute of Human Movement Sciences

Winterthurerstrasse 190

8057 Zurich, Switzerland

Tel: +41 44 635 50 07

Fax: +41 44 635 68 14

E-mail: spengler@ethz.ch

Table of contents

Figure Captions	4
Abstract	5
Introduction	7
Methods	11
Search	11
Selection	11
Quality assessment	12
Data abstraction	13
Quantitative data synthesis	13
Results	16
Trial flow and study characteristics	16
Study design: presence/absence and type of control group	16
Linear regression model	17
Meta-analysis	17
Discussion	19
Study design: presence/absence and type of control group	19
Effect of subject's fitness on improvements in exercise performance	20
Influence and type of RMT on improvements in exercise performance	20
Effect of type of exercise and test duration on the improvement in exercise performance	22
Effects of RMT in different types of sports	25
Limitations	26
Conclusions	27
References	29
Tables and Figures	41

Figure captions

Figure 1. Flow diagram of the studies excluded from and included in the linear regression model and / or the meta-analysis.

Figure 2. Effect of respiratory muscle training on exercise performance in constant load tests, time trials, intermittent incremental test, and conventional (non-intermittent) incremental tests. Only those studies providing the necessary information are included in this forest plot. RMT = Respiratory muscle training group; sham / control = sham-training / no-training control group; IV = inverse variance; Random = random effects model; 95% CI = 95% confidence interval.

Figure 3. Funnel plot of the studies included in the meta-analysis. CLT = constant load test; TT = time trial; IIT = intermittent incremental test; IT = conventional (non-intermittent) incremental test; SMD = standardised mean difference; SE = standard error.

Figure 4. Mean difference in the effect of respiratory muscle training on exercise performance between intervention and sham-training or no-training control groups. Black circles: average mean difference of each type of exercise test. Grey circles: tests also included in the forest plot of Figure 2. White circles: tests not included in the meta-analysis because data to calculate the confidence interval was not provided. The size of the circles represents the number of subjects included in the study. RMET = respiratory muscle endurance training; RMST.IN = inspiratory muscle strength training; RMST.INEX = inspiratory and expiratory muscle strength training.

Abstract

Objectives: Two distinct types of specific respiratory muscle training (RMT), i.e. respiratory muscle strength (resistive/threshold) and endurance (hyperpnoea) training, have been established to improve endurance performance of healthy individuals. We performed a systematic review and meta-analysis in order to determine the factors that affect the change in endurance performance after RMT in healthy subjects.

Data sources: A computerised search was performed without language restriction in MEDLINE, EMBASE, and CINAHL and references of original studies and reviews were searched for further relevant studies.

Review methods: RMT studies with healthy individuals, assessing changes in endurance exercise performance by maximal tests (constant load, time trial, intermittent incremental, conventional (non-intermittent) incremental) were screened and abstracted by two independent investigators. A multiple linear regression model was used to identify effects of subjects' fitness, type of RMT (inspiratory or combined inspiratory/expiratory muscle strength training, respiratory muscle endurance training), type of exercise test, test duration, and type of sport (rowing, running, swimming, cycling) on changes in performance after RMT. In addition, a meta-analysis was performed to determine the effect of RMT on endurance performance in those studies providing the necessary data.

Results: The multiple linear regression analysis including 46 original studies revealed that less fit subjects benefit more from RMT than highly trained athletes (6.0% per 10 ml·kg⁻¹·min⁻¹ decrease in $\dot{V}O_{2,max}$, 95% confidence interval [CI] 1.8 to 10.2% p = 0.005), that improvements do not differ significantly between inspiratory muscle strength and respiratory muscle endurance training (p = 0.208) while combined inspiratory and expiratory muscle strength training seems to be superior in improving performance, although based on only 6

studies (+12.8% compared to inspiratory muscle strength training, 95% CI 3.6 – 22.0%, $p = 0.006$). Furthermore, constant load tests (+16%, 95% CI 10.2 – 22.9%) and intermittent incremental tests (+18.5%, 95% CI 10.8 – 26.3%) detect changes in endurance performance better than conventional incremental tests (both $p < 0.001$) with no difference between time trials and conventional incremental tests ($p = 0.286$). With increasing test duration, improvements in performance are greater (+0.4% per minute test duration, 95% CI 0.1 – 0.6%, $p = 0.011$) and the type of sport does not influence the magnitude of improvements (all $p > 0.05$). The meta-analysis, performed on eight controlled trials, revealed a significant improvement in performance after RMT which was detected by constant load tests, time trials, and intermittent incremental tests, but not by conventional incremental tests.

Conclusion: RMT improves endurance exercise performance in healthy individuals with greater improvements in less fit individuals and in sports of longer durations. The two most common types of RMT (inspiratory muscle strength and respiratory muscle endurance training) do not differ significantly in their effect while combined inspiratory/expiratory strength training might be superior. Improvements are similar between different types of sports. Changes in performance can be detected by constant load tests, time trials, and intermittent incremental tests only. Thus, all types of RMT can be used to improve exercise performance in healthy subjects but care must be taken regarding the test used to investigate the improvements.

Word count: 500

Introduction

Respiratory muscle fatigue is known to compromise exercise performance in healthy subjects.^[1, 2] Evidence is emerging that fatiguing respiratory muscles may affect exercise performance via the so-called metaboreflex,^[3] i.e. accumulation of metabolites, such as lactic acid, in the respiratory muscles activates group III and especially group IV nerve afferents^[4-6] that then trigger an increase in sympathetic outflow from the brain causing vasoconstriction in the (exercising) limbs.^[7-11] This consequently increases limb muscle fatigue during exercise^[12, 13] and results in earlier exercise termination compared to conditions where respiratory muscle fatigue is prevented.^[14, 15]

Respiratory muscle training (RMT) has been shown to reduce the development of respiratory muscle fatigue,^[16-18] blood lactate concentration during exercise,^[18-21] and sympathetic activation.^[12, 22] Therefore, a reduction or delay of the metaboreflex^[3] described above might be an important mechanism for improving exercise performance by RMT. Interestingly, however, of those studies addressing the effects of specific RMT on exercise performance in healthy subjects, only about two thirds report significant improvements. Therefore, a detailed analysis of potential factors that may contribute to success or failure of RMT is urgently needed. A brief overview of these factors is given below.

Firstly, study outcome may be related to study design, considering that only about half of the RMT studies included a sham-training group to account for a possible placebo effect of RMT. *Secondly*, subject selection might influence study outcome, since the extent to which respiratory muscles fatigue may differ, for example, with subjects' fitness level. Indeed, several studies showed increased respiratory muscle endurance in physically trained compared to sedentary subjects.^[23-25] However, when comparing subjects' physical

performance relative to their maximal performance, trained subjects worked at a higher percentage of their maximum and performed more respiratory muscle work^[26] which may theoretically neutralise the effect of increased respiratory muscle endurance on fatigue development. Only two studies^[27, 28] investigated the difference in development of respiratory muscle fatigue depending on subjects' fitness. These suggested that respiratory muscles indeed fatigue less in endurance trained compared to sedentary subjects during exhaustive physical exercise.^[27, 28] This indicates that less fit subjects would generally benefit more from RMT than highly trained athletes. *Thirdly*, it is unclear whether the type of RMT might influence the degree of improvement in exercise performance. Currently two distinct forms of RMT are used in healthy subjects: respiratory muscle strength training (RMST; also known as inspiratory muscle (strength) training [IM(S)T], inspiratory (flow) resistive loading [I(F)RL], resistive/resistance respiratory muscle training (RRMT), concurrent inspiratory and expiratory muscle training [CRMT], or expiratory muscle training [EMT]) and respiratory muscle endurance training (RMET; also referred to as ventilatory muscle training [VMT], voluntary isocapnic hyperpnoea [VIH], or endurance respiratory muscle training [ERMT]). RMST is performed by breathing against an external inspiratory and/or expiratory load. This load consists either of a flow-dependent resistance or of a pressure threshold that needs to be overcome and sustained to generate flow. RMST includes high force, low velocity contractions, and was shown to specifically increase respiratory muscle strength, i.e. maximal pressure generation capacity of the inspiratory and/or expiratory muscles against a closed airway^[29]. In contrast, RMET is performed using normocapnic hyperpnoea. This training consists of low force, high velocity contractions of in- and expiratory muscles, and results in improved respiratory endurance^[29]. Whether strength or endurance training of the respiratory muscles is more effective in terms of improving exercise performance remains unclear. From a physiological point of view, it seems that training both inspiratory and expiratory muscles

would be most effective, since with elevated breathing, inspiratory as well as expiratory muscles are increasingly recruited. In fact, it has been shown by objectively assessing changes in transdiaphragmatic and abdominal muscle contractility after exercise that not only inspiratory^[30-33] but also expiratory muscles^[16, 34-36] fatigue during exhaustive high intensity endurance exercise. Therefore, a closer look at the effects of different training regimes is needed. *Fourthly*, different studies use different types of exercise testing, e.g. incremental tests (IT), constant load tests (CLT), or time trials (TT) of different intensities, to assess the effect of RMT on exercise performance. Whether RMT is more likely to result in positive effects during some types of performance compared to others remains to be verified. Considering the degree to which respiratory muscles fatigue after these different types of tests, it could be argued that effects of RMT are less likely to be detected in ITs than in the other types of tests. This assumption is based on results of Romer et al.,^[37] who demonstrated that the diaphragm of moderately fit subjects did not fatigue during an incremental cycling test, despite subjects reaching maximal exercise intensity. This is surprising, since Johnson et al.^[30] showed that higher exercise intensities (oxygen consumption at > 85% maximal oxygen uptake, $\dot{V}O_{2,max}$) increase the likelihood for diaphragmatic fatigue to develop. It seems, therefore, that the duration for which a given intensity is sustained is as important as the intensity itself with respect to both development of respiratory muscle fatigue and a possible benefit from RMT. *Finally*, the effect of RMT on performance might differ depending on the exercise modality used, e.g. rowing, running, swimming, or cycling, since respiratory muscles are well known to realise more than just respiratory tasks and these tasks differ between exercise modalities. In rowing, for instance, respiratory muscles need to combine the motion of the thorax expanding and contracting with the – sometimes opposing – rowing stroke movement.^[38-40] In running, intra-abdominal pressure is increased which has been attributed to a protecting function of the spine by the abdominal muscles.^[41] Furthermore, the diaphragm

has been shown to be activated to increase intra-abdominal pressure during movements of upper limbs, such as when running.^[42, 43] Thus, when running, respiratory muscles of the trunk also serve postural tasks. During swimming and diving the work of breathing is increased due to the hydrostatic pressure against which the thorax expands, causing an increase in end-expiratory lung volume, which in turn leads to suboptimal length for tension development of respiratory muscles.^[44] In addition, respiratory muscles are involved in propulsion. Thus, subjects performing exercise modalities that require additional work from respiratory muscles might be more susceptible to respiratory muscle fatigue.^[45] Consequently, subjects performing these exercise modalities might benefit most from RMT.

The aim of the present work was therefore to assess the importance of the above factors on the effect of RMT to improve exercise performance. For this purpose, a systematic review was performed in MEDLINE, EMBASE and CINAHL (up to October 2011) without language restriction on all studies including an RMT intervention and assessment of endurance performance as outcome variable, independent of the presence or absence of a sham/control group. To specifically analyse the evidence of a positive effect of RMT on exercise performance, a meta-analysis including only controlled studies was performed.

Methods

A systematic review and meta-analysis were performed on original studies that assessed the effect of RMT (RMST or RMET) on endurance performance in healthy humans by use of at least one of the following exercise tests: a CLT with fixed exercise intensity and subjects performing to exhaustion; a TT with either a fixed distance or a fixed duration and with subjects being required to row, run, swim, cycle, etc. as fast as possible or to cover the largest possible distance; an intermittent incremental test (IIT) with a stepwise increase in exercise intensity including active recovery between steps and subjects performing to exhaustion; or a conventional (non-intermittent) IT with a stepwise increase in exercise intensity and subjects performing to exhaustion, a test that is frequently used to determine $\dot{V}O_{2,max}$ and/or the anaerobic threshold.

Search

A computerised search without language restriction was performed in MEDLINE, EMBASE, and CINAHL (up to October 31, 2011). The search strategy included the following keywords: “respiratory muscle training”, “inspiratory muscle training”, “expiratory muscle training”, “inspiratory training”, “expiratory training”, “hyperpnoea training”, “hyperpnea training”, “respiratory muscle endurance training”, “threshold training”, “resistive training”, “inspiratory loading”, “expiratory loading”, and “resistive loading” combined with “human”, “healthy”, and “not patient”. Only published studies were included in the analysis.

Selection

All studies performing RMT in healthy subjects and assessing endurance performance as a main outcome were selected. RMT had to consist of either RMST or RMET. One study^[46]

combined RMST and RMET and was excluded due to the interaction of combined strength and endurance training in skeletal muscles yielding different specific adaptations, compared to training one modality alone.^[47] Studies performing unloaded breathing exercises, breathing therapy, or similar, were not considered. First, all titles of the primary search were screened for potentially relevant articles. Of those, abstracts, reviews, short reports, case reports, editorials, and letters were excluded. Original studies were excluded when RMT was not performed, endurance performance was not assessed, physical training was included as an additional intervention, and when exercise tests were non-exhaustive. References of the included studies and of the excluded reviews were searched for further relevant studies.

Quality assessment

The quality of the selected RMT-studies was assessed using the following criteria.^[48, 49] (i) *Randomisation*: Random allocation of the subjects to intervention and sham-training or control group. If a trial was called "randomised controlled" but randomisation was not described, it was considered to be a randomised trial (0 points if not reported or not randomised; 1 point if reported; 2 points if randomisation procedure specified); (ii) *Blinding*: Blinding of the observer to group allocation of the subjects (0 points if not reported; 1 point if the observer was blinded); (iii) *Allocation of concealment*: Person in charge of subject recruitment was (at that time) unaware of potential group allocation (0 points if not reported; 1 point if specified); (iv) *Dropouts*: Information about missing data (0 points if not reported; 1 point if reported); (v) *Intention to treat analysis*: All subjects initially considered for the study were included and data assessed (0 points if not performed; 1 point if performed); (vi) *Power calculation*: Statistical power of the study. (0 points if not reported; 1 point if reported). Thus, a maximum of 7 points corresponding to 100% could be reached.

Data abstraction

Two investigators (IF, SKI) independently abstracted the data. Inconsistencies were cross-checked, discussed with the third investigator (CMS), and resolved by consensus.

Quantitative data synthesis

The main variable of interest was the change in endurance performance reported or calculated as the relative difference in test duration or – in case of a TT with fixed duration – the relative change in maximal distance covered. Additional variables of interest were (i) fitness level of the subjects [categorised as follows: level 1 if $\dot{V}O_{2,max} < 40 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, level 2 if $\dot{V}O_{2,max}$ 40 - 49 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, level 3 if $\dot{V}O_{2,max}$ 50 - 59 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, level 4 if $\dot{V}O_{2,max} \geq 60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; if $\dot{V}O_{2,max}$ was not provided,^[50-59] fitness level was estimated from a) endurance performance of subjects and b) description of daily activities compared to subjects in the other studies using the same exercise modality]; (ii) respiratory muscles that were trained, i.e. inspiratory and/or expiratory muscles and type of training, i.e. RMST or RMET [since specific expiratory muscle training was investigated in one single subgroup only,^[60] it was excluded from the analysis and three categories were generated for the remaining types of training: RMST.IN (inspiratory muscle strength training), RMST.INEX (combined inspiratory and expiratory muscle strength training), and RMET (respiratory muscle endurance training)]; (iii) type of test, i.e. CLT, TT, IIT, or IT; (iv) test duration before RMT, and (v) exercise modality, i.e. rowing, running, swimming (including diving), or cycling. Further potentially relevant variables such as training modalities (e.g. number of training sessions, duration of a single training session, training intensity, etc.), intensity of the physical endurance test, or subjective ratings of breathlessness and respiratory effort were not included in the multiple linear regression model in order to prevent collinearity and/or as a consequence of missing information in too many of the studies. Collinearity means that two or more variables are

interchangeable, e.g. test duration and test intensity are interchangeable because test duration becomes shorter with higher test intensity. If both variables were included in the model at the same time, this would mean a high degree of multi-collinearity and would give invalid estimates for individual predictors.

Generalised estimating equations (GEE with exchangeable correlation structure) were fitted to the dependent variable “change in endurance performance” in order to account for clustered data. Independent variables in the multiple linear regression model were fitness, type of training (RMST.IN, RMST.INEX, and RMET), type of test (CLT, TT, IIT, and IT), test duration, and type of sport (rowing, running, swimming, and cycling), including all RMT-studies independent of the presence or absence of a sham-training or control group. The multiple linear regression model thus accounts for the influence of the above confounders on changes in exercise performance after RMT. The analyses were performed with R 2.13.1.^[61] Data from two studies were reported in more than one publication.^[17, 62-64] In this case, the study that provided more details of the relevant data^[63, 64] was included in the analysis. Data from two tests were reported in two studies.^[65, 66] This data appears only once in the present analysis.^[66] In three studies,^[55, 67, 68] test duration at baseline was not indicated nor could it be calculated by use of the test protocol. Therefore, these studies were excluded from the regression model.

Furthermore, a meta-analysis was performed on the main outcome of those studies that included a sham-training or control group, and that reported the relative change and standard deviation in exercise performance such that the overall difference in exercise performance including 95% confidence intervals (95% CI) between RMT and sham/control-group could be calculated. Additionally, subgroup analysis for the different exercise tests was performed.

Heterogeneity of the studies was assessed by calculating the I^2 -statistics, which is known to be independent of the number of studies included in the meta-analysis, and thus preferable compared to the Cochrane's χ^2 - or Q-test.^[69] A value of $I^2 > 50\%$ was considered as evidence for heterogeneity.^[70] A random effects model was chosen for all tests since substantial heterogeneity was expected due to differences between fitness level, type of RMT, type and duration of test, and exercise modality. As relative improvements in TTs are generally much smaller compared to those in CLTs, mean relative differences in exercise performance were standardised based on their standard deviations. A potential publication bias was assessed by use of a funnel plot. These analyses were performed with Review Manager (RevMan, Version 5.1. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2011).

In both, the multiple linear regression model and the meta-analysis, a p-value of 0.05 was considered significant.

In those studies that did not report the standard deviations of relative changes in endurance performance, the relative differences between RMT- and sham/control-group are presented without 95% CI. If this difference was not given, it was calculated from the difference in mean absolute values before and after RMT.

Results

Trial flow and study characteristics

7385 citations were identified of which 236 potentially relevant articles remained for further evaluation (Figure 1). Finally, 49 studies were selected.^[16, 20, 21, 38, 39, 50-60, 63-68, 71-97] Of these, 28 (57%) were randomised controlled trials, 6 (12%) were controlled trials, and 15 (31%) were non-controlled trials. Further characteristics of the studies are given in Table I of the online supplement. Note that three^[55, 67, 68] of the 49 studies were excluded from the multiple regression analysis due to missing test duration. Of these, the study by Lomax et al.^[55] was included in the meta-analysis and the study by Chatham et al.^[67] was included in Figure 4 only. Methodological quality scored between 14 and 86% (median 29%, i.e. 2 of maximum 7 points; Table II of the online supplement). Study quality did not correlate with the main outcome, i.e. with the relative change in performance.

Study design: presence/absence and type of control group

Thirteen studies (27%) included a no-training control group while twenty-one studies (43%) had a sham-training group. 75% of the non-controlled studies showed an improvement in exercise performance after RMT. In studies with no-training or sham-training control groups, improvements for the RMT group were seen in 54% and 71%, respectively. In those studies that compared improvements of RMT and control groups, improvements in the RMT group were significantly greater in 75% of studies with no-training control and in 69% of studies with sham-training control.

Linear regression model

Table I depicts the linear regression model. The model revealed that (i) less fit subjects benefit more from RMT than fitter subjects, (ii) effects of RMET and RMST.IN are similar, while RMST.INEX seems to be superior to RMST.IN and RMET, (iii) improvements in performance are greater in CLTs and IITs than in ITs, with no significant difference between TTs and ITs, (iv) greater improvements are seen with increasing test duration, and (v) improvements are independent of exercise modality.

Meta-analysis

RMT results in a significant increase in exercise performance (Figure 2, standardised mean difference (SMD) 1.11 [95% CI 0.61 – 1.61], $p < 0.001$), although with moderate heterogeneity ($I^2 = 71\%$). Subgroup analysis of different tests revealed significant improvements in exercise performance when assessed by a CLT (SMD 0.66 [95% CI 0.20 – 1.12], $p = 0.005$), a TT (SMD 1.85 [95% CI 0.88 – 2.82], $p < 0.001$), or by an IIT (SMD 2.96 [95% CI 1.12 – 4.80], $p = 0.002$), whereas no significant improvement in exercise performance was detected when assessed by an IT (SMD 0.30 [95% CI -0.20 – 0.79], $p = 0.30$). Furthermore, a significant difference between groups was found ($p = 0.003$) favouring TT and IIT over CLT and IT (individual p values not shown), although with substantial heterogeneity ($I^2 = 78.3\%$). Subgroup analysis showed evidence for low heterogeneity in CLT and IT ($I^2 = 0\%$ and 18% , respectively) but high heterogeneity in TT ($I^2 = 77\%$). Heterogeneity for IIT could not be calculated as only one study was included in the meta-analysis. Figure 3 shows a funnel plot of those studies that were included in the meta-analysis.

Figure 4 shows the overall mean difference of the relative change in exercise performance for all controlled studies. The overall improvement for the RMT group over the no-training or sham-training control group was 11%, while subgroup differences were 21% for CLT, 2% for TT, 13% for IIT, and 7% for IT (2% without the studies by Enright et al.^[51] and Enright and Unnithan^[50]). These results are in agreement with those of the controlled studies included in the meta-analysis, i.e. RMT-effects are seen in CLTs, IITs, and TTs.

Discussion

The key finding of this analysis is that RMT improves performance in healthy subjects, independent of the type of RMT and exercise modality. Less fit individuals seem to benefit more from RMT than highly trained athletes, and improvements are greater with longer exercise durations. Improvements are significant when the effect of RMT is tested in CLTs, TTs, and IITs, while none are seen in ITs, commonly used to assess $\dot{V}O_{2,max}$ or anaerobic threshold.

Study design: presence/absence and type of control group

It could be assumed that study outcome may be related to study design, since only 43% of RMT studies included a sham-training group to account for a possible placebo effect of RMT. However, a closer look reveals that the presence and type of control group do not influence outcome. When considering differences between RMT and control groups, 75% of studies including a no-training control group and 69% of placebo-controlled studies showed a positive outcome for RMT (i.e. performance improvements for the RMT groups significantly exceeded those for the control groups), similar to the 75% positive outcome in studies without any controls. Thus, the presence or absence and type of control group did not affect the outcome regarding performance improvements for RMT studies in healthy subjects.

Likely reasons for the lack of improvement in exercise performance after RMT in some studies include the use of only an IT to evaluate the effects of RMT on endurance performance,^[73, 82, 86, 94] low power of the studies,^[78, 89] lack of recovery time for respiratory muscles prior to the endurance exercise test,^[38, 46, 76, 78, 96, 97] very high exercise intensity,^{[20, 38,}

^{58, 78, 89]} a highly trained group of subjects,^[58, 78, 96, 97] or an increased respiratory drive with concomitantly increased work of breathing in some subjects after RMET.^[16, 96]

Effect of subjects' fitness on improvements in exercise performance

The multiple linear regression analysis showed that less fit subjects benefit more from RMT than highly trained athletes. This finding is in accordance with the initial hypothesis suggesting that untrained subjects might benefit more from RMT since respiratory muscles of less fit subjects were shown to fatigue more during exhaustive endurance performance.^[27, 28] However, although less fit subjects have a higher potential to increase their physical endurance performance compared to highly trained athletes,^[98-101] respiratory muscle performance seems to improve to a similar extent with all levels of fitness. Also, when analysing improvements in MIP, MEP, or respiratory muscle endurance separately for the different types of training, no effect of fitness could be observed (data not shown).

On the other hand, it might be argued that greater improvements in performance are associated with older age rather than lower fitness since $\dot{V}O_{2,max}$ is known to decrease with age.^[102] However, separate analyses showed, that the relative improvement in exercise performance was negatively correlated with the level of fitness ($r = -0.440$, $p < 0.001$), while it was not correlated with age ($r = -0.018$, $p = 0.882$). Thus, it seems that the level of fitness is more important than age in affecting the amount of improvement in performance after RMT.

Influence of type of RMT on improvements in exercise performance

The multiple regression analysis revealed that RMST.IN and RMET did not differ in their effect on improving exercise performance. This result seems astonishing since the degree of fatigue developing during exhaustive exercise was shown to be similar in inspiratory and

expiratory muscles^[16, 30-36] and both of these muscle groups^[7, 10] were shown to elicit the metaboreflex that is known to impair exercise performance.^[14] Thus, one would assume that training both muscle groups, as with RMET, would yield a greater effect than training inspiratory muscles alone, such as during RMST.IN.

Thus, the question arises, why increased inspiratory muscle strength would be advantageous for exercise hyperpnoea? Despite exercise hyperpnoea being characterised by high flows it is known that inspiratory rib cage muscles produce the pressures needed to expand the rib cage and thereby let the diaphragm act as the main flow generator.^[103] Consequently, rib cage muscles fatigue during high flow tasks,^[104] although to a lesser extent than with high resistances.^[105] Thus, it seems likely that RMST.IN provides a larger training stimulus to inspiratory muscles than RMET and that more effectively trained inspiratory muscles as with RMST.IN may be superior in preventing or delaying the development of inspiratory rib cage muscle fatigue compared to RMET. This *per se* would translate into a greater improvement in exercise performance with RMST.IN than with RMET of inspiratory muscles only. It has, however, been shown that RMET also trains expiratory rib cage and abdominal muscles in addition to the inspiratory muscles which is substantiated in a smaller degree of expiratory muscle fatigue during exercise after this type of training.^[16] Therefore, an explanation for the similar improvements in performance with RMST.IN and RMET might be that, on the one hand, inspiratory muscles were trained more effectively with RMST.IN than with RMET, and on the other hand, the combination of 'less effective' inspiratory muscle training with expiratory muscle training during RMET results in the same net effect with respect to improvements in exercise performance.

The need for training the expiratory in addition to the inspiratory muscles on the one hand and the potential superiority of respiratory muscle strength over endurance training to improve exercise performance on the other hand would also be supported by the model showing that the combination of both inspiratory as well as expiratory muscle strength training, i.e. RMST.INEX, improved exercise performance more than RMST.IN or RMET. It should, however, be pointed out that so far only three research groups (six studies) used RMST.INEX and – although the model accounted for differences in fitness, type of testing and sports – one might need to consider that subjects in these studies were slightly less fit than those performing RMST.IN and RMET and evidence for physical improvements came from one single research group (four studies) testing with CLTs only (known to yield greater improvements). Final proof of a potential difference between RMST.INEX vs. RMST.IN and RMET can therefore only be provided when all three types of training are tested in the same study, having similar groups of subjects and similar performance tests. For example, a direct comparison of RMST.IN and RMET in one single study showed that effects of RMET were larger than those of RMST.IN with respect to the reduction in blood lactate concentration and perception of respiratory sensations.^[18] Thus, it also remains to be tested whether alternating RMST and RMET yield even greater improvements in performance than one type of RMT alone.

Effect of type of exercise test and test duration on the improvement in exercise performance

The multiple regression analysis showed that improvements in exercise performance after RMT were significantly greater when tested with CLTs or IITs compared to ITs with no difference between TTs and ITs. The meta-analysis of controlled studies revealed no significant effect of RMT when tested with ITs while improvements in CLTs, TTs, and in the IIT were all significant. The fact that RMT does not seem to affect IT-performance is

consistent with the notion that the duration a subject spends exercising above the threshold of $85\% \dot{V}O_{2,max}$, the exercise intensity where respiratory muscles are most likely to fatigue,^[30] is too short to elicit respiratory muscle fatigue.^[37] This is also supported by the finding that improvements in performance after RMT are greater with longer test duration (+0.4% per minute test duration, Table I). Furthermore, of 22 studies assessing $\dot{V}O_{2,max}$ before and after RMT, all but two studies found no change in $\dot{V}O_{2,max}$, Leddy et al.^[85] observed a significant increase while Verges et al.^[96] observed a significant decrease in $\dot{V}O_{2,max}$.

Interestingly, half of those tests that reported exercise intensity (n=40) were performed below the threshold of $85\% \dot{V}O_{2,max}$, maximal workload (W_{max}), or maximal velocity (v_{max}) – the average of the forty tests being $80\% \dot{V}O_{2,max}$, $81\% W_{max}$, or $98\% v_{max}$. All but two of the twenty tests that were performed below 85% showed an improvement in exercise performance after RMT. In contrast, only nine of the twenty tests that were performed above 85% showed increased performance. However, subjects performing above $85\% \dot{V}O_{2,max}$, W_{max} , or v_{max} were fitter than those performing below this threshold (fitness level of 3.1 and 2.1, respectively) which could partly explain this finding and illustrates the importance of using a model that accounts for confounders. Nevertheless, if respiratory muscles do not fatigue below the suggested threshold of $85\% \dot{V}O_{2,max}$, this would mean that a reduction in respiratory muscle fatigue could not be the only mechanism to increase endurance performance after RMT.

It is known, for example, that in CLTs psychological factors such as motivation or boredom may play an important role in determining the point of exhaustion.^[106] Accordingly, after an extended period of RMT, motivation to withstand task failure in a CLT might be higher. However, in studies using CLTs at intensities below the threshold and including a sham-

training group, improvements in the RMT groups exceeded those of the sham-training groups^[66, 71, 79, 85, 88] with only one exception.^[83] Thus again, motivation cannot be the only reason for improvements in CLT performance after RMT. Another possible explanation for improved endurance performance after RMT is a reduced perception of respiratory exertion and/or breathlessness. Of the fifteen studies testing with a CLT below the 85% threshold, only three specified changes in respiratory sensations, two^[79, 88] of them reported a significant decrease while one^[83] did not.

While the regression model, which accounted for confounders such as test duration, subjects' fitness, type of training and type of sports, did not find TTs to be more sensitive than ITs in showing improvements after RMT, the meta-analysis showed greater standardised mean differences in TTs and in the IIT compared to CLTs and ITs meaning that TTs would detect changes better than CLTs and ITs. This seems confusing at first. However, it should be considered that the model is based on all RMT studies while the meta-analysis is based only on those studies that provided the necessary data. A comparison of average changes of the studies included in the regression model and in the meta-analysis shows that the average change in test duration in studies included in the regression model was significantly larger (+15%) than that of the studies included in the meta-analysis (+5%; $p = 0.002$). However, the average fitness of subjects included in the regression model tended to be lower (2.6) than fitness of subjects included in the meta-analysis (3.1; $p = 0.065$) which might possibly explain the greater average improvement in performance of subjects included in the regression model. Thus, it seems that the studies included in the meta-analysis – despite a similar number of positive outcomes – are not fully representative of all of the RMT studies included in the regression model. Also, the studies by Enright et al.^[51] and Enright and Unnithan^[50] might contribute to the discrepancy between model and meta-analysis. These authors used a protocol

resulting in much shorter test durations (4.4 to 4.5 min) than the suggested 8-12 min required for $\dot{V}O_{2,max}$ determination.^[107] Improvements after RMT^[50, 51] were even greater (approximately 25%) than those reported for physical endurance training (approximately 10%^[108]), which raises questions regarding the validity of this protocol. Without the two studies by Enright,^[50, 51] the overall difference between improvements in IT performance after RMT and sham/control- training is 2% – equal to that for TTs. Thus, the relatively small improvements generally seen in TTs, although consistent, might be too small to exceed the changes found in ITs. However, it must be noted that these small improvements in TT performance are highly relevant. For example, mean improvements in the forty TTs would result in 40 m or five skiff lengths in a 2 km rowing regatta, 100 m in a 2 km running race, 1.2 m in a 200 m swimming competition, and 1 km in a 30 km cycling race.

The fact that improvements in exercise performance after RMT were significantly greater (19%) also in IITs compared to ITs suggests that amateur and professional athletes performing intermittent sports such as football, soccer, basketball, team handball, etc. might benefit from RMT similar to subjects performing endurance type sports. This is further supported by one study that showed a reduction in recovery duration between sprints, which was in part attributed to a decreased perception of respiratory effort.^[20]

Effects of RMT in different types of sports

Although physiological evidence would suggest that RMT might be more effective in sports where respiratory muscles are subjected to increased respiratory work^[44] (swimming) and/or increased non-respiratory work, i.e. postural^[41-43] (running) or moving^[38-40] (rowing) tasks, the model did not reveal any significant difference between improvements in the different types of sports. Thus, one could assume that respiratory muscles involved in additional tasks

resulting in higher respiratory muscle work are sufficiently trained such that the likelihood to fatigue is similar to that during, for example, cycling. Supporting of this assumption is the following interesting observation. For the studies included in the present review giving respiratory muscle strength data and including subjects with a fitness level of 3 or 4, baseline values of MIP and especially MEP expressed as percent predicted values^[109] are lowest in cycling and increase with rowing, running, and swimming (data not shown).

Limitations

Several variables of interest were not included in the analysis. For example, duration of the training period or training intensity might also influence changes in endurance performance although these variables were quite similar within RMST and within RMET-studies. Therefore, only type of training was included in the multiple linear regression model while factors describing training regimes were omitted to prevent collinearity. Furthermore, exercise intensity is believed to play a crucial role with respect to the development of respiratory muscle fatigue and therefore with respect to a possible benefit from RMT. Intensity of the exercise tests was not, however, included in the model. Since too many studies did not provide detailed information on exercise intensity (n=24), the inclusion of this variable would have led to the exclusion of too many studies from the regression model. Furthermore, since only exhaustive tests were included in the model, test duration and intensity would have led to collinearity with the consequence to exclude one or the other variable from the model. The same holds true for ratings of perceived breathlessness or respiratory effort which have been shown to be lower after RMT in some studies^[16, 20, 39, 53, 55, 59, 60, 63, 67, 72, 73, 76, 79, 88, 96, 110] but not in others.^[38, 56, 58, 60, 83, 97, 111] As only 21 studies provided this information, the inclusion of these variables in the linear regression model would have led to the exclusion of too many studies. Therefore, the variables “intensity” and “respiratory sensations” were omitted despite

their potential to explain possible changes after RMT. These variables might, however, be included in the intercept. The significance of the intercept indicates that additional factors not included in the model play a role in determining improvements in exercise performance.

A further consideration is that the funnel plot shows a potential publication bias. In general: without publication bias, studies would be evenly distributed around the mean, in form of a triangle. Studies with small standard errors (often those with many subjects included) are found at the top of the triangle close to the mean. Studies with large standard errors (frequently smaller studies) are found at the bottom of the triangle with some of them having a greater distance to the mean. In the present meta-analysis, studies at the bottom left of the triangle are missing. This could mean that smaller studies with negative outcome were not published in addition to the possibility that no such studies were ever conducted. If those small studies with negative outcome were present in the funnel plot, this would mean that the effect of RMT would be smaller than shown in the present analysis.

Conclusions

This is the first study to systematically assess the effect of different types of RMT used to improve exercise performance in healthy subjects. It clearly shows that RMT significantly improves endurance performance, independent of the type of RMT or the type of sport. No difference was found between the effects of the two most commonly used respiratory muscle training modalities, RMST.IN and RMET, while RMST.INEX seemed to be superior. Less fit individuals benefit more from RMT than highly trained athletes and improvements are greater with longer exercise durations even at intensities lower than the postulated threshold for development of respiratory muscle fatigue ($85\% \dot{V}O_{2,max}$). This emphasises the importance to report changes in respiratory sensations after RMT so that this variable can be included in

future regression models as well. Furthermore, when assessing the effect of RMT, care must be taken regarding the choice of the test since effects are not seen in ITs that are commonly used to assess $\dot{V}O_{2,max}$ or anaerobic threshold. Also, more well-controlled studies are needed to prove a superiority of RMST.INEX over the commonly used types of RMT, to confirm the positive results observed in the few studies using IITs, and to investigate a possible additional benefit from alternating RMET and RMST.

References

1. Mador MJ, Acevedo FA. Effect of respiratory muscle fatigue on subsequent exercise performance. *J Appl Physiol*. 1991 May; 70 (5): 2059-65.
2. Verges S, Sager Y, Erni C, et al. Expiratory muscle fatigue impairs exercise performance. *Eur J Appl Physiol*. 2007 Sep; 101 (2): 225-32.
3. Dempsey JA, Romer L, Rodman J, et al. Consequences of exercise-induced respiratory muscle work. *Respir Physiol Neurobiol*. 2006 Apr 28; 151 (2-3): 242-50.
4. Hill JM. Discharge of group IV phrenic afferent fibers increases during diaphragmatic fatigue. *Brain res*. 2000 Feb 21; 856 (1-2): 240-4.
5. Graham R, Jammes Y, Delpierre S, et al. The effects of ischemia, lactic acid and hypertonic sodium chloride on phrenic afferent discharge during spontaneous diaphragmatic contraction. *Neurosci lett*. 1986 Jun 30; 67 (3): 257-62.
6. Jammes Y, Balzamo E. Changes in afferent and efferent phrenic activities with electrically induced diaphragmatic fatigue. *J Appl Physiol*. 1992 Sep; 73 (3): 894-902.
7. Derchak PA, Sheel AW, Morgan BJ, et al. Effects of expiratory muscle work on muscle sympathetic nerve activity. *J Appl Physiol*. 2002 Apr; 92 (4): 1539-52.
8. Rodman JR, Henderson KS, Smith CA, et al. Cardiovascular effects of the respiratory muscle metaboreflexes in dogs: rest and exercise. *J Appl Physiol*. 2003 Sep; 95 (3): 1159-69.
9. Sheel AW, Derchak PA, Morgan BJ, et al. Fatiguing inspiratory muscle work causes reflex reduction in resting leg blood flow in humans. *J Physiol*. 2001 Nov 15; 537 (Pt 1): 277-89.
10. St Croix CM, Morgan BJ, Wetter TJ, et al. Fatiguing inspiratory muscle work causes reflex sympathetic activation in humans. *J Physiol*. 2000 Dec 1; 529 Pt 2: 493-504.

11. Harms CA, Babcock MA, McClaran SR, et al. Respiratory muscle work compromises leg blood flow during maximal exercise. *J Appl Physiol*. 1997 May; 82 (5): 1573-83.
12. McConnell AK, Lomax M. The influence of inspiratory muscle work history and specific inspiratory muscle training upon human limb muscle fatigue. *J Physiol*. 2006 Nov 15; 577 (Pt 1): 445-57.
13. Romer LM, Lovering AT, Haverkamp HC, et al. Effect of inspiratory muscle work on peripheral fatigue of locomotor muscles in healthy humans. *J Physiol*. 2006 Mar 1; 571 (Pt 2): 425-39.
14. Harms CA, Wetter TJ, St Croix CM, et al. Effects of respiratory muscle work on exercise performance. *J Appl Physiol*. 2000 Jul; 89 (1): 131-8.
15. Babcock MA, Pegelow DF, Harms CA, et al. Effects of respiratory muscle unloading on exercise-induced diaphragm fatigue. *J Appl Physiol*. 2002 Jul; 93 (1): 201-6.
16. Verges S, Lenherr O, Haner AC, et al. Increased fatigue resistance of respiratory muscles during exercise after respiratory muscle endurance training. *Am J Physiol Regul Integr Comp Physiol*. 2007 Mar; 292 (3): R1246-53.
17. Romer LM, McConnell AK, Jones DA. Inspiratory muscle fatigue in trained cyclists: effects of inspiratory muscle training. *Med Sci Sports Exerc*. 2002 May; 34 (5): 785-92.
18. Verges S, Renggli AS, Notter DA, et al. Effects of different respiratory muscle training regimes on fatigue-related variables during volitional hyperpnoea. *Respir Physiol Neurobiol*. 2009 Dec 31; 169 (3): 282-90.
19. McConnell AK, Sharpe GR. The effect of inspiratory muscle training upon maximum lactate steady-state and blood lactate concentration. *Eur J Appl Physiol*. 2005 Jun; 94 (3): 277-84.

20. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training upon recovery time during high intensity, repetitive sprint activity. *Int J Sports Med.* 2002 Jul; 23 (5): 353-60.
21. Spengler CM, Roos M, Laube SM, et al. Decreased exercise blood lactate concentrations after respiratory endurance training in humans. *Eur J Appl Physiol Occup Physiol.* 1999 Mar; 79 (4): 299-305.
22. Witt JD, Guenette JA, Rupert JL, et al. Inspiratory muscle training attenuates the human respiratory muscle metaboreflex. *J Physiol.* 2007 Nov 1; 584 (Pt 3): 1019-28.
23. Clanton TL, Dixon GF, Drake J, et al. Effects of swim training on lung volumes and inspiratory muscle conditioning. *J Appl Physiol.* 1987 Jan; 62 (1): 39-46.
24. Martin BJ, Stager JM. Ventilatory endurance in athletes and non-athletes. *Med Sci Sports Exerc.* 1981; 13 (1): 21-6.
25. Robinson EP, Kjeldgaard JM. Improvement in ventilatory muscle function with running. *J Appl Physiol.* 1982 Jun; 52 (6): 1400-6.
26. Aaron EA, Seow KC, Johnson BD, et al. Oxygen cost of exercise hyperpnea: implications for performance. *J Appl Physiol.* 1992 May; 72 (5): 1818-25.
27. Choukroun ML, Kays C, Gioux M, et al. Respiratory muscle function in trained and untrained adolescents during short-term high intensity exercise. *Eur J Appl Physiol Occup Physiol.* 1993; 67 (1): 14-9.
28. Coast JR, Clifford PS, Henrich TW, et al. Maximal inspiratory pressure following maximal exercise in trained and untrained subjects. *Med Sci Sports Exerc.* 1990 Dec; 22 (6): 811-5.
29. Leith DE, Bradley M. Ventilatory muscle strength and endurance training. *J Appl Physiol.* 1976 Oct; 41 (4): 508-16.
30. Johnson BD, Babcock MA, Suman OE, et al. Exercise-induced diaphragmatic fatigue in healthy humans. *J Physiol.* 1993 Jan; 460: 385-405.

31. Mador MJ, Magalang UJ, Rodis A, et al. Diaphragmatic fatigue after exercise in healthy human subjects. *Am Rev Respir Dis*. 1993 Dec; 148 (6 Pt 1): 1571-5.
32. Babcock MA, Johnson BD, Pegelow DF, et al. Hypoxic effects on exercise-induced diaphragmatic fatigue in normal healthy humans. *J Appl Physiol*. 1995 Jan; 78 (1): 82-92.
33. Babcock MA, Pegelow DF, McClaran SR, et al. Contribution of diaphragmatic power output to exercise-induced diaphragm fatigue. *J Appl Physiol*. 1995 May; 78 (5): 1710-9.
34. Taylor BJ, How SC, Romer LM. Exercise-induced abdominal muscle fatigue in healthy humans. *J Appl Physiol*. 2006 May; 100 (5): 1554-62.
35. Taylor BJ, Romer LM. Effect of expiratory muscle fatigue on exercise tolerance and locomotor muscle fatigue in healthy humans. *J Appl Physiol*. 2008 May; 104 (5): 1442-51.
36. Verges S, Schulz C, Perret C, et al. Impaired abdominal muscle contractility after high-intensity exhaustive exercise assessed by magnetic stimulation. *Muscle Nerve*. 2006 Oct; 34 (4): 423-30.
37. Romer LM, Miller JD, Haverkamp HC, et al. Inspiratory muscles do not limit maximal incremental exercise performance in healthy subjects. *Respir Physiol Neurobiol*. 2007 Jun 15; 156 (3): 353-61.
38. Riganas CS, Vrabas IS, Christoulas K, et al. Specific inspiratory muscle training does not improve performance or VO₂max levels in well trained rowers. *J Sports Med Phys Fitness*. 2008 Sep; 48 (3): 285-92.
39. Volianitis S, McConnell AK, Koutedakis Y, et al. Inspiratory muscle training improves rowing performance. *Med Sci Sports Exerc*. 2001 May; 33 (5): 803-9.
40. Cunningham DA, Goode PB, Critz JB. Cardiorespiratory response to exercise on a rowing and bicycle ergometer. *Med Sci Sports*. 1975 Spring; 7 (1): 37-43.

41. Grillner S, Nilsson J, Thorstensson A. Intra-abdominal pressure changes during natural movements in man. *Acta Physiol Scand*. 1978 Jul; 103 (3): 275-83.
42. Hodges PW, Butler JE, McKenzie DK, et al. Contraction of the human diaphragm during rapid postural adjustments. *J Physiol*. 1997 Dec 1; 505 (Pt 2): 539-48.
43. Hodges PW, Gandevia SC. Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *J Appl Physiol*. 2000 Sep; 89 (3): 967-76.
44. Pendergast DR, Lundgren CE. The underwater environment: cardiopulmonary, thermal, and energetic demands. *J Appl Physiol*. 2009 Jan; 106 (1): 276-83.
45. Guenette JA, Sheel AW. Physiological consequences of a high work of breathing during heavy exercise in humans. *J Sci Med Sport*. 2007 Dec; 10 (6): 341-50.
46. Sonetti DA, Wetter TJ, Pegelow DF, et al. Effects of respiratory muscle training versus placebo on endurance exercise performance. *Respir Physiol*. 2001 Sep; 127 (2-3): 185-99.
47. Leveritt M, Abernethy PJ, Barry BK, et al. Concurrent strength and endurance training. A review. *Sports Med*. 1999 Dec; 28 (6): 413-27.
48. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health*. 1998 Jun; 52 (6): 377-84.
49. Jadad AR, Moore RA, Carroll D, et al. Assessing the quality of reports of randomized clinical trials: is blinding necessary? *Control Clin Trials*. 1996 Feb; 17 (1): 1-12.
50. Enright SJ, Unnithan VB. Effect of inspiratory muscle training intensities on pulmonary function and work capacity in people who are healthy: a randomized controlled trial. *Phys Ther*. 2011 Jun; 91 (6): 894-905.

51. Enright SJ, Unnithan VB, Heward C, et al. Effect of high-intensity inspiratory muscle training on lung volumes, diaphragm thickness, and exercise capacity in subjects who are healthy. *Phys Ther.* 2006 Mar; 86 (3): 345-54.
52. Johnson MA, Sharpe GR, Brown PI. Inspiratory muscle training improves cycling time-trial performance and anaerobic work capacity but not critical power. *Eur J Appl Physiol.* 2007 Dec; 101 (6): 761-70.
53. Kilding AE, Brown S, McConnell AK. Inspiratory muscle training improves 100 and 200 m swimming performance. *Eur J Appl Physiol.* 2010 Feb; 108 (3): 505-11.
54. Kohl J, Koller EA, Brandenberger M, et al. Effect of exercise-induced hyperventilation on airway resistance and cycling endurance. *Eur J Appl Physiol Occup Physiol.* 1997; 75 (4): 305-11.
55. Lomax M, Grant I, Corbett J. Inspiratory muscle warm-up and inspiratory muscle training: separate and combined effects on intermittent running to exhaustion. *J Sports Sci.* 2011 Mar; 29 (6): 563-9.
56. Nicks CR, Morgan DW, Fuller DK, et al. The influence of respiratory muscle training upon intermittent exercise performance. *Int J Sports Med.* 2009 Jan; 30 (1): 16-21.
57. Tong TK, Fu FH, Chung PK, et al. The effect of inspiratory muscle training on high-intensity, intermittent running performance to exhaustion. *Appl Physiol Nutr Metab.* 2008 Aug; 33 (4): 671-81.
58. Wells GD, Plyley M, Thomas S, et al. Effects of concurrent inspiratory and expiratory muscle training on respiratory and exercise performance in competitive swimmers. *Eur J Appl Physiol.* 2005 Aug; 94 (5-6): 527-40.
59. Huang CH, Yang GG, Wu YT, et al. Comparison of inspiratory muscle strength training effects between older subjects with and without chronic obstructive pulmonary disease. *J Formos Med Assoc.* 2011 Aug; 110 (8): 518-26.

60. Griffiths LA, McConnell AK. The influence of inspiratory and expiratory muscle training upon rowing performance. *Eur J Appl Physiol*. 2007 Mar; 99 (5): 457-66.
61. Team RDC. R: A Language and Environment for Statistical Computing. 2011; Available from: <http://www.R-project.org/>.
62. Markov G, Spengler CM, Knöpfli-Lenzin C, et al. Respiratory muscle training increases cycling endurance without affecting cardiovascular responses to exercise. *Eur J Appl Physiol*. 2001 Aug; 85 (3-4): 233-9.
63. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training on time-trial performance in trained cyclists. *J Sports Sci*. 2002 Jul; 20 (7): 547-62.
64. Stuessi C, Spengler CM, Knöpfli-Lenzin C, et al. Respiratory muscle endurance training in humans increases cycling endurance without affecting blood gas concentrations. *Eur J Appl Physiol*. 2001 Jun; 84 (6): 582-6.
65. Lindholm P, Wylegala J, Pendergast DR, et al. Resistive respiratory muscle training improves and maintains endurance swimming performance in divers. *Undersea Hyperb Med*. 2007 May-Jun; 34 (3): 169-80.
66. Wylegala JA, Pendergast DR, Gosselin LE, et al. Respiratory muscle training improves swimming endurance in divers. *Eur J Appl Physiol*. 2007 Mar; 99 (4): 393-404.
67. Chatham K, Baldwin J, Griffiths H, et al. Inspiratory muscle training improves shuttle run performance in healthy subjects. *Phys Ther*. 1999; 85 (12): 676-83.
68. Esposito F, Limonta E, Alberti G, et al. Effect of respiratory muscle training on maximum aerobic power in normoxia and hypoxia. *Respir Physiol Neurobiol*. 2010 Mar 31; 170 (3): 268-72.
69. Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med*. 2002 Jun 15; 21 (11): 1539-58.

70. Higgins JPT, Thompson SG, Deeks JJ, et al. Measuring inconsistency in meta-analyses. *BMJ*. 2003 Sep 6; 327 (7414): 557-60.
71. Aznar-Lain S, Webster AL, Cañete S, et al. Effects of inspiratory muscle training on exercise capacity and spontaneous physical activity in elderly subjects: a randomized controlled pilot trial. *Int J Sports Med*. 2007 Dec; 28 (12): 1025-9.
72. Bailey SJ, Romer LM, Kelly J, et al. Inspiratory muscle training enhances pulmonary O₂ uptake kinetics and high-intensity exercise tolerance in humans. *J Appl Physiol*. 2010 Aug; 109 (2): 457-68.
73. Belman MJ, Gaesser GA. Ventilatory muscle training in the elderly. *J Appl Physiol*. 1988 Mar; 64 (3): 899-905.
74. Boutellier U, Büchel R, Kundert A, et al. The respiratory system as an exercise limiting factor in normal trained subjects. *Eur J Appl Physiol Occup Physiol*. 1992; 65 (4): 347-53.
75. Boutellier U, Piwko P. The respiratory system as an exercise limiting factor in normal sedentary subjects. *Eur J Appl Physiol Occup Physiol*. 1992; 64 (2): 145-52.
76. Downey AE, Chenoweth LM, Townsend DK, et al. Effects of inspiratory muscle training on exercise responses in normoxia and hypoxia. *Respir Physiol Neurobiol*. 2007 May 14; 156 (2): 137-46.
77. Edwards AM, Cooke CB. Oxygen uptake kinetics and maximal aerobic power are unaffected by inspiratory muscle training in healthy subjects where time to exhaustion is extended. *Eur J Appl Physiol*. 2004 Oct; 93 (1-2): 139-44.
78. Fairbairn MS, Coutts KC, Pardy RL, et al. Improved respiratory muscle endurance of highly trained cyclists and the effects on maximal exercise performance. *Int J Sports Med*. 1991 Feb; 12 (1): 66-70.
79. Gething AD, Williams M, Davies B. Inspiratory resistive loading improves cycling capacity: a placebo controlled trial. *Br J Sports Med*. 2004 Dec; 38 (6): 730-6.

80. Guenette JA, Martens AM, Lee AL, et al. Variable effects of respiratory muscle training on cycle exercise performance in men and women. *Appl Physiol Nutr Metab*. 2006 Apr; 31 (2): 159-66.
81. Hanel B, Secher NH. Maximal oxygen uptake and work capacity after inspiratory muscle training: a controlled study. *J Sports Sci*. 1991 Spring; 9 (1): 43-52.
82. Hart N, Sylvester K, Ward S, et al. Evaluation of an inspiratory muscle trainer in healthy humans. *Respir Med*. 2001 Jun; 95 (6): 526-31.
83. Holm P, Sattler A, Fregosi RF. Endurance training of respiratory muscles improves cycling performance in fit young cyclists. *BMC Physiol*. 2004 May 6; 4.
84. Kwok TMK, Jones AYM. Target-flow inspiratory muscle training improves running performance in recreational runners: a randomized controlled trial. *Hong Kong Physiother J*. 2009; 27: 48-54.
85. Leddy JJ, Limprasertkul A, Patel S, et al. Isocapnic hyperpnea training improves performance in competitive male runners. *Eur J Appl Physiol*. 2007 Apr; 99 (6): 665-76.
86. Markov G, Orlor R, Boutellier U. Respiratory training, hypoxic ventilatory response and acute mountain sickness. *Respir Physiol*. 1996 Sep; 105 (3): 179-86.
87. McMahon ME, Boutellier U, Smith RM, et al. Hyperpnea training attenuates peripheral chemosensitivity and improves cycling endurance. *J Exp Biol*. 2002 Dec; 205 (Pt 24): 3937-43.
88. Mickleborough TD, Nichols T, Lindley MR, et al. Inspiratory flow resistive loading improves respiratory muscle function and endurance capacity in recreational runners. *Scand J Med Sci Sports*. 2010 Jun; 20 (3): 458-68.
89. Morgan DW, Kohrt WM, Bates BJ, et al. Effects of respiratory muscle endurance training on ventilatory and endurance performance of moderately trained cyclists. *Int J Sports Med*. 1987 Apr; 8 (2): 88-93.

90. Mucci P, Lesaignoux Y. Inspiratory-muscle training and critical velocity [in French]. *Sci Sports*. 2008; 23: 255-7.
91. Ray AD, Pendergast DR, Lundgren CEG. Respiratory muscle training improves swimming endurance at depth. *Undersea Hyperb Med*. 2008 May-Jun; 35 (3): 185-96.
92. Ray AD, Pendergast DR, Lundgren CEG. Respiratory muscle training reduces the work of breathing at depth. *Eur J Appl Physiol*. 2010 Mar; 108 (4): 811-20.
93. Spengler CM, Laube SM, Roos M, et al. The effect of breathing pattern during respiratory training on cycling endurance. In: Steinacker JM, Ward SA, editors. *The physiology and pathophysiology of exercise tolerance*. New York: Plenum Press; 1996. p. 315-9.
94. Sperlich B, Fricke H, de Mares M, et al. Does respiratory muscle training increase physical performance? *Mil Med*. 2009 Sep; 174 (9): 977-82.
95. Swanson GD. Pulmonary training may alter exertional dyspnea and fatigue via an exercise-like training effect of a lowered heart rate. *Adv Exp Med Biol*. 1998; 450: 231-6.
96. Verges S, Kruttli U, Stahl B, et al. Respiratory control, respiratory sensations and cycling endurance after respiratory muscle endurance training. *Adv Exp Med Biol*. 2008; 605: 239-44.
97. Williams JS, Wongsathikun J, Boon SM, et al. Inspiratory muscle training fails to improve endurance capacity in athletes. *Med Sci Sports Exerc*. 2002 Jul; 34 (7): 1194-8.
98. Pollock ML. The quantification of endurance training programs. *Exerc Sport Sci Rev*. 1973; 1: 155-88.
99. Saltin B, Hartley LH, Kilbom A, et al. Physical training in sedentary middle-aged and older men. II. Oxygen uptake, heart rate, and blood lactate concentration at

- submaximal and maximal exercise. *Scand J Clin Lab Invest*. 1969 Dec; 24 (4): 323-34.
100. Sharkey BJ. Intensity and duration of training and the development of cardiorespiratory endurance. *Med Sci Sports*. 1970 Winter; 2 (4): 197-202.
 101. Wenger HA, Bell GJ. The interactions of intensity, frequency and duration of exercise training in altering cardiorespiratory fitness. *Sports Med*. 1986 Sep-Oct; 3 (5): 346-56.
 102. Wilson TM, Tanaka H. Meta-analysis of the age-associated decline in maximal aerobic capacity in men: relation to training status. *Am J Physiol Heart Circ Physiol*. 2000 Mar; 278 (3): H829-34.
 103. Aliverti A, Cala SJ, Duranti R, et al. Human respiratory muscle actions and control during exercise. *J Appl Physiol*. 1997 Oct; 83 (4): 1256-69.
 104. Illi SK, Hostettler S, Mohler E, et al. Compartmental chest wall volume changes during volitional normocapnic hyperpnoea. *Respir Physiol Neurobiol*. 2011 Aug 15; 177 (3): 294-300.
 105. McCool FD, Hershenson MB, Tzelepis GE, et al. Effect of fatigue on maximal inspiratory pressure-flow capacity. *J Appl Physiol*. 1992 Jul; 73 (1): 36-43.
 106. Jeukendrup A, Saris WHM, Brouns F, et al. A new validated endurance performance test. *Med Sci Sports Exerc*. 1996 Feb; 28 (2): 266-70.
 107. Buchfuhrer MJ, Hansen JE, Robinson TE, et al. Optimizing the exercise protocol for cardiopulmonary assessment. *J Appl Physiol*. 1983 Nov; 55 (5): 1558-64.
 108. Jones AM, Carter H. The effect of endurance training on parameters of aerobic fitness. *Sports Med*. 2000 Jun; 29 (6): 373-86.
 109. Wilson SH, Cooke NT, Edwards RH, et al. Predicted normal values for maximal respiratory pressures in caucasian adults and children. *Thorax*. 1984 Jul; 39 (7): 535-8.
 110. Suzuki S, Sato M, Okubo T. Expiratory muscle training and sensation of respiratory effort during exercise in normal subjects. *Thorax*. 1995 Apr; 50 (4): 366-70.

111. Suzuki S, Yoshiike Y, Suzuki M, et al. Inspiratory muscle training and respiratory sensation during treadmill exercise. *Chest*. 1993 Jul; 104 (1): 197-202.

Table I. Multiple linear regression model

	Estimate	SE	95% CI	p-value
Intercept	17.8	8.8	0.6; 35.1	0.043
Fitness	-6.0	2.1	-10.2; -1.8	0.005
RMST.INEX vs. RMST.IN	12.8	4.7	3.6; 22.0	0.006
RMET vs. RMST.IN	-4.7	3.7	-12.0; 2.6	0.208
CLT vs. IT	16.5	3.2	10.2; 22.8	0.000
TT vs. IT	-3.7	3.4	-10.4; 3.1	0.286
IIT vs. IT	18.5	3.9	10.8; 26.3	0.000
Testduration	0.4	0.1	0.1; 0.6	0.011
Rowing vs. Cycling	1.9	4.9	-7.7; 11.4	0.701
Running vs. Cycling	-4.6	5.3	-14.9; 5.8	0.390
Swimming vs. Cycling	5.2	5.5	-5.6; 16.1	0.347

SE = standard error of the mean; 95% CI = 95% confidence interval; RMST.INEX = inspiratory and expiratory muscle strength training; RMST.IN = inspiratory muscle strength training; RMET = respiratory muscle endurance training; CLT = constant load test; TT = time trial; IIT = intermittent incremental test; IT = conventional (non-intermittent) incremental test. *Note:* When RMET was chosen as the reference group, the estimate for the comparison between RMST.INEX and RMET (17.5, SE 4.8, 95% CI 8.2 - 26.9) was also significant ($p = 0.000$).

Figure 1

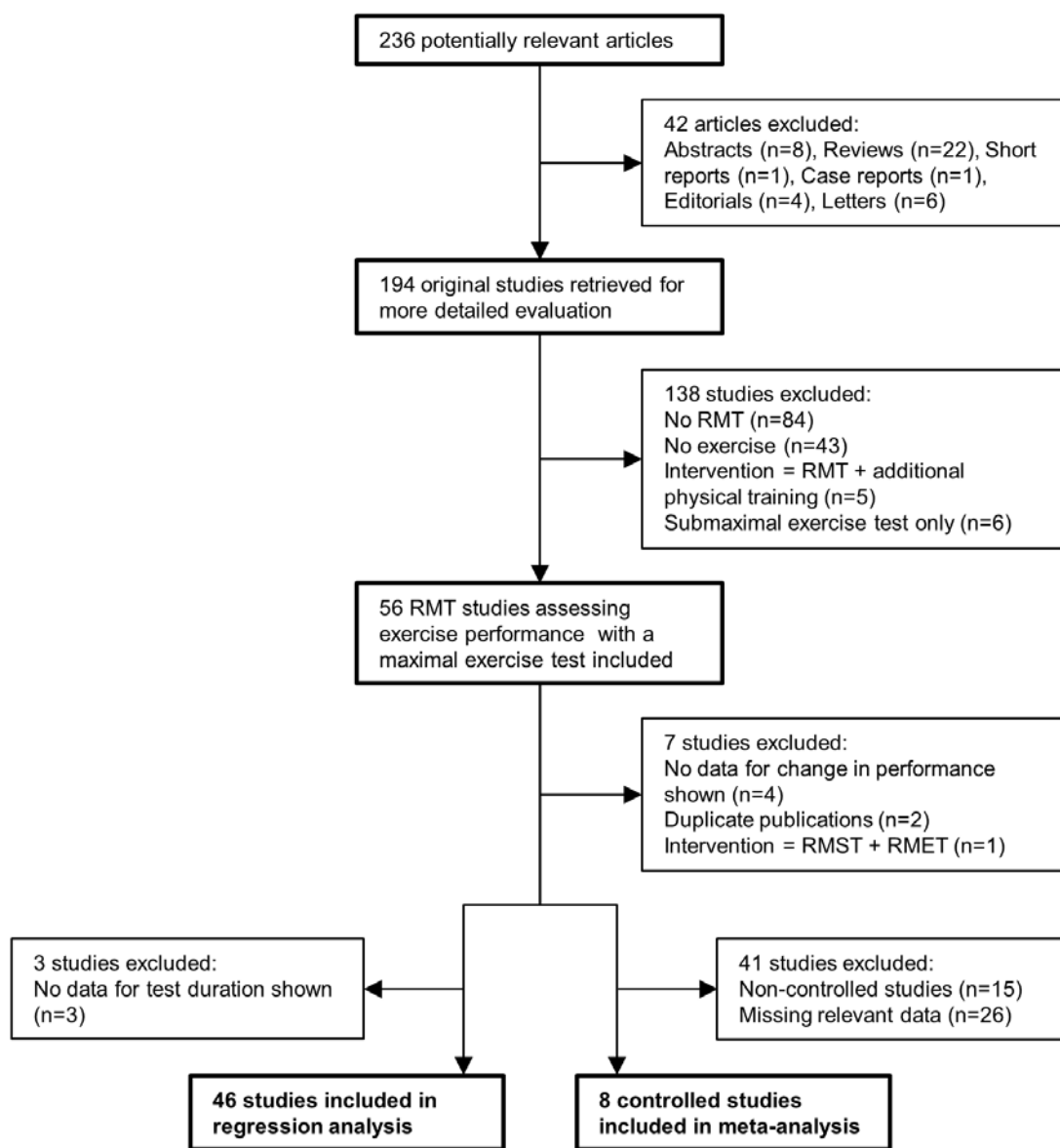


Figure 2

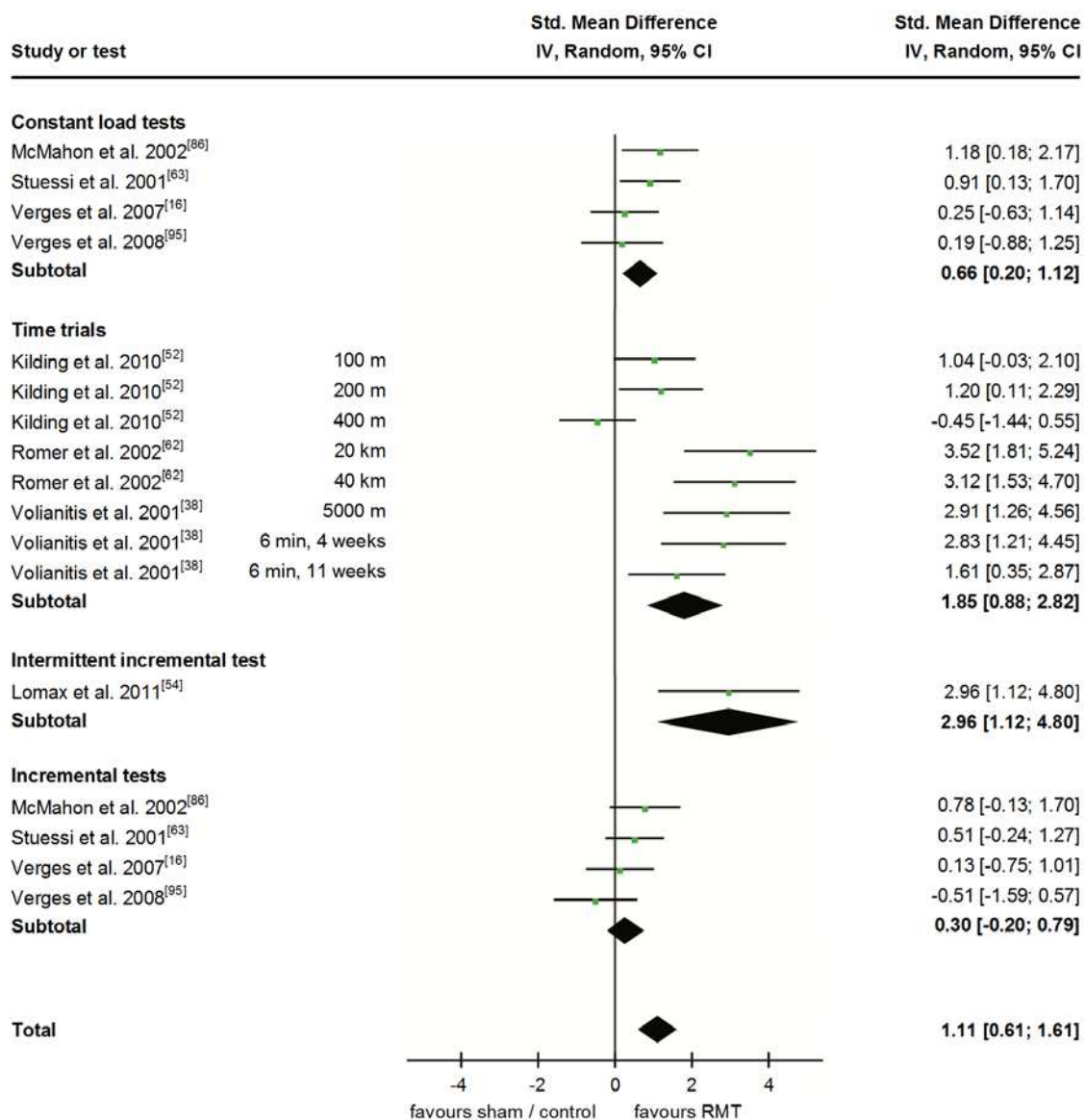


Figure 3

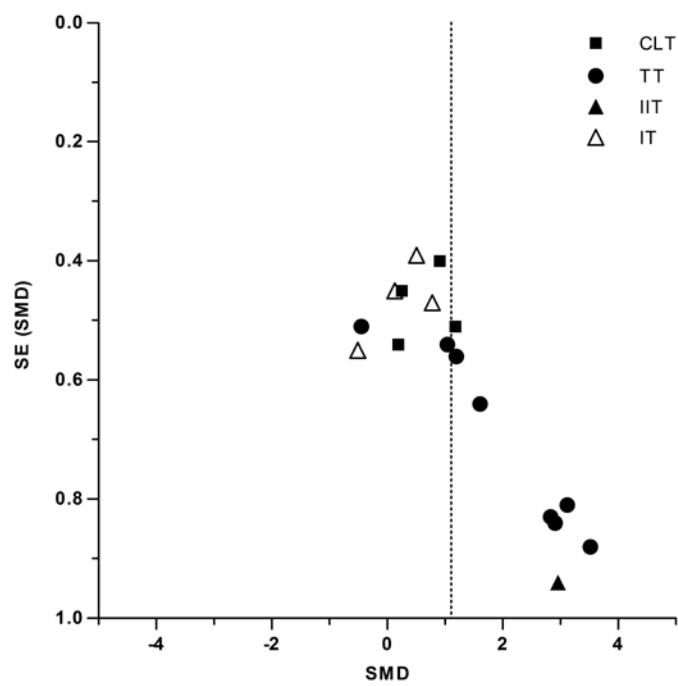
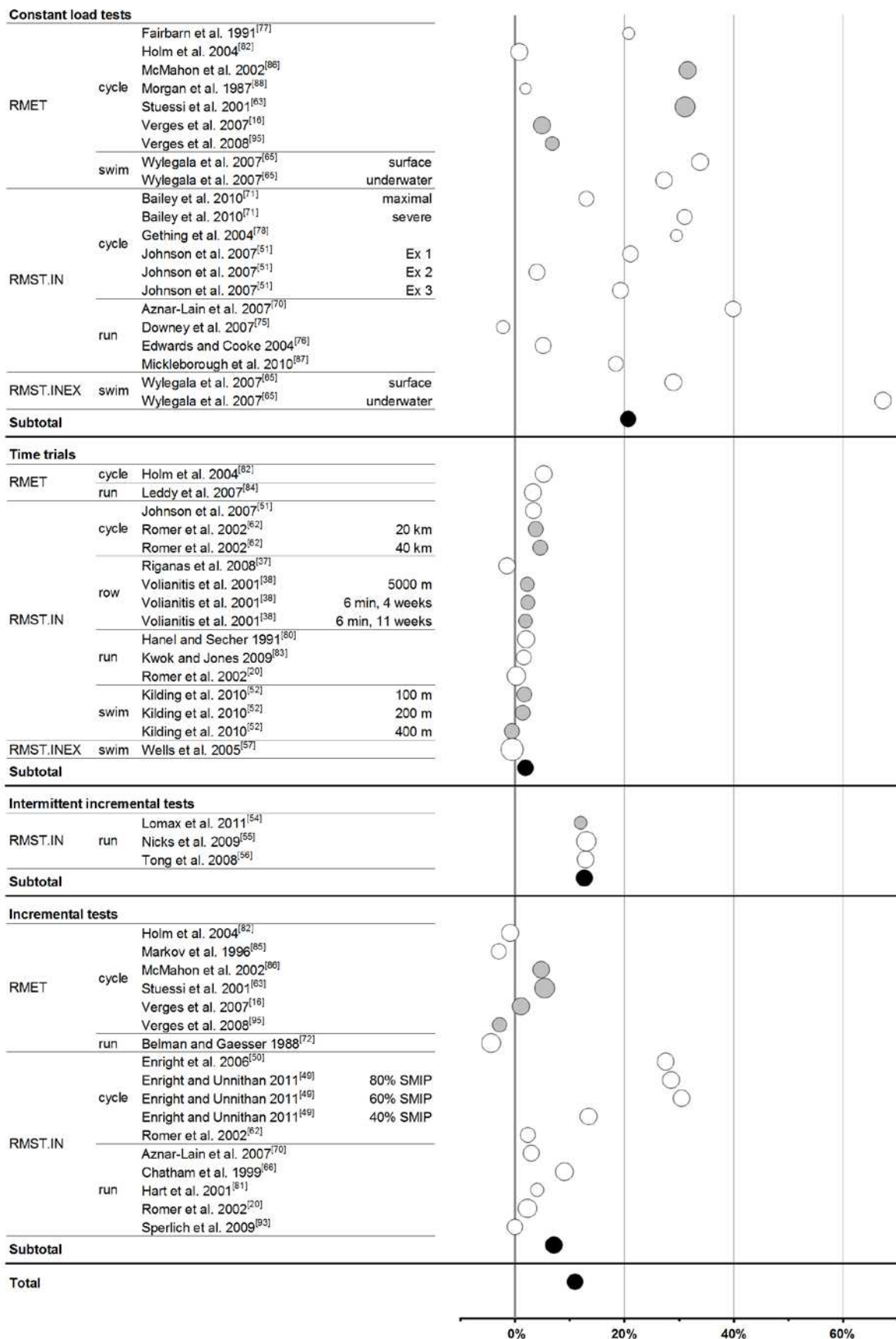


Figure 4



Online Supplement

Table I. Study characteristics	II
Table II. Methodological study quality	XXXI
References	XXXIV

Please note that References are numbered according to the numbering in the original manuscript.

Table I. Study characteristics

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Aznar-Lain et al. 2007 ^[71]	Randomised controlled trial Single-blind RMST: n = 9 (2/7) Sham: n = 9 (2/7)	<u>RMST:</u> Age = 68.5 y Height = 1.58 m Body mass = 66.0 kg MIP = 54 cmH ₂ O (n=8) $\dot{V}O_{2,max}$ = 24.2 ml/kg/min CLT (run) = 18.1 min IT (run) = 14.9 min <u>Sham:</u> Age = 67.8 y Height = 1.59 m Body mass = 77.6 kg MIP = 68 cm H ₂ O $\dot{V}O_{2,max}$ = 22.8 ml/kg/min CLT (run) = 15.1 min IT (run) = 12.8 min	<u>RMST:</u> 40-60 (mean 54) repetitions at 50-80 (mean 69)% MIP (load↑ with MIP↑ after 4 weeks) once per day 3-5 (mean 4.8) times per week 8 weeks <u>Sham:</u> 40-60 (mean 54) repetitions at 7 cmH ₂ O resistance once per day 3-5 (mean 4.8) times per week 8 weeks	<u>RMST:</u> MIP: +46%*, sig (n=8) $\dot{V}O_{2,max}$ +3% CLT: +36%*, sig IT: +11% <u>Sham:</u> MIP: +5% $\dot{V}O_{2,max}$ -9% CLT: -4% IT: +8%	43%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Bailey et al. 2010 ^[72]	Randomised controlled trial Single-blind RMST: n = 8 (6/2) Sham: n = 8 (6/2)	<u>RMST:</u> Age = 20 y Height = 1.75 m Body mass = 74 kg MIP = 155 cmH ₂ O $\dot{V}O_{2,max}$ = 47 ml/kg/min CLT _{max} (cycle) = 2.95 min CLT _{severe} (cycle) = 12.75 min <u>Sham:</u> Age = 22 y Height = 1.75 m Body mass = 74 kg MIP = 153 cmH ₂ O $\dot{V}O_{2,max}$ = 48 ml/kg/min CLT _{max} (cycle) = 2.78 min CLT _{severe} (cycle) = 16.53 min	<u>RMST:</u> 30 dynamic inspiratory efforts at 50% MIP (load↑ with 30RM↑) twice per day 7 times per week 4 weeks <u>Sham:</u> 60 slow protracted breaths at 15% MIP once per day 7 times per week 4 weeks	<u>RMST:</u> MIP: +17%* CLT _{max} : +18%*, sig CLT _{severe} : +39%* <u>Sham:</u> MIP: +4% CLT _{max} : +5% CLT _{severe} : +8%	43%
Belman and Gaesser 1988 ^[73]	Randomised controlled trial Blinding not specified RMET: n = 12 (7/5) Control: n = 13 (4/9)	<u>RMET:</u> Age = 69.7 y Height = 1.66 m Body mass = 75.8 kg MVV = 116 l/min $\dot{V}O_{2,max}$ = 24.8 ml/kg/min IT (run) = 13.70 min <u>Control:</u> Age = 67.2 y Height = 1.65 m Body mass = 74.8 kg MVV = 113 l/min $\dot{V}O_{2,max}$ = 23.6 ml/kg/min IT (run) = 12.78 min	<u>RMET:</u> 15 min at 90-100% MSVC twice per day (10 min rest) (ventilation↑ with 15 min↑) 4.2 times per week (minimum of 4 times per week required) 8 weeks <u>Control:</u> No training	<u>RMET:</u> MVV: +17%* $\dot{V}O_{2,max}$: -2% IT: -2% <u>Control:</u> MVV: +4% $\dot{V}O_{2,max}$: -2% IT: +2%	43%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Boutellier et al. 1992 ^[74]	Non-controlled trial RMET: n = 8 (7/1)	<u>RMET:</u> Age = 23.1 y Height = 1.74 m Body mass = 64.8 kg MVV = 192 l/min $\dot{V}O_{2,max}$ = 4.4 l/min CLT (cycle) = 22.8 min	<u>RMET:</u> 30 min at 55-68 (mean 61) %MVV (ventilation↑ with 30 min↑) once per day 5 times per week 4 weeks	<u>RMET:</u> MVV: +6%* $\dot{V}O_{2,max}$: -5% CLT: +38%*	14%
Boutellier and Piwko 1992 ^[75]	Non-controlled trial RMET: n = 4 (3/1)	<u>RMET:</u> Age = 23.3 y Height = 1.73 m Body mass = 60.3 kg MVV = 149 l/min $\dot{V}O_{2,max}$ = 2.9 l/min CLT (cycle) = 26.8 min	<u>RMET:</u> 30 min at 76-102.5 l/min (breathing frequency↑ 1 breath·min ⁻¹ per week, starting at 38 breaths min ⁻¹) once per day 5 times per week 4 weeks	<u>RMET:</u> MVV: +2% CLT: +50%*	14%
Chatham et al. 1999 ^{[67]o}	Randomised controlled trial Blinding not specified RMST: n = 11 (5/6) Control: n = 11 (5/6)	<u>RMST:</u> Age = na Height = na Body mass = na MIP = 134 cmH ₂ O $\dot{V}O_{2,max}$ = (38.6%pred) IT (run) = na <u>Control:</u> Age = na Height = na Body mass = na MIP = 113 cmH ₂ O $\dot{V}O_{2,max}$ = (38.5%pred) IT (run) = na	<u>RMST:</u> TIRE at 80% SMIP once per day 3 times per week 10 weeks <u>Control:</u> No training	<u>RMST:</u> MIP: +31%* IT: +9.8%* (n=8) <u>Control:</u> MIP: +11% IT: +0.8%	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Downey et al. 2007 ^[76]	Randomised controlled trial Single-blind RMST: n = 7 (4/3) Sham: n = 5 (2/3)	<u>RMST:</u> Age = 20.7 y Height = 1.73 m Body mass = 70.9 kg MIP = 126 cmH ₂ O MEP = 145 cmH ₂ O MVV = 162 l/min $\dot{V}O_{2,max}$ = 47.5 ml/kg/min CLT (run) = 17.9 min <u>Sham:</u> Age = 19.6 y Height = 1.70 m Body mass = 66.5 kg MIP = 129 cmH ₂ O MEP = 149 cmH ₂ O MVV = 152 l/min $\dot{V}O_{2,max}$ = 43.9 ml/kg/min CLT (run) = 21.3 min	<u>RMST:</u> 40 breaths at 50% MIP and high inspiratory flow rates (weekly load↑ with MIP↑) twice per day 5 times per week 4 weeks <u>Sham:</u> 40 breaths at 15% MIP twice per day 5 times per week 4 weeks	<u>RMST:</u> MIP: +24.5%* CLT: +1%, ns <u>Sham:</u> MIP: +9.0% CLT: +3%	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Edwards and Cooke 2004 ^[77]	Controlled trial Blinding not specified RMST: n = 10 (10/0) Sham: n = 8 (8/0)	<u>RMST:</u> Age = na Height = 1.80 m Body mass = 83.3 kg MIP = 105 cmH ₂ O MVV = 157 l/min $\dot{V}O_{2,max}$ = 47.9 ml/kg/min CLT (run) = 3.8 min <u>Sham:</u> Age = na Height = 1.81 m Body mass = 85.3 kg MIP = 107 cmH ₂ O MVV = 154 l/min $\dot{V}O_{2,max}$ = 47.4 ml/kg/min CLT (run) = 3.7 min	<u>RMST:</u> 30 maximal inspiratory efforts at 30RM once per day 7 times per week 4 weeks <u>Sham:</u> 30 breaths at 15% MIP once per day 7 times per week 4 weeks	<u>RMST:</u> MIP: +25% MVV: +1% $\dot{V}O_{2,max}$: +1% CLT: +8%*, sig <u>Sham:</u> MIP: +7% MVV: +1% $\dot{V}O_{2,max}$: -1% CLT: +3%*	14%
Enright et al. 2006 ^[51]	Randomised controlled trial Double-blind RMST: n = 10 (4/6) Control: n = 10 (5/5)	<u>RMST:</u> Age = 22.0 y Height = 1.69 m Body mass = 59.9 kg MIP = 90 cmH ₂ O IT (cycle) = 5.0 min <u>Control:</u> Age = 21.8 y Height = 1.72 m Body mass = 54.9 kg MIP = 93 cmH ₂ O IT (cycle) = 4.4 min	<u>RMST:</u> TIRE at 80% SMIP once per day 3 times per week 9 weeks <u>Control:</u> No training	<u>RMST:</u> MIP: +41%*, sig IT: +23%*, sig <u>Control:</u> MIP: -2% IT: -5%	71%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Enright and Unnithan 2011 ^[50]	Randomised controlled trial Double-blind RMST _{80%} : n = 10 (4/6) RMST _{60%} : n = 10 (5/5) RMST _{40%} : n = 10 (6/4) Control: n = 10 (5/5)	<u>RMST:</u> Age _{80%} = 21.0 y Age _{60%} = 21.7 y Age _{40%} = 22.8 y Height _{80%} = 1.68 m Height _{60%} = 1.71 m Height _{40%} = 1.68 m Body mass _{80%} = 59.9 kg Body mass _{60%} = 54.9 kg Body mass _{40%} = 56.5 kg MIP _{80%} = 68 cmH ₂ O MIP _{60%} = 73 cmH ₂ O MIP _{40%} = 76 cmH ₂ O IT _{80%} (cycle) = 5.0 min IT _{60%} (cycle) = 5.4 min IT _{40%} (cycle) = 4.5 min <u>Control:</u> Age = 21.3 y Height = 1.70 m Body mass = 58.3 kg MIP = 68 cmH ₂ O IT (cycle) = 4.4 min	<u>RMST:</u> 80%: TIRE at 80% SMIP 60%: TIRE at 60% SMIP 40%: TIRE at 40% SMIP once per day 3 times per week 9 weeks <u>Control:</u> No training	<u>RMST:</u> MIP _{80%} : +140%*, sig MIP _{60%} : +74%*, sig MIP _{40%} : +20%*, sig IT _{80%} : +24%*, sig IT _{60%} : +26%*, sig IT _{40%} : +9%, ns <u>Control:</u> MIP: -1% IT: -5%	86%
Esposito et al. 2010 ^{[68]o}	Non-controlled trial RMET n = 9 (9/0)	<u>RMET:</u> Age = 24 y Height = 1.75 m Body mass = 72 kg MIP = 69 cmH ₂ O $\dot{V}O_{2,max}$ = 3.71 l/min IIT (cycle) = na	<u>RMET:</u> 6.6-13.7 min (excl. warm-up) at increasing bag volume (3.0-3.3 l) and breathing frequency (31-36 breaths·min ⁻¹) once per day 5 times per week 8 weeks	<u>RMET:</u> MIP: +75% $\dot{V}O_{2,max}$: -5% IIT: -2%	14%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Metho- dological quality
Fairbarn et al. 1991 ^[78]	Controlled trial Blinding not specified RMET: n = 5 (5/0) Control: n = 5 (5/0)	<u>RMET:</u> Age = 22 y Height = 1.74 m Body mass = 69 kg MVV = 206 l/min $\dot{V}O_{2,max}$ = 64.2 ml/kg/min CLT (cycle) = 5.7 min <u>Control:</u> Age = 23 y Height = 1.78 m Body mass = 73 kg MVV = 215 l/min $\dot{V}O_{2,max}$ = 68.0 ml/kg/min CLT (cycle) = 5.5 min	<u>RMET:</u> First 8 then 10 min at MSVC (ventilation↑ with first 8/10 min↑) 3 times per day (8 min rest) 3-4 times per week 4-5 weeks Total of 16 sessions <u>Control:</u> No training	<u>RMET:</u> $\dot{V}O_{2,max}$ +2% CLT: +25% <u>Control:</u> $\dot{V}O_{2,max}$ -1% CLT: +4%	14%
Gething et al. 2004 ^[79]	Randomised controlled trial Single-blind RMST: n = 5 Sham: n = 5	<u>RMST:</u> Age = na Height = na Body mass = na MIP = 134 cmH ₂ O MEP = 138 cmH ₂ O CLT (cycle) = 60.2 min <u>Sham:</u> Age = na Height = na Body mass = na MIP = 136 cmH ₂ O MEP = 126 cmH ₂ O CLT (cycle) = 51.2 min	<u>RMST:</u> TIRE at 80% SMIP once per day 3 times per week 10 weeks <u>Sham:</u> TIRE at 10 cmH ₂ O/l/s once per day 3 times per week 10 weeks	<u>RMST:</u> MIP: +34%* MEP: +4% CLT: +36%* <u>Sham:</u> MIP: +3% MEP: +0% CLT: +7%	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Griffiths and McConnell 2007 ^[60]	Non-controlled trial RMST: n _{IN} = 10 n _{EX} = 7	<u>RMST:</u> Age _{IN} = 24.9 y Age _{EX} = 28.7 y Height _{IN} = 1.90 m Height _{EX} = 1.90 m Body mass _{IN} = 83.7 kg Body mass _{EX} = 82.6 kg MIP _{IN} = 129 cmH ₂ O MIP _{EX} = 139 cmH ₂ O MEP _{IN} = 145 cmH ₂ O MEP _{EX} = 134 cmH ₂ O TT _{IN} (row) = 6 min (1765 m) TT _{EX} (row) = 6 min (1770 m)	<u>RMST:</u> 30 inspiratory (group IN) or expiratory (group EX) efforts at 50% MIP or MEP (load↑ with 30RM↑) twice per day 7 times per week 4 weeks Both groups (8 subjects of IN → IN-INEX and all of EX → EX- INEX) continued with combined inspiratory and expiratory efforts twice per day 7 times per week 6 weeks	<u>RMST:</u> MIP _{IN} : +26%* MIP _{IN-INEX} : +30%* MIP _{EX-INEX} : +13%* MEP _{IN} : +4% MEP _{IN-INEX} : +23% MEP _{EX-INEX} : +31%* TT _{IN} : +0.92* TT _{IN-INEX} : +1.6% TT _{EX-INEX} : -0.3%	43%
Guenette et al. 2006 ^[80]	Non-controlled trial RMST: n _{male} = 7 n _{female} = 8	<u>RMST:</u> Age _{male} = 22.1 y Age _{female} = 24.5 y Height _{male} = 1.79 m Height _{female} = 1.70 m Body mass _{male} = 74.7 kg Body mass _{female} = 66.7 kg MIP _{male} = 100 cmH ₂ O MIP _{female} = 90 cmH ₂ O MVV _{male} = 185 l/min MVV _{female} = 166 l/min V̇O _{2,max} male = 46.1 ml/kg/min V̇O _{2,max} female = 42.1 ml/kg/min CLT _{male} (cycle) = 5.0 min CLT _{female} (cycle) = 5.6 min	<u>RMST:</u> 30 quick and forceful inspirations at 50% MIP (weekly load↑ with ↑MIP) twice per day (10 min rest) 5 times per week 5 weeks	<u>RMST:</u> MIP _{male} : +41%* MIP _{female} : +34%* CLT _{male} : +17%* CLT _{female} : +23%*	14%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Hanel and Secher 1991 ^[81]	Randomised controlled trial Blinding not specified RMST: n = 10 (7/3) Sham: n = 10 (3/7)	<u>RMST:</u> Age = 21 y Height = 1.78 m Body mass = 70 kg MIP = 93 cmH ₂ O $\dot{V}O_{2,max}$ = 59 ml/kg/min TT (run) = 12 min (2.81 km) <u>Sham:</u> Age = 21 y Height = 1.70 m Body mass = 68 kg MIP = 102 cmH ₂ O $\dot{V}O_{2,max}$ = 54 ml/kg/min TT (run) = 12 min (2.68 km)	<u>RMST:</u> 10 min at 50% MIP and at 5 cmH ₂ O expiratory load (weekly load↑ with MIP↑) twice per day 7 times per week 4 weeks (27.5 days) <u>Sham:</u> 10 min at no resistive loading twice per day 7 times per week 4 weeks (27.5 days)	<u>RMST:</u> MIP: +32%* $\dot{V}O_{2,max}$ +3% TT: +8%*, ns <u>Sham:</u> MIP: +10% $\dot{V}O_{2,max}$ +6% TT: +6%*	29%
Hart et al. 2001 ^[82]	Randomised controlled trial Blinding not specified RMST: n = 6 (6/0) Sham: n = 6 (3/3)	<u>RMST:</u> Age = na Height = na Body mass = na MIP = 128 cmH ₂ O MVV = 174 l/min $\dot{V}O_{2,max}$ = 44 ml/kg/min IT (run) = 14.1 min <u>Sham:</u> Age = na Height = na Body mass = na MIP = 109 cmH ₂ O MVV = 151 l/min $\dot{V}O_{2,max}$ = 39 ml/kg/min IT (run) = 12.5 min	<u>RMST:</u> 30 rapid inspirations at 30RM (load↑ with 30RM↑) twice per day 7 times per week 6 weeks <u>Sham:</u> 30 inspirations at minimal opening pressure twice per day 7 times per week 6 weeks	<u>RMST:</u> MIP: +12.2%*, sig MVV: +7% $\dot{V}O_{2,max}$ -9% IT: +5%, ns <u>Sham:</u> MIP: +1% MVV: +5% $\dot{V}O_{2,max}$ +0% IT: +1%	57%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Holm et al. 2004 ^[83]	Controlled trial Blinding not specified RMET: n = 10 (7/3) Sham [#] : n = 4 (4/0) Control [#] : n = 6 (5/1)	<u>RMET:</u> Age = 30.3 y Height = 1.73 m Body mass = 70.1 kg MIP = 84 cmH ₂ O MEP = 91 cmH ₂ O MVV = 160 l/min $\dot{V}O_{2,max}$ = 54.0 ml/kg/min CLT (cycle) = 37.5 min TT (cycle) = 47.1 min IT (cycle) = 10.4min <u>Sham/Control:</u> Age = 26.7 y Height = 1.78 m Body mass = 73.3 kg MIP = 87 cmH ₂ O MEP = 104 cmH ₂ O MVV = 186 l/min $\dot{V}O_{2,max}$ = 56.8 ml/kg/min CLT (cycle) = 43.4 min TT (cycle) = 42.9 min IT (cycle) = 11.4min	<u>RMET:</u> 30 min at a ventilatory target (initially = maximal tidal volume and breathing frequency of IT, increasing ventilation in order to reach a value of 18-19 on the 20 point respiratory effort scale, adding 3-4 MVVs) once per day 5 times per week 4 weeks <u>Sham:</u> 5 min at a ventilatory target (65% of maximal tidal volume and breathing frequency of IT, fixed intensity) once per day 5 times per week 4 weeks <u>Control:</u> No training	<u>RMET:</u> MIP: +12% MEP: -3% $\dot{V}O_{2,max}$: +3% CLT: -1% TT: +4.75%*, sig IT: +3% <u>Sham/Control:</u> MIP: +3% MEP: -7% $\dot{V}O_{2,max}$: -2% CLT: -2% TT: -0.46% IT: +4%	14%
Huang et al. 2011 ^[59]	Non-controlled trial RMST: n = 24	<u>RMST:</u> Age = 70.6 y Height = 1.64 m Body mass = 67.5 kg MIP = 59.1 cmH ₂ O TT (run) = 6 min (walking 393m)	<u>RMST:</u> 4 sets of 6 training breaths at 75% MIP (weekly load ↑ with ↑ MIP) 5 times per week 6 weeks	<u>RMST:</u> MIP: +39%* TT: +11%*	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Johnson et al. 2007 ^[52]	Randomised controlled trial Single-blind RMST: n = 9 (9/0) Sham: n = 9 (9/0)	<u>RMST:</u> Age = 31.6 y Height = 1.81 m Body mass = 75.5 kg MIP = 150 cmH ₂ O MVV = 188 l/min CLT _{EX1} (cycle) = 6.2 min CLT _{EX2} (cycle) = 15.6 min CLT _{EX3} (cycle) = 23.4 min TT (cycle) = 36.29 min <u>Sham:</u> Age = 29.9 y Height = 1.78 m Body mass = 73.8 kg MIP = 153 cmH ₂ O MVV = 167 l/min CLT _{EX1} (cycle) = 7.2 min CLT _{EX2} (cycle) = 13.5 min CLT _{EX3} (cycle) = 23.3 min TT (cycle) = 35.72 min	<u>RMST:</u> 30 dynamic inspiratory efforts at 50% MIP twice per day 7 times per week 6 weeks <u>Sham:</u> 15 min at no resistance (sham hypoxic trainer) once per day 5 times per week 6 weeks	<u>RMST:</u> MIP: +17.1%* CLT _{EX1} : +18.3%*, ns CLT _{EX2} : +10.8% CLT _{EX3} : +15.3%*, ns TT: +2.66%*, sig <u>Sham:</u> MIP: +1.8% CLT _{EX1} : -2.8% CLT _{EX2} : +6.8% CLT _{EX3} : -3.9% TT: -0.7%	43%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Metho- dological quality
Kilding et al. 2010 ^[53]	Randomised controlled trial Double-blind RMST: n = 8 (5/3) Sham: n = 8 (5/3)	<u>RMST:</u> Age = 19.1 y Height = 1.77 m Body mass = 71.1 kg MIP = 115 cmH ₂ O TT _{100m} (swim) = 1.1 min TT _{200m} (swim) = 2.2 min TT _{400m} (swim) = 4.7 min <u>Sham:</u> Age = 19.0 y Height = 1.81 m Body mass = 73.4 kg MIP = 117 cmH ₂ O TT _{100m} (swim) = 1.0 min TT _{200m} (swim) = 2.2 min TT _{400m} (swim) = 4.7 min	<u>RMST:</u> 30 dynamic inspiratory efforts at 50% MIP (load↑ with 30RM↑) twice per day 7 times per week 6 weeks <u>Sham:</u> 60 slow protracted breaths at 15% MIP once per day 7 times per week 6 weeks	<u>RMST:</u> MIP: +9.1%*, sig TT _{100m} : +2.7±1.9%*, sig TT _{200m} : +1.2±1.1%*, sig TT _{400m} : -0.1±1.6%, ns <u>Sham:</u> MIP: +0.3% TT _{100m} : +1.0±1.1% TT _{200m} : -0.2±1.1% TT _{400m} : +0.5±0.8%	57%
Kohl et al. 1997 ^[54]	Non-controlled trial RMET: n = 8 (6/2)	<u>RMET:</u> Age = 27.5 y Height = 1.80 m Body mass = 76.9 kg CLT (cycle) = 22.7 min	<u>RMET:</u> 30 min at 50% MVV (load↑ with 30 min↑) once per day 5 times per week 4 weeks	<u>RMET:</u> CLT: -19%*	14%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Kwok and Jones 2009 ^[84]	Randomised controlled trial Blinding not specified RMST: n = 8 (5/3) Sham: n = 8 (6/2)	<u>RMST:</u> Age = 26.1 y Height = 1.67 m Body mass = 58.8 kg MIP = 80 cmH ₂ O $\dot{V}O_{2,max}$ = 50.1 ml/kg/min TT (run) = 7.95 min <u>Sham:</u> Age = 25.9 y Height = 1.67 m Body mass = 59.4 kg MIP = 80 cmH ₂ O $\dot{V}O_{2,max}$ = 45.6 ml/kg/min TT (run) = 7.83 min	<u>RMST:</u> 30 breaths at 80% MIP (increased to 90% MIP during the first two weeks) twice per day 7 times per week 6 weeks <u>Sham:</u> 30 repetitions of shoulder circumduction exercise, known to induce respiratory resistance of < 15% MIP twice per day 7 times per week 6 weeks	<u>RMST:</u> MIP: +20%*, sig $\dot{V}O_{2,max}$: -2% TT: +2%*, sig <u>Sham:</u> MIP: +4% $\dot{V}O_{2,max}$: +4% TT: +0%	86%
Leddy et al. 2007 ^[85]	Randomised controlled trial Single-blind RMET: n = 15 (15/0) Sham: n = 7 (7/0)	<u>RMET:</u> Age = 29 y Height = 1.79 m Body mass = 75 kg MIP = 130 cmH ₂ O (n=7) MEP = 138 cmH ₂ O (n=7) MVV = 189 l/min $\dot{V}O_{2,max}$ = 56.4 ml/kg/min CLT (run) = 54.13 min TT (run) = 28.79 min (n=8) <u>Sham:</u> Age = 34 y Height = 1.75 m Body mass = 78 kg MVV = 189 l/min $\dot{V}O_{2,max}$ = 52.1 ml/kg/min TT (run) = 28.42 min	<u>RMET:</u> 30 min at 50% MVV (breathing frequency↑ by 1-2 breaths·min ⁻¹ every day) once per day 5 times per week 4 weeks (n=15) (+ 12 weeks (n=8)) <u>Sham:</u> 30 min inhale to TLC, hold breath for 10s, interval of normal breathing (decreasing from 90 s in the first week, to 80 s, 70 s, and 60 s in weeks 2, 3, and 4) once per day 5 times per week 4 weeks	<u>RMET:</u> MIP: -24% (n=7) MEP: -9% (n=7) MVV: +10%* $\dot{V}O_{2,max}$: +2%* CLT: +50%*, sig TT: +4%* (n=8) <u>Sham:</u> MVV: +2% $\dot{V}O_{2,max}$: +3% TT: +1%	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Lindholm et al. 2007 ^[65]	Non-controlled trial RMST: n = 10	<u>RMST:</u> Age = 22.9 y Height = 1.80m Body mass = 81.7 kg MIP = 113 cmH ₂ O MEP = 131 cmH ₂ O MVV = 166 l/min $\dot{V}O_{2,max}$ = 31.1 ml/kg/min CLT _{surface} (swim) = 25.49 min CLT _{underwater} (swim) = 25.48 min	<u>RMST:</u> 30 min / 60 vital capacities against resistance (spring loaded inspiration and expiration valves imposing opening pressures of 61.0 and 70.1 cmH ₂ O and sustained pressures of 40.1 and 46.6 cmH ₂ O) once per day 3 times per week 4 weeks (for data of 5 times per week see Wylegala et al. 2007)	<u>RMST:</u> MIP: +25%* MEP: +20%* MVV: +18%* CLT _{surface} : +50%* CLT _{underwater} : +88%*	29%
Lomax et al. 2011 ^{[55]o}	Controlled trial Blinding not specified RMST: n = 6 Sham: n = 6	<u>RMST:</u> Age = na Height = na Body mass = na MIP = 134 cmH ₂ O MEP = 172 cmH ₂ O IIT (run) = na <u>Sham:</u> Age = na Height = na Body mass = na MIP = 123 cmH ₂ O MEP = 167 cmH ₂ O IIT (run) = na	<u>RMST:</u> 30 breaths at 50-60% MIP (load↑ with 30RM↑) twice per day 7 times per week 4 weeks <u>Sham:</u> 30 breaths at 15% MIP twice per day 7 times per week 4 weeks	<u>RMST:</u> MIP: +20%* IIT: +18%*, sig <u>Sham</u> MIP: +2.3% IIT: +6%*	

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Markov et al. 1996 ^[86]	Randomised controlled trial Blinding not specified RMET: n = 8 Control: n = 8	<u>RMET:</u> Age = 28 y Height = 1.73 m Body mass = 65 kg MVV = 146 l/min $\dot{V}O_{2,max}$ = 3.03 l/min IT (cycle) = 25.7 min <u>Control:</u> Age = 31 y Height = 1.71 m Body mass = 65 kg MVV = 168 l/min $\dot{V}O_{2,max}$ = 2.90 l/min (n=6) IT (cycle) = 23.1 min (n=6)	<u>RMET:</u> 30 min (starting at 35-40 breaths·min ⁻¹ , breathing frequency↑ with 30 min↑) once per day 4-5 times per week 4-5 weeks Total of 20-24 sessions <u>Control:</u> No training	<u>RMET:</u> MVV: +15% $\dot{V}O_{2,max}$: -3% IT: +1% (n=6) <u>Control:</u> MVV: +1% $\dot{V}O_{2,max}$: +4% IT: +4% (n=6)	43%
McMahon et al. 2002 ^[87]	Randomised controlled trial Blinding not specified RMET: n = 10 (10/0) Control: n = 10 (10/0)	<u>RMET:</u> Age = 26 y Height = 1.79 m Body mass = 69 kg MVV = 182 l/min $\dot{V}O_{2,max}$ = 73.6 ml/kg/min CLT (cycle) = 16.32 min IT (cycle) = 19.9 min <u>Control:</u> Age = 28 y Height = 1.80 m Body mass = 70 kg MVV = 203 l/min $\dot{V}O_{2,max}$ = 70.1 ml/kg/min CLT (cycle) = 14.14 min IT (cycle) = 19.3 min	<u>RMET:</u> 30 min at 60% MVV (ventilation↑ with 30-40 min↑) once per day 3-5 times per week 4-6 weeks Total of 20 training sessions <u>Control:</u> No training	<u>RMET:</u> MVV: +11%* $\dot{V}O_{2,max}$: -1% CLT: +19.3±28.5%*, sig IT: +1.3±5.9% <u>Control:</u> MVV: -1% $\dot{V}O_{2,max}$: -1% CLT: -12.3±22.1% IT: -3.4±5.6%	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Mickleborough et al. 2010 ^[88]	Randomised controlled trial Single-blind RMST: n = 8 (4/4) Sham: n = 8 (4/4)	<u>RMST:</u> Age = na Height = na Body mass = na MIP = 129 cmH ₂ O MVV = 145 l/min CLT (run) = 20.7 min <u>Sham:</u> Age = na Height = na Body mass = na MIP = 131 cmH ₂ O MVV = 126 l/min CLT (run) = 20.0 min	<u>RMST:</u> TIRE at 80% SMIP once per day 3 times per week 6 weeks <u>Sham:</u> TIRE at 30% SMIP once per day 3 times per week 6 weeks	<u>RMST:</u> MIP: +43.9%* MVV: +9.2% CLT: +16%*, sig <u>Sham:</u> MIP: +9.1% MVV: +22.1% CLT: -2%	43%
Morgan et al. 1987 ^[89]	Controlled trial Blinding not specified RMET: n = 4 (4/0) Control: n = 5 (5/0)	<u>RMET:</u> Age = 24 y Height = 1.80 m Body mass = 76.7 kg MVV = 213 l/min $\dot{V}O_{2,max}$ = 50.7 ml/kg/min CLT (cycle) = 8.3 min <u>Control:</u> Age = 25 y Height = 1.83 m Body mass = 77.8 kg MVV = 205 l/min $\dot{V}O_{2,max}$ = 50.2 ml/kg/min CLT (cycle) = 9.1 min	<u>RMET:</u> 2+5+9+12 min at 85% MVV (increased by 5% MVV if every training bout was finished) once per day (with adequate recovery periods between the 4 bouts) 5 days per week 3 weeks <u>Control:</u> No training	<u>RMET:</u> MVV: +14%*, sig $\dot{V}O_{2,max}$: +1% CLT: -6%, ns <u>Control:</u> MVV: +0% $\dot{V}O_{2,max}$: +0% CLT: -8%	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Mucci and Lesaignoux 2008 ^[90]	Non-controlled trial RMST: n = 8 (8/0)	<u>RMST:</u> Age = 23.7 y Height = 1.79 m Body mass = 73.8 kg MIP = 128 cmH ₂ O $\dot{V}O_{2,max}$ = 46.5 ml/kg/min CLT _{90%} (run) = 12.4 min CLT _{100%} (run) = 6.4 min CLT _{110%} (run) = 3.8 min	<u>RMST:</u> 5 min / 25-40 breaths at 50% MIP (30 seconds with 5-8 efforts, followed by 30 seconds of rest) twice per day 5 times per week 6 weeks	<u>RMST:</u> MIP: +33%* $\dot{V}O_{2,max}$: -6% CLT _{90%} : +26.3%* CLT _{100%} : +17.4%* CLT _{110%} : +8.8%	14%
Nicks et al. 2009 ^[56]	Randomised controlled trial Blinding not specified RMST: n = 13 Control: n = 14	<u>RMST:</u> Age = 19.8 y Height = 1.74 m Body mass = 74.3 kg MIP = 138 cmH ₂ O IIT (run) = 5.3 min <u>Control:</u> Age = 19.9 y Height = 1.72 m Body mass = 74.7 kg MIP = 147 cmH ₂ O IIT (run) = 4.8 min	<u>RMST:</u> 30 inhalation repetitions at 50% MIP (load↑ with 30RM↑) twice per day 5 times per week 5 weeks <u>Control:</u> No training	<u>RMST:</u> MIP: +20%*, sig IIT: +17%*, sig <u>Control:</u> MIP: +2% IIT: +4%	29%
Ray et al. 2008 ^[91]	Non-controlled trial RMST: n = 9 (9/0)	<u>RMST:</u> Age = 25.6 y Height = 1.77 m Body mass = 80.0 kg MIP = 117 cmH ₂ O MEP = 123 cmH ₂ O MVV = 194 l/min $\dot{V}O_{2,max}$ = 2.7 l/min CLT (swim) = 31.3 min	<u>RMST:</u> 30 min / 60 vital capacities against resistance (spring loaded inspiration and expiration valves imposing opening pressures of 61.0 and 70.1 cmH ₂ O and sustained pressures of 40.1 and 46.6 cmH ₂ O) once per day 5 times per week 4 weeks	<u>RMST:</u> MIP: +18% MEP: +14% MVV: +12.9%* $\dot{V}O_{2,max}$: -4% CLT: +59%*	14%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Metho- dological quality
Ray et al. 2010 ^[92]	Non-controlled trial RMST: n = 8 (8/0)	<u>RMST:</u> Age = 30.3 y Height = 1.78 m Body mass = 85.5 kg MIP = 111 cmH ₂ O MEP = 147 cmH ₂ O MVV = 195 l/min $\dot{V}O_{2,max}$ = 2.54 l/min CLT (swim) = 26.4 min	<u>RMST:</u> 30 min at 60% MIP and MEP (average inspiratory and expiratory opening pressure 43.9 cmH ₂ O, increasing by ca. 10 cmH ₂ O each week) once per day 5 times per week 4 weeks	<u>RMST:</u> MIP: +40%* MEP: +30%* MVV: +8.2%* $\dot{V}O_{2,max}$: -6% CLT: +87%*	14%
Riganas et al. 2008 ^[38]	Randomised controlled trial Blinding not specified RMST: n = 11 Control: n = 8	<u>RMST:</u> Age = 21.7 y Height = 1.79 m Body mass = 78.9 kg MIP = 137 cmH ₂ O MVV = 174 l/min $\dot{V}O_{2,max}$ = 51.8 ml/kg/min TT (row) = 6.6 min <u>Control:</u> Age = 19.8 y Height = 1.81 m Body mass = 77.9 kg MIP = 125 cmH ₂ O MVV = 192 l/min $\dot{V}O_{2,max}$ = 50.8 ml/kg/min TT (row) = 6.9 min	<u>RMST:</u> 30 min (5-7 sets of 4-5 min of loaded breathing with 1-2 min rest in between) at 72% MIP (increasing from 30% to 80% within the first two weeks, then weekly load↑ with MIP↑) once per day 5 times per week 6 weeks <u>Control:</u> No training	<u>RMST:</u> MIP: +23%*, sig MVV: +10*, sig $\dot{V}O_{2,max}$: +0% TT: +0% <u>Control:</u> MIP: -6% MVV: +1% $\dot{V}O_{2,max}$: +2% TT: +1%	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Romer et al. 2002 ^[63]	Randomised controlled trial Double-blind RMST: n = 8 (8/0) Sham: n = 8 (8/0)	<u>RMST:</u> Age = 29.5 y Height = 1.78 m Body mass = 70.1 kg MIP = 102 cmH ₂ O MVV = 195 l/min $\dot{V}O_{2,max}$ = 4.58 l/min TT _{20km} (cycle) = 29.6 min TT _{40km} (cycle) = 59.0 min IT (cycle) = 25.3 min <u>Sham:</u> Age = 30.5 y Height = 1.80 m Body mass = 74.5 kg MIP = 100 cmH ₂ O MVV = 197 l/min $\dot{V}O_{2,max}$ = 4.70 l/min TT _{20km} (cycle) = 30.2 min TT _{40km} (cycle) = 60.0 min IT (cycle) = 27.4 min	<u>RMST:</u> 30 dynamic inspiratory efforts at 50% MIP (load↑ with 30RM↑) twice per day 7 times per week 6 weeks <u>Sham:</u> 60 slow protracted breaths at 15% MIP once per day 7 times per week 6 weeks	<u>RMST:</u> MIP: +28%* TT _{20km} : +3.5±0.8%*, sig TT _{40km} : +3.4±1.7%*, sig IT: +1.0% <u>Sham:</u> MIP: -1% TT _{20km} : -0.3±1.2% TT _{40km} : -1.2±1.0% IT: -1.4%	57%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Metho- dological quality
Romer et al. 2002 ^[20]	Randomised controlled trial Double-blind RMST: n = 12 (12/0) Sham: n = 12 (12/0)	<u>RMST:</u> Age = 21.3 y Height = 1.74 m Body mass = 72.2 kg MIP = 130 cmH ₂ O MEP = 172 cmH ₂ O MVV = 186 l/min (101%pred) $\dot{V}O_{2,max}$ = (56.3 ml/kg/min) TT (run) = 0.8 min IT (run) = 25.6 min <u>Sham:</u> Age = 20.2 y Height = 1.77 m Body mass = 75.0 kg MIP = 133 cmH ₂ O MEP = 174 cmH ₂ O MVV = 190 l/min (101%pred) $\dot{V}O_{2,max}$ = (55.8 ml/kg/min) TT (run) = 0.8 min IT (run) = 25.3 min	<u>RMST:</u> 30 dynamic inspiratory efforts at 50% MIP (load↑ with 30RM↑) twice per day 7 times per week 6 weeks <u>Sham:</u> 60 slow protracted breaths at 15% MIP once per day 7 times per week 6 weeks	<u>RMST:</u> MIP: +30.5%* MEP: +1.1% MVV: +2.5% $\dot{V}O_{2,max}$: +1% TT: +0.0% IT: +1.7% <u>Sham:</u> MIP: +0.7% MEP: -0.5% MVV: -0.3% $\dot{V}O_{2,max}$: +0% TT: -0.2% IT: -0.6%	71%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Metho- dological quality
Spengler et al. 1996 ^[93]	Non-controlled trial RMET: n _V = 10 (10/0) n _F = 10 (10/0)	<u>RMET:</u> Age _V = 26 y Age _F = 26 y Height _V = 1.77 m Height _F = 1.81 m Body mass _V = 68 kg Body mass _F = 71 kg MVV _V = 201 l/min MVV _F = 189 l/min CLT _V (cycle) = 19.1 min CLT _F (cycle) = 16.8 min IT _V (cycle) = 17.8 min IT _F (cycle) = 18.6 min	<u>RMET:</u> Group V: 30 min at fixed breathing frequency of 40 breaths·min ⁻¹ and increasing tidal volume: 2.9-3.8 l (56- 75% MVV) Group F: 30 min at fixed individual tidal volume of 2.2-3.4 l and increasing breathing frequency from 38-42 to 60 breaths·min ⁻¹ (68- 90% MVV) once per day 5 times per week 4 weeks	<u>RMET:</u> MVV _V : +18%* MVV _F : +21%* CLT _V : +36%* CLT _F : +28%* IT _V : +0% IT _F : +1%	14%
Spengler et al. 1999 ^[21]	Non-controlled trial RMET: n = 20 (20/0)	<u>RMET:</u> Age = 26.3 y Height = 1.79 m Body mass = 70.3 kg MVV = 196 l/min VO _{2,max} = 61.5 ml/kg/min CLT (cycle) = 20.9 min IT (cycle) = 18.2 min	<u>RMET:</u> 30 min at 63-83% MVV (weekly ventilation↑ by 5-10 l·min ⁻¹) once per day 5 times per week 4 weeks	<u>RMET:</u> MVV: +19%* VO _{2,max} : +4% CLT: +27%* IT: +1%	14%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Sperlich et al. 2009 ^[94]	Randomised controlled trial Blinding not specified RMST: n = 9 Sham: n = 8	<u>RMST:</u> Age = na Height = 1.80 m Body mass = 74.2 kg MIP = 91 cmH ₂ O MEP = 98 cmH ₂ O $\dot{V}O_{2,max}$ = 53.5 l/min IT (run) = 11.6 min <u>Sham:</u> Age = na Height = 1.76 m Body mass = 68.6 kg MIP = 118 cmH ₂ O MEP = 135 cmH ₂ O $\dot{V}O_{2,max}$ = 55.7 l/min IT (run) = 11.2 min	<u>RMST:</u> 30 breaths at 90% MIP (weekly load↑ with MIP↑) twice per day (with 1 min rest between interval series) 7 times per week 6 weeks <u>Sham:</u> 30 breaths at no resistance twice per day (with 1 min rest between interval series) 7 times per week 6 weeks	<u>RMST:</u> MIP: +11% MEP: +7% $\dot{V}O_{2,max}$ +4% IT: +0% <u>Sham:</u> MIP: +1% MEP: -6% $\dot{V}O_{2,max}$ +0% IT: +0%	43%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Metho- dological quality
Stuessi et al. 2001 ^[64]	Randomised controlled trial Blinding not specified RMET: n = 13 (8/5) Control: n = 15 (8/7)	<u>RMET:</u> Age = 43 y Height = 1.70 m Body mass = 67 kg MVV = 170 l/min $\dot{V}O_{2,max}$ = 2.39 l/min CLT (cycle) = 35.6 min IT (cycle) = 12.3 min <u>Control:</u> Age = 37 y Height = 1.70 m Body mass = 68 kg MVV = 151 l/min $\dot{V}O_{2,max}$ = 2.35 l/min CLT (cycle) = 32.8 min IT (cycle) = 12.0 min	<u>RMET:</u> 30 min at 60% MVV (ventilation↑ with 30 min↑) once per day 2-3 times per week 15 weeks A total of 40 training sessions <u>Control:</u> No training	<u>RMET:</u> MVV: +6% $\dot{V}O_{2,max}$ +0% CLT: +26±43%*, sig IT: +1±8% <u>Control:</u> MVV: +7% $\dot{V}O_{2,max}$ -5% CLT: -5±21% IT: -5±12%	29%
Swanson 1998 ^[95]	Non-controlled trial RMET: n = 4 (4/0)	<u>RMET:</u> Age = na Height = na Body mass = na CLT (cycle) = 47.6 min	<u>RMET:</u> 20 min once per day 5 times per week 6 weeks	<u>RMET:</u> CLT: +35%	14%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Tong et al. 2008 ^[57]	Randomised controlled trial Single-blind RMST: n = 10 (10/0) Sham: n = 10 (10/0)	<u>RMST:</u> Age = 21.3 y Height = 1.75 m Body mass = 67.8 kg MIP = 145 cmH ₂ O MVV = 175 l/min $\dot{V}O_{2,max}$ = 60.8 ml/kg/min IIT (run) = 6.3 min <u>Sham:</u> Age = 21.5 y Height = 1.75 m Body mass = 65.8 kg MIP = 160 cmH ₂ O MVV = 186 l/min $\dot{V}O_{2,max}$ = 55.8 ml/kg/min IIT (run) = 6.9 min	<u>RMST:</u> 30 inspiratory efforts at 50% MIP (load↑ by 10-15 cmH ₂ O with 30RM↑/without a break) twice per day 6 times per week 6 weeks <u>Sham:</u> 30 slow breaths at 15% MIP twice per day 6 times per week 6 weeks	<u>RMST:</u> MIP: +32%* IIT: +15%* <u>Sham:</u> MIP: -2% IIT: +2%	29%
Verges et al. 2007 ^[16]	Randomised controlled trial Single-blind RMET: n = 13 (13/0) Sham: n = 8 (8/0)	<u>RMET:</u> Age = 31 y Height = 1.79 m Body mass = 73 kg MVV = 209 l/min $\dot{V}O_{2,max}$ = 55.6 ml/kg/min CLT (cycle) = 15.49 min IT (cycle) = 18.00 min <u>Sham:</u> Age = 31 y Height = 1.79 m Body mass = 71 kg MVV = 203 l/min $\dot{V}O_{2,max}$ = 55.6 ml/kg/min CLT (cycle) = 15.16 min IT (cycle) = 17.75 min	<u>RMET:</u> 30 min at 60% MVV (ventilation↑ with 30 min↑) once per day 4-5 times per week 4-5 weeks Total of 20 training sessions <u>Sham:</u> 30 min at 70% VC (incentive spirometer) once per day 4-5 times per week 4-5 weeks Total of 20 training sessions	<u>RMET:</u> MVV: +4%, ns CLT: +9.5±18.4%, ns IT: -4.1±7.1%, ns <u>Sham:</u> MVV: -3% CLT: +4.6±18.7% IT: -5.1±7.7%	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Metho- dological quality
Verges et al. 2008 ^[96]	Controlled trial Blinding not specified RMET: n = 8 (8/0) Control: n = 6 (6/0)	<u>RMET:</u> Age = 28 y Height = 1.83 m Body mass = 74 kg $\dot{V}O_{2,max}$ = 4.55 l/min CLT (cycle) = 16.4 min IT (cycle) = 19.0 min <u>Control:</u> Age = 29 y Height = 1.76 m Body mass = 70 kg $\dot{V}O_{2,max}$ = 4.24 l/min CLT (cycle) = 19.2 min IT (cycle) = 17.3 min	<u>RMET:</u> 15 min at 60-100% MVV (mean 80% MVV, breathing frequency↑ linearly) once per day 5 times per week 8 weeks <u>Control:</u> No training	<u>RMET:</u> $\dot{V}O_{2,max}$ -2%* CLT: +0±15.7%, ns IT: -5±5.2%, ns <u>Control:</u> $\dot{V}O_{2,max}$ -4% CLT: -7±49.8% IT: -2±5.1%	14%
Volianitits et al. 2001 ^[39]	Randomised controlled trial Single-blind RMST: n = 7 (0/7) Sham: n = 7 (0/7)	<u>RMST:</u> Age = na Height = na Body mass = na MIP = 104 cmH ₂ O TT _{5000m} (row) = 19.4 min TT (row) = 6 min (1561 m) <u>Sham:</u> Age = na Height = na Body mass = na MIP = 130 cmH ₂ O TT _{5000m} (row) = 20.4 min TT (row) = 6 min (1566 m)	<u>RMST:</u> 30 inspiratory efforts at 50% MIP twice per day 7 times per week 11 weeks <u>Sham:</u> 60 breaths at 15% MIP once per day 7 times per week 11 weeks	<u>RMST:</u> MIP _{4wks} : +40.7%*, sig MIP _{11wks} : +45.3%*, sig TT _{5000m} : +3.1±0.8%*, sig TT _{6min,4wks} : +3.4±1.0%*, sig TT _{6min,11wks} : +3.5±1.2%*, sig <u>Sham:</u> MIP _{4wks} : +4.6% MIP _{11wks} : +5.3% TT _{5000m} : +0.9±0.6%* TT _{6min,4wks} : +1.1±0.4%* TT _{6min,11wks} : +1.6±1.0%*	29%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Wells et al. 2005 ^[58]	Randomised controlled trial Blinding not specified RMST: n = 17 (7/10) Sham: n = 17 (7/10)	<u>RMST:</u> Age = na Height = na Body mass = na MIP = 122 cmH ₂ O MEP = 152 cmH ₂ O MVV = 122 l/min TT (swim) = 2.3 min <u>Sham:</u> Age = na Height = na Body mass = na MIP _{0wks} = 127 cmH ₂ O MIP _{6wks} = 131 cmH ₂ O MEP _{0wks} = 152 cmH ₂ O MEP _{6wks} = 157 cmH ₂ O MVV _{0wks} = 126 l/min MVV _{6wks} = 146 l/min TT _{0wks} (swim) = 2.4 min TT _{6wks} (swim) = 2.3 min	<u>RMST:</u> 30 breaths at 50% MIP and MEP (weeks 1-3), 60% MIP and MEP (weeks 4-6), 70% MIP and MEP (weeks 7-9), and 80% MIP and MEP (weeks 10-12) once-twice per day 10 times per week 12 weeks <u>Sham:</u> 30 breaths at 10% MIP and MEP once-twice per day for a total of 10 times per week 1st 6 weeks 30 breaths at 50% MIP and MEP (weeks 7-9), 60% MIP and MEP (weeks 10-12) once-twice per day 10 times per week 2nd 6 weeks After 6 weeks, the Sham group started with RMST and was therefore no longer considered a Sham group.	<u>RMST:</u> MIP _{6weeks} : +2% MIP _{12weeks} : +9%* MEP _{6weeks} : +5% MEP _{12weeks} : +6%* MVV _{6weeks} : +15% MVV _{12weeks} : +20%* TT _{6weeks} : +0.69%, ns TT _{12weeks} : +1.09% <u>Sham:</u> MIP _{6weeks} : +3% MIP _{12weeks} : +5% MEP _{6weeks} : +3% MEP _{12weeks} : +5% MVV _{6weeks} : +16% MVV _{12weeks} : +3% TT _{6weeks} : +1.23% TT _{12weeks} : -0.12%	43%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Williams et al. 2002 ^[97]	Non-controlled trial RMST: n = 7 (5/2)	RMST: Age = 20.9 y Height = 1.75 m Body mass = 63.6 kg MIP = 142 cmH ₂ O MVV = 189 l/min (126%pred) $\dot{V}O_{2,max}$ = 59.9 ml/kg/min CLT (run) = 19.6 min	RMST: Ca. 25 min (4-5min of loaded breathing with 1-2 min rest between sets) at 50% MIP (increasing by approx. 5% MIP every week) 5-7 sets per session / day 4-5 times per week 4 weeks	RMST: MIP: +31%* $\dot{V}O_{2,max}$ +1% CLT: -7%	14%

Author Year	Study design Blinding n [total (male/female)]	Subject characteristics	Intervention and Sham/Control	Results [% change from baseline]	Methodological quality
Wylegala et al. 2007 ^[66]	Randomised controlled trial Single-blind RMST: n = 10 (10/0) RMET: n = 10 (10/0) Sham: n = 10 (10/0)	<u>RMST:</u> Age = na Height = 1.79 m Body mass = 81.7 kg MIP = 117 cmH ₂ O MEP = 125 cmH ₂ O MVV = 214 l/min CLT _{surf} (swim) = 31.6 min CLT _{underw} (swim) = 18.9 min <u>RMET:</u> Age = na Height = 1.81 m Body mass = 82.1 kg MIP = 121 cmH ₂ O MEP = 120 cmH ₂ O MVV = 190 l/min CLT _{surf} (swim) = 35.4 min CLT _{underw} (swim) = 20.3 min <u>Sham:</u> Age = na Height = 1.80 m Body mass = 83.4 kg MIP = 125 cmH ₂ O MEP = 124 cmH ₂ O MVV = 191 l/min CLT _{surf} (swim) = 25.9 min CLT _{underw} (swim) = 15.9 min	<u>RMST:</u> 30 min / 60 vital capacities at inspiratory and expiratory opening pressures of 50 cmH ₂ O once per day 5 times per week 4 weeks <u>RMET:</u> 30 min at 60% MVV (ventilation↑ with 30 min↑) once per day 5 times per week 4 weeks <u>Sham:</u> 30 min, inhale to TLC and hold breath for 10 s, decreasing rest intervals from week 1 to week 4 (90 s, 80 s, 70 s, 60 s) once per day 5 times per week 4 weeks	<u>RMST:</u> MIP: +10.8%* MEP: +15.2%* MVV: -3.4% CLT _{surf} : +33.2%* CLT _{underw} : +66%* <u>RMET:</u> MIP: +4.1% MEP: +4.8% MVV: +7.4%* CLT _{surf} : +38.1%* CLT _{underw} : +26%* <u>Sham:</u> MIP: -0.8% MEP: +3.4% MVV: +2.3% CLT _{surf} : +4.3% CLT _{underw} : -1.3%	57%

RMST = Respiratory muscle strength training

RMET = Respiratory muscle endurance training

CLT = constant load test

TT = time trial

IIT = intermittent incremental test

IT = conventional (non-intermittent) incremental test

load↑ with MIP↑ = intensity (load) adjusted to increasing MIP

load↑ with 30RM↑ = intensity (load) adjusted to only just complete 30 repetitions

ventilation↑ with first 8/10 / 15 / 30 / 30-40 min↑ = intensity (ventilation) adjusted to only just complete the first 8 or 10 min / 15 min / 30 min / a minimum of 30 but a maximum of 40 min

* = significant change within group

sig = significant difference between change of RMET / RMST and change of sham / control

ns = difference between change of RMET / RMST and change of sham / control is not significant

MSVC = maximum sustained ventilatory capacity

° Study not included in the multiple linear regression model due to missing indication of test duration

TIRE = test of incremental respiratory endurance: A maximum of 36 efforts at a target pressure of 80% SMIP (assessed on every training day) was performed across vital capacity with decreasing resting periods (60 s, 45 s, 30 s, 15 s, 10 s, 5 s) between inspiratory efforts after 6 breaths. Training was stopped if 90% of the target could no longer be sustained.

SMIP = sustained maximal inspiratory pressure = maximal pressure generation from residual volume to total lung capacity

IN = inspiratory training, EX = expiratory training, IN-INEX = combined inspiratory and expiratory training after inspiratory training, EX-INEX = combined inspiratory and expiratory training after expiratory training

Sham and Control considered as one group, because there were no individual results published, except for MSVC

V = group V, training at increasing tidal volumes, F = group F, training at increasing breathing frequencies

Table II. Methodological study quality

Study	Randomization	Blinding	Allocation of concealment	Dropouts	Intention to treat analysis	Power calculation	Overall score	
	0: not random 1: random, 2: specified	0: not reported 1: observer blinded	0: not reported 1: specified	0: not reported 1: specified	0: not performed 1: performed	0: not reported 1: reported	Max. 7 points	Max. 100%
Aznar-Lain et al. 2007 ^[71]	1	0	1	1	0	0	3	43%
Bailey et al. 2010 ^[72]	1	0	1	0	1	0	3	43%
Belman and Gaesser 1988 ^[73]	1	0	1	1	0	0	3	43%
Boutellier et al. 1992 ^[74]	0	0	0	0	1	0	1	14%
Boutellier and Piwko 1992 ^[75]	0	0	0	0	1	0	1	14%
Chatham et al. 1999 ^[67]	1	0	0	1	0	0	2	29%
Downey et al. 2007 ^[76]	1	0	0	1	0	0	2	29%
Edwards and Cooke 2004 ^[77]	0	0	0	0	1	0	1	14%
Enright et al. 2006 ^[51]	2	1	1	0	1	0	5	71%
Enright and Unnithan 2011 ^[50]	2	1	1	1	0	1	6	86%
Esposito et al. 2010 ^[68]	0	0	0	0	1	0	1	14%
Fairbairn et al. 1991 ^[78]	0	0	0	0	1	0	1	14%
Gething et al. 2004 ^[79]	1	0	0	0	1	0	2	29%
Griffiths and McConnell 2007 ^[60]	0	0	1	1	0	1	3	43%
Guenette et al. 2006 ^[80]	0	0	0	0	1	0	1	14%
Hanel and Secher 1991 ^[81]	1	0	0	0	1	0	2	29%
Hart et al. 2001 ^[82]	1	0	0	1	1	1	4	57%
Holm et al. 2004 ^[83]	0	0	0	0	1	0	1	14%
Huang et al. 2011 ^[59]	0	0	0	1	1	0	2	29%

Study	Randomization	Blinding	Allocation of concealment	Dropouts	Intention to treat analysis	Power calculation	Overall score	
	0: not random 1: random, 2: specified	0: not reported 1: observer blinded	0: not reported 1: specified	0: not reported 1: specified	0: not performed 1: performed	0: not reported 1: reported	Max. 7 points	Max. 100%
Johnson et al. 2007 ^[52]	1	0	1	0	1	0	3	43%
Kilding et al. 2010 ^[53]	1	1	1	0	1	0	4	57%
Kohl et al. 1997 ^[54]	0	0	0	0	1	0	1	14%
Kwok and Jones 2009 ^[84]	2	0	1	1	1	1	6	86%
Leddy et al. 2007 ^[85]	1	0	0	1	0	0	2	29%
Lindholm et al. 2007 ^[65]	0	0	0	1	1	0	2	29%
Lomax et al. 2011 ^[55]	0	0	0	0	1	0	1	14%
Markov et al. 1996 ^[86]	1	0	1	1	0	0	3	43%
McMahon et al. 2002 ^[87]	1	0	0	1	0	0	2	29%
Mickleborough et al. 2010 ^[88]	1	0	1	0	1	0	3	43%
Morgan et al. 1987 ^[89]	0	0	0	1	0	1	2	29%
Mucci and Lesaignoux 2008 ^[90]	0	0	0	0	1	0	1	14%
Nicks et al. 2009 ^[56]	1	0	0	1	0	0	2	29%
Ray et al. 2008 ^[91]	0	0	0	0	1	0	1	14%
Ray et al. 2010 ^[92]	0	0	0	0	1	0	1	14%
Riganas et al. 2008 ^[38]	1	0	0	0	1	0	2	29%
Romer et al. 2002 ^[63]	1	1	1	0	1	0	4	57%
Romer et al. 2002 ^[20]	1	1	1	0	1	1	5	71%
Spengler et al. 1996 ^[93]	0	0	0	0	1	0	1	14%
Spengler et al. 1999 ^[21]	0	0	0	1	0	0	1	14%

Study	Randomization	Blinding	Allocation of concealment	Dropouts	Intention to treat analysis	Power calculation	Overall score	
	0: not random 1: random, 2: specified	0: not reported 1: observer blinded	0: not reported 1: specified	0: not reported 1: specified	0: not performed 1: performed	0: not reported 1: reported	Max. 7 points	Max. 100%
Sperlich et al. 2009 ^[94]	1	0	1	0	1	0	3	43%
Stuessi et al. 2001 ^[64]	1	0	0	1	0	0	2	29%
Swanson 1998 ^[95]	0	0	0	1	0	0	1	14%
Tong et al. 2008 ^[57]	1	0	0	0	1	0	2	29%
Verges et al. 2007 ^[16]	1	0	0	0	1	0	2	29%
Verges et al. 2008 ^[96]	0	0	0	0	1	0	1	14%
Volianitis et al. 2001 ^[39]	1	0	0	0	1	0	2	29%
Wells et al. 2005 ^[58]	1	0	1	0	1	0	3	43%
Williams et al. 2002 ^[97]	0	0	0	0	1	0	1	14%
Wylegala et al. 2007 ^[66]	1	0	1	1	1	0	4	57%

References

16. Verges S, Lenherr O, Haner AC, et al. Increased fatigue resistance of respiratory muscles during exercise after respiratory muscle endurance training. *Am J Physiol Regul Integr Comp Physiol*. 2007 Mar; 292 (3): R1246-53.
20. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training upon recovery time during high intensity, repetitive sprint activity. *Int J Sports Med*. 2002 Jul; 23 (5): 353-60.
21. Spengler CM, Roos M, Laube SM, et al. Decreased exercise blood lactate concentrations after respiratory endurance training in humans. *Eur J Appl Physiol Occup Physiol*. 1999 Mar; 79 (4): 299-305.
38. Riganas CS, Vrabas IS, Christoulas K, et al. Specific inspiratory muscle training does not improve performance or VO₂max levels in well trained rowers. *J Sports Med Phys Fitness*. 2008 Sep; 48 (3): 285-92.
39. Volianitis S, McConnell AK, Koutedakis Y, et al. Inspiratory muscle training improves rowing performance. *Med Sci Sports Exerc*. 2001 May; 33 (5): 803-9.
50. Enright SJ, Unnithan VB. Effect of inspiratory muscle training intensities on pulmonary function and work capacity in people who are healthy: a randomized controlled trial. *Phys Ther*. 2011 Jun; 91 (6): 894-905.
51. Enright SJ, Unnithan VB, Heward C, et al. Effect of high-intensity inspiratory muscle training on lung volumes, diaphragm thickness, and exercise capacity in subjects who are healthy. *Phys Ther*. 2006 Mar; 86 (3): 345-54.
52. Johnson MA, Sharpe GR, Brown PI. Inspiratory muscle training improves cycling time-trial performance and anaerobic work capacity but not critical power. *Eur J Appl Physiol*. 2007 Dec; 101 (6): 761-70.

53. Kilding AE, Brown S, McConnell AK. Inspiratory muscle training improves 100 and 200 m swimming performance. *Eur J Appl Physiol*. 2010 Feb; 108 (3): 505-11.
54. Kohl J, Koller EA, Brandenberger M, et al. Effect of exercise-induced hyperventilation on airway resistance and cycling endurance. *Eur J Appl Physiol Occup Physiol*. 1997; 75 (4): 305-11.
55. Lomax M, Grant I, Corbett J. Inspiratory muscle warm-up and inspiratory muscle training: separate and combined effects on intermittent running to exhaustion. *J Sports Sci*. 2011 Mar; 29 (6): 563-9.
56. Nicks CR, Morgan DW, Fuller DK, et al. The influence of respiratory muscle training upon intermittent exercise performance. *Int J Sports Med*. 2009 Jan; 30 (1): 16-21.
57. Tong TK, Fu FH, Chung PK, et al. The effect of inspiratory muscle training on high-intensity, intermittent running performance to exhaustion. *Appl Physiol Nutr Metab*. 2008 Aug; 33 (4): 671-81.
58. Wells GD, Plyley M, Thomas S, et al. Effects of concurrent inspiratory and expiratory muscle training on respiratory and exercise performance in competitive swimmers. *Eur J Appl Physiol*. 2005 Aug; 94 (5-6): 527-40.
59. Huang CH, Yang GG, Wu YT, et al. Comparison of inspiratory muscle strength training effects between older subjects with and without chronic obstructive pulmonary disease. *J Formos Med Assoc*. 2011 Aug; 110 (8): 518-26.
60. Griffiths LA, McConnell AK. The influence of inspiratory and expiratory muscle training upon rowing performance. *Eur J Appl Physiol*. 2007 Mar; 99 (5): 457-66.
63. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training on time-trial performance in trained cyclists. *J Sports Sci*. 2002 Jul; 20 (7): 547-62.

64. Stuessi C, Spengler CM, Knöpfli-Lenzin C, et al. Respiratory muscle endurance training in humans increases cycling endurance without affecting blood gas concentrations. *Eur J Appl Physiol*. 2001 Jun; 84 (6): 582-6.
65. Lindholm P, Wylegala J, Pendergast DR, et al. Resistive respiratory muscle training improves and maintains endurance swimming performance in divers. *Undersea Hyperb Med*. 2007 May-Jun; 34 (3): 169-80.
66. Wylegala JA, Pendergast DR, Gosselin LE, et al. Respiratory muscle training improves swimming endurance in divers. *Eur J Appl Physiol*. 2007 Mar; 99 (4): 393-404.
67. Chatham K, Baldwin J, Griffiths H, et al. Inspiratory muscle training improves shuttle run performance in healthy subjects. *Phys Ther*. 1999; 85 (12): 676-83.
68. Esposito F, Limonta E, Alberti G, et al. Effect of respiratory muscle training on maximum aerobic power in normoxia and hypoxia. *Respir Physiol Neurobiol*. 2010 Mar 31; 170 (3): 268-72.
71. Aznar-Lain S, Webster AL, Cañete S, et al. Effects of inspiratory muscle training on exercise capacity and spontaneous physical activity in elderly subjects: a randomized controlled pilot trial. *Int J Sports Med*. 2007 Dec; 28 (12): 1025-9.
72. Bailey SJ, Romer LM, Kelly J, et al. Inspiratory muscle training enhances pulmonary O₂ uptake kinetics and high-intensity exercise tolerance in humans. *J Appl Physiol*. 2010 Aug; 109 (2): 457-68.
73. Belman MJ, Gaesser GA. Ventilatory muscle training in the elderly. *J Appl Physiol*. 1988 Mar; 64 (3): 899-905.
74. Boutellier U, Büchel R, Kundert A, et al. The respiratory system as an exercise limiting factor in normal trained subjects. *Eur J Appl Physiol Occup Physiol*. 1992; 65 (4): 347-53.

75. Boutellier U, Piwko P. The respiratory system as an exercise limiting factor in normal sedentary subjects. *Eur J Appl Physiol Occup Physiol*. 1992; 64 (2): 145-52.
76. Downey AE, Chenoweth LM, Townsend DK, et al. Effects of inspiratory muscle training on exercise responses in normoxia and hypoxia. *Respir Physiol Neurobiol*. 2007 May 14; 156 (2): 137-46.
77. Edwards AM, Cooke CB. Oxygen uptake kinetics and maximal aerobic power are unaffected by inspiratory muscle training in healthy subjects where time to exhaustion is extended. *Eur J Appl Physiol*. 2004 Oct; 93 (1-2): 139-44.
78. Fairbairn MS, Coutts KC, Pardy RL, et al. Improved respiratory muscle endurance of highly trained cyclists and the effects on maximal exercise performance. *Int J Sports Med*. 1991 Feb; 12 (1): 66-70.
79. Gething AD, Williams M, Davies B. Inspiratory resistive loading improves cycling capacity: a placebo controlled trial. *Br J Sports Med*. 2004 Dec; 38 (6): 730-6.
80. Guenette JA, Martens AM, Lee AL, et al. Variable effects of respiratory muscle training on cycle exercise performance in men and women. *Appl Physiol Nutr Metab*. 2006 Apr; 31 (2): 159-66.
81. Hanel B, Secher NH. Maximal oxygen uptake and work capacity after inspiratory muscle training: a controlled study. *J Sports Sci*. 1991 Spring; 9 (1): 43-52.
82. Hart N, Sylvester K, Ward S, et al. Evaluation of an inspiratory muscle trainer in healthy humans. *Respir Med*. 2001 Jun; 95 (6): 526-31.
83. Holm P, Sattler A, Fregosi RF. Endurance training of respiratory muscles improves cycling performance in fit young cyclists. *BMC Physiol*. 2004 May 6; 4.
84. Kwok TMK, Jones AYM. Target-flow inspiratory muscle training improves running performance in recreational runners: a randomized controlled trial. *Hong Kong Physiother J*. 2009; 27: 48-54.

85. Leddy JJ, Limprasertkul A, Patel S, et al. Isocapnic hyperpnea training improves performance in competitive male runners. *Eur J Appl Physiol*. 2007 Apr; 99 (6): 665-76.
86. Markov G, Orlor R, Boutellier U. Respiratory training, hypoxic ventilatory response and acute mountain sickness. *Respir Physiol*. 1996 Sep; 105 (3): 179-86.
87. McMahon ME, Boutellier U, Smith RM, et al. Hyperpnea training attenuates peripheral chemosensitivity and improves cycling endurance. *J Exp Biol*. 2002 Dec; 205 (Pt 24): 3937-43.
88. Mickleborough TD, Nichols T, Lindley MR, et al. Inspiratory flow resistive loading improves respiratory muscle function and endurance capacity in recreational runners. *Scand J Med Sci Sports*. 2010 Jun; 20 (3): 458-68.
89. Morgan DW, Kohrt WM, Bates BJ, et al. Effects of respiratory muscle endurance training on ventilatory and endurance performance of moderately trained cyclists. *Int J Sports Med*. 1987 Apr; 8 (2): 88-93.
90. Mucci P, Lesaignoux Y. Inspiratory-muscle training and critical velocity [in French]. *Sci Sports*. 2008; 23: 255-7.
91. Ray AD, Pendergast DR, Lundgren CEG. Respiratory muscle training improves swimming endurance at depth. *Undersea Hyperb Med*. 2008 May-Jun; 35 (3): 185-96.
92. Ray AD, Pendergast DR, Lundgren CEG. Respiratory muscle training reduces the work of breathing at depth. *Eur J Appl Physiol*. 2010 Mar; 108 (4): 811-20.
93. Spengler CM, Laube SM, Roos M, et al. The effect of breathing pattern during respiratory training on cycling endurance. In: Steinacker JM, Ward SA, editors. *The physiology and pathophysiology of exercise tolerance*. New York: Plenum Press; 1996. p. 315-9.

94. Sperlich B, Fricke H, de Marees M, et al. Does respiratory muscle training increase physical performance? *Mil Med.* 2009 Sep; 174 (9): 977-82.
95. Swanson GD. Pulmonary training may alter exertional dyspnea and fatigue via an exercise-like training effect of a lowered heart rate. *Adv Exp Med Biol.* 1998; 450: 231-6.
96. Verges S, Kruttli U, Stahl B, et al. Respiratory control, respiratory sensations and cycling endurance after respiratory muscle endurance training. *Adv Exp Med Biol.* 2008; 605: 239-44.
97. Williams JS, Wongsathikun J, Boon SM, et al. Inspiratory muscle training fails to improve endurance capacity in athletes. *Med Sci Sports Exerc.* 2002 Jul; 34 (7): 1194-8.