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Research Article

Respiratory Muscle Endurance Training Improves Breathing Pattern in Triathletes

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- Breathing pattern
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- Oxygen consumption

Abstract

Recent studies show that endurance training of respiratory muscle (RMET) improves exercise performance and decreases ventilation (VE) during exercise.

Purpose: To evaluate the effect of RMET with normocapnic hyperpnoea (Spirotiger®) on respiratory function, ventilatory efficiency, cycling and running performance in triathletes.

Methods: 20M triathletes (age 21-45) were randomly allocated to two groups: RMT group (10) and control group (10). At baseline (T0) athletes underwent respiratory function tests and maximal incremental cardiopulmonary tests performed with both cycle ergometer and treadmill; the same protocol was repeated after five weeks (T1). The RMT group trained at home for five weeks for 20 min daily, seven days a week. Between T0-T1 the daily training program didn't change.

Results: In the RMT group maximal inspiratory pressure (MIP) significantly increased (T0: 8.9±2.4, T1: 9.4±2.1 kPa; $P < 0.05$) and an improvement of maximum workload (T0: 389±106 T1: 429±119W; $P<0.05$) and speed (T0: 18.2±2.0, T1: 19.3±2.5 km·h^{-1}; $P<0.05$) was found; VE/VT (tidal volume) and oxygen consumption (VO_2) trend were significantly lower (2-way ANOVA, $P<0.05$). An inverse correlation between MIP and VE during both running and cycling was found (running: $r^2 = 0.51$; cycling: $r^2 = 0.41$; $P<0.05$). During running, but not cycling, the change in VE was significantly correlated with the reduction in VO_2 ($r^2 = 0.57$; $P = 0.001$). VE/VO_2 significantly improved. No differences were found in control group in any of the tests.

Conclusion: RMET significantly increases exercise performance and ventilatory efficiency by means of an improvement of respiratory muscle strength and breathing pattern.

ABBREVIATIONS

RMET: Respiratory Muscle Endurance Training; **VE:** Ventilation; **MVV:** Maximal Voluntary Ventilation; **MIP:** Maximal Inspiratory Pressure; **VT:** Tidal Volume; **VO_2:** Oxygen Consumption; **RMT:** Respiratory Muscle Training Group; **CON:** Control Group; **PFTs:** Pulmonary Function Test; **T0:** Baseline; **T1:** After 5 weeks of training; **BMI:** Body Mass Index; **FEV_1:** forced expiratory volume in the first second; **VC:** Vital Capacity; **FVC:** Forced Vital Capacity; **RR:** Respiratory Rate; **VCO_2:** Carbon Dioxide Output; **VT:** Ventilatory Threshold; **RC**: Respiratory Compensation Point; **SD:** Standard Deviation.

INTRODUCTION

Exercise performance in healthy subjects can be compromised by respiratory muscle fatigue [1-5]. Boutellier et al. demonstrated that respiratory muscle fatigue induces hyperventilation which limits exercise performance at the anaerobic threshold in both healthy subjects [2] and athletes [6].

Recently a growing number of papers have shown a positive effect of respiratory muscle training on exercise performance [7,8]. Understanding the implication of respiratory muscle training in exercise performance, and its effect on respiratory muscle function and ventilatory parameters at rest and during exercise, is becoming an important issue.

One method of respiratory muscle training is voluntary isocapnic hyperponea which is an endurance training (RMET) requiring subjects to maintain a high level of ventilation simulating an endurance competition (low-force, high-velocity). This technique specifically increases respiratory muscle endurance [9], maximum inspiratory pressure [10] and exercise tolerance in many endurance sports (i.e. cycling [11], running [12]) both in athletes and in untrained subjects [2,13,14]. The mechanisms for the RMET ergogenic effect are not entirely clear [7,8]. According to some authors, this effect could be due to the more efficient ventilatory system and to the lower ventilation for a given exercise intensity [12,15].

Another important point when analyzing the ventilatory response to exhaustive exercise is the observation of breathing pattern (i.e. the tidal volume change related to minute ventilation) which can vary, not only depending on the type of exercise [16,17], but also during the development of respiratory muscle fatigue. In fact it has been shown that with induction of respiratory muscle fatigue, breathing pattern significantly changes with a greater increase in respiratory rate than in tidal volume [4], which is related to a reduced respiratory muscle oxygenation [18].

`In the light of all this information, we reasoned that RMET could change the breathing pattern during exercise toward a reduction of respiratory rate for the same ventilation level (VE/VT) with different results in running and cycling, due to the different ventilatory impairment during exhaustive exercise in the two types of sports. This should therefore allow the athletes to improve exercise capacity.

So our aim is to evaluate the effects of RMET on respiratory function, breathing pattern, ventilatory efficiency and exercise performance, during both cycling and running, in a group of amateur trained triathletes involved in both sports every day.

MATERIALS AND METHODS

Subjects

20 amateur triathletes (male, age 21-45 y) were recruited and randomly allocated to two groups: respiratory muscle training (RMT) group and control (CON) group.

All athletes were nonasthmatic, with no evidence of other respiratory diseases. The anthropometric characteristics are summarized in (Table 1). The Ethics Committee of the University Hospital of Ferrara approved the study; informed consent was obtained by each subject.

Study design

At baseline (T0) all subjects underwent: physical evaluation, pulmonary function tests (PFTs) and exercise tests: running and cycling maximal incremental test. After five weeks (T1) all tests were repeated.

Anthropometrics parameters: Weight and height were measured.

Pulmonary function tests: PFTs were performed by spirometer (Quark b2, Cosmed, Rome, Italy) according to international guidelines [19]: forced expired volume in the first second (FEV_1), vital capacity (VC), forced vital capacity (FVC) and 12 s maximal voluntary ventilation (MVV) were measured.

The maximal inspiratory pressure (MIP) was measured with a manometer connected to a mouthpiece (Micro RPM, Care Fusion, San Diego, California, USA) according to international guidelines [20]; subjects repeated the manoeuvre for a minimum of five attempts and reproducibility had to be within 5-10%. The highest value was considered for statistical evaluation.

Exercise performance: The subjects were instructed to avoid intensive exercise for two days before the test and refrain from food and caffeine for at least two hours beforehand. All subjects were already acquainted with the protocols.

Calibration of the system was performed before each test. The environmental conditions were similar (room temperature 21-22°C, humidity 45-55%).

During each exercise test the ventilatory parameters [ventilation (VE), tidal volume (VT), respiratory rate (RR)] and gas exchange [oxygen uptake (VO_2), carbon dioxide output (VCO_2)] were measured breath-by-breath by a metabolic cart (Quark b2, Cosmed, Rome, Italy) and averaged for 15 s intervals.

The heart rate was continuously monitored using a Polar Accurex Plus (Polar Electro, Kemple, Finland).

During incremental tests the peak oxygen uptake (VO_2 peak) was defined as the highest value of VO_2 achieved at the end of the test. Ventilatory threshold (VT) was calculated by using the V-slope method [21] and respiratory compensation point (RC) was determined by the intersection of the two linear segments of VE vs VCO_2 data [21].

For the maximal running test, subjects warmed up on the treadmill (Excite Med, Technogym, Gambettola, FC, Italy) for 15 min according to the "Conconi protocol" [22]. The test started at 8 $km \cdot h^{-1}$ and the speed was increased by 0.3 $km \cdot h^{-1}$ every 30 s until the perceived exertion was close to maximum (burning sensation in limb muscles and heavy breathing corresponding to a dyspnoea Borg score of 8/10); they then started the final acceleration: 0.5 $km \cdot h^{-1}$ every 20 s until exhaustion.

The maximal incremental cycling test was performed on the personal bicycle of each triathlete clamped to an electromagnetic roller, simulating real outdoor cycling (RealAxiom, Elite, PD, Italy). The subjects warmed up for 30 min according to the "Conconi protocol" [23]. The protocol consisted of time-based increments in cadence: increase of 1 rpm every 30 s starting from 60 rpm (corresponding to an increase of 6 W every 30 s starting

Table 1: RMT and CON group characteristic before and after 5 weeks of training.

	RMT-T0	RMT-T1	CON-T0	CON-T1
Anthropometric parameters				
Age (y)	28 ± 7	-	33±7	-
Weight (kg)	74 ± 6	73 ± 6*	72±7	72 ± 6
Pulmonary function parameters				
FEV_1 (l)	4.9 ± 0.6	5.1 ± 0.5	4.9 ± 0.7	4.8± 0.6
FEV_1 % pred	114 ± 9	115 ± 11	116 ± 15	113 ± 13
FVC (l)	6.4 ± 0.8	6.4 ± 0.8	6.0 ± 1.0	5.9 ± 0.7
FVC % pred	120 ± 10	120 ± 10	118 ± 12	106 ± 35
MIP (kPa)	8.9 ± 2.4	9.4 ± 2.1*	10.9 ± 3.0	11.0 ± 2.0§
MVV ($l \cdot min^{-1}$)	213 ± 17	231 ± 19*	200 ± 34	197 ± 39§

at 90 W) until a dyspnoea Borg score of 8/10 was reached; then the final acceleration started (1 rpm corresponding to 9 W every 20 s) until exhaustion.

Endurance respiratory muscle training

The training protocol lasted for five weeks and was performed by means of a Spirotiger® (MVM, Linate, MI, Italy), consisting of a hand-held unit with a pouch and a base station. A two-way piston valve connected to a rebreathing bag allows a constant isocapnic end-tidal CO_2 fraction [24] to be maintained.

The use of the instrument and the software, the assembly of the various components and the hygiene standards were explained to the subjects.

Before starting the protocol the subjects underwent four supervised training sessions to learn the technique and to define the appropriate size of the bag and the respiratory rate. While performing the RMET, the athletes wore a nose clip to ensure that they were breathing through the training device only.

The volume of the bag was initially set at a value corresponding to 60% of the subject's vital capacity. The RR was progressively increased in order to reach the same ventilation measured at RC point during the incremental test (roughly corresponding to 50% of MVV). The subjects trained for 20 min daily, seven days a week, for five weeks.

The compliance to home-based training was evaluated by a diary.

Subjects were required not to change their daily training and diet during the study.

Statistical analysis

Data are reported as mean ± standard deviation (SD). The unpaired T-test was used for comparison between RMT group and CON group parameters at T0 and T1. The 2-way ANOVA test was used to evaluate the effect of training on the anthropometric parameters, pulmonary function, and ventilatory pattern and VO_2 trend during the tests; the P values were adjusted according to the Bonferroni correction. Comparison between groups at different points (after the warming up, at VT point, at RC point and at maximum load) was performed by using repeated-measures analysis of variance (mixed model). The parametric Pearson correlation coefficient was used to describe the relationships between variables: MIP vs VE and VE vs VO_2.

Statistical significance was accepted at $P \leq 0.05$.

All the analyses were performed using GraphPad Prism 40.

RESULTS

General characteristics of the subjects in the RMT and CON groups are summarized in (Table 1). They had similar experience in cycling and running and had similar VO_2 peak at T0 (unpaired T-test, P>0.05), (*Table 1*).

Pulmonary function tests

No difference is found in FEV_1 and FVC in both groups while in RMT group, but not in CON, a significant increase in MIP and MVV is shown (P = 0.03, 2-way ANOVA); (Table 1). The comparison between RMT and CON at T1 shows a significant difference in MIP improvement and in MVV (unpaired T-Test, P = 0.03 and P = 0.004 respectively).

Endurance Respiratory Muscle Training

According to the training program all athletes performed RMET for 20 min daily, seven days a week, for five weeks. They started RMET with the following average work load: volume of the bag of 3.45 ± 0.37 l, respiratory rate 23 ± 1.4 $b \cdot min^{-1}$. At the end of the training period the volume of the bag didn't change, respiratory rate increased: 29.6 ± 2.1 $b \cdot min^{-1}$ (+28%, P<0.001) corresponding to a ventilation of 102.5 ± 13.1 $l \cdot min^{-1}$, roughly the same ventilation measured at RC point during incremental test (106.8 ± 0.3 $l \cdot min^{-1}$ and 98.2 ± 0.5 $l \cdot min^{-1}$ respectively for running and cycling).

Maximal incremental tests

During both cycling and running tests, the subjects in the RMT group show a higher exercise capacity: wattage and speed

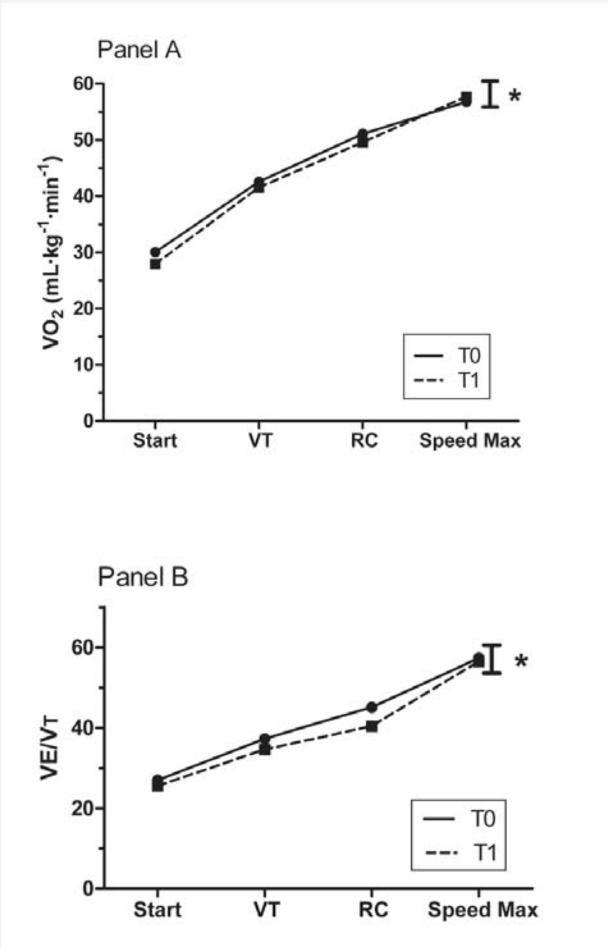

Figure 1 The oxygen consumption trend (VO2, Panel A) and ventilatory pattern trend (VE/VT, Panel B) in RMT group during running test before (T0) and after (T1) RMET.
* ANOVA test between T0 and T1, P<0.05.
Mean value after warming up (start), at ventilatory threshold (VT) point, at respiratory compensation point (RC) and at maximum load reached at T0.

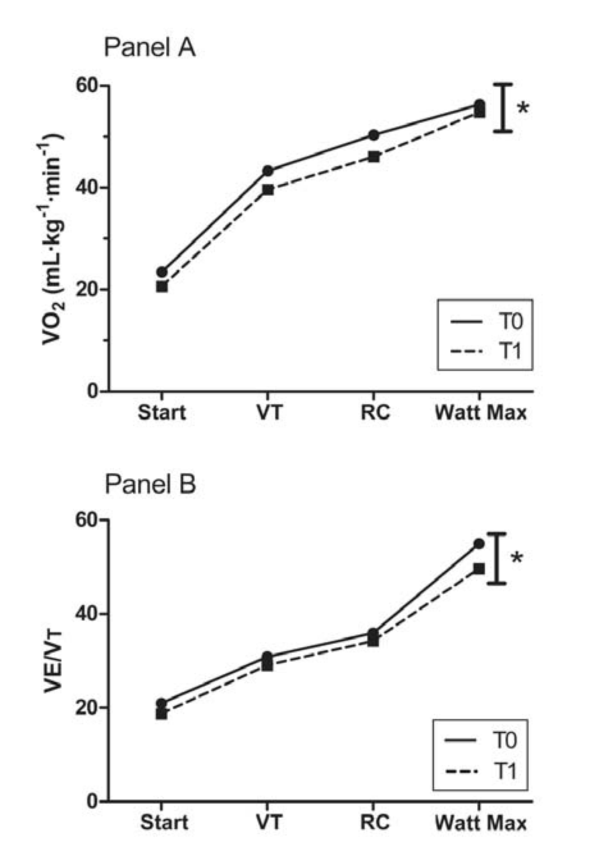

Figure 2 The oxygen consumption trend (VO2, Panel A) and ventilatory pattern trend (VE/VT, Panel B) in RMT group during cycling test before (T0) and after (T1) RMET.
* ANOVA test between T0 and T1, P<0.05. Mean value after warming up (start), at ventilatory threshold (VT) point, at respiratory compensation point (RC) and at the maximum load reached at T0.

significantly increase at the peak of exercise (Table 2) with no changes in VT and RC points. The subjects in the CON group don't show any significant change (Table 2). A significant difference in maximum wattage and speed is found between the two groups at T1 (unpaired T-test, P = 0.001).

During both tests we also analysed the VO_2 trend and the breathing pattern referring to four different points: after the warming up, at VT point, at RC point and at maximum load reached at T0. VO_2 and VE/VT trends are significantly lower after RMET in both tests in the RMT group (Figures 1,2) while in the CON group no differences are observed (Figures. 3, 4). The comparison between the groups shows a difference in VO_2 and VE/VT trends at T1 (P < 0.05).

The analysis of respiratory exchange ratio doesn't show any difference before and after the training in any of the five points. Data not reported.

An inverse correlation is found in the RMT group between changes in MIP and changes in mean VE for both tests (running: r^2 = 0.44, P = 0.03; cycling: r^2 = 0.50, P = 0.02). Moreover, only during the running test the changes in mean VE are significantly correlated with the changes in mean VO_2 (r^2 = 0.57, P = 0.01); no similar correlation is observed in cycling (Figure 5).

The analysis of breathing pattern shows that VE/VT at T0 is significantly higher in running as compared to cycling. After RMET, VE/VT significantly decreases in both tests maintaining the differences between the two types of exercise.

As regards the VE/VO_2, at T0 there is a significant difference between the two types of exercises, with cycling showing a better ventilatory efficiency than running. After RMET, the efficiency significantly improves in running but not in cycling and the difference between the two exercises are cancelled (Table 2). No difference in this parameter between T0 and T1 is observed in the control group (Table 2).

DISCUSSION

The new important finding of this study is the change of breathing pattern during exercise with the adoption of a slower and deeper ventilation. This result is mainly due to the increased strength and performance of respiratory muscle (significantly higher MIP and MVV) as demonstrated by the strong correlation between the reduced ventilation and the higher pressure generated by respiratory muscle. These changes in turn affect the maximal exercise capacity during running and cycling.

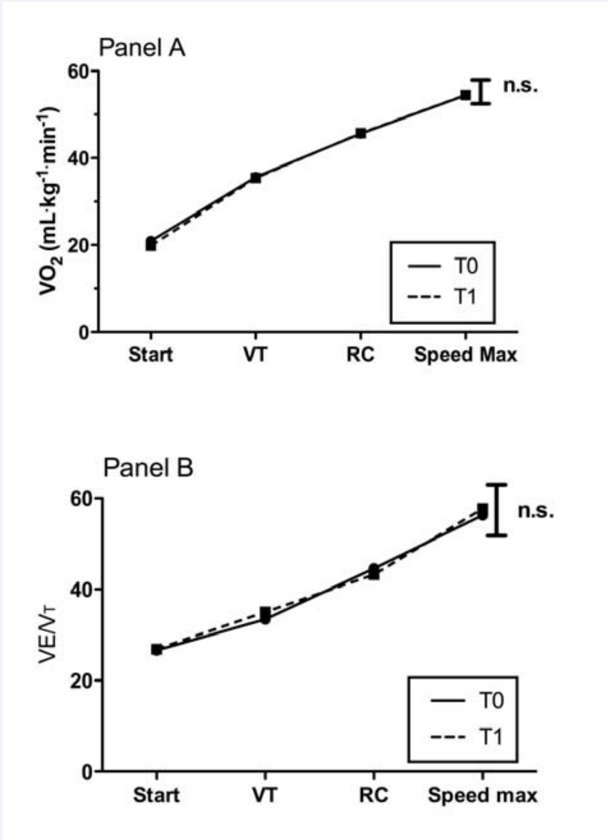

Figure 3 The oxygen consumption trend (VO2, Panel A) and ventilatory pattern trend (VE/VT, Panel B) in CON group during running test before (T0) and after 5 weeks (T1).
ANOVA test between T0 and T1. Mean value after warming up (start), at ventilatory threshold (VT) point, at respiratory compensation point (RC) and at maximum load reached at T0.

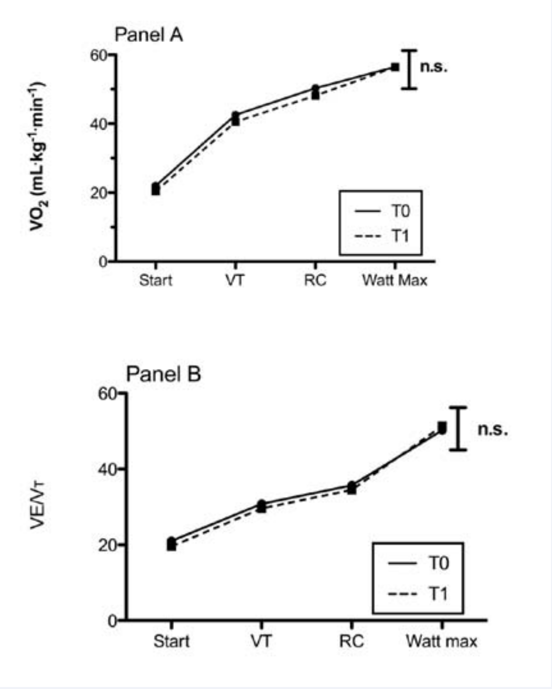

Figure 5 The oxygen consumption trend (VO2, Panel A) and ventilatory pattern trend (VE/VT, Panel B) in CON group during cycling test before (T0) and after 5 weeks (T1).
ANOVA test between T0 and T1. Mean value after warming up (start), at ventilatory threshold (VT) point, at respiratory compensation point (RC) and at the maximum load reached at T0.

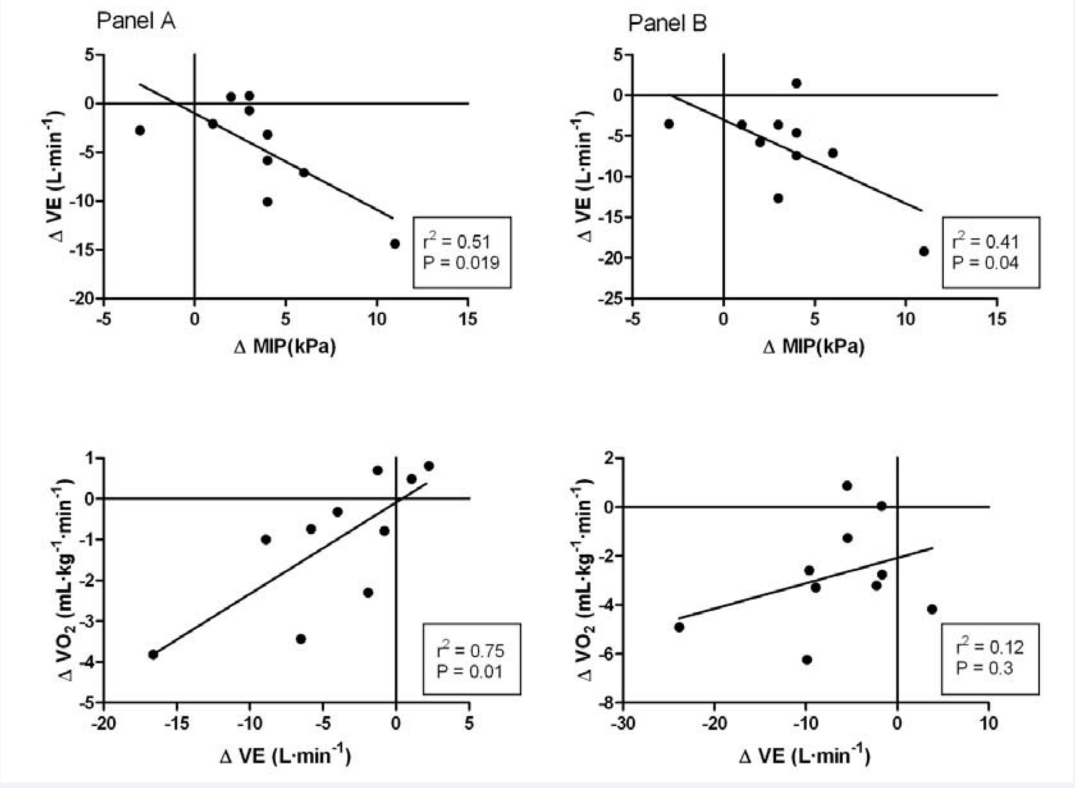

Figure 5 Panel A running, panel B cycling. Upper panels: Correlation between the change in minute ventilation (ΔVE) and the change in maximal inspiratory pressure (ΔMIP). Lower panels: correlation between the change in oxygen consumption (ΔVO2) and the change in minute ventilation (ΔVE) before and after RMET.

Table 2: Exercise performance during maximal incremental tests before and after training in RMT and CON group.

Running	**RMT -T0**	**RMT -T1**	**CON-T0**	**CON-T1**
Load max ($km \cdot h^{-1}$)	18.2 ± 2.0	19.3 ± 2.5*	17.8 ± 1.5	17.8 ± 1.4§
Load at VT ($km \cdot h^{-1}$)	11.9 ± 1.4	12.7 ± 2.4	9.8 ± 1.3	10.1 ± 2.3
Load at RC ($km \cdot h^{-1}$)	14.7 ± 1.7	15.0 ± 2.2	13.8 ± 1.6	13.8 ± 1.7
VO_2 peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	56.8 ± 7.6	58.9 ± 7.3	54.4 ± 5.7	54.5 ± 5.6
HR max (bpm)	185 ± 4	189 ± 6	181 ± 8	180 ± 11
VE max ($l \cdot min^{-1}$)	150.6 ± 13.0	148.8 ± 12.5	150.0 ± 14.2	153.0 ± 14.3
RR max ($b \cdot min^{-1}$)	57 ± 5	56 ± 7	54 ± 5	53 ± 15
VE/VO_2	29 ± 2	28 ± 3*	30 ± 4	31 ± 6§
Cycling	**RMT -T0**	**RMT -T1**	**CON-T0**	**CON-T1**
Load max (W)	389 ± 106	429 ± 119*	386 ± 102	395 ± 98§
Load at VT (W)	198 ± 37	211 ± 51	195 ± 27	192 ± 30
Load at RC (W)	263 ± 47	276 ± 51	260 ± 41	261 ± 38
VO_2 peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	56.3 ± 8.4	55.3 ± 8.5	56.0 ± 8.0	56.2 ± 7.5
HR max (bpm)	181 ± 5	182 ± 7	178 ± 7	180 ± 9
VE max ($l \cdot min^{-1}$)	154.4 ± 15.4	145.6 ± 21.8	148.2 ± 13.4	150.3 ± 17.7
RR max ($b \cdot min^{-1}$)	55 ± 7	48 ± 6	53 ± 9	50± 7
VE/VO_2	25 ± 3	25 ± 3	27 ± 4	27 ± 5

Data are represented as mean ± SD. * Statistical significance (ANOVA test) from T0 to T1, $P<0.05$. § Statistical significance (unpaired T-test) from T0 to T1 between RMT group and CON group, $P<0.05$.

Abbreviations: RMT, respiratory muscle endurance training group; CON, control group; T0, baseline evaluation; T1, after five weeks. VT, ventilatory threshold; RC, respiratory compensation point; HR max, maximum heart rate; VO_2 peak, peak oxygen consumption; VE max, maximum ventilation; RR max, maximum respiratory rate; VE/VO_2 ventilatory equivalent of VO_2.

As regards VE/VT we observe a different response to exercise between running and cycling. This is in line with the literature [17]. In fact, cycling and running are characterized by a different breathing pattern, ventilatory efficiency and mode of increase in ventilation. According to Kalsas and Thorsen [16], cycling is characterized by a steeper rise in VT and sharper curvature of VE/VT, implying that VT max is achieved at a lower VE. Our results are similar to those reported in literature. At baseline we found a different VE/VT during the two tests. RMET reduces the ventilatory response for identical exercise tasks and induces the adoption of a more efficient breathing pattern characterized by a lower respiratory rate. This is true for both exercises: in fact, the differences between running and cycling remain significant.

As for VE/VO_2, at baseline we found a better ventilatory efficiency in cycling (lower VE/VO_2). After RMET, VE/VO_2 significantly improves only in running, erasing the difference between the two types of exercises.

Moreover, only in running is the reduction in ventilation significantly related to the reduction in VO_2. We can therefore say that the effect of RMET in running is almost completely due to the increase in strength and resistance of respiratory muscles, as confirmed also by the strong correlation between the increase in MIP and the reduction in ventilation.

This is not completely true for cycling. In fact, during this type of exercise the reduction in ventilation is significantly related to the increase in MIP but not with the lower VO_2. The explanation of this result can be only speculative. According to previous papers [25,26], we might hypothesize that different entrainment of breathing and different breathing strategies during cycling and running can play a role.

In this study we also show that, after five weeks of RMET, the exercise capacity of amateur triathletes significantly improves as demonstrated by the higher workload reached during both incremental tests. Despite the increase in maximal workload, no difference in VO_2 peak is found after RMET and this result is consistent with previous data. As reported by Illi et al [7], only in two studies out of 22 was a significant change in VO_2 max after RMET observed [12,24]. This could be due to the fact that RMET involves a small group of muscle (only respiratory) while to improve the VO_2max a large group of muscle must be trained. So, there should be no reason to observe a significant change in the central cardiocirculatory response and O_2 tissue utilization after RMET as pointed out by Markov et al [27]. Even if the VO_2 peak does not change significantly, the VO_2 trend during both incremental tests shows a significant improvement. The less O_2 required to perform the same workload reflects the fact that an improvement in respiratory efficiency has been shown.

Interestingly, no change in both ventilatory threshold and respiratory compensation point is found as if respiratory muscle training improves the ability to sustain exercise beyond anaerobic threshold.

This study has some limitations. The major limitation is the lack of either an endurance exhaustive constant-load test or time-trials at different intensities; this is due to the fact that our aim was the evaluation of the effect of RMET on respiratory function and breathing pattern during maximal exercise tests. Another limitation is that the control group is not a placebo group:

in fact they did not perform breathing exercise (i.e. a "sham" respiratory).

In conclusion, respiratory muscle endurance training increases respiratory muscle strength and changes the breathing pattern during exercise toward a more efficient one characterized by a lower respiratory rate. After the training the athletes can tolerate a higher workload enhancing the exercise performance.

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