Ventilatory Muscle Endurance Training - Effect on Endurance Exercise Performance in Trained Cyclists

Jackson P. Wai
The Chinese University of Hong Kong

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Abstract

There is evidence suggesting that the functional capacity of the ventilatory muscle may limit endurance exercise performance. The purpose of this study was to improve the endurance exercise performance of cyclists by incorporating inspiratory muscle endurance training (IMET) into the regular training routine. 16 cyclists were assigned randomly into either the control or the IMET group. All subjects trained 2-3 months in almost the same course. The IMET group wore modified face masks with small inspiratory orifices to increase inspiratory resistance. After the training, maximum oxygen uptake (+5%) and 30-min endurance output (+9%) increased significantly in the IMET group but not in the control group. It was concluded that exercise performance improved after IMET in moderately trained cyclists but the slightly younger and the initially less trained subjects of the IMET group might contribute to some of the improvement.

Objectives

The functional capacity or fatigue of the ventilatory muscle is considered a limiting factor to exercise performance. By training the endurance of ventilatory muscles, endurance exercise performance in the untrained and the trained have been found to be significantly enhanced. This project studied how effective an inspiratory muscle endurance training (IMET) program could improve the performance of trained cyclists.

Background

During exercise, the locomotive muscles (muscles of the extremities) function to produce body movements, while the ventilatory muscles function to ventilate the lungs to obtain sufficient oxygen and eliminate metabolic waste such as carbon dioxide. The capacity of either muscle groups can affect the whole body exercise performance of an athlete. A recent study done by Wai and Hodgson (1992) demonstrated that progressive cycling exercise performance was limited by the maximum energy output of the ventilatory muscles. Improvement of the capacity of the ventilatory muscles would theoretically improve exercise performance.

A few sports scientists have theorized that if fatigue of the ventilatory muscle may limit the ability to perform maximum exercise, then by improving the endurance of the ventilatory muscle, fatigue of the ventilatory muscle could be delayed, which would then lead to an increase of exercise ability.

There is indirect evidence suggesting that exercise performance may be associated with the fatigue of the ventilatory muscle. Long term exhaustive exercise can induce loss of ventilatory muscle strength and endurance (Loke et al. 1982, Bender & Martin 1985). On the other hand, respiratory muscle endurance exercise causes a decrease in subsequent short-term maximum running time and oxygen uptake (Martin et al. 1982). Roussos and Macklem (1977) have shown that the diaphragm begins to fatigue when transdiaphragmatic pressure, an indicator of the force generated by the diaphragm, is greater than 40% of its maximum under an inspiratory resistive loading condition. Animal studies found that diaphragm fatigues during loaded breathing is related to a decline of glycogen content and triglyceride content (Gorski et al. 1978, Bazzy et al. 1985).

Since Leith & Bradley (1976) demonstrated that the endurance of the ventilatory muscles can be improved after ventilatory muscle endurance training (VMET) in normal human, VMET has become one important therapy for the chronic obstructive pulmonary disease (COPD) patients based on the belief that weakness of the ventilatory muscles contributes to limit their ability to do work. A number of studies (Levine et al. 1986, Pardy et al. 1981, Sonne & Davies et al. 1982) have reported that after receiving VMET, COPD patients showed improvement in inspiratory muscle endurance, decrease of dyspnea, and more importantly increase of exercise ability.

There are two common methods used to train the endurance of the ventilatory muscles, the isocapnic hyperpnea and the flow resistive loading methods. In the isocapnic hyperpnea method, the subject is provided with a rebreathing circuit which allows control of the inspiratory concentration of carbon dioxide and oxygen, and also is provided with a target ventilation to follow. The intensity of ventilatory exercise is therefore determined by the level of ventilation. During flow resistive loading, the subject breaths through a small orifice or a series of small orifices. The intensity of load is thus determined by the size of orifice. A third method which is sometimes used is the threshold loading method. This method requires the subjects to generate more than the threshold pressure which is necessary to open an inspiratory valve to allow inspiration to occur.

The effects of VMET upon the exercise performance of normal subjects and of athletes have been studied by a few investigators. The results seems to be beneficial if appropriate assessment methods are used.

Morgan et al. (1987) employed the isocapnic hyperpnea method to train 4 moderated trained cyclists 5 times per week for 3 weeks. In their study, the subjects breathed at 85% of their pre-training maximum voluntary ventilation (MVV). Each subject engaged in 4 daily training bouts (2, 5, 9, and 12 minutes duration) with recovery period between bouts. When the last training bout was achieved, training intensity would increase by 5% MVV on the next day. After VMET, the subjects improved both their ventilatory muscle power and endurance, however, neither maximum aerobic power nor high intensity cycling time was changed.

Fairbarn et al. (1991) conducted a 4-week isocapnic hyperpnea study on 5 highly trained cyclists. Their subjects were trained 4 times per week. Each session included three 8-minute work intervals alternated with rest periods. The initial training load was the same as their pre-training maximum sustained ventilatory capacity (the highest ventilatory level that a subject can achieve for 15 minutes under isocapnic conditions). The level of ventilation and the duration of training were progressively increased. At the end of the 4-week training period, the duration of the training session had increased to 10 minutes. The VMET improved the subjects' ventilatory muscle endurance, but did not affect their maximum aerobic power, or short-term high intensity exercise performance.

Boutellier & Piwko (1992) trained 4 sedentary subjects daily for 4 weeks using isocapnic hyperpnea method. The training intensity during each training session was on the average 90 (76 - 103) liters per minute with tidal volume set at 50-53% of vital capacity. The breathing frequency was initially set at 38 times per minute, and was increased 1 time each week. After VMET, their cycling endurance time at an exercise intensity of 170 beats per minute heart rate improved from 27 to 40 minutes.

In another study, Boutellier and his colleges (1992) used the same VMET method to train endurance athletes and found their ventilatory muscle endurance increased from 6 minutes to 40 minutes, and the cycling endurance at the anaerobic threshold (about 260 watts) increased from 23 to 32 minutes.

A reasonable explanation for obtaining non-significant results in Morgan's et al. (1987) and Fairbarn's et al. (1991) studies is that the performance tests used were short-term high intensity exercise which would not tax the endurance of the ventilatory muscle. In contrast, Boutellier and his co-workers (1992, 1992) used long-term exercise, a more valid means to assess the effect of VMET upon whole body exercise performance.

Methodology

Procedure

A cycling team consisted of 10 males participated in this study. Explanation of the study including discussion of the benefits and potential risks were provided before signing informed consent forms. All subjects were healthy non-smokers. They were randomly assigned to either the control group or the inspiratory muscle endurance training (IMET) group. Pulmonary functions, maximum aerobic power ($\dot{V}O_{2max}$), and 30-min endurance output were measured before and after training.

After the pre-tests, all subjects performed their training on the same road course as much and as frequent as possible. The distance of the course was 28 km with 43% distance as hills, which have an average of 2.34 degrees inclination. Each workout was a near-exhausted trial. The IMET group wore face masks with the inlet covered by a perforated 2-mm thick rubber mat. Each orifice was 2-mm in diameter. They began with 24 orifices and most of them gradually decreased the number to 20. All subjects were refrained from vigorous exercise one day prior to performance tests, and their training milages were recorded.

Instrumentation and Measurement

Pulmonary function measurements, consisting of forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), forced mid-expiratory flow between 25% and 75% of FVC ($FEF_{25-75\%}$), and maximum voluntary ventilation in 12 seconds (MVV_{12}), were assessed using a 10-liter capacity spirometer following standard methods and procedures (Quanjer 1983).

Maximum oxygen uptake was measured using Douglas bag technique with the subjects exercising on a Monark mechanical leg cycle ergometer. The intensity started at 1 kp for 4 min, then increased .25 kp thereafter and for every two minute work until exhaustion. The peddling frequency was maintained at 90 rounds per minute.

Endurance exercise test was a 30-min maximum power output trial using 75-80% $\dot{V}O_{2max}$ intensity as initial load. After 5 min, the subjects were allowed and encouraged to increase the resistance as much as possible for the target time while maintaining 90 rpm. The goal was to exhaust at the end of the 30 min.

Statistical Analysis

Paired t-tests were used to examine whether there was significant difference between pre-test and post-test measurements for each group. Independent t-tests were used to examine difference between the 2 group of subjects. The statistical significance level was set at 0.05.

Results

Due to injury of one subject in the IMET group and time restraint of another subject in the control group, they were unable to complete the entire training, thus each group was left with 4 subjects. There was no significant different ($p > .05$) between the control and the IMET group in age and height, however, the IMET subjects tended to be younger and taller (Table 1). The training period was 2-3 months. The total training milage and the amount of hills as a percentage of the total milage were not different ($p > .05$) between the two groups. There were two control subjects who sometimes trained on different courses of which the amount of inclination was not assessed and regarded as flat route. Thus the amount of hill milage should be closer between the two groups. It should be noted that it was during the hill training that IMET was taking place due to the increase of breathing resistance associated with the increase of pulmonary ventilation. The two group was not different ($p > .05$) in body weight either pre- or post-training. The IMET had a higher pre-test weight after the training. Pulmonary function data are shown in Table 2. There was a significant decrease of $FEF_{25-75\%}$ in the IMET group after training.

We found a 5% increase ($p < .05$) of $\dot{V}o_{2max}$ and a 9% increase ($p < .05$) of endurance output in the IMET group, while no change was found in the control group (Table 3). Although there was no initial difference of these two performance variables, the IMET subjects were slightly younger and had less training experience prior to the study, we could not rule out the possibility that these two factor might contributed to the improvement of performance.

Table 1. Physical characteristics and training record of subjects. Values are mean±SD.

	Age (yrs)	Ht (cm)	Years of Training*	Total milage (km)	Hill milage (%)	Wt_I Pre (kg)	Wt_I Post (kg)	Wt_E Pre (kg)	Wt_E Post (kg)
Control	27.3	169.5	3.6	407.8	35.7	61.2	60.6	60.8	60.4
(n=4)	±8.9	±1.7	±1.5	±119.8	±12.8	±7.0	±6.8	±7.1	±7.4
IMET	21.0	174.2	1.4	443.7	43.0	62.7	64.3*	62.9	63.6
(n=4)	±8.1	±9.1	±.9	±83.8	±0.1	±9.8	±9.6	±9.7	±9.7

The two subject groups were different ($p<.05$) in years of training prior to this study. Body weight obtained immediately before measurement of maximum oxygen was higher ($p<.05$) in the IMET group after training.

Control Subjects received cycle training only.
IMET Subjects received both inspiratory muscle and cycle training.
Wt_I Body weight obtained immediately before the incremental test.
Wt_E Average of the two body weights obtained immediately before and after the endurance test.

Table 2. Pulmonary functions of subjects. Values are mean±SD.

	FVC (L)		FEV_1 (L)		$FEF_{25-75\%}$ ($L.s^{-1}$)		MVV ($L.min^{-1}$)	
	Pre	Post	Pre	Post	Pre*	Post**	Pre	Post
Control (n=4)	4.26 ±.27	4.45 ±.26	3.66 ±.26	3.75 ±.24	4.29 ±.52	4.03 ±.40	156.0 ±18.8	161.7 ±12.8
IMET (n=4)	4.55 ±.95	4.59 ±.92	4.19 ±.60	4.17 ±.50	5.69 ±.62	5.21** ±.46	174.2 ±28.9	172.7 ±31.1

The two subject groups were different in the mid-range forced expiratory flow both before ($p < .05$) and after ($p < .01$) the training period. A decrease ($p < .01$) of the same flow parameter was found in the subject group who received both inspiratory muscle and cycle training.

Table 3. Exercise performance of subjects. Values are mean±SD.

	$\dot{V}O_{2max}$ (ml.kg^{-1}.min^{-1}) Pre	Post	Endurance (watts) Pre	Post
Control (n=4)	55.8 ±6.1	55.8 ±6.4	193.4 ±24.6	201.7 ±13.2
IMET (n=4)	51.7 ±3.7	54.1* ±3.9	180.0 ±23.9	196.2* ±29.8

Subjects who received both inspiratory muscle and cycle training had significant increase ($p<.05$) in maximum oxygen uptake and 30-min cycling mechanical power.

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Applications and Significance

Athletic training is a scientific process where the outcome reflects the effectiveness of this process. The training method should be designed and carried out in such a way that desirable results can be maximized. During exercise, the body systems which are particularly in demand should be trained to improve its capacity so as not to limit the body's ability to perform work. The conventional training program emphasizes on the training of the locomotive muscles, while the ventilatory muscles, which are also working during exercise, are being neglected. The present study applied inspiratory muscle endurance training (IMET) on a group of moderately trained cyclists during their road training to improve their exercise performance, so that the capacity of the inspiratory muscles would not impair their exercise ability. We found that exercise performance (maximum aerobic power and exercise endurance) improved after IMET in moderately trained cyclists but the slightly younger and the initially less trained subjects of the IMET group might contribute to some of the improvement. Since IMET is still new as an training aids, more studies should be conducted on finding out the optimum IMET mode and/or intensity for various types of athletes. It is very important that we should apply IMET soon so that our athletes would gain the benefits in advance of the others.

Appendix 1. Physical characteristics and training records of each subject.

Subject No.	Age (yrs)	Ht (cm)	Years of Training	Total milage (km)	Hill milage (%)	Wt_I Pre (kg)	Wt_I Post (kg)	Wt_E Pre (kg)	Wt_E Post (kg)
1	32	170	5.0	374.00	43.21	50.9	50.7	50.5	49.6
2	14	168.7	1.5	309.40	43.09	63.8	62.9	62.1	63.1
3	32	167.7	4.0	582.27	16.65	63.7	62.3	63.8	62.1
4	31	171.5	4.0	365.37	39.81	66.3	66.3	66.6	66.6
5	19	173.1	1.0	422.50	43.03	54.8	56.1	55.0	56.5
6	16	161.9	.5	365.90	43.06	53.8	55.8	54.1	53.9
7	33	178.8	2.5	562.71	43.08	70.6	72.9	70.6	72.4
8	16	182.9	1.5	423.60	42.92	71.7	72.3	72.0	71.5

Subject number 1 to 4 were the control group.
Subject number 5 to 8 were the IMET group.

Appendix 2. Pulmonary functions of each subject.

Subject No.	FVC (L)		FEV_1 (L)		$FEF_{25-75\%}$ ($L.s^{-1}$)		MVV ($L.min^{-1}$)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	4.04	4.13	3.41	3.54	4.08	3.86	159.1	154.1
2	4.55	4.66	4.01	4.07	4.72	4.61	139.1	168.8
3	4.43	4.35	3.68	3.61	3.64	3.73	181.1	175.8
4	4.01	4.66	3.55	3.79	4.70	3.90	144.5	148.2
5	3.93	4.13	3.73	3.92	4.89	4.62	184.2	174.1
6	3.93	3.85	3.76	3.69	5.86	5.37	132.2	132.2
7	5.93	5.91	5.02	4.85	5.62	5.12	198.1	207.9
8	4.40	4.48	4.23	4.20	6.38	5.71	182.2	176.7

Subject number 1 to 4 were the control group.
Subject number 5 to 8 were the IMET group.

Appendix 3. Exercise performance of each subject.

Subject No.	$\dot{V}O_{2max}$ (ml.kg^{-1}.min^{-1})		Endurance (watts)	
	Pre	Post	Pre	Post
1	64.4	64.4	212.7	206.6
2	55.6	56.0	160.2	182.2
3	51.8	53.8	189.2	211.3
4	51.3	49.1	211.4	206.8
5	50.4	54.2	164.8	178.3
6	52.4	54.5	162.2	170.3
7	56.4	58.5	214.1	237.0
8	47.7	49.1	179.0	199.3

Subject number 1 to 4 were the control group.
Subject number 5 to 8 were the IMET group.