

The Effect of an Inspiratory Muscle Training Period at High Altitude on Arterial Oxygen Saturation and Performance of Iran's National Team Endurance Runners

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Abstract

The aim of this study was to investigate the effect of inspiratory muscle training at high altitude on peripheral capillary oxygen saturation and performance among endurance runners. Twelve endurance male runners (age: 24 yrs \pm 3 yrs, height: 180.5 cm \pm 4.2 cm, weight: 66.7 kg \pm 3 kg, Body mass index: 20.5 \pm 1.0) among Iranian national team were randomly divided into case and control group in hypoxic condition. Exhaustive testing free 1500 m, strength Index and arterial oxygen saturation tests were taken before and 24 h after training period. Training program include same continues, interval, aerobic and resistance training for two groups. Runners performed 16 training session per week in high altitude within four weeks. Data were analyzed by analysis of variance ($P \leq 0.05$). Inspiratory muscle training at hypoxia due to significant decrease in 1500 m running performance, inspiratory muscle strength and peak inspiratory flow in both group, but the differences in volume and peripheral capillary oxygen saturation were not significant ($P \leq 0.05$).

This study suggests that using inspiratory muscle training along with specified training in hypoxia increases inspiratory muscle strength and peak inspiratory flow pressure meanwhile it decreases ventilation and 1500 m running time in lower altitude.

Keywords: Respiratory muscle training; Hypoxia; Peripheral capillary oxygen saturation (SpO_2); Endurance performance

Introduction

Competition drives athletes to continually seek new ways to gain the edge over their fellow competitors. Historically, training for high performance has focused on rigorous peripheral muscle and cardiovascular training using partial or full-body exercises. Respiratory muscle training (RMT) and particularly inspiratory muscle training (IMT) have been investigated as a method which athletes could improve their performance [1]. Mechanisms postulated to explain improved sport performance from IMT are decreases in the rating of perceived breathlessness (RPB) or rating of perceived exertion (RPE) and attenuation of the metaboreflex phenomenon that may result in the redirection of blood flow from the locomotor muscles to respiratory muscles [2-5].

Evidence is emerging that respiratory muscles fatigue may affect exercise performance via metaboreflex [6,7]. Accumulation of metabolites such as lactic acid in respiratory muscles activates group III and especially group IV nerve afferents which ultimately triggers brain sympathetic outflow increase and causes vasoconstriction in exercising limbs [8,9].

Improved aerobic capacity of primary and accessory respiration muscles has reported amongst athletes likely during IMT/RMT because of enhanced aerobic metabolism and oxygen delivery. This in turn may have delayed the onset of fatigue and reduced competitive blood flow between the exercising respiratory and limb muscles during sport performance. There is some evidence that specific training of respiratory muscles can attenuate the respiratory muscle metaboreflex [10,11].

In consequence, a certain similarity between the stresses induced in the human body by altitude exposure and by a maximal intensity specific training can be deduced [12-24]. Switching phosphofructokinase gene expression to anaerobic pathway and increased energy production via anaerobic pathways as a compensatory mechanism for the reduced energy supplied by aerobic pathways [16]. The most plausible explanation for IMT-induced performance

adaptations probably lies within the reports of reduced effort sensations and increasing SpO_2 at altitude [25,26]. It is therefore surprising that experimental models examining the effects of IMT have tended to do so in isolation rather than utilising IMT as an additional aid to a hypoxia training programme [23]. We have previously proposed that the inclusion of IMT within a training programme might positively alter the perception of effort during training bouts and consequently augment the ventilation parameters and quality of work accomplished. This in turn could be expected to enhance endurance performance [24]. Several studies previously have suggested that inclusion of IMT within a training program might positively improves respiratory indexes including oxygen partial pressure (PaO_2), peripheral capillary oxygen saturation (SpO_2), hemoglobin oxygen saturation (SaO_2), and Endurance performance. This consequently augments the volume and quality of accomplished work [12-27]. This study has conducted to investigate whether IMT would significantly increase the magnitude of arterial saturation experienced at rest and improve 1500 m performance at 2500 m altitude.

Methods and Materials

Twelve endurance male runners among Iranian national team were randomly divided into case and control group in hypoxic conditions agreed to participate in this study (Table1). All procedures were approved by the institutional ethics committee (Olympic committee letter number 2634). We ensured that there was no evidence of respiratory cardiovascular or infection diseases, diabetes. Allergy,

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Parameter	EXP (n=6)		CON (n=6)	
	Pre- altitude	Post-altitude	Pre- altitude	Post- altitude
Age	2.8 ± 23.1	2.8 ± 23.1	3.1 ± 25.6	3.1 ± 25.6
Height (cm)	4.0 ± 178.3	4.0 ± 178.3	3.3 ± 182.6	3.3 ± 182.6
Body mass (kg)	3.1 ± 67.5	2.6 ± 66.1	3.8 ± 66.0	3.4 ± 65.5
BMI (kg.m ²)	0.3 ± 21.2	0.4 ± 20.8	1 ± 20.7	1 ± 19.7

Table 1: Pre- and post-altitude anthropometric characteristics of the subjects in the Experimental (EXP) and in the Control (CON) groups (mean ± SD).

smoking or supplemental use were other excluding criterion. Written consents were taken from all participants.

Experimental design

Study was conducted after competitive season and during their period of rest. First, all participants were called to Olympic camp for checking their height, weight, body mass index (BMI). After getting familiar with Power Breath device (K5 model, UK) and SPIROLAB pulse oximeter device (MIR, Italy) they were randomly divided to experimental group (EXP) (n=6) and placebo or control group (CON) (n=6). Then functional performances in 1500 m were taken place in 200 m standard indoor track at 1400 m altitude from both groups. Power Breath was used for inspiratory indexes measurement such as maximum inspiratory pressure (MIP) and peak inspiratory flow (PIF) as well as inspiratory volume. SpO₂ in altitude was measured by pulse oximeter. Then Runners performed special training by R2M method at 2500 m altitude in Delfan camp at Zagros Mountain. They trained in combinational sessions including endurance, speed, power and plyometric trainings with different volumes and intensities. All inspiratory indexes were measured and 1500 m executive function performance test were taken right 24 h after the end of the fourth week. Field trainings such as altitude living-training and live high train high (LHTH) were done (Table 2).

Inspiratory muscle training

First of all, we measured the maximum muscular power (cm H₂O) for an inspiration (S-Index) which is considered equal with MIP. Training protocol was considered including thirty deep inspirations with closed nose with Power Breath device for EXP group within seven days.

Altitude training intervention

All participants performed the altitude program. Similar training program such as interval, aerobic and resistance training have been conducted for both groups. The runners performed 16 training session per week within four weeks in high altitude (just three tracks training sessions per week at seven days performed at low altitude). SpO₂ measurement was carried out only in altitude at least for three minutes in flat position and just during night time.

Data collection and statistical analyses

Data were collected and analyzed by SPSS software (version 21.0, SPSS, Chicago, Illinois) parametric data assumptions were met (Shapiro-Wilks test), pre training, post training and group interactions results were statistically compared using two-ways repeated measures analyses of variance (ANOVA) and post hoc Bonferroni tests of Honestly Significant Difference as appropriate. Probability values of less than 0.05 were considered significant. All results were expressed as mean standard deviation (SD) unless otherwise stated.

Results

Results driven by ANOVA repeated measurements of altitude's effect on variables along with between-group factor revealed that despite

of group and training protocol type, 1500 m running time performance showed significant difference (T=838/65, P=0/01). Post hoc Bonferroni test showed significant difference (1%) between experiment group and control group (p ≤ 0.05). Statistical assessment of S-Index (T=26/13, P=0/01) and PIF (T=7/33, P=0/02) showed significant difference in duration of being exposed to Altitude condition (P ≤ 0.05). But no significant differences between groups was indicated by post hoc Bonferroni tests (P ≤ 0.05). Results also indicated that excepting SpO₂ (T=1/31, P=0/27) and Volume (T=0/643, P=0/44) there were no significant difference in other variables in both groups (P ≥ 0.05) (Table 3 and Figures 1-3).

Discussion

Current study mainly shows that IMT significantly increased inspiratory muscle strength (S-Index) and PIF (EXP=18.48%, CON=15.60%). At the same time it significantly decreased 1500 m running time after hypoxic period. Even though significant differences of between-group S-Index and PIF were expected, but there were no statistical significant differences in these cases. These findings are consistent with results of McConnell [28] and Kilding et al. [29] studies and show inconsistency with Nicks et al. [30] and Wylegala et al. [31] results. McConnell [28] and Kilding et al. [29] showed that S-Index and PIF had been improved by IMT in every sport filed excepting snorkeling and swimming. The main reason for not being effective on swimmers might be related to water pressure on their chest during exercise. Besides, elite swimmers may have reached to their own optimum level of respiratory muscle functioning therefore they won't increase their PIF after IMT anymore.

Our study indicated the importance of exposure to hypoxia despite of IMT device impact for both groups. Hypoxia itself can cause hyper-ventilation, tachypnea and consequently hyper-respiratory function, so muscular endurance will be improved as result of higher blood flow. Brown et al. [32] have reported significant increase of S-Index and PIF fifty male after IMT which is admitting the results of current study. According to Brown et al. [33,34] study skeletal and respiratory muscle's endurance decrease in older age and respiratory muscle alterations in elderly people are similar with musculoskeletal changes during weight training. Nicks [30] has reported the same result. He has suggested the reason of better outcomes amongst rowers might be related to physiological and mechanical nature of their exercise.

It is pertinent to mention that not only the main respiratory muscles and accessories are deploying for ventilation during rowing but also they have considerable role in terms of stabilizing the chest and transferring the force throughout the paddling process. These dual demands from respiratory muscles creates respiratory pattern for keeping performance for rowers [30]. This shows a close relation between running and rowing as both need frequent constrictions along with high intensity.

We didn't observe any alteration in SpO₂ during relax time after IMT in hypoxic condition. Downey et al. [22] have assessed IMT effect on physiological variables and observed SpO₂ alterations in hypoxic condition. Mitch Lomax [20] has obtained about 6% O₂ Sat in 4880 m and 5550 m altitudes among his study group. This is not admitting the results of current study. Because SpO₂ decreases in higher altitude this inconsistency might be due to higher altitude in Mitch Lomax [20] study. On one hand, being in high altitude enhances SpO₂ and on the other hand it decreases at higher altitude than 2500 m, so the reason of not changing SpO₂ can be justified in this way.

Training load	Very high					
	high					
	Medium					
	low					
Very low						
Training Intensity			Int ≤ VT1 MHR ≤ 160	Int ≤ VT1 Int ≤ VT2 MHR ≤ 160-170	Int ≤ VT1 Int ≤ VT2 Int ≤ MAP1 MHR ≤ 170-180	Int ≤ VT1 Int ≤ VT2 Int ≤ MAP2 MHR ≤ 180-190
Training type			Speed endurance Strength endurance Tempo endurance Running endurance Power speed Speed Strength Plyometric Isodynamic	Speed endurance Strength endurance Tempo endurance Running endurance Power speed Speed Strength Plyometric Isodynamic Competition strategy	Speed endurance Strength endurance Tempo endurance Running endurance Power speed Speed Strength Plyometric Isodynamic Competition strategy	Speed endurance Strength endurance Tempo endurance Running endurance Power speed Speed Strength Plyometric Isodynamic Competition strategy
Season week			18	18	16	15
IMT 50% S-Index			30 breaths morning and evening	30 breaths morning and evening	30 breaths morning and evening	30 breaths morning and evening
Measure at high altitude		S-index, SpO ₂				S-index, SpO ₂
Measure at low altitude		1500 m				1500 m
days		1	7	7	7	7+2 taper
Measure		pre				post

Table 2: IMT plan and training system R2M (this is an acronym for running at middle distance to marathon) at altitude. Quantities of training intensity (Int), maximal aerobic power (MAP), Maximal heart rate (MHR), first Ventilatory threshold (VT1) and second Ventilatory threshold (VT2) [1,44-48].

indexes	CON group		EXP group	
	PRE	POST	PRE	POST
S-Index (cm H ₂ O)	110/23 ± 22/3	10/8 ± 130/60	22 ± 122/45	18/35 ± 141/54
PIF (L/sec)	1/14 ± 5/98	0/62 ± 6/19	1/14 ± 6/78	0/96 ± 6/97
Volume (liter)	0/63 ± 2/83	1/02 ± 2/99	0/59 ± 3/54	0/44 ± 3/54
SpO ₂ (%)	0/32 ± 94/30	0/22 ± 94/33	0/24 ± 94/35	0/62 ± 94/58
Performance 1500 m (min)	0/18 ± 4:03:29	0/30 ± 3:56:52	0/20 ± 4:01:20	0/50 ± 3:52:31

Table 3: Pre- and post-training characteristics in experiment and in control group.

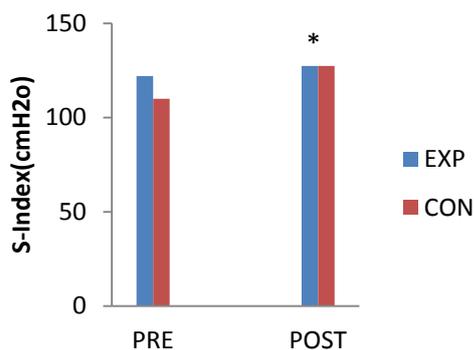


Figure 1: Mean pre- to post-training S-Index for EXP and CON groups. *significant post-training S-Index increase in, EXP (p=0.01). Post-training S-Index Significantly increased in EXP (p=0.05).

Not being exposed to hypoxic condition probably lead to minute hyperventilation as primary response. Consequently *peripheral chemoreceptors* in respiratory system may cope with hypoxia. However respiratory organs are ultra-structured against any applied changes in

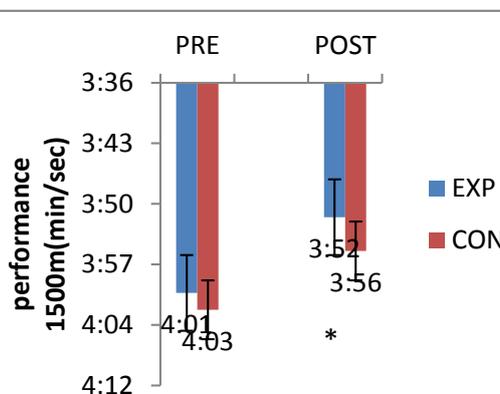


Figure 2: Mean pre- to post-training 1500 m performance times for EXP and CON groups. *significant post-training increase in performance (p=0.00). Post-training performance significantly increased in EXP group (p=0.05).

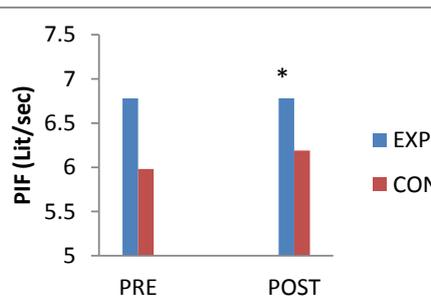


Figure 3: Mean pre- to post-training PIF for EXP and CON groups. *significant post-training change in PIF, (p=0.02). PIF significant increase post-training change in EXP group (p=0.05).

different environmental conditions. SpO₂ reduction due to climbing from sea level will decrease SaO₂ [10]. Long alkalosis that occurs in high altitude as well as increasing 2,3-diphosphoglycerate (dpg) concentration won't lead to complete respiratory compensation, but will navigate the balance between extra oxygen loading in lung, oxygen tissue proliferation and ultimately minimum pH disturbance. IMT may modify natural hyper-ventilation in response to hypoxia through such process [10-12].

In our study IMT in hypoxic condition made significant difference in pre-test and post-test PIF among experimental group (3.5%). Haung (2003) has also reported PIF increase (45%) after eleven weeks IMT. This higher percentage surely is related to longer training period. We did not find any significant difference in PIF between both groups under hypoxic condition which is inconsistent with results of Mazzeo and Fulco [35], and Brown et al. [33]. This contradiction might be due to training protocol or even we did not set training protocol specifically for endurance runners.

Our results show significant decrease in 1500 m between-group running time among experimental group (3.65%). Astinchap et al. [36] and Behparvar (2015) also have reported that IMT in hypoxic condition is effective in 25 m length amongst female swimmers. But this effect was not significant in 50 m and 100 m length. One of the probable reasons for this outcome may be depended on stronger respiratory system in swimmers [36]. Likewise, McConnell and Romer [37] have shown that IMT improves time trail performance, accelerates recovery period, decreases lactate blood level and delays muscles fatigue [37-44]. Verges et al. [45] have shown that exposure to hypoxia lead to improve endurance performance. The mechanism of the improvement appear to be a stimulation of erythropoiesis leading to an apparent increase in oxygen delivery to peripheral tissues as evidenced by a near doubling of plasma erythropoietin concentration, a rise in soluble transferrin receptor concentration and increase in hemoglobin concentration and hematocrit with chronic exposure to altitude on return to sea level [45]. Martin et al. (2012) have shown a significant effect of BMI on the performance of male long distance runners. BMI influenced the performance, yielding a positive correlation with the race time, the speed being higher in athletes from the underweight to the overweight [46]. In fact, chronic exposure to reduced partial pressure of oxygen as it is the case at high altitude, decreases arterial oxygen saturation, provoking shifts in substrate metabolism. This increases the difficulty for the body to use oxidative phosphorylation to produce the energy needed for endurance exercise; the glycolytic pathway is therefore favored rather than other catabolic pathways, including fat catabolism for energy production, because it has the lowest oxygen cost [47].

It should be noted that unlike swimming, there is no perceived exertion throughout the running. Utilizing IMT under hypoxia can reduce perceived exertion and improve performance without any side effects on respiration indexes. Some reports admit that time trial performance and maximal oxygen uptake (VO₂ max) get better amongst cyclists after IMT [37,38]. The significant increase of running performance after training in high altitude is not consistency with Siebenmann et al. [39] findings. They assessed LHTL in sixteen male endurance cyclists and did not observe any significant difference in 26 km time trial performance among them under normoxic condition [39].

Finally, based on current literatures, 1500 m performance improve, S-Index and PIF have considerably enhanced among runners after returning from higher altitude to lower levels.

Conclusion

Achieving better physiological condition for athletics in each sport field is the main reason of specific training and IMT, explicit training protocol for each field can be helpful for researchers. Even though 1500 m performance, PIF and S-Index were improved in this study but there was no exclusive change in SpO₂ as it was primarily expected. Therefore deploying specific tailored training program for runners can be recommended for future studies in order to obtain SpO₂ alteration precisely. So coaches should pay more attention to training features in accordance with requirement of each sport field. For endurance runners more studies on IMT effectiveness might be considered because they need more ventilation for improving their performances.

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