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Four Week of "Living High, Training High, Low" With IMT Stimulate SpO_2 and Enhance Performance in Elite Distance Runners

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Abstract

Objectives: The aim of this study was to investigate the effect of Four week of "living high, training high, low" with IMT stimulate SpO_2 and enhance performance in elite distance runners.

Equipment and methods: The study was carried on a group of Twelve endurance male runners (age: 24.4 ± 3.1 yrs, height: 180.5 ± 4.2 cm, weight: 66.7 ± 3.4 kg, Body mass index: 20.5 ± 1.0) among Iranian national team were randomly divided into case and control group in hypoxic condition. Exhaustive testing free 3000m, strength Index with Power Breath device (K5 model, UK) and arterial oxygen saturation tests with SPIROLAB pulse oximeter device (MIR, Italy) were taken before and 24 hour 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.

Results: Data were analyzed by analysis of variance ($P \leq 0.05$). Inspiratory muscle training at hypoxia due to significant decrease in 3000m 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 ($P \leq 0.05$).

Keywords: *Respiratory muscle training; Hypoxia; Peripheral capillary oxygen saturation; Endurance performance*

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Introduction

Acclimatization to high altitude accompanied by training at low altitude (living high-training low) has been shown to improve sea level endurance performance in accomplished, but not elite, runners. Whether elite athletes, who may be closer to the maximal structural and functional adaptive capacity of the respiratory (i.e., oxygen transport from environment to mitochondria) system, may achieve similar performance gains is unclear (Stray-Gundersen, Chapman and Levine).

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 (HajGhanbari., *et al.*). Mechanisms postulated to explain improved sport performance from IMT are decreases in the rating of perceived breathlessness (RPB) and attenuation of the metaboreflex phenomenon that may result in the redirection of blood flow from the locomotors muscles to respiratory muscles (Harms., *et al.*; Legrand., *et al.*; Johnson, Sharpe and Brown; Sheel).

Evidence is emerging that respiratory muscles fatigue may affect exercise performance via metaboreflex (Illi., *et al.*; Dempsey., *et al.*). 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 (Hill; Derchak., *et al.*).

Improved aerobic capacity of primary and accessory respiration muscles have 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. (Harms., *et al.*; Witt., *et al.*; Harms).

During the years, substantial focus has been placed on the role of the lung, ventilation and pulmonary gas exchange limitations on exercise impairment at altitude. Certainly, oxygen delivery to the periphery is dependent on various factors that occur downstream from the lung. 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 (Bisschop., *et al.*; Wilber; J Álvarez-Herms., *et al.*; Wolski, McKenzie and Wenger; Meeuwsen, Hendriksen and Holewijn; Terrados., *et al.*; Bailey and Davies; Vogt., *et al.*; Lomax; Etheridge., *et al.*; Downey., *et al.*; Edwards, Wells and Butterly; Volianitis., *et al.*; Romer, McConnell and Jones; Suzuki, Sato and Okubo; Edwards and Cooke; Loenneke., *et al.*). This study has conducted to investigate whether IMT would significantly increase the magnitude of arterial saturation experienced at rest and improve 3000m performance at 2500m altitude.

Methods and Materials

Twelve male endurance runners from national team agreed to participate in this Quasi-Experimental 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, smoking or supplemental use were other excluding criterion. Written consents were taken from all participants.

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

Table1: *Pre-and post-altitude anthropometric characteristics of the subjects in the Experimental (EXP) and in the Control (CON) groups (mean ± SD).*

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 oximetry 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 3000m were taken place in 200m 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. SpO_2 in altitude was measured by pulse oximetry. 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 3000m executive function performance test were taken right 24h after the end of the forth week. Field trainings such as altitude living-training and live high train high, low (LHTH, L) were done [Table 2].

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		3000m					3000m
days		1	7	7	7	7+2 taiper	1
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) (Jesús Álvarez-Herms., et al.; Barry W. Fudge; Di Michele and Merni; Saunders., et al.; Le Meur, Hausswirth and Mujika; HajGhanbari., et al.).*

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) (Jesús Álvarez-Herms., *et al*.; Barry W. Fudge; Di Michele and Merni; Saunders., *et al*.; Le Meur, Hausswirth and Mujika; HajGhanbari., *et al*.).

Inspiratory muscle training

First of all, we measured the maximum muscular power (cm H_2O) for an inspiration (S-Index) which is considered equal with MIP. Training protocol was considered including thirty deep inspirations with closed nose 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). Rest SpO_2 measurement was carried out only in altitude at least for three minutes in flat position for both groups during night time and training SpO_2 measurement was with thirty deep inspirations with closed nose for both groups within seven days and just during night time.

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) (Jesús Álvarez-Herms., *et al*.; Barry W. Fudge; Di Michele and Merni; Saunders., *et al*.; Le Meur, Hausswirth and Mujika; HajGhanbari., *et al*.).

Data collection and Statistical analyses

Data were collected and analyzed by SPSS software (version 21.0, SPSS, Chicago, Illinois) Parametric 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, 3000 meter running time performance showed significant difference (T10 = 838/65, P = 0/01). Post hoc Bonferroni test showed significant difference (1%) between experiment group and control group ($p \leq 0.05$). Statistical assessment of S-Index (T10 = 26/13, P = 0/01) and PIF (T10 = 7/33, P = 0/02) showed significant difference in duration of being exposed to Altitude condition ($P \leq 0.05$). But no significant differences between groups was indicated by post hoc Bonferroni tests ($P \leq 0.05$). Results also indicated that excepting rest SpO_2 (T10 = 1/31, P = 0/27) train SpO_2 (T10 = 43/71, P = 0/81) and Volume (T10 = 0/643, P = 0/44) there were no significant difference in other variables in both groups ($P \geq 0.05$). Table 3, Figure1-3

Indexes	CON group		EXP group	
	PRE	POST	PRE	POST
S-Index (cm H_2o)	110/23 ± 22/3	130/60 ± 10/8	122/45 ± 22	141/54 ± 18/35
PIF (L/sec)	5/98 ± 1/14	6/19 ± 0/62	6/78 ± 1/14	6/97 ± 0/96
Volume (liter)	2/83 ± 0/63	2/99 ± 1/02	3/54 ± 0/59	3/54 ± 0/44
Rest SpO_2 (%)	94/30 ± 0/32	94/33 ± 0/22	94/35 ± 0/24	94/58 ± 0/62
Train SpO_2 (%)	94/98 ± 2/56	93/33 ± 2/22	96/76 ± 0/76	94/61 ± 1/45
Performance 3000m (min)	9:03:29 ± 0/18	8:40:52 ± 0/30	9:01:20 ± 0/20	8:30:31 ± 0/50

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

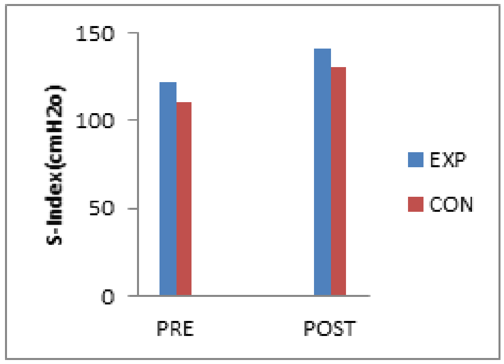

Figure 1: *Mean pre- to post-training S-Index for EXP and CON groups.*
**significant post-training S-Index increase in, EXP (p = 0.01).*
Post-training S-Index Significantly increased in EXP (p = 0.05.)

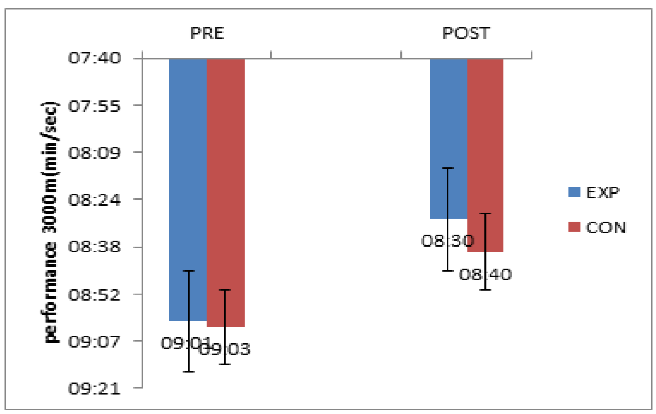

Figure 2: *Mean pre- to post-training 3000 m performance times for EXP and CON groups.*
**significant post-training increase in performance (p = 0.00).*
Post-training performance significantly increased in EXP group (p = 0.05)

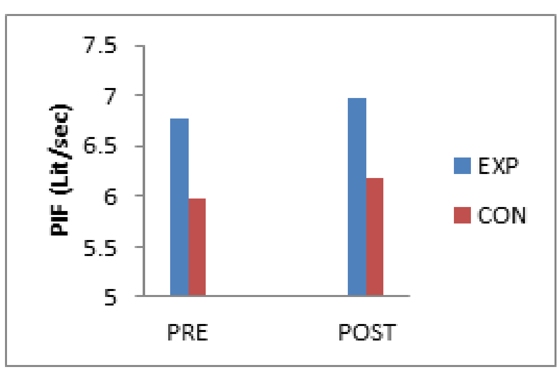

Figure 3: *Mean pre-to post-training PIF for EXP and CON groups.*
**significant post-training change in PIF, (p = 0.02).*
PIF significant increase post-training change in EXP group (p = 0.05)

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 3000m 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 (2009) and Kilding., *et al.* (2010) studies and show inconsistency with Nicks (2009) and Leddy (2009) results (McConnell; Kilding, Brown and McConnell; Nicks., *et al*.; Leddy JJ). McConnell and Kilding 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 any more (McConnell; Kilding, Brown and McConnell).

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.* (2014) have reported significant increase of S-Index and PIF fifty male after IMT which is admitting the results of current study (Brown, Johnson and Sharpe; Brown, Sharpe and Johnson). According to Brown’s 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 (Brown, Johnson and Sharpe). Nicks (2009) 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 (Nicks., *et al*.).

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 (Nicks., *et al*.). IMT implementation is similar to normocapnic hyperpnea (Brown, Johnson and Sharpe; Brown, Sharpe and Johnson). 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 SpO_2 during relax time and inspiratory muscle training after IMT in hypoxic condition. Downey., *et al.* (2007) have assessed IMT effect on physiological variables and observed SpO_2 alterations in hypoxic condition (Downey., *et al*.). Mitch Lomax (2010) has obtained about 6% O_2Sat in 4880m and 5550m altitudes among his study group (Lomax). This is not admitting the results of current study. Because SpO_2 decreases in higher altitude this inconsistency might be due to higher altitude in Mitch Lomax study. On one hand, being in high altitude enhances SpO_2 and on the other hand it decreases at higher altitude than 2500 meter, so the reason of not changing SpO_2 can be justified in this way.

Not being exposed to hypoxic condition probably lead to minute hyperventilation as primary response. Consequently peripheral chemo-receptors in respiratory system may cope with hypoxia. However respiratory organs are ultra-structured against any applied changes in different environmental conditions. SpO_2 reduction due to climbing from sea level will decrease SaO_2 (Harms). 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 (Harms; Witt., *et al*.; Bisschop., *et al*.). Additionally, increasing respiratory muscle work at high ventilations has been associated with a sympathetic metaboreflex response, where vasoconstriction causes blood flow to the locomotors muscles to decrease, likely in an effort to priorities blood flow to the respiratory musculature (Dempsey., *et al*.; Harms., *et al*.).

Therefore, while increasing ventilation during heavy exercise in hypoxia may be seen as a mechanism to defend PAO_2 and SaO_2, locomotors muscle oxygen delivery may be compromised, however this has not been rigorously tested. Alvares herms (2014) have shown that significant declines in SaO_2 during exercise in hypoxia in comparison with normoxia after A series of 6 consecutive jumps, lasting for 15 seconds with an intervening rest period of 3 minutes (J Álvarez-Herms., *et al*.).

In our study IMT in hypoxic condition made significant difference in pre-test and post-test PIF among experimental group (6.08%). 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 (2006) and Peter (2014) (Mazzeo RS; Brown, Sharpe and Johnson). 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 3000m between-group running time among experimental group (2.66%). Astinchap and Behparvar (2015) also have reported that IMT in hypoxic condition is effective in 25 meter length amongst female swimmers. But this effect was not significant in 50m and 100m length. One of the probable reasons for this outcome may be depended on stronger respiratory system in swimmers (Astinchap. A). Likewise, McConnell and Romer (2005) have shown that IMT improves time trail performance, accelerates recovery period, decreases lactate blood level and delays muscles fatigue (McConnell and Romer).

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 (Johnson, Sharpe and Brown; McMahon., *et al*.). The significant increase of running performance after training in high altitude is not consistence with Siebenmann Table 3. Pre- and post-training characteristics in experiment and in control group (2012) 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 (Siebenmann., *et al*.).

On the other hand, VO2max increased 9 days after training in hypoxia in the study of Meeuwsen., *et al.* (Meeuwsen, Hendriksen and Holewijn). Whereas it was unchanged after 2 days. This may be explained by the higher concentration and duration of the training sessions. Nevertheless, a 5% increase in VO2max has also been found by Dufour., *et al.* (Dufour SP). After 6 weeks of IHT in endurance trained runners. Furthermore, a dramatic improvement of the time to exhaustion (+35%) as well as a higher VO2 at VT2 (+7%) was also reported in this study. According to the authors, these results were due to the combination of the hypoxic stimulus and the high training intensity that was established at VT2.

Finally, based on current literatures, 3000m 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 3000 meter performance, PIF and S-Index were improved in this study but there was no exclusive change in SpO_2 as it was primarily expected. Therefore deploying specific tailored training program for runners can be recommended for future studies in order to obtain SpO_2 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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