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Effects of IMT on Energy Cost in Elite Endurance Runners

by Roohollah Mohammadi Mirzaei and Mirdar Shadmehr

ABSTRACT

Hypoxia is known to negatively affect endurance performance, mainly because the energy for exercise supplied by the aerobic pathways decreases and the work of breathing becomes harder. The aim of this study was to investigate the effects of inspiratory muscle training (IMT) during a period of hypoxic altitude training. Twelve male endurance runners from the Iranian national team performed 3000m time trials and were tested for energy cost, peripheral capillary oxygen saturation and inspiratory muscle strength (S-Index). They then underwent four weeks of training that included living at 2500m altitude and 16 training sessions per week, three of which were at 1400m. The experimental group also performed IMT in the form of thirty deep inspirations twice daily, seven days per week. At the end of four weeks the athletes performed a second time trial and underwent the other parameter tests. The authors found that IMT in an altitude training programme improves 3000m performance and increases S-Index but differences in peripheral capillary oxygen saturation and energy cost were not significant. They recommend further studies using more specific training programmes to understand the impact of IMT on peripheral capillary oxygen saturation and energy cost more precisely.

AUTHORS

Roohollah Mohammadi Mirzaei is the National Head Coach for middle- and long-distance running and a PhD candidate at the University of Mazandaran, Islamic Republic of Iran.

Mirdar Shadmehr is an associate professor at the University of Mazandaran, Islamic Republic of Iran.

Introduction

In a hypoxic environment the cardiopulmonary system faces several distinct challenges and it is well known that hypoxia negatively affects performance in endurance activities, including the middle and long distance events of athletics. Such a situation is found with increasing altitude as oxygen density and air pressure are reduced. Consequently, the energy for exercise supplied by the aerobic pathways decreases and the work of breathing becomes harder. This in turn leads to poor mechanical efficiency and increased dyspnea – difficulty in breathing[1]

Some of the effects of hypoxic conditions on endurance exercise performance may be via the metaboreflex mediator of cardiovascular exercise response[2, 3]. In this phenomenon, the accumulation of metabolites such as lactic acid in the respiratory muscles activates group III and especially group IV nerve afferents. This ultimately triggers a brain sympathetic outflow increase and causes vasoconstriction in the exercising limbs, redirecting blood flow from the locomotor muscles to assist the respiratory muscles[4, 5].

Multiple studies demonstrate that respiratory muscle training (RMT) helps improve endurance exercise performance. Runners[6, 7], cyclists[8-12] and swimmers exercising both on the surface[13, 14] and at various depths[15] have increased their endurance following RMT, sometimes by as much as 85%[16]. A particular form of RMT known as inspiratory muscle training (IMT) has been investigated as a method of particular value to sportsmen and sportswomen[17]. Mechanisms postulated to explain improvement from IMT include decreases in the rating of perceived breathlessness (RPB) or rating of perceived exertion (RPE) and an attenuation of the metaboreflex phenomenon[4, 5].

We have previously proposed that the inclusion of IMT within a training programme might positively alter the perception of effort during training and consequently augment the ventilation parameters and quality of work accomplished. This in turn could be expected to enhance endurance performance[18]. Several other studies previously suggested that inclusion of IMT within a training programme might positively improve respiratory indexes including peripheral capillary oxygen saturation (SpO_2), oxygen partial pressure (PaO_2), hemoglobin oxygen saturation (SaO_2), and endurance performance, which would consequently augment the volume and quality of accomplished work[19-27].

Elite endurance athletes have utilised altitude/hypoxic training in preparation for both high altitude and sea-level competition. The main methods currently used are ‘live high-train high’ (LHTH), ‘live high-train low’ (LHTL), intermittent hypoxic exposure during rest (IHE), intermittent hypoxic exposure during continuous sessions (IHT) and live high-train low and high’ (LHTLH)[21]. In each case, exposure to hypoxia is intended to lead to the body switching the phosphofructokinase gene expression to anaerobic pathways and to increased energy production via these pathways as a compensatory mechanism for the reduced energy supplied by the aerobic pathways[28]. As the most plausible explanation for IMT-induced performance adaptations lies within the reports of reduced effort sensations and increased SpO_2 at altitude[29, 30], it is 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 an altitude/hypoxic training programme[31].

The aim of this study was to investigate whether inclusion of IMT in an altitude/hypoxic training programme would a) significantly improve 3000m running performance at low altitude, b) increase maximum muscular power (cm H_2O) for an inspiration (S-Index), and c) increase the magnitude of SpO_2 measured at rest.

Methods and Materials

Subjects

Twelve male endurance runners from the national athletics team of the Islamic Republic of Iran agreed to participate in the study and written consent was taken from each of them. The institutional ethics committee approved all procedures employed in the study in advance (National Olympic Committee of the Islamic Republic of Iran letter no. 2634). We ensured that there was no evidence of respiratory, cardiovascular or infection diseases or diabetes in any of the study subjects. Allergies, smoking and supplement use were other excluding criteria.

Experimental design

The study was conducted after the competitive season during the subject athletes’ period of rest. They were first called to the Olympic training camp for checks of their height, weight, and Body Mass Index (BMI). After they became familiar with the Power Breath device (K5 model, United Kingdom) and SPIROLAB pulse oximeter device (MIR, Italy), we used the Power Breath to measure the maximum muscular power (cm H_2O) for an inspiration (S-

Table 1: Pre- and post-altitude training anthropometric characteristics for the experimental (EXP) and in the control (CON) groups (mean ± SD)

	EXP (n=6)		CON (n=6)	
Parameter	Pre-altitude	Post-altitude	Pre-altitude	Post-altitude
Age (yrs)	23.1±2.8	23.1±2.8	25.6±3.1	25.6±3.1
Height (cm)	178.3±4.0	178.3±4.0	182.6±3.3	182.6±3.3
Body mass (kg)	67.5±3.1	66.1±2.6	66.0±3.8	65.5±3.4
BMI (kg.m²)	21.2±0.3	20.8±0.4	20.7±1	19.7±1

Index), which is considered equal to maximum inspiratory pressure (MIP), and energy cost for all subjects. We used the SPIROLAB to measure SpO_2 at altitude. We randomly divided the participants into an experimental group (EXP) (n=6) and a control group (CON) (n=6) and time trials over 3000m were staged for both groups on a standard 400m indoor track located at 1400m altitude (see Table 1).

At the end of the four weeks all the subjects performed a second 3000m time trial at 1400m and all inspiratory indexes were measured again.

Altitude training intervention

After the initial data was collected, the subject athletes underwent training based at the Delfan Camp (2500m altitude) in the Zagros Mountains in western Iran. All the subjects followed similar programmes for four weeks. These included 16 training sessions per week, three of which were track sessions at low altitude. The training means used included most of those employed by contemporary endurance runners such as continuous aerobic, interval and repetition running, speed work, power and plyometric training at different volumes and intensities (Table 2). In the evenings a measurement of SpO_2 was carried out at altitude on each subject for at least three minutes in a flat position using the SPIROLAB device.

Inspiratory muscle training and energy cost measurement

The training protocol for the EXP group included IMT in the form of thirty deep inspirations performed twice daily (morning and evening), seven days per week for four weeks. These were performed with closed nose using the Power Breath device, which was also used to measure energy cost during the IMT.

Data collection and statistical analyses

Data were collected and analysed using 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-way repeated measures analyses of variance (ANOVA), and post hoc Bonferroni tests of Honestly Significant Difference were conducted as appropriate. Probability values of less than 0.05 were considered significant. All results were expressed as mean and standard deviation (SD) unless otherwise stated.

Results

Measurements of the effect of altitude training on the variables studied (see Table 3 and Figures 1 to 3) along with the between-group factor revealed that the 3000m time trial performance showed a significant difference (T=838/65, P=0/01) regardless of the group or training protocol followed. The post hoc

Table 2: Training programme and IMT plan (quantities of different training intensity (Int), maximal aerobic power (MAP), maximal heart rate (MHR), first ventilatory threshold (VT1) and second ventilatory threshold (VT2))

						Very high	**Training Load**
						high	
						Medium	
						low	
						Very low	
	Int ≤ VT1 Int ≤ VT2 Int ≤ MAP2 MHR ≤ 180-190	Int ≤ VT1 Int ≤ VT2 Int ≤ MAP1 MHR ≤ 170-180	Int ≤ VT1 Int ≤ VT2 MHR ≤ 160-170	Int ≤ VT1 MHR ≤ 160			**Training Intensity**
	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	Speed enduance Strength endurance Tempo endurance Running endurance Power speed speed Strength Plyometric Isodynamic			**Training type**
	15	16	18	18			**Season week**
	30 breaths morning and evening	30 breaths morning and evening	30 breaths morning and evening	30 breaths morning and evening			**IMT 50% S-Index**
S-index, **SpO_2**					S-index, SpO_2		**Measure at high altitude**
3000m					3000m		**Measure at low altitude**
1	7+ 2 taper training	7	7	7	1		**days**
post					pre		**Measure**

Table 3: Pre- and post-training characteristics of the experiment and in control groups

Indexes	CON group		EXP group	
	PRE	POST	PRE	POST
S-Index (cmH_20)	110.23±22.3	130.60±10.8	122.45±22	141.54±18.35
Energy cost (J)	237±0.63	244±1.02	345±0.59	419±0.44
SpO_2 (%)	94.30±0.32	94.33±0.22	94.35±0.24	94.58±0.62
Performance 3000m (min)	9:03.29±0.18	8:40.52±0.30	9:01.20±0.20	8:30.31±0.50

Bonferroni test showed a significant difference (%2/66) between the EXP group and the CON group ($p \leq 0.05$).

Statistical assessment of the S-Index measurements (T=26/13, P=0/01) showed a significant difference related to the duration of being exposed to altitude conditions ($P \leq 0.05$). But no significant differences between the groups due to IMT were indicated by post hoc Bonferroni tests ($P \leq 0.05$).

The results also indicated that, except for SpO_2 (T=1/31, P=0/27) and energy cost (T=3/20, P=0/10), there were no significant differences in other variables in either group ($P \geq 0.05$).

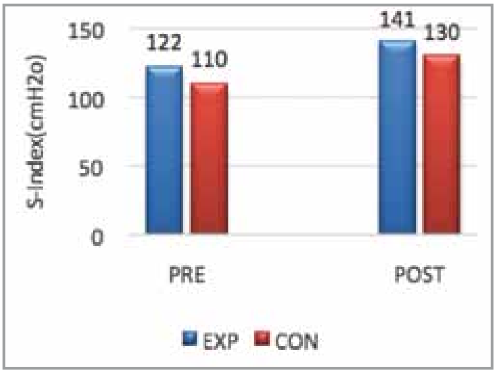

Figure 1: Mean pre- to post-training S-Index for EXP and CON groups

**significant post-training S-Index increase in, EXP (p=0.01). Post-training S-Index Significantly increased in EXP (p=0.05.)*

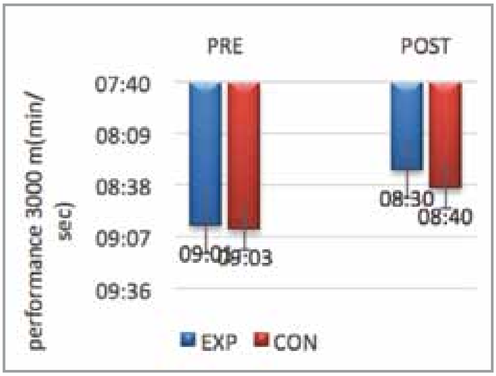

Figure 2: Mean pre- to post-training 3000m performance times for EXP and CON groups

**significant post-training increase in performance (p=0.00). Post-training performance significantly increased in EXP group (p=0.05)*

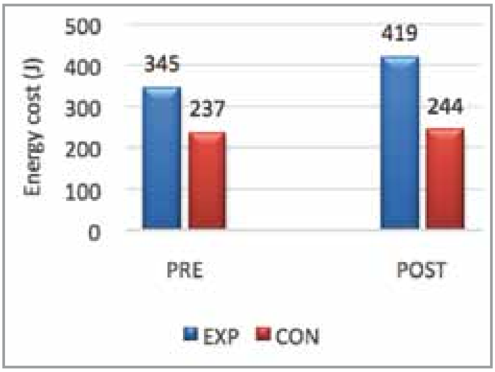

Figure 3: Mean pre- to post-training energy cost for EXP and CON groups

No significant post-training in energy cost (p=0.10). Post-training energy cost significantly in EXP group (p=0.05)

Discussion

The current study showed that IMT contributed to significantly improved 3000m time trial performances and S-Index scores after a four-week period of altitude/hypoxic training and it indicated the importance of hypoxic training for both the EXP and CON groups, regardless of IMT device impact. Even though significant differences of between-group S-Index were expected, none was found.

3000m performance

All 12 subjects, in both the EXP and CON groups, showed improved 3000m running times. These findings are consistent with those of MOHAMMADI MIRZAEI & MIRDAR[32] and several other research groups, which have shown that exposure to hypoxia leads to improve endurance performance and 3–10% improvements in exercise economy with altitude training. This might come from a decreased cost of ventilation, greater carbohydrate (CHO) use for phosphorylation, or, more likely, from improved mitochondrial efficiency (as denoted by P/O ratio or an increase in ATP production per mole of oxygen used)[33, 34]. LEVINE et al reported that sea-level endurance performance indicators were significantly increased for 14 elite men and eight elite women runners after 27 days of living at 2500m and training at 1250m (LHTL strategy): a 1.1% improvement in 3000m time and a 3% increase in VO_2max[35]. LEVINE & STRAY-GUNDERSEN showed that four weeks of living at moderate altitude (2500m) and training at low altitude (1250m) improved sea-level performance more than equivalent sea-level or LHTH training in 13 well-trained runners[36]. Significant increase of running performance after living and training in high altitude is not consistence with the findings of SIEBENMANN et al, who assessed the effects of LHTL in 16 male endurance cyclists and did not observe any significant difference in 26km time trial performance under normoxic conditions[37].

Our results also show significant improvement in 3000m performance between-group in the EXP group using IMT (%2.66). ASTINCHAP & BEHPARVAR have reported that IMT in hypoxic conditions is effective for improving 25m performance in female swimmers, but this effect was not significant at 50m or 100m. One of the probable reasons for this outcome may be the already stronger respiratory system in swimmers[38]. LIKEWISE, MCCONNELL & ROMER have shown that IMT improves time trial performance, accelerates recovery period, decreases lactate blood level and delays muscle fatigue[39]. Utilising IMT in hypoxic conditions can reduce perceived exertion and improve performance without any side effects on respiration indexes. There are reports that time trial performance and maximal oxygen uptake (VO_2 max) improve in cyclists after IMT[10, 40].

Maximum muscular power for an inspiration (S-Index)

The current study also shows significantly improved S-Index scores (EXP=18.48%, CON=15.60%). These findings are consistent with those of MCCONNELL, KILDING et al and BROWN et al. They show inconsistency with the results of NICKS and WYLEGALA[14, 41-43]. MCCONNELL, KILDING et al showed that S-Index improved with IMT in every sport studied except snorkelling and swimming. The main reason for not being effective in these cases might be related to water pressure on the chest during exercise. In addition, it is possible that the elite swimmers studied may have reached their optimal level of respiratory muscle function and therefore increases in the S-Index were not possible[28-29]. BROWN et al reported a significant increase of the S-Index in fifty males after IMT and found that skeletal and respiratory muscle endurance decreases in older age and respiratory muscle alterations in elderly people are similar with musculoskeletal changes during weight training[44, 45].

Arterial oxygen saturation (SpO_2)

We did not observe any alteration in SpO_2 at rest after IMT in hypoxic conditions. DOWNEY et al assessed the effect of IMT and observed SpO_2 alterations in hypoxic conditions[27]. LOMAX obtained results of about 6% SpO_2 at 4880m and 5550m altitudes[25]. Because SpO_2 decreases with altitudes above 2500m, this inconsistency might be due to the higher altitude used by LOMAX.

Not being previously exposed to hypoxic condition probably leads to minute hyperventilation as a primary response at first exposure. Consequently, peripheral chemo-receptors in the respiratory system may cope with hypoxia. However the 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[46]. Long alkalosis that occurs at 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 the lungs, oxygen tissue proliferation and ultimately minimum PH disturbance. IMT may modify natural hyper-ventilation in response to hypoxia through such process[19, 46, 47].

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 favoured rather than other catabolic pathways, including fat catabolism for energy production, because it has the lowest oxygen cost [48].

Energy cost

In the current study, IMT in hypoxic conditions made no significant difference in pre-test and post-test energy cost among the EXP group. We also found no significant difference in energy muscle cost between the groups under hypoxic conditions. This was unexpected and the contradiction might be due to training protocol or even that we did not set the training protocol specifically for endurance runners. Several authors have shown that ventilation (VE) decrease, primarily due to lower breath frequency (F), led to reduction in respiratory muscle work during exercise. During rest, the decreases in VE and F were accompanied by a decrease in inspiratory time of one breath/total time of one breath (TI/T_{Tot}), owing primarily to an increase in the expiratory phase of the breath. The longer expiratory duration during submersion at the shallower depths, when hyperventilation was observed—to passive expiration. This would allow more time for respiratory muscle relaxation, which has been shown to increase perfusion. While this should increase oxygen delivery to and metabolite clearance from the muscles, the change in TI/T_{Tot} was only significant at rest and therefore is probably not part of the mechanism by which RRMT improves exercise performance[13, 49-51].

Conclusion

Although IMT was shown to improve 3000m running performance and S-Index, we found no significant changes in SpO_2 and energy cost, contrary to what was expected. We recommend further studies using training programmes specifically designed for runners to understand the impact of IMT on SpO_2 and energy cost more precisely.

Please send all correspondence to:
Mohammadi Mirzaei Roohollah
coach.iri@gmail.com

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REFERENCES

1. HELD, H.E.& PENDERGAST, D.R. (2014). The effects of respiratory muscle training on respiratory mechanics and energy cost. *Respiratory Physiology & Neurobiology*, 200: 7-17.

2. ILLI, S.K.; HELD, U.; FRANK, I. & SPENGLER, C.M. (2012). Effect of respiratory muscle training on exercise performance in healthy individuals. *Sports Medicine,* 42 (8): 707-24.

3. DEMPSEY, J.A.; ROMER, L.; RODMAN, J.; MILLER, J. & SMITH C. (2006). Consequences of exercise-induced respiratory muscle work. *Respiratory Physiology & Neurobiology*,151 (2): 242-50.

4. HILL, J.M. (2000). Discharge of group IV phrenic afferent fibers increases during diaphragmatic fatigue. *Brain Research*, 856 (1): 240-4.

5. DERCHAK, P.A.; SHEEL, A.W.; MORGAN, B.J. & DEMPSEY, J.A. (2002). Effects of expiratory muscle work on muscle sympathetic nerve activity. *Journal of Applied Physiology*, 92 (4): 1539-52.

6. LEDDY, J.J.; LIMPRASETKUL, A.; PATELI, S. Modlich, F.; Buyea, C.; Pendergast, D.R. & Lundgren, C.E. (2007). Isocapnic hypernea training improves performance in comnpetitive male runners. *European Journal of Applied Physiology*, 99 (6): 665-76.

7. UEMURA, H.; LUNDGREN, C.E.; RAY, A.D. & PENDERGAST, D.R. (2012). Effects of different types of respiratory muscle training on exercise performance in runners. *Military Medicine*,177 (5): 559-66.

8. BOUTELLIER, U.; BÜCHEL, R.; KUNDERT, A. & SPENGLER, C. (1992). The respiratory system as an exercise limiting factor in normal trained subjects. *European Journal of Applied Physiology and Occupational Physiology*, 65 (4): 347-53.

9. MARKOV, G.; SPENGLER, C.M.; KNOÈPFLI-LENZIN, C.; STUESSI, C. & BOUTELLIER, U. (2001). Respiratory muscle training increases cycling endurance without affecting cardiovascular responses to exercise. *European Journal of Applied Physiology*, 85 (3-4): 233-9.

10. MCMAHON, M.E.; BOUTELLIER, U.; SMITH, R.M. & SPENGLER, C.M. (2002). Hyperpnea training attenuates peripheral chemosensitivity and improves cycling endurance. *Journal of Experimental Biology*, 205 (24): 3937-43.

11. STUESSI, C; SPENGLER, C.M.; KNOÈPFLI-LENZIN, C.; MARKOV, G. & BOUTELLIER, U. (2001). Respiratory muscle endurance training in humans increases cycling endurance without affecting blood gas concentrations. *European Journal of Applied Physiology,* 84 (6): 582-6.

12. VERGES, S.; LENHERR, O.; HANER, A.C.; SCHULZ, C. & SPENGLER, C.M. (2007). Increased fatigue resistance of respiratory muscles during exercise after respiratory muscle endurance training. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, 292 (3): R1246-R53.

13. LINDHOLM, P.; WYLEGALA, J.; PENDERGAST, D. & LUNDGREN, C. (2007) Resistive respiratory muscle training improves and maintains endurance swimming performance in divers. *Undersea & Hyperbaric Medicine*, 34 (3): 169.

14. WYLEGALA, J.A.; PENDERGAST, D.R.; GOSSELIN, L.E.; WARKANDER, D.E. & LUNDGREN, C.E. (2007). Respiratory muscle training improves swimming endurance in divers. *European Journal of Applied Physiology*, 99 (4): 393-404.

15. RAY, A.; PENDERGAST, D. & LUNDGREN, C. (2008). Respiratory muscle training improves swimming endurance at depth. *Undersea & Hyperbaric Medicine*, 35 (3): 185.

16. RAY, A.D.; PENDERGAST, D.R. & LUNDGREN, C.E. (2010). Respiratory muscle training reduces the work of breathing at depth. *European Journal of Applied Physiology,* 108 (4): 811-20.

17. HAJGHANBARI, B.; YAMABAYASHI, C.; BUNA, T.R.; COELHO, J.D.; FREEDMAN, K.D.; MORTON, T.A. & ET AL. (2013). Effects of respiratory muscle training on performance in athletes: a systematic review with meta-analyses. T*he Journal of Strength & Conditioning Research*, 27 (6): 1643-63.

18. VOLIANITIS, S.; MCCONNELL, A.K.; KOUTEDAKIS, Y.; MCNAUGHTON, L.R.; BACKX, K. & JONES, D.A. (2001). Inspiratory muscle training improves rowing performance. *Med Sci Sports Exerc*, 33(5):803-9.

19. BISSCHOP, A.; GAYAN-RAMIREZ, G.; ROLLIER, H.; GOSSELINK, R.; DOM, R.; DE BOCK, V. & ET AL. (1997). Intermittent inspiratory muscle training induces fiber hypertrophy in rat diaphragm. *American Journal of Respiratory and Critical Care Medicine*, 155 (5): 1583-9.

20. ÁLVAREZ-HERMS, J.; JULIÀ-SÁNCHEZ, S.; CORBI, F.; PAGÈS, T. & VISCOR, G. (2014). Anaerobic erformance after endurance strength training in hypobaric environment. *Science & Sports*, 29 (6): 311-8.

21. WOLSKI, L.A.; MCKENZIE, D. & WENGER, H. (1996). Altitude training for improvements in sea level performance. *Sports Medicine*, 22 (4): 251-63.

22. TERRADOS, N.; MELICHNA, J.; SYLVÉN, C.; JANSSON, E. & KAIJSER, L. (1988). Effects of training at simulated altitude on performance and muscle metabolic capacity in competitive road cyclists. *European Journal of Applied Physiology and Occupational Physiology*, 57 (2): 203-9.

23. BAILEY, S.J.; ROMER, L.M.; KELLY, J.; WILKERSON, D.P.; DIMENNA, F.J. & JONES, A.M. (2010). Inspiratory muscle training enhances pulmonary O2 uptake kinetics and high-intensity exercise tolerance in humans. *Journal of Applied Physiology*, 109 (2): 457-68.

24. VOGT, M.; PUNTSCHART, A.; GEISER, J.; ZULEGER, C.; BILLETER, R. & HOPPELER, H. (2001). Molecular adaptations in human skeletal muscle to endurance training under simulated hypoxic conditions. *Journal of Applied Physiology*, 91 (1): 173-82.

25. LOMAX, M. (2010). Inspiratory muscle training, altitude, and arterial oxygen desaturation: a preliminary investigation. *Aviation, Space, and Environmental Medicine*, 81 (5): 498-501.

26. ETHERIDGE, T.; ATHERTON, P.J.; WILKINSON, D.; SELBY, A.; RANKIN, D.; WEBBORN, N. & ET AL. (2011). Effects of hypoxia on muscle protein synthesis and anabolic signaling at rest and in response to acute resistance exercise. A*merican Journal of Physiology-Endocrinology and Metabolism*, 301 (4): E697-E702.

27. DOWNEY, A.E.; CHENOWETH, L.M.; TOWNSEND, D.K.; RANUM, J.D.; FERGUSON, C.S. & HARMS, C.A. (2007). Effects of inspiratory muscle training on exercise responses in normoxia and hypoxia. *Respiratory Physiology & Neurobiology*, 156 (2): 137-46.

28. MEEUWSEN, T.; HENDRIKSEN, I.J. & HOLEWIJN, M. (2001). Training-induced increases in sea-level performance are enhanced by acute intermittent hypobaric hypoxia. *European Journal of Applied Physiology*, 84 (4):283-90.

29. ROMER, L.M.; MCCONNELL, A.K. & JONES, D.A. (2002). Effects of inspiratory muscle training on time-trial performance in trained cyclists. *Journal of Sports Sciences*, 20 (7): 547-90.

30. SUZUKI, S.; SATO, M. & OKUBO, T. (1995). Expiratory muscle training and sensation of respiratory effort during exercise in normal subjects. *Thorax*, 50 (4): 366-70.

31. EDWARDS, A.M.; WELLS, C. & BUTTERLY, R. (2008). Concurrent inspiratory muscle and cardiovascular training differentially improves both perceptions of effort and 5000 m running performance compared with cardiovascular training alone. *British Journal of Sports Medicine*, 42 (10): 823-7.

32. MOHAMMADI MIRZAEI, R. & MIRDAR, S.H. (2016). The Effect of an Inspiratory Muscle Training at Intermediate Altitude on Arterial Oxygen Saturation and 1500 m Performance Endurance Runners. *Medicina dello Sport*, 69 (3): 10.

33. SCHMITT, L.; HELLARD, P.; MILLET, G.; ROELS, B.; RICHALET, J. & FOUILLOT, J. (2006). Heart rate variability and performance at two different altitudes in well-trained swimmers. *International Journal of Sports Medicine,* 27 (3): 226-31.

34. GORE, C.J.P; HAHN, A.G.; AUGHEY, R.J.; MARTIN, D.T.; ASHENDEN, M.; CLARK, S.A. & ET AL. (2001). Live high: train low increases muscle buffer capacity and submaximal cycling efficiency. *Acta Physiologica Scandinavica*, 173 (3): 275-86.

35. LEVINE, B. (1991). "Living high-training low": the effect of altitude acclimatization/normoxic training in trained runners. *Med Sci Sports Exerc*, 23: S25.

36. LEVINE, B.D. & STRAY-GUNDERSEN, J. (1997). “Living high-training low”: effect of moderate-altitude acclimatization with low-altitude training on performance. *Journal of Applied Physiology,* 83 (1): 102-12.

37. SIEBENMANN, C.; ROBACH, P.; JACOBS, R.A.; RASMUSSEN, P.; NORDSBORG, N.; DIAZ, V. & ET AL. (2012). “Live high–train low” using normobaric hypoxia: a double-blinded, placebo-controlled study. *Journal of Applied Physiology,* 112 (1): 106-17.

38. ASTINCHAP, A.; NASSER, B. & TADIBI. V. (2015) The effect of inspiratory muscle training for six weeks (IMT) on swimming speed. J*ournal of Physiology and Sports Management*, 7(1):10.

39. VERGES, S.; BACHASSON, D. & WUYAM, B. (2010). Effect of acute hypoxia on respiratory muscle fatigue in healthy humans. *Respiratory Research*, 11 (1): 1-9.

40. JOHNSON, M.A.; SHARPE, G.R. & BROWN, P.I. (2007). Inspiratory muscle training improves cycling time-trial performance and anaerobic work capacity but not critical power. *European Journal of Applied Physiology*, 101 (6): 761-70.

41. MCCONNELL, A.K. (2009). Respiratory muscle training as an ergogenic aid. *Journal of Exercise Science & Fitness,* 7 (2): S18-S27.

42. KILDING, A.E.; BROWN, S. & MCCONNELL, A.K. (2010). Inspiratory muscle training improves 100 and 200 m swimming performance. *European Journal of Applied Physiology*, 108 (3): 505-11.

43. NICKS, C.; MORGAN, D.; FULLER, D. & CAPUTO, J. (2009). The influence of respiratory muscle training upon intermittent exercise performance. *International Journal of Sports Medicine*, 30 (1): 16-21.

44. BROWN, P.I.; SHARPE, G.R. & JOHNSON, M.A. (2010). Loading of trained inspiratory muscles speeds lactate recovery kinetics. *Medicine and Science in Sports and Exercise*, 42 (6): 1103-12.

45. BROWN, P.I.; JOHNSON, M.A.; SHARPE, G.R. (2014). Determinants of inspiratory muscle strength in healthy humans. *Respiratory Physiology & neurobiology,* 196: 50-5.

46. HARMS, C.A. (2007). Insights into the role of the respiratory muscle metaboreflex. *The Journal of Physiology,* 584 (3): 711.

47. WITT, J.D.; GUENETTE, J.A.; RUPERT, J.L.; MCKENZIE, D.C. & SHEEL, A.W. (2007). Inspiratory muscle training attenuates the human respiratory muscle metaboreflex. T*he Journal of Physiology*, 584 (3): 1019-28.

48. BENSO, A.; BROGLIO, F.; AIMARETTI, G.; LUCATELLO, B.; LANFRANCO, F.; GHIGO, E. & ET AL. (2007). Endocrine and metabolic responses to extreme altitude and physical exercise in climbers. *European Journal of Endocrinology*, 157 (6): 733-40.

49. ROMER, L.M.; LOVERING, A.T.; HAVERKAMP, H.C.; PEGELOW, D.F. & DEMPSEY, J.A. (2006). Effect of inspiratory muscle work on peripheral fatigue of locomotor muscles in healthy humans. *The Journal of Physiology*, 571 (2): 425-39.

50. SHEEL, A.W.; DERCHAK, P.A.; MORGAN, B.J.; PEGELOW, D.F.; JACQUES, A.J. & DEMPSEY, J.A. (2001). Fatiguing inspiratory muscle work causes reflex reduction in resting leg blood flow in humans. *The Journal of Physiology*, 537 (1): 277-89.

51. SIMPSON, A.E.; RAY, A.; LUNDGREN, C. & PENDERGAST, D. (2012). Energy cost of breathing at depth: Effect of respiratory muscle training. *Undersea & Hyperbaric Medicine*, 39 (4): 829.