Journal of Physical Education and Sport ® (JPES), Vol. 21 (3), Art 170, pp. 1337 - 1345, May 2021
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Effect of wearing an elevation training mask on physiological adaptation

WAEL RAMADAN[1], CHRYSOVALANTOU E. XIROUCHAKI[2], REFAAT MUSTAFA[3], AMR SAAD[4], SANDRA APARECIDA BENITE-RIBEIRO[5]
[1] Department of Sports Training, Faculty of Physical Education, Mansoura University, EGYPT
[2] Department of Biochemistry and Molecular Biology, Monash University, VIC, AUSTRALIA
[3] Department of games, Faculty of Physical Education, Aswan University, EGYPT
[4] Department of psychology, Faculty of Physical Education, Mansoura University, EGYPT
[5]Unidade Acadêmica Especial de Ciências Biológicas, Universidade Federal de Jataí, BRAZIL

(Accepted for publication May 15, 2021)
DOI:10.7752/jpes.2021.03170

Abstract
The use of an Elevation Training Mask during resistance training bouts has recently been considered a new strategy for providing an effective exercise stimulus. To adequately assess athletic performance and explore the effect of training programs, it is necessary to understand the responses produced by body systems to bouts of resistance training. The aim of the present study is to evaluate the impact of using Elevation Training Mask during resistance training on physiological responses and performance variables. 20 male participants were randomly assigned to either a control group or a mask group. Participants underwent pre- and post-intervention tests including Cardiopulmonary Exercise Testing, Blood Lactate measurements, vertical jump, and Grip strength within 48 h before and after the training protocol. No statistically significant differences were seen in vertical jump and Grip strength between the two groups. The Mask group showed a significant increase in Oxygen Consumption/ Heart Rate, Minute Ventilation/ Oxygen Consumption, Ventilatory Threshold ($p< 0.05$), Maximal Oxygen Consumption, Maximal Heart Rate, Minute Ventilation ($p < 0.001$), and Blood Lactate ($p< 0.01$) compared to the control group. In conclusion, the current study suggested that an Elevation Training Mask enhancesthe physiological responses and the performance in resistance training.
Keywords: sport training, sport physiology, resistance training

Introduction

Athletes and coaches tried to find innovative methods to improve the performance and to make altitude training more accessible (Robertson et al., 2010). Several products, strategies, and techniques have been suggested such as nitrogen houses, hypoxia tents, and masks, in addition to special breathing apparatuses designed to provide inspired hypoxia during training. These products are developed to simulate the critical elements of altitude training (Levine, 2002). Several relevant concepts have been studied carefully such as " Intermittent hypoxic training" (IHT), " living low training high" (LLTH), and " living high training low" (LHTL) and these concepts are widely used now as a part of training programs to improve exercise performance (Meeuwsen et al., 2001). Currently, in the presence of advanced technology, hypoxia can be simulated by using altitude simulation hypoxia masks to obtain the best adaptations for enhancing sea-level performance (Hahn & Gore, 2001; Stray-Gundersen et al., 2001).

The Elevation Training Mask (ETM) is one of the products that are designed to simulate altitude training. This mask covers both nose and mouth and it comes in different opening sizes and flux valves. To simulate different degrees of altitude, the openings and valves of the mask can be adjusted by increasing the resistance of respiration that makes breathing more difficult. The multi-level resistance function enables users to simulate altitudes from 3,000 ft to 18,000 ft. When elevation exceeds 3,900 ft, acute physiological adaptations occur to compensate for the reduced partial pressure of oxygen in the atmosphere (Porcari et al. 2016). Two physiological improvements take place early in the acclimatization process and they have particular importance. Firstly, an increase in pulmonary ventilation during rest and at exercise. Secondly, an increase in cardiac output in the early stages of altitude exposure at rest and during submaximal exercises due to an increase in heart rate (Howarth et al., 2009).

Although resistance training is important to athletic performance, the skeletal muscle response under the impact of hypoxia has not been addressed in detail. Unfortunately, only limited research has been conducted on adaptations in strength performance that take place when ETM is used in a resistance exercise program (Kon et

Corresponding Author: WAEL RAMADAN, E-mail: dr.wael2050@gmail.com

al., 2010). An optimization of muscle growth has been reported due to acute hypoxic exposure during resistance training. This can be explained by the increased aggregation of certain metabolites and hormones that constitute key components in signaling critical anabolic responses (Kon et al., 2010; Schoenfeld, 2010). Moreover, hypoxic exposure combined with resistance training contributes to advanced fiber type recruitment that may lead to significant increases in maximal strength (Scott et al., 2014). The manufacturers of ETM claimed that this mask could improve the performance in high- volume and high-intensity resistance training assuming that oxygen restriction may lead to adaptations related to improved buffering capacity (Jagim et al., 2018).

Kon et al.(2010) have suggested that adopting systemic hypoxia in resistance training can be just as effective as occlusion training in terms of greater anabolic hormone responses. Researchers have also reported that when subjects performed leg press and bench press exercises at 50% and 70% of 1 repetition max (1RM) under normobaric hypoxic conditions (FiO2= 13%), greater anabolic hormone response and greater accumulation of metabolites were seen compared with normoxic conditions. Further studies are still required to explore whether short term and moderate-intensity resistance training applied with systemic hypoxia, can result in greater muscular strength. Hence, this study aimed to define the different characteristics of training or acclimatization between the control group (CON) and the MASK group before and after eight weeks of resistance training.

Material and Methods

Participants

20 participants volunteered for the study (age; 24.11±.274 y, body mass; 74.45±6.24 kg, height; 179.30±8.04 cm, and BMI; 21.90±1.41 kg/m2) for mask group and (age; 23.96±.231 y, body mass; 71.40±7.12 kg, height; 176.60±10.20 cm, and BMI 21.20±1.13 kg/m2) for the control group. All students had received moderate training before and the participant completed a familiarization session before any testing. Participants were excluded if they would suffer from metabolic disease or renal, pulmonary, or cardiovascular problems. Before the initiation of any testing or training session, it was required to obtain the oral and written signed consent of participants. The study was approved by the Institutional Review Board (275). Table (1) showed the physical characteristics of the two groups.

Table 1. Physical characteristics of subjects

Variables	MASK group n=10	CON group n=10
Age, (yr)	**24.11±.274**	**23.96±.231**
Body weight (kg)	**74.45±6.24**	**71.40±7.12**
Height (cm)	**179.30±8.04**	**176.60±10.20**
BMI (kg/m^2)	**21.90±1.41**	**21.20±1.13**

Values are represented as (mean ± sem)

Training program

Participants were assigned randomly to two groups including 10 participants in each group. None of the participants had participated in any resistance training for 4 months at least before the initiation of the study. The groups carried out their training program (3 sessions per weeklasting 2h after lunch) for 8 weeks on alternate days (Sunday, Tuesday, and Thursday). Experienced physical education instructors were responsible for supervising each lab training session.

The Mask group started with warm-up exercises for 10 min followed by resistance training for 40 min (Table 2) and ended with cool-down exercises for 10 min. During weeks 1 and 2, masks had set to simulate 3,000 ft and 6,000 ft during weeks 3 and 4, 9,000 ft during weeks 5 and 6, and 12,000 ft during weeks 7 and 8. Participants in the Control group started warm-up exercises for 10 min followed by resistance training without ETM and an additional elevation for 40 min and finished with cool-down exercises for 10 min.

Repetition maximum (1RM) was measured for each subject according to existing references.12 Subjects had to perform a warm-up set of 8-10 repetitions at 50% of their estimated 1RM and they had to move to a warm-up set of 3-5 repetitions at 85% of their estimated 1RM. Participants performed 1RM attempts during 4-5 trials separated by 3 min rest intervals to determine squat 1RM. 1RM was measured again and intensity was reestablished after 4 weeks of resistance training.

Table 2. Resistance Training Program First Four Weeks

Session	Exercises	Week 1	Week 2	Week 3	Week 4
		(Sets× Reps) %	(Sets× Reps) %	(Sets× Reps) %	(Sets× Reps) %
1	Standing shoulder press	(3×8) 60%	(3×8) 65%	(3×8) 70%	(3×5) 75%
	Back squat	(3×8) 60%	(3×8) 65%	(3×8) 70%	(3×5) 75%
	bench press	(3×8) 60%	(3×8) 65%	(3×8) 70%	(3×5) 75%
	Lateral shoulder raise	(3×8) 60%	(3×8) 65%	(3×8) 70%	(3×5) 75%
	Supine leg raise	Max in 60 s	Max in 60 s	Max in 60 s	Max in 60 s
2	Dumbbell Bent Lateral Raise	(3×8) 50%	(3×8) 55%	(3×8) 60%	(3×5) 65%
	Barbell Bent-Row	(3×8) 50%	(3×8) 55%	(3×8) 60%	(3×5) 65%
	Clean grip MTP	(3×8) 50%	(3×8) 55%	(3×8) 60%	(3×5) 65%
	Clean grip SLDL	(3×8) 50%	(3×8) 55%	(3×8) 60%	(3×5) 65%
	Abdominal crunch	Max in 60 s	Max in 60 s	Max in 60 s	Max in 60 s
3	Hang clean	(3×8) 60%	(3×8) 65%	(3×8) 70%	(3×5) 65%
	Front squat	(3×8) 60%	(3×8) 65%	(3×8) 70%	(3×5) 65%
	High pull	(3×8) 60%	(3×8) 65%	(3×8) 70%	(3×5) 65%
	Barbell biceps curl	(3×8) 60%	(3×8) 65%	(3×8) 70%	(3×5) 65%
	Supine leg raise	Max in 60 s	Max in 60 s	Max in 60 s	Max in 60 s

Reps = repetitions; % = Percent of repetition maximum; MTP = mid-thigh pull; SLDL = stiff-legged deadlift

The Physiological Responses Testing

All participants underwent a Cardiopulmonary Exercise Testing (CPET) on an electronic treadmill using (MetaMax 3B, Electrochemical sensor, Bidirectional 19200 Baud, CORTEX, Germany) (breath-by-breath system) (Macfarlane & Wong, 2012). It is noteworthy that (CPET) tests were carried out for one week until 48 hours before the initiation of the training protocol. The height and weight of every participant were measured before each (CPET) test.

After warming up briefly, participants ran for 2 min. at 9.0 (mph) at 0% grade. The speed was increased every 2 min by 2 km/h until volitional exhaustion. A Polar H7 belt (Polar, USA) was attached to every participant and they were asked to give maximum effort so that they reach their maximal capacity. During the Cardiopulmonary Exercise Testing (CPET), data were collected including VO2max, RER, MHR, VE, VT, VCO2. Blood Lactate (BL) sample was acquired from the fingertip and was measured by the Accusport device (Peter, 2001).

Performance variables tests

The athletic performance of the participants was measured by two field tests: The Vertical Jump test (VJ) where participants jumped as high as possible and made a chalk mark on the wall that was then measured and the best of three trials was recorded to the nearest 1.0 cm. In addition, the Grip strength test were used by usinga Jamar hand dynamometer to the nearest kilogram of each participant (Lafayette – Model 78010) (Haff&Triplett, 2015).

Table 3. Resistance Training Program Last Four Weeks

Session	Exercises	Week 5	Week 6	Week 7	Week 8
		(Sets× Reps) %	(Sets× Reps) %	(Sets× Reps) %	(Sets× Reps) %
1	Hang snatch	(3×5) 70%	(5×5) 75%	(3×3) 77%	(2×3) 80%
	Step-up	(3×5) 70%	(5×5) 75%	(3×3) 77%	(2×3) 80%
	Grip bench press	(3×5) 70%	(5×5) 75%	(3×3) 77%	(2×3) 80%
	Lat pull-down	(3×5) 70%	(5×5) 75%	(3×3) 77%	(2×3) 80%
	Abdominal crunch	Max in 60 s	Max in 60 s	Max in 60 s	Max in 60 s
2	Dumbbell Bent Lateral Raise	(3×5) 65%	(5×5) 70%	(3×3) 75%	(2×3) 65%
	Barbell Bent-Row	(3×5) 65%	(5×5) 70%	(3×3) 75%	(2×3) 65%
	Clean grip MTP	(3×5) 65%	(5×5) 70%	(3×3) 75%	(2×3) 65%
	Clean grip SLDL	(3×5) 65%	(5×5) 70%	(3×3) 75%	(2×3) 65%
	Abdominal crunch	Max in 60 s	Max in 60 s	Max in 60 s	Max in 60 s
3	Push jerk	(3×5) 70%	(5×5) 75%	(3×3) 77%	(2×3) 70%
	Forward step lung	(3×5) 70%	(5×5) 75%	(3×3) 77%	(2×3) 70%
	Grip bench press	(3×5) 70%	(5×5) 75%	(3×3) 77%	(2×3) 70%
	Upright row	(3×5) 70%	(5×5) 75%	(3×3) 77%	(2×3) 70%
	Abdominal crunch	Max in 60 s	Max in 60 s	Max in 60 s	Max in 60 s

Reps = repetitions; % = Percent of repetition maximum; MTP = mid-thigh pull; SLDL = stiff-legged deadlift

The Physiological Responses Testing

Statistical Analysis

Statistical Package for Social Sciences (SPSS) (version 23.0.) and GraphPad Prism (version 8.4.2. GraphPad Software 154 LLC, CA, USA) were used to perform all statistical analyses. This study used a 2-way analysis of variance (ANOVA) with repeated measures for each group. Data include 'T' value and mean ± standard deviation and the statistical significance level was set at ($p < 0.05$), ($p < 0.01$), ($p < 0.001$).

Results

The descriptive characteristics of participants are illustrated in Table (1) (age, 24.11±.274 y, body mass, 74.45±6.24 kg, height, 179.30±8.04 cm, BMI 21.90±1.41 kg/m2) for Mask group and (age, 23.96±.231 y, body mass, 71.40±7.12 kg, height, 176.60±10.20 cm, BMI 21.20±1.13 kg/m2) for Control group.

Figure (1) illustrated pre- and post-testing performance variables between control and mask groups in terms of VT, BL, HR, VO2max, RER, VE, GS, and VJ. No statistically significant difference was detected between the two groups in terms of performance variables. An increase in a vertical jump by 16.54% and in grip strength by 10.74% in the control group versus increases in the vertical jump of 17.69% and grip strength by 11.54% in the mask group. According to other variables, the Mask group showed better improvement in VO2max (17.65%), VO2/HR (20%), VE/VO2 (6.86%), RER (19.6%), VT (6.03%), and BL (16.44%).

Figure (2) clarified line and scatter charts for the CPET for physiological responses as follows; Maximal Oxygen Uptake (VO2 max), Carbon dioxide production (VCO2), Oxygen Uptake/ Consumption (VO2), Ventilatory threshold (VT), Minute Ventilation (VE), Maximal Ventilation (VE), Respiratory Exchange ratio (VE peak), Blood lactate (BL), Maximal Heart Rate (MHR), Vertical jump, and Grip Strength. In addition, for two group control and Mask in pre- and post-testing. Values are means $^*P<0.05$, $P<0.01$ and $P<0.001$ between Variables for groups.

The general linear model (two-way ANOVA) for the Mask group showed a significant effect in (VO2/HR; $p < 0.05$), VE/VO2; $p < 0.05$), (VE/VCO2; $p < 0.05$), (VT; $p < 0.05$) and for BL; $p < 0.01$) and for (VO2max; $p < 0.001$), MHR; $p < 0.001$), VE; $p < 0.001$) compared to the control group.

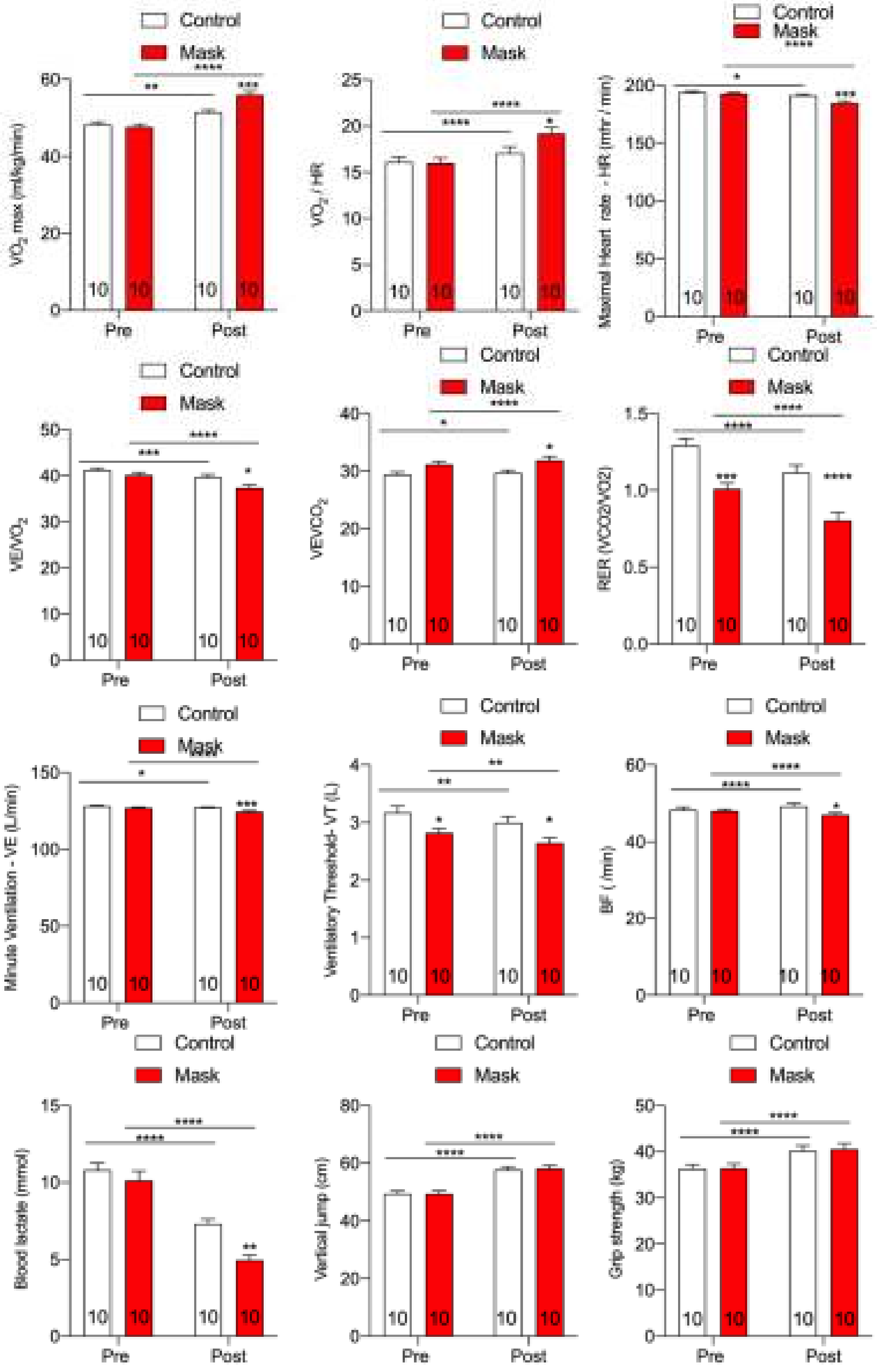

*Figure 1. VO2max, VO2/HR, MHR, VE/VO2, VE/VCO2, RER, VE, VT, BL, Vertical jump, and Grip Strength for control and Mask group in pre- and post-training, *-p<0.05, **- p<0.01, *** - p<0.0005, **** - p<0.0001*

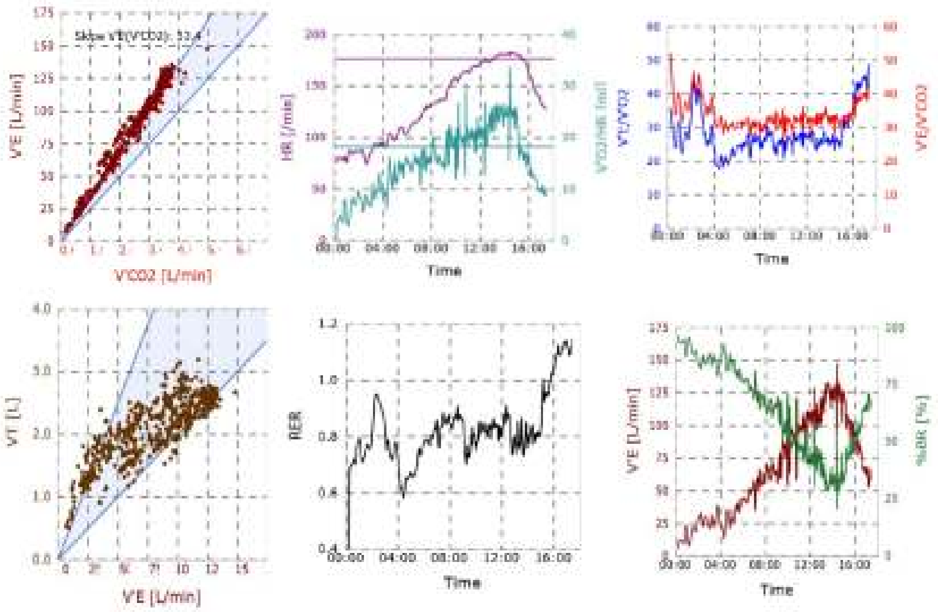

Figure 2. VE, HR, VE/VO2, VT, RER, VE for control and Mask groups pre- and post -training.

Discussion

The present study sheds light on the probable beneficial effect of using ETM during resistance training on physiological responses and other performance variables. After applying the resistance training program for 8 weeks, the Mask group showed better improvement in VO2max (17.65%), BL (16.44%), VO2/HR (20%), VE/VO2 (6.86%), RER (19.6%), and VT (6.03%) compared to the control group. According to the other variables, a significant increase in performance variables has been noticedand the mask group has improved vertical jump by 17.69% and grip strength by 11.54%. No substantial differences have been detected between the two groups.

Many scientific concerns have been assigned to the mechanisms of physiological responses that have been improved after using ETM during resistance training. In addition, several investigations showed that the improvements have been noticed with increased anaerobic capacity (Roberts, 2003), increased hypoxic ventilatory response(Townsend et al.,2002), reduced blood lactate production (Clark et al., 2004), as well as an increase in red blood cell volume (Levine & Stray-Gundersen, 1985). Although other researchers have not confirmed all the results of the present study, yet some factors have been proved to improve performance after altitude training. Such factors may depend on the duration of hypoxic exposure (Robertson et al.,2010; Stray-Gundersen& Levine, 2008).

The present study has reached new observations suggesting that the individual variability that occurred in response to resistance training with ETM might be explained by two mechanistic ways: wearing a mask that increased VO2max and O2 carrying capacity, training that improved VO2max, and the maintenance of training velocity and O2 flux near sea-level values. These findings supported previous observations concerning appropriate strategies of altitude training (Levine & Stray-Gundersen, 1985). Similar results were obtained by Dufour et al. (2005) after applying an intermittent hypoxic training program for 6 weeks. After following the same training protocols, the hypoxic group has improved VO2max by 4%, whereas the normoxic group has been improved by 3%. However, most literature supports improvement in altitude training groups, 22 it is assumed that high-intensity hypoxic training has stimulated peripheral muscle adaptations that led to increasingthe performance capacity in hypoxic groups only (Porcari, 2016).

Increased oxygen usage was considered a teleological adaptation to the shortage of Oxygen in tissues in a hypoxic environment. Results that were obtained from independent research groups have shown a 6-20% improvement in physiological responses. This was demonstrated by reduced consumption of Oxygen after various forms of altitude acclimatization during submaximal exercise (Neya et al., 2007; Manimmanakorn et al., 2013). Thus, a large number of studies have confirmed the relation between performance and physiological responses (Saunders et al., 2004). This guaranteed the ability to enhance VO2max after altitude training. Yet, the review that was conducted by Lundby et al. (2007) has not reflected any significant changes in VO2max after the exposure to 4100m for 8 weeks. In spite of a reduction in submaximal VO2 by 15% compared with 3-10% significant changes as mentioned above.

Levine & Stray-Gundersen,(1985) have used a randomized and well-designed three-armed trial to examine whether acclimatization to moderate altitude and training at low altitude (1.250 m) "living high- training low" can enhance the sea-level performance of well-trained runners compared to an equivalent altitude or sea-level control group (Levine & Stray-Gundersen, (1985). A significant increase in VO2max (5%) in both altitude groups has been reported in direct proportion to an increase in the mass volume of red cells (9%). Only 5km have been improved by the high-low group in proportion to an increase in VO2max. Consequently, authors have concluded that living high-training low for 4 weeks could improve sea-level training performance of well-trained runners because of altitude acclimatization increase in VO2max and mass volume of red cells (de Paula &Niebauer, 2012).

As mentioned earlier, both groups have followed the same resistance training protocols and training workloads. Consequently, it is assumed that wearing a mask constituted an additional stimulus. It is noticed that blood lactate decreased significantly after resistance training in the mask group only. This result suggested that resistance training while wearing ETM might improve body lactate metabolism and overall performance at sea-level alone compared to the control group. This result also referred to an adjustment in skeletal muscle to adopt a more oxidative mode of energy provision (Clark et al., 2004). Other studies that included low-intensity resistance training (20%1RM) and moderate vascular occlusion have reported greater accumulation of blood lactate (Takarada et al., 2000). Kon et al. (2010) have conducted a study demonstrating higher concentrations of blood lactate after resistance training that was performed in systemic hypoxic conditions. In 2010, Nishimura et al. have found that applying a 6-week program of resistance training (4sets ×10 repetitions at 70% 1RM, 1 min rest) in normobaric hypoxic conditions (16% FiO2) has improved arm strength levels (66 vs. 48%, non-significant) compared tonormoxic conditions. In addition, researchers have noticed greater blood lactate and anabolic hormone responses even though the used load was below the low-limit threshold of the "moderate-load" and above the "lower load" (Feriche B, et al., 2017).

Individual responses have shown that some athletes responded better than others. Moreover, the degree of within-athlete variation in response to repeated bouts suggested that ETM should be adjusted carefully under other training and competitive conditions. Future research is still needed to consolidate the transfer of these benefits to competitive performance. Furthermore, it is required to determine the time-course of advanced physiological responses and performance after exposure to hypoxic conditions. The factor of time is very important for both athletes and coaches to determine when to start hypoxic exposure before any competition and to manage training loads.

Conclusion

It has been demonstrated that resistance training while wearing an ETM could lead to effective physiological responses and an increase in VO2max. The following variables should be kept in mind to reconcile ETM with resistance training programs: the number of exercises, length of specific exercises, repetitions per set, sets per session, sessions per week, and the relative stress and difficulty of exercises.

References

Robertson, E. Y., Aughey, R. J., Anson, J. M., Hopkins, W. G., & Pyne, D. B. (2010). Effects of simulated and real altitude exposure in elite swimmers. Journal of strength and conditioning research, 24(2), 487–493. https://doi.org/10.1519/JSC.0b013e3181c06d56

Levine B. D. (2002). Intermittent hypoxic training: fact and fancy. High altitude medicine & biology, 3(2), 177–193. https://doi.org/10.1089/15270290260131911

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), 283–290. https://doi.org/10.1007/s004210000363

Hahn, A. G., & Gore, C. J. (2001). The effect of altitude on cycling performance: a challenge to traditional concepts. Sports medicine (Auckland, N.Z.), 31(7), 533–557. https://doi.org/10.2165/00007256-200131070-00008

Stray-Gundersen J, Chapman RF, Levine BD. (2001) "Living high-training low" altitude training improves sea level performance in male and female elite runners. Journal of Applied Physiology, 91(3):1113-1120. DOI: 10.1152/jappl.2001.91.3.1113.

Porcari, J. P., Probst, L., Forrester, K., Doberstein, S., Foster, C., Cress, M. L., & Schmidt, K. (2016). Effect of Wearing the Elevation Training Mask on Aerobic Capacity, Lung Function, and Hematological Variables. Journal of sports science & medicine, 15(2), 379–386.

Howarth, K. R., Moreau, N. A., Phillips, S. M., &Gibala, M. J. (2009). Coingestion of protein with carbohydrate during recovery from endurance exercise stimulates skeletal muscle protein synthesis in humans. Journal of applied physiology (Bethesda, Md.:1985), 106(4), 1394–1402. https://doi.org/10.1152/japplphysiol.90333.2008

Kon, M., Ikeda, T., Homma, T., Akimoto, T., Suzuki, Y., & Kawahara, T. (2010). Effects of acute hypoxia on metabolic and hormonal responses to resistance exercise. Medicine and science in sports and exercise, 42(7), 1279–1285. https://doi.org/10.1249/MSS.0b013e3181ce61a5

Schoenfeld B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. Journal of strength and conditioning research, 24(10), 2857–2872. https://doi.org/10.1519/JSC.0b013e3181e840f3

Scott, B. R., Slattery, K. M., Sculley, D. V., &Dascombe, B. J. (2014). Hypoxia and resistance exercise: a comparison of localized and systemic methods. Sports medicine (Auckland, N.Z.), 44(8), 1037–1054. https://doi.org/10.1007/s40279-014-0177-7

Jagim, A. R., Dominy, T. A., Camic, C. L., Wright, G., Doberstein, S., Jones, M. T., & Oliver, J. M. (2018). Acute Effects of the Elevation Training Mask on Strength Performance in Recreational Weight lifters. Journal of strength and conditioning research, 32(2), 482–489. https://doi.org/10.1519/JSC.0000000000002308

Kraemer, W. J., &Ratamess, N. A. (2004). Fundamentals of resistance training: progression and exercise prescription. Medicine and science in sports and exercise, 36(4), 674–688. https://doi.org/10.1249/01.mss.0000121945.36635.61

Macfarlane, D. J., & Wong, P. (2012). Validity, reliability and stability of the portable Cortex Metamax 3B gas analysis system. European journal of applied physiology, 112(7), 2539–2547. https://doi.org/10.1007/s00421-011-2230-7

Peter J. (2001) Lactate threshold training. Human kinetic. USA

Haff, G., Triplett, N. T. (2015) Essentials of strength training and conditioning. National Strength & Conditioning Association; Human kinetic (U.S.)

Roberts, A. D., Clark, S. A., Townsend, N. E., Anderson, M. E., Gore, C. J., & Hahn, A. G. (2003). Changes in performance, maximal oxygen uptake and maximal accumulated oxygen deficit after 5, 10 and 15 days of live high:train low altitude exposure. European journal of applied physiology, 88(4-5), 390–395. https://doi.org/10.1007/s00421-002-0720-3

Townsend, N. E., Gore, C. J., Hahn, A. G., McKenna, M. J., Aughey, R. J., Clark, S. A., Kinsman, T., Hawley, J. A., & Chow, C. M. (2002). Living high-training low increases hypoxic ventilatory response of well-trained endurance athletes. Journal of applied physiology (Bethesda, Md. : 1985), 93(4), 1498–1505. https://doi.org/10.1152/japplphysiol.00381.2002

Clark, S. A., Aughey, R. J., Gore, C. J., Hahn, A. G., Townsend, N. E., Kinsman, T. A., Chow, C.-M., Mckenna, M. J., & Hawley, J. A. (2004). Effects of live high, train low hypoxic exposure on lactate metabolism in trained humans. Journal of Applied Physiology, 96(2):517-525. DOI: 10.1152/japplphysiol.00799.2003.

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 (Bethesda, Md. : 1985), 83(1), 102–112. https://doi.org/10.1152/jappl.1997.83.1.102

Stray-Gundersen, J., & Levine, B. D. (2008). Live high, train low at natural altitude. Scandinavian journal of medicine & science in sports, 18 Suppl 1, 21–28. https://doi.org/10.1111/j.1600-0838.2008.00829.x

Dufour, S. P., Ponsot, E., Zoll, J., Doutreleau, S., Lonsdorfer-Wolf, E., Geny, B., Lampert, E., Flück, M., Hoppeler, H., Billat, V., Mettauer, B., Richard, R., &Lonsdorfer, J. (2006). Exercise training in normobaric hypoxia in endurance runners. I. Improvement in aerobic performance capacity. Journal of applied physiology (Bethesda, Md. : 1985), 100(4), 1238–1248. https://doi.org/10.1152/japplphysiol.00742.2005

Robertson, E. Y., Saunders, P. U., Pyne, D. B., Gore, C. J., & Anson, J. M. (2010). Effectiveness of intermittent training in hypoxia combined with live high/train low. European journal of applied physiology, 110(2), 379–387. https://doi.org/10.1007/s00421-010-1516-5

Neya, M., Enoki, T., Kumai, Y., Sugoh, T., & Kawahara, T. (2007). The effects of nightly normobaric hypoxia and high intensity training under intermittent normobaric hypoxia on running economy and hemoglobin mass. Journal of applied physiology (Bethesda, Md.: 1985), 103(3), 828–834. https://doi.org/10.1152/japplphysiol.00265.2007

Manimmanakorn, A., Hamlin, M. J., Ross, J. J., Taylor, R., &Manimmanakorn, N. (2013). Effects of low-load resistance training combined with blood flow restriction or hypoxia on muscle function and performance in netball athletes. Journal of science and medicine in sport, 16(4), 337–342. https://doi.org/10.1016/j.jsams.2012.08.009

Saunders, P. U., Pyne, D. B., Telford, R. D., & Hawley, J. A. (2004). Factors affecting running economy in trained distance runners. Sports medicine (Auckland, N.Z.), 34(7), 465–485. https://doi.org/10.2165/00007256-200434070-00005

Lundby, C., Calbet, J. A., Sander, M., van Hall, G., Mazzeo, R. S., Stray-Gundersen, J., Stager, J. M., Chapman, R. F., Saltin, B., & Levine, B. D. (2007). Exercise economy does not change after acclimatization to moderate to very high altitude. Scandinavian journal of medicine & science in sports, 17(3), 281–291. https://doi.org/10.1111/j.1600-0838.2006.00530.x de Paula, P., &Niebauer, J. (2012). Effects of high altitude training on exercise capacity: fact or myth. Sleep & breathing = Schlaf&Atmung, 16(1), 233–239. https://doi.org/10.1007/s11325-010-0445-1

Takarada, Y., Nakamura, Y., Aruga, S., Onda, T., Miyazaki, S., & Ishii, N. (2000). Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. Journal of applied physiology (Bethesda, Md. : 1985), 88(1), 61–65. https://doi.org/10.1152/jappl.2000.88.1.61

Nishimura, A., Sugita, M., Kato, K., Fukuda, A., Sudo, A., & Uchida, A. (2010). Hypoxia increases muscle hypertrophy induced by resistance training. International journal of sports physiology and performance, 5(4), 497–508. https://doi.org/10.1123/ijspp.5.4.497

Feriche, B., García-Ramos, A., Morales-Artacho, A. J., &Padial, P. (2017). Resistance Training Using Different Hypoxic Training Strategies: a Basis for Hypertrophy and Muscle Power Development. Sports medicine - open, 3(1), 12. https://doi.org/10.1186/s40798-017-0078-z