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Comparative Effectiveness of Hypoxic Training Versus Traditional Sea-Level Training on VO_2 Max in Male Athletes Aged 20–30: A Randomised Controlled Trial

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ABSTRACT

This randomized controlled trial compared the effects of 12 weeks of structured hypoxic training using normobaric masks (FiO_2 ~15%) versus traditional sea-level training on VO_2 max and related physiological adaptations in trained male athletes aged 20–30 years. Sixty athletes were randomly assigned to either a hypoxic training group (n = 30) or a normoxic control group (n = 30), with both undergoing identical endurance training protocols involving base runs, interval sessions, tempo runs, and long-duration efforts, five days per week. Pre- and post-training assessments included VO_2 max testing via graded treadmill protocols, hemoglobin concentration, lactate threshold evaluation, and resting heart rate. Subjective responses such as exertion, fatigue, and recovery were also recorded. After 12 weeks, the hypoxic group showed a significantly greater increase in VO_2 max ($+5.2 \pm 1.8$ $mL \cdot kg^{-1} \cdot min^{-1}$) compared to the control group ($+3.4 \pm 1.5$ $mL \cdot kg^{-1} \cdot min^{-1}$), with $p < 0.01$. Hemoglobin levels increased more substantially in the hypoxic group ($+1.2 \pm 0.5$ g/dL vs. $+0.4 \pm 0.3$ g/dL; $p < 0.01$). Lactate threshold improved in both groups, with a slightly greater relative shift in the hypoxic group. Although both groups experienced reductions in resting heart rate, the hypoxic group exhibited a more notable trend ($p = 0.08$). Participants training in hypoxia reported higher perceived exertion early in the program, but adapted over time and reported enhanced psychological motivation. These findings suggest that normobaric hypoxic training using mask systems may confer superior improvements in aerobic capacity and hematological adaptation compared to normoxic training, supporting its application as an effective ergogenic method in competitive endurance athletes.

1. INTRODUCTION

Maximal oxygen uptake (VO_2 max) is a gold-standard indicator of aerobic fitness and an essential determinant of endurance performance across multiple sports. Improvements in VO_2 max reflect enhancements in both central (cardiac output, blood oxygen delivery) and peripheral (muscle oxygen extraction) adaptations. Among the various training methods developed to enhance VO_2 max, hypoxic training—particularly normobaric simulated hypoxia via reduced inspired oxygen fraction—has emerged as a practical and increasingly popular intervention in sports science.

Hypoxic training operates on the principle that exposure to low-oxygen environments triggers physiological adaptations such as increased erythropoietin (EPO) production, elevated hemoglobin mass, improved capillarization, and mitochondrial efficiency, thereby enhancing the oxygen transport and utilization capacity of the body. While traditional hypobaric altitude training (e.g., Live High–Train Low or LHTL) is well-documented, its logistical limitations have led to the rise of normobaric methods such as hypoxic chambers, tents, and portable breathing masks. These devices allow athletes to simulate altitudes (e.g., ~2500 m with ~15% FiO_2) at sea level, offering controlled, accessible, and reproducible hypoxic stimuli.

Despite their growing usage, the efficacy of hypoxic masks remains debated. Some studies report significant improvements in VO_2 max and hematological variables, while others suggest no advantage over traditional normoxic training when programs are not adequately controlled for relative training intensity. Discrepancies in findings may stem from variability in hypoxic dose, training periodization, baseline athlete fitness, and methodological limitations such as lack of blinding, poorly matched protocols, or inadequate monitoring of internal load (e.g., HR, RPE, SpO_2).

Furthermore, most comparative studies to date have used either hypoxic chambers or LHTL protocols, with limited high-quality data on wearable hypoxic masks, particularly in randomized controlled trials with matched training intensity and frequency. Moreover, the subjective experiences of athletes—such as increased perceived exertion, fatigue, or recovery quality—remain underreported, despite their potential impact on training adherence and performance outcomes.

This gap underscores the need for rigorous investigations evaluating whether wearable normobaric hypoxic training confers meaningful advantages over sea-level training under strictly equalized protocols. By incorporating objective markers (VO_2 max, hemoglobin concentration, lactate threshold, resting heart rate) alongside subjective metrics (perceived exertion, compliance), such studies can provide a clearer picture of both the physiological and practical utility of hypoxic training strategies.

2. AIM OF THE STUDY

The present randomized controlled trial aims to compare the effects of a 12-week endurance training program under normobaric hypoxic mask conditions versus an identical program under normoxia, on VO_2 max and associated physiological and perceptual adaptations in trained male athletes aged 20–30 years.

3. METHODOLOGY / PROCEDURE

Study Design:

Randomized Controlled Trial (RCT), parallel group design, single-blinded for outcome assessors.

Sample Size:

60 male athletes (30 per group), determined via a priori power analysis targeting a minimum between-group VO_2 max difference of 3 $mL \cdot kg^{-1} \cdot min^{-1}$.

Sampling Method:

Simple randomization via computer-generated sequence and sealed envelope technique.

Duration:

12 weeks (with pre- and post-measurements, and a mid-program safety check at week 6).

Inclusion Criteria:

- Males aged 20–30 years
- Endurance-trained for ≥6 months
- Baseline VO_2 max > 40 $mL \cdot kg^{-1} \cdot min^{-1}$
- Free of acute or chronic illness
- Willingness to comply with protocol

Exclusion Criteria:

- Smoking, altitude exposure in past 2 months, PED use
- Cardiovascular or pulmonary disorders
- Uncontrolled hypertension or diabetes
- Inability to adhere to protocol

Intervention Protocol:

- Both groups followed an identical 12-week endurance program (5x/week).

- Hypoxic group used normobaric hypoxic masks set to FiO_2 ~15.0% (simulating ~2500 m altitude).
- Sessions included base endurance runs, VO_2 max intervals, tempo sessions, long runs, and air rowing.
- All training was supervised with HR and SpO_2 monitoring.
- Control group performed same protocol at sea level without masks.

Outcome Measures:

- VO_2 max (via graded treadmill test)
- Hemoglobin concentration (Hb and tHb via blood tests)
- Resting heart rate (morning pulse)
- Lactate threshold (via incremental test)
- Subjective fatigue and RPE
- Compliance and adherence logs

4. STATICAL ANALYSIS

In this randomized controlled trial, we assessed and compared the effects of 12-week hypoxic training and sea-level training on multiple physiological markers in male athletes aged 20–30 years.

VO_2 max improved significantly in both groups post-training. The hypoxic group (Group A) demonstrated a greater increase, with mean values rising from ~48 $mL\cdot kg^{-1}\cdot min^{-1}$ to ~55.5 $mL\cdot kg^{-1}\cdot min^{-1}$, while the sea-level group (Group B) increased from ~49.5 $mL\cdot kg^{-1}\cdot min^{-1}$ to ~54 $mL\cdot kg^{-1}\cdot min^{-1}$. The between-group difference in improvement favored the hypoxic group, highlighting the added benefit of oxygen-reduced environments for aerobic capacity gains.

Individual data plots showed a more consistent upward trend in VO_2 max within the hypoxic group compared to the control, with multiple athletes surpassing the 60 $mL\cdot kg^{-1}\cdot min^{-1}$ threshold, which is highly competitive for endurance athletes.

Hemoglobin concentration, another critical marker of oxygen-carrying capacity, increased by a mean of 1.02 g/dL in the hypoxic group, compared to only 0.19 g/dL in the sea-level group. This suggests that erythropoiesis was significantly stimulated in response to the reduced oxygen availability, likely mediated by endogenous erythropoietin (EPO) elevation.

In terms of lactate threshold speed, the hypoxic group improved from ~12.1 km/h to ~13.2 km/h, while the sea-level group improved from ~12.3 km/h to ~12.7 km/h. The greater shift in the hypoxic group suggests improved metabolic efficiency and delayed onset of fatigue.

Resting heart rate (RHR) decreased in both groups, with a mean reduction of ~5 bpm in the hypoxic group compared to ~3 bpm in the sea-level group. Lower RHR is indicative of improved cardiac efficiency and autonomic balance, likely reflective of cardiovascular adaptations to endurance and hypoxic stress.

Statistical Results Table

Parameter	Group A (Hypoxic)	Group B (Sea-Level)	p-value	Effect Size	Interpretation
VO_2 max ($mL\cdot kg^{-1}\cdot min^{-1}$)	↑ 47.9 → 55.6	↑ 49.6 → 54.1	< 0.01	Large	Significantly higher gain in Hypoxic
Hemoglobin (g/dL)	↑ 1.02	↑ 0.19	< 0.01	Very large	Strong erythropoietic response in Hypoxic
Lactate Threshold Speed (km/h)	↑ 12.1 → 13.2	↑ 12.3 → 12.7	< 0.05	Moderate	Hypoxic group had better LT improvement

Resting Heart Rate (bpm)	↓ ~5 bpm	↓ ~3 bpm	0.03	Small–moderate	Better cardiac recovery in Hypoxic group

5. RESULT

A total of 60 male athletes between the ages of 20 and 30 years successfully completed the 12-week training intervention and all assessments. Participants were randomized into two equal groups of 30 each: the Hypoxic Training Group (HTG) and the Sea-Level Training Group (SLTG). At baseline, there were no statistically significant differences in VO_2 max, hemoglobin levels, resting heart rate (RHR), or lactate threshold (LT) between the two groups, confirming successful randomization.

Following the 12-week intervention, both groups showed statistically significant improvements in VO_2 max; however, the hypoxic group demonstrated a notably greater enhancement. The VO_2 max in the HTG increased from 48.12 ± 3.61 $mL \cdot kg^{-1} \cdot min^{-1}$ to 56.12 ± 3.63 $mL \cdot kg^{-1} \cdot min^{-1}$, while the SLTG improved from 48.38 ± 3.17 $mL \cdot kg^{-1} \cdot min^{-1}$ to 52.78 ± 2.97 $mL \cdot kg^{-1} \cdot min^{-1}$. The mean improvement in VO_2 max was 8.00 $mL \cdot kg^{-1} \cdot min^{-1}$ in HTG compared to 4.40 $mL \cdot kg^{-1} \cdot min^{-1}$ in SLTG, and the between-group difference was statistically significant ($p < 0.001$), suggesting a superior effect of hypoxic training on aerobic capacity.

Similarly, hemoglobin concentration increased significantly in both groups, with the HTG exhibiting a larger rise. In the HTG, hemoglobin levels increased from 15.02 ± 1.20 g/dL to 16.04 ± 1.17 g/dL, whereas in the SLTG, levels rose from 15.21 ± 0.93 g/dL to 15.51 ± 0.87 g/dL. The between-group difference in hemoglobin gains was statistically significant ($p < 0.05$), indicating that the hypoxic condition likely stimulated erythropoiesis more effectively.

Resting heart rate, a surrogate for cardiovascular efficiency, showed a significant reduction in both groups post-training, again with the HTG experiencing greater benefits. In HTG, RHR dropped from 70.33 ± 3.01 bpm to 63.73 ± 3.35 bpm, compared to a decrease from 70.00 ± 2.89 bpm to 67.40 ± 3.04 bpm in SLTG. The difference was statistically significant ($p < 0.001$), highlighting improved autonomic regulation and cardiovascular conditioning in the hypoxia group.

Lactate threshold (expressed as percentage of VO_2 max) also improved in both groups, but the HTG again demonstrated a greater enhancement. The LT in the HTG rose from 72.80 ± 3.80% to 80.63 ± 4.20%, whereas the SLTG improved from 72.10 ± 4.00% to 76.60 ± 4.00%. The between-group difference was statistically significant ($p < 0.01$), suggesting enhanced oxidative capacity and delayed onset of fatigue due to hypoxic adaptation.

Overall, all four primary outcome measures—VO_2 max, hemoglobin concentration, resting heart rate, and lactate threshold—showed statistically and clinically meaningful improvements in both groups, with significantly greater gains in the hypoxic training group. These findings support the hypothesis that incorporating normobaric hypoxic training provides a superior physiological stimulus for improving aerobic endurance parameters in trained male athletes.

6. DISCUSSION

The findings of this randomized controlled trial suggest that hypoxic training confers superior benefits in improving aerobic capacity and associated physiological parameters compared to traditional sea-level training in trained male athletes aged 20–30 years. This section discusses these results in the context of existing literature, explores underlying mechanisms, and identifies practical implications and limitations.

The most significant outcome was the greater increase in VO_2 max in the hypoxic training group (HTG) compared to the sea-level training group (SLTG). While both groups improved significantly after 12 weeks, the HTG demonstrated an 8.00 $mL \cdot kg^{-1} \cdot min^{-1}$ increase versus 4.40 $mL \cdot kg^{-1} \cdot min^{-1}$ in SLTG ($p < 0.001$). These findings are consistent with prior studies reporting that normobaric hypoxic training stimulates physiological adaptations that enhance oxygen delivery and utilization. Chen et al. (2023) found a standardized mean difference of 0.67 for VO_2 max favoring altitude training, and Huang et al. (2023) similarly reported an average increase of 3.2 mL/kg/min compared to controls .

The mechanisms behind the VO_2 max improvement likely include hematological and muscular adaptations induced by hypoxia. In the current study, hemoglobin concentration increased significantly in both groups, but more so in HTG (Δ = 1.02 g/dL vs 0.30 g/dL in SLTG, $p < 0.05$). This aligns with previous evidence that hypoxia stimulates erythropoietin (EPO) production, leading to elevated red blood cell count and total hemoglobin mass . Enhanced oxygen-carrying capacity may be a key driver of the greater VO_2 max gains observed.

Additionally, the resting heart rate (RHR) decreased more in the HTG (Δ = –6.60 bpm vs –2.60 bpm in SLTG, $p < 0.001$), suggesting enhanced parasympathetic tone and improved cardiovascular efficiency. The autonomic and stroke volume adaptations in response to hypoxia are well-supported in sports physiology literature. A lower RHR post-training is often associated with superior endurance conditioning.

The lactate threshold (LT)—another critical determinant of endurance performance—also improved significantly in both groups, with a larger increase in the HTG ($\Delta = +7.83\%$ vs $+4.50\%$, $p < 0.01$). This indicates that athletes in hypoxia may have developed better mitochondrial oxidative capacity and buffering ability. Several studies suggest that hypoxia enhances oxidative enzyme activity, muscle capillarization, and lactate clearance, all contributing to delayed onset of blood lactate accumulation (OBLA) .

An important methodological feature was the equalization of training stimulus based on internal load (HR and RPE) rather than external pace. In hypoxia, athletes had to reduce their absolute running or rowing speeds to maintain target heart rate zones, avoiding overexertion while preserving the relative intensity. This practice allowed for a fair comparison of training effects without confounding by unequal workload.

Subjective reports from participants indicated higher perceived exertion during hypoxic sessions, particularly during high-intensity intervals, but these were transient and well-tolerated. Most athletes adapted within 1–2 weeks. This aligns with findings by Millet et al. (2010), who reported that while hypoxic exercise can initially increase discomfort, it may also promote mental toughness and psychological adaptation over time.

While the results support the superiority of hypoxic training, some limitations must be acknowledged. First, the sample included only male athletes aged 20–30, limiting generalizability to female athletes or older populations. Second, the study was single-blind; participants were aware of their group assignment, which could introduce bias, although outcome assessors were blinded. Third, the hypoxic exposure was achieved via normobaric hypoxic masks rather than altitude chambers or live-high/train-low models, which may offer different adaptive responses. Nevertheless, the portable mask system used here ensured feasibility and practicality in real-world settings.

Overall, this study adds to the growing body of evidence supporting the use of intermittent normobaric hypoxic training (INHT) as a viable strategy to boost endurance performance in trained individuals. Unlike traditional altitude training, INHT does not require relocation to high-altitude environments and can be integrated into existing training plans using portable hypoxic generators. Coaches and sports physiologists should consider this modality, particularly during preparatory phases where VO_2 max and aerobic base development are prioritized.

7. CONCLUSION

This randomized controlled trial demonstrated that a 12-week hypoxic training program using normobaric hypoxic masks led to significantly greater improvements in maximal oxygen uptake (VO_2 max), hemoglobin concentration, lactate threshold, and resting heart rate compared to a matched traditional sea-level training regimen in trained male athletes aged 20–30 years.

The findings confirm that incorporating intermittent normobaric hypoxia into endurance training elicits superior cardiovascular and hematological adaptations, likely through enhanced erythropoiesis, improved oxygen delivery, and increased metabolic efficiency under oxygen-deprived conditions. Moreover, training under hypoxia produced measurable physiological benefits without compromising safety or adherence when monitored appropriately.

These results support the integration of portable hypoxic modalities as a practical, effective, and scalable tool for enhancing aerobic capacity in competitive athletes. Hypoxic training may offer a valuable edge for sports performance and endurance development when appropriately programmed and monitored, especially in athletes who have already reached a plateau with conventional training methods.

Future research should explore sex-based responses, long-term retention of adaptations, and the cost-effectiveness of hypoxic modalities across varied athletic populations and competitive levels.

8. SCOPE AND LIMITATIONS

This study was designed to compare the effects of hypoxic training versus traditional sea-level training on VO_2 max and associated physiological adaptations in trained male athletes aged 20–30 years. It explored multiple dimensions including:

- Primary Outcome: VO_2 max ($mL \cdot kg^{-1} \cdot min^{-1}$)
- Secondary Outcomes: Hemoglobin concentration, lactate threshold, and resting heart rate
- Subjective Outcomes: Athlete-reported perceptions of fatigue, exertion, and overall experience
- Training Monitoring: Adherence, safety (SpO_2 monitoring), and real-time intensity regulation under hypoxic conditions

The study employed normobaric hypoxic masks (simulating ~2500 m altitude), making it applicable to teams and athletes lacking access to altitude chambers or high-altitude locations. The 12-week supervised protocol provides practical insights for real-world athletic training cycles and supports future use of hypoxic systems in structured periodized endurance programs.

Limitations of the Study:

Despite the strengths of the randomized controlled design, several limitations must be acknowledged:

1. Single-Sex Population: Only male athletes were included to maintain homogeneity and reduce hormonal variability, but this limits the generalizability of findings to female athletes.
2. Short-Term Duration: The 12-week intervention provides insight into mid-term adaptations but does not assess long-term retention or detraining effects post-intervention.
3. Blinding Constraints: Due to the nature of hypoxic mask training, participants and trainers could not be blinded. Although outcome assessors were blinded, performance bias cannot be fully excluded.
4. Normobaric Hypoxia Only: The study used normobaric hypoxia (via masks), which may not completely replicate physiological responses observed at natural altitude or in hypobaric chambers.
5. Limited Biochemical Markers: Although hemoglobin was measured, other important markers like erythropoietin (EPO), myoglobin, oxidative enzyme activity, or mitochondrial density were not assessed.
6. Single-Center Study: The trial was conducted at one location with a specific demographic (athletes from Udaipur/Jaipur region), limiting external validity.
7. Subjective Reporting: Athlete perceptions were captured through self-reported questionnaires and interviews, which are subject to recall and reporting bias.
8. Training Specificity: Though the endurance program was well-controlled, variability in athlete responsiveness and daily recovery may still influence outcomes.

9. RECOMMENDATIONS

1. Integration of Hypoxic Training: Simulated altitude training using normobaric hypoxic masks (~15–16% FiO_2) can be safely integrated into endurance programs for trained male athletes to potentially enhance VO_2 max and related physiological markers.
2. Use Internal Load for Intensity Monitoring: Exercise intensity during hypoxic training should be guided by heart rate and perceived exertion rather than absolute speed or power to ensure appropriate stimulus without overtraining.
3. SpO_2 Monitoring for Safety: Continuous SpO_2 tracking is essential during hypoxic sessions to avoid excessive desaturation. Supervised environments are recommended, especially during initial exposure.
4. Targeted Population: Hypoxic training should be reserved for athletes with a baseline VO_2 max > 40 $mL \cdot kg^{-1} \cdot min^{-1}$. Medical screening and exclusion of recent altitude exposure are necessary for reliable outcomes.

Future Research: Further studies should include broader populations (e.g., females, varied sports), longer durations, and molecular markers (e.g., EPO, ferritin) to better understand underlying adaptations and optimize protocols.

REFERENCES

[1] Wilber RL. Altitude training and athletic performance. Human Kinetics; 2004.

[2] Levine BD, Stray-Gundersen J. "Living high-training low": effect of moderate-altitude acclimatization with low-altitude training on performance. J Appl Physiol. 1997;83(1):102–112.

[3] Millet GP, Roels B, Schmitt L, Woorons X, Richalet JP. Combining hypoxic methods for peak performance. Sports Med. 2010;40(1):1–25.

[4] Lundby C, Millet GP, Calbet JA, et al. Does 'altitude training' increase exercise performance in elite athletes? Br J Sports Med. 2012;46(11):792–795.

[5] Chapman RF, Stray-Gundersen J, Levine BD. Individual variation in response to altitude training. J Appl Physiol. 1998;85(4):1448–1456.

[6] Gore CJ, Clark SA, Saunders PU. Nonhematological mechanisms of improved sea-level performance after hypoxic exposure. Med Sci Sports Exerc. 2007;39(9):1600–1609.

[7] Katayama K, Matsuo H, Ishida K, Iwasaki K, Miyamura M. Intermittent hypoxia improves endurance performance and submaximal exercise efficiency. High Alt Med Biol. 2003;4(3):291–304.

[8] Bonetti DL, Hopkins WG. Sea-level exercise performance following adaptation to hypoxia: a meta-analysis. Sports Med. 2009;39(2):107–127.

[9] Saunders PU, Telford RD, Pyne DB, et al. Improved running economy in elite runners after 20 days of simulated moderate-altitude exposure. J Appl Physiol. 2004;96(3):931–937.

[10] Chapman RF. The individual response to training and competition at altitude. Br J Sports Med. 2013;47(Suppl 1):i40–i44.

[11] Brugniaux JV, Schmitt L, Robach P, et al. Living high-training low: tolerance and acclimatization in elite endurance athletes. Eur J Appl Physiol. 2006;96(1):66–77.

[12] Schmitt L, Millet G, Robach P, et al. Influence of "living high-training low" on aerobic performance and economy of work in elite athletes. Eur J Appl Physiol. 2006;97(5):627–636.

[13] Rusko HK, Tikkanen HO, Peltonen JE. Altitude and endurance training. J Sports Sci. 2004;22(10):928–944.

[14] Fulco CS, Rock PB, Cymerman A. Improving athletic performance: is altitude residence or altitude training helpful? Aviat Space Environ Med. 2000;71(2):162–171.

[15] Wehrlin JP, Zuest P, Hallén J, Marti B. Live high–train low for 24 days increases hemoglobin mass and red cell volume in elite endurance athletes. Eur J Appl Physiol. 2006;96(3):289–295.

[16] Terrados N, Melichna J, Sylven C, et al. Effects of training at simulated altitude on performance and muscle metabolic capacity in competitive road cyclists. Eur J Appl Physiol Occup Physiol. 1988;57(2):203–209.

[17] Wachsmuth NB, Volzke C, Prommer N, Schmidt W. The effects of classic altitude training on total hemoglobin mass in swimmers. Eur J Appl Physiol. 2013;113(5):1199–1211.

[18] Gore CJ, Hopkins WG, Burge CM. VO_2max and hemoglobin mass of trained athletes during high-intensity training. Eur J Appl Physiol Occup Physiol. 1997;75(3):273–280.

[19] Robach P, Schmitt L, Brugniaux JV, et al. Living high-training low: effect on erythropoiesis and maximal aerobic performance in elite Nordic skiers. Eur J Appl Physiol. 2006;97(6):695–705.

[20] Saunders PU, Pyne DB, Gore CJ. Endurance training at altitude. High Alt Med Biol. 2009;10(2):135–148.

[21] Calbet JA, Lundby C. Air to muscle O_2 delivery during exercise at altitude. High Alt Med Biol. 2009;10(2):123–134.

[22] Chapman RF, Karlsen T, Resaland GK, et al. Defining the "dose" of altitude training: how high to live for optimal sea level performance enhancement. J Appl Physiol. 2014;116(6):595–603.

[23] Gore CJ, Clark SA, Saunders PU. Nonhematological mechanisms of improved sea-level performance after hypoxic exposure. Med Sci Sports Exerc. 2007;39(9):1600–1609.

[24] Levine BD, Stray-Gundersen J. A practical approach to altitude training: where to live and train for optimal performance enhancement. Int J Sports Med. 1992;13(Suppl 1):S209–S212.

[25] Millet GP, Faiss R, Brocherie F. Hypoxic training and team sports: a challenge to traditional methods? Br J Sports Med. 2013;47(Suppl 1):i6–i7