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Repeated-Sprint Training in Normobaric Hypoxia Enhances Aerobic and Anaerobic Performance Without Altering Hematological Parameters in Athletes

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Abstract

The purpose of this study was to explore the effects of four weeks of intermittent hypoxic (IHT) repeated sprint training administered to athletes via a hypoxia device at sea level on their hematological parameters, anaerobic performance, and aerobic capacity. Twenty-eight subjects with moderate training levels participated voluntarily in the study. The subjects were randomly assigned to either an experimental (hypoxia, n=14) or a control (n=14) group. The subjects in the experimental group received repeated sprint training with a resistance cycle under normobaric hypoxic conditions equivalent to approximately 2550 meters in altitude, with two sessions per week for 4 weeks. The subjects in the control group performed the same training as the experimental group under normoxic conditions.. Prior to and following this research, anaerobic performance, aerobic performance, and hematological parameters (HGB, HCT, RBC, MCV, and MCHC) were assessed. Two-way ANOVA with mixed measurements was used to analyze the data. Significant increases in anaerobic power and anaerobic capacity values were detected in the experimental group ($p<0.05$). Significant differences were observed in the VO_2 max values in terms of measurement and group*measurement interactions, and it was determined that hypoxic training positively affected aerobic capacity ($p<0.05$). Conversely, no

significant changes were detected in body weight or basic hematological parameters such as hemoglobin, hematocrit, or erythrocyte count ($p>0.05$). Overall, four weeks of IHT repeated sprint training performed with a hypoxia device at sea level is an effective method, particularly for enhancing athletes' anaerobic performance and aerobic capacity. However, short-term hypoxic exposure did not elicit significant hematological adaptations.

Trial Registration: Australian New Zealand Clinical Trials Registry (ANZCTR) ACTRN12626000865314. Registered 15 July 2026.

Keywords: Hypoxia, intermittent hypoxic training, repeated sprint, anaerobic performance, $\text{VO}_{2\text{max}}$

Introduction

In recent years, hypoxia-based methods have gained importance among training approaches aimed at improving sports performance. Hypoxic training stimulates the physiological adaptations of an organism to oxygen restriction and enables the emergence of various adaptation mechanisms at the hematological, metabolic, and musculoskeletal system levels [1]. Furthermore, hypoxic conditions may contribute to both aerobic and anaerobic performance through various effects on lactate accumulation, buffering capacity, oxygen utilization efficiency, and muscle metabolism [2]. Hypoxia-based training methods are generally classified under the models of live high–train high (LHTH), live high–train low (LHTL), and intermittent hypoxic training (IHT) [3].

Intermittent hypoxic training (IHT) is a training method in which athletes reside at or near sea level but are subjected to hypoxic conditions during specific training sessions. This exposure can occur through environmental hypoxia or the use of hypoxia devices. Compared with traditional high-altitude camps, IHT provides several key benefits, including greater control of

the hypoxic dose, a reduction in logistical requirements, and maintenance of training continuity [4]. While IHT has been reported to elicit adaptations at certain levels in hematological parameters (i.e., hemoglobin concentration, hematocrit, and oxygen-carrying capacity), the magnitude of the response elicited is variable based on the duration of the training program, the intensity of the training, and the degree of hypoxia experienced [5].

Repeated sprint training is a key determinant of performance in many individual and team sports and is characterized by brief bouts of high-intensity muscle contractions interspersed with short recovery periods. Compared with training in normoxic environments, repeated sprint training performed under hypoxic conditions has been reported to induce greater metabolic stress, which may increase the stimulation of glycolytic energy systems and peripheral muscle adaptations [6]. Thus, hypoxic repeated sprint training is suggested to have positive effects on anaerobic power, sprint performance, and resistance to fatigue [7,8].

Furthermore, high-intensity sprint-based hypoxic training is likely to affect not only anaerobic performance but also aerobic performance via adaptations in recovery kinetics, muscular oxygen utilization efficiency and mitochondrial function [9]. However, the literature does not provide consistent evidence regarding the effects of IHT interventions on maximal oxygen uptake ($\text{VO}_2 \text{ max}$), and it appears that aerobic improvements are possible but may be limited, particularly after short-term hypoxic interventions [10].

The limited amount of existing research investigating the effects of short-term (4-week) intermittent hypoxic repeated sprint training on anaerobic performance, aerobic performance, and hematologic parameters in the same study limits our understanding of how these factors are interrelated. In addition, further research is needed to clarify the relationship between hematological adaptations and performance variables following controlled IHT protocols implemented using hypoxia devices at sea level.

Accordingly, this study aimed to explore the effects of a 4-week repeated sprint training program implemented via the IHT method on hematological parameters, aerobic performance, and anaerobic performance in athletes. We hypothesized that repeated sprint training performed under hypoxic conditions would lead to significant improvements, particularly in anaerobic performance and selected hematological variables, and would additionally contribute to aerobic performance.

Method

Subjects

A total of 28 moderately trained athletes voluntarily participated in the study. The required sample size was determined prior to the study using GPower software (version 3.1.9.7). Based on an effect size of $f = 0.3$, an alpha level of $\alpha = 0.05$, and a statistical power ($1 - \beta$) of 0.80 for a two-way ANOVA with mixed measures ($2 \text{ groups} \times 2 \text{ time points}$), a minimum total sample size of 24 participants was calculated. To account for potential dropouts, 28 participants were recruited for the study. Participant recruitment and baseline testing were conducted between April 2, 2018, and April 16, 2018. The 4-week supervised hypoxic training intervention and final post-testing were completed on May 25, 2018. All participants were nonsmokers living at sea level. None of the participants were acclimatized to altitude or had been recently exposed to high altitude, and they were instructed to avoid exposure to altitudes above 1500 m throughout the study protocol.

Study Design

The experimental protocol involved two testing sessions conducted before (pre) and after (post) a four-week supervised specialized training period, including eight training sessions. Each participant was randomly assigned to one of two study groups using a computer-generated random number sequence (1:1 allocation ratio): a control group (CON, $n = 14$, age = $18.78 \pm$

0.80 years) and a training group (ANT, n = 14, age = 19.35 ± 1.33 years). Participants were randomly assigned using a computer-generated random number sequence created in Microsoft Excel. No separate allocation concealment mechanism was implemented during participant assignment. The random allocation sequence was generated by E.A. Participant recruitment and enrollment were performed by E.E. and Y.K., and participants were subsequently assigned to their respective intervention groups by A.İ. Only the pre-test and post-test assessments were completed by members of the control group; they continued their routine training without participation in the specialized training program for the four-week period. The subjects were previously unfamiliar with 10-second cycling sprints but were accustomed to laboratory testing and longer-duration high-intensity cycling exercises. The participants in both groups were told that their training sessions would be conducted at high altitude; however, the exact altitude was withheld. Therefore, participants were blinded to their group assignment and environmental conditions. To maintain single blinding, the hypoxicator settings and gas mixture displays were kept out of the participants' view. Furthermore, outcome assessors and blood sample analysts at the biochemistry laboratory were blinded to group allocations during data collection and analysis. This trial was designed, conducted, and is reported in accordance with the CONSORT 2010 guidelines for randomized controlled trials; the completed CONSORT checklist is provided as Additional file 1.

Supervised Training Protocol

The participants completed eight specialized cycling training sessions involving repeated sprints over a four-week period, beginning in the week following the pre-assessment and ending in the week preceding the post-assessment. Intermittent hypoxic training (IHT) was conducted using a Hypoxico Everest Summit II hypoxicator (USA), which was designed to generate hypoxic gas mixtures through membrane separation of oxygen and nitrogen molecules from ambient air via a masking system. Training sessions were performed twice per week at the same

time of day in a well-ventilated laboratory (80 m²) located at an altitude of 4 m (Ordu, Türkiye), with an average ambient temperature of approximately 25 °C.

The participants were comfortably seated on the cycle ergometer saddle. The SpO₂ values were continuously monitored during the training sessions using a Braun YK-81 (Germany) pulse oximeter sensor. The hypoxicator was set to simulate an altitude equivalent to 2550 m (8366 feet) above sea level. The athlete breathed the prescribed hypoxic gas mixture via a tightly fitted face mask. No adverse events, injuries, or unintended harmful effects were observed or reported in either group during the 4-week intervention period.

Training sessions

All of the training sessions started with an initial 10-minute warm-up at 120 W. Following this warm-up, the subjects completed 3 sets of five 10-second all-out repeated sprints. The 5-minute active recovery at 120 W was performed between sprint and sets. Every training session included a 10-minute cool-down at 120 W (Figure 1). The subjects were instructed to perform each sprint with maximal effort, with the intention of reaching and maintaining maximal power output throughout each sprint. The total length of the repeated sprint protocol was 36 minutes and 30 seconds. The subjects spent approximately 40 minutes in the laboratory for each session (total laboratory exposure time of 320 minutes over the four-week training period). Training sessions were conducted via magnetically braked cycle ergometers (Monark LC6 Novo Duo, Sweden; Lode Excalibur Sport, Netherlands), with a maximum of two subjects exercising simultaneously. Heart rate and SpO₂ were continuously monitored throughout each training session. Water was provided for the subjects to ensure that they remained hydrated during training. After each session, the subjects reported their rating of perceived exertion on the basis of the Borg scale (6–20). Training sessions were scheduled with at least 48 hours of rest between sessions to facilitate optimal recovery. In addition to the laboratory setting, the subjects were

instructed to continue performing their normal training regimens and refrain from performing any high-intensity training.

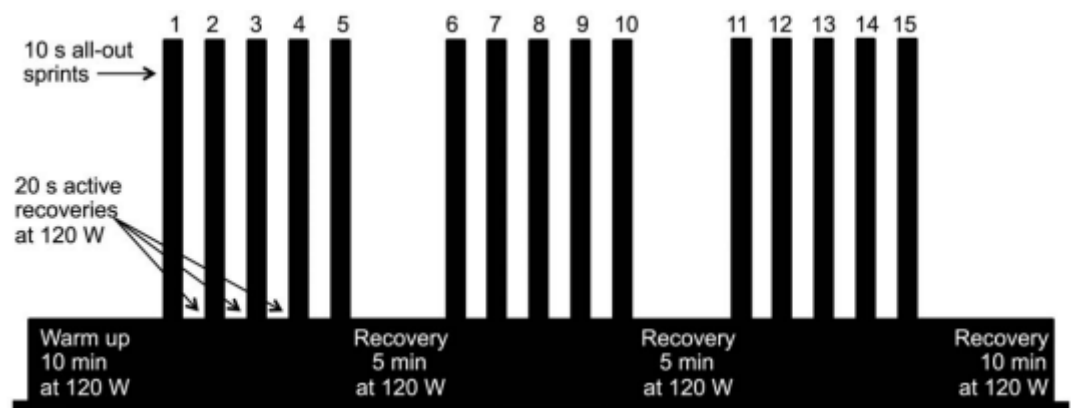


Figure1. Description of a typical training unit. (doi:10.1371/journal.pone.0056522.g001) [6].

Baseline (Pre) and Post Tests

The participants were instructed to avoid any training or strenuous physical activity for 48 hours prior to each testing session. Because of the high intensity of the test, the participants were required to report to the laboratory in a fed state; therefore, a standardized breakfast was recommended. In all cases, the participants were instructed to replicate their least meal prior to testing and to refrain from alcohol and caffeine consumption for three days prior to testing and during the 24 hours preceding each test. Water was provided ad libitum during testing. Pre- and post-tests were conducted under normoxic conditions in a well-ventilated laboratory at a constant ambient temperature of 24 °C and in the same order for all the participants.

Hematological analyses

To assess hematological parameters such as hemoglobin (HGB), hematocrit (HCT), red blood cell count (RBC), mean corpuscular volume (MCV), and mean corpuscular hemoglobin concentration (MCHC), a total of 6 mL of venous blood was collected at rest under normoxic conditions before and after the training period. Among the collected samples, 5 mL of venous blood was transferred into ethylenediaminetetraacetic acid (EDTA) tubes for whole blood

analysis, while 1 mL was transferred into serum separation tubes for serum analysis. The EDTA tubes were gently inverted several times immediately after blood collection to ensure anticoagulation and were stored at -20°C until analysis. The venous blood samples collected in the serum separation tubes were centrifuged at 3500 rpm for 10 minutes. The separated serum was stored at -70°C until analysis. The frozen serum samples were subsequently analyzed by specialized personnel at the Biochemistry Laboratory of Ordu University Teaching and Research Hospital.

Exercise performance tests and measurements

Anaerobic Performance:

The Wingate test was used to measure the anaerobic performance of the athletes using a Wingate cycle ergometer (Monark 894E, Sweden). The participants' individual adjustments to their saddle and handlebar positions on the ergometer were established prior to testing and remained constant throughout all testing sessions. Each participant completed a standard, low-intensity warm-up of 5 minutes prior to testing, which consisted of several short sprints (4–6 s) performed at the maximum pedal rate [11]. For each performance test, in addition to calculating the peak power output (W), mean power output (W), and fatigue index (%), these results were also normalized to the participant's body mass and recorded as the relative power output ($\text{W}\cdot\text{kg}^{-1}$). All tests were performed for 30 seconds using the Wingate mode of the ergometer at a fixed load corresponding to 7.5% of the body mass ($\text{Nm}\cdot\text{kg}^{-1}$).

Aerobic Performance:

The 20-m shuttle run test was performed over a 20-m distance, starting at a running speed of $8.5\text{ km}\cdot\text{h}^{-1}$, with increments of $0.5\text{ km}\cdot\text{h}^{-1}$ every minute [12]. The test was terminated when the participant failed to reach the line in time for two consecutive audio signals. At the completion of the test, the predicted maximal oxygen uptake ($\text{VO}_{2\text{max}}$, $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) values were

calculated using an equation based on the final shuttle run level completed. The equation developed for men was $VO_{2max} = 2.75 \times A + 28.8$ ($r^2 = 0.77$, $SEE = 4.07 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), where A represents the final level completed during the shuttle run test [13].

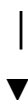
Statistical analysis

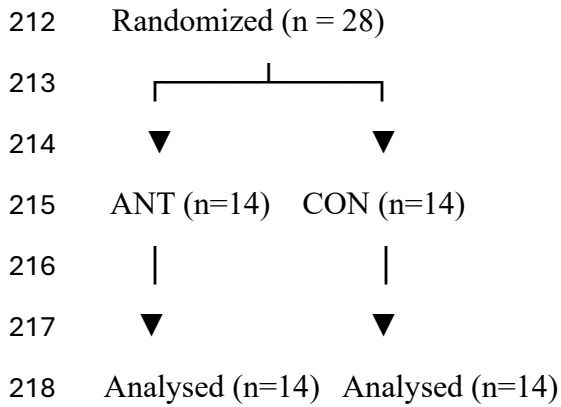
The descriptive statistics of the studies are presented as the means $\pm$ standard deviations. The normality of the data distribution was examined via the Shapiro–Wilk test. The effects of the independent variables (group factor (experiment and control), measurement factor (pre-test and post-test) and interaction of group and measurement factors) on the dependent variables (weight, anaerobic power, anaerobic capacity, fatigue index, maximum oxygen uptake (Max.VO_2), hemoglobin (HGB) concentration, hematocrit (HCT), red blood cell (RBC) count, mean corpuscular volume (MCV), and mean corpuscular hemoglobin concentration (MCHC)) were analyzed via two-way ANOVA for mixed measures. The hypothesis of sphericity was tested by Mauchly’s test in the analysis of two-way ANOVA for mixed measures. The SPSS statistical package program was used for statistical analyses (SPSS 22.0, SPSS Inc., Chicago, USA). All statistical analyses were performed according to the original assigned groups on an intention-to-treat (ITT) basis. The denominator for each analysis was $n = 14$ for the experimental group and $n = 14$ for the control group. The statistical analyses were applied at the $p < 0.05$ significance level.

Results

A total of 28 participants were enrolled, randomly assigned to either the experimental group ($n = 14$) or the control group ($n = 14$), and all completed the study protocol without any dropouts (Figure 2).

Enrolled ($n = 28$)





219 Figure 2. CONSORT flow diagram of participant progress through the phases of the trial.

220 Table 1. Descriptive and physical characteristics of the study groups at baseline

	Group	N	Mean	Std. Deviation
Age	Experiment	14	19,3571	1,33631
	Control	14	18,7857	,80178
Height	Experiment	14	174,8571	4,95917
	Control	14	174,8571	4,57177

221

222 **Table 1.** Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-

223 test Weight Values of Athletes

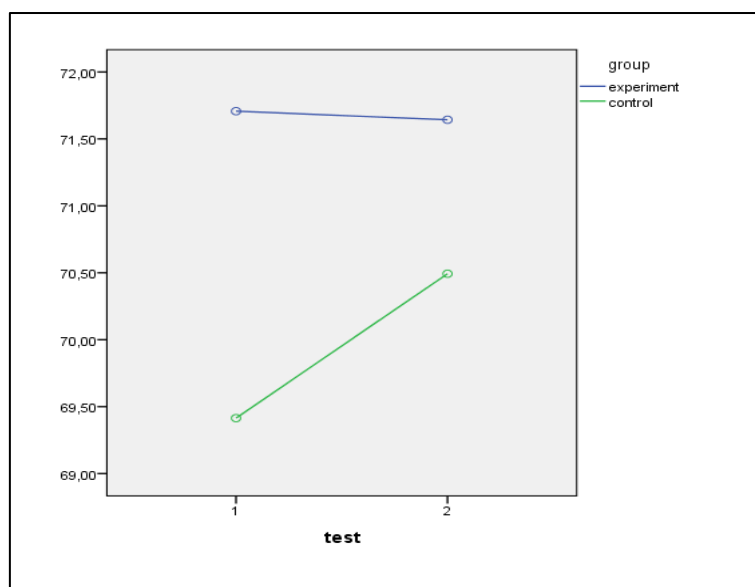
	Group	n	$\bar{x}$ (kg)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	14	71.71	6.21	57.20	81.70	Group (Experiment/Control)	0.390	0.538
	Control	14	69.41	8.23	58.00	86.00			
	Total	28	70.56	7.25	57.20	86.00	Measurement (Pre-test/Post-test)	3.059	0.092
Post-test	Experiment	14	71.64	5.67	58.00	79.00	Group*Measurement	3.883	0.060
	Control	14	70.49	8.75	58.50	88.00			
	Total	28	71.07	7.26	58.00	88.00			

224

225 As shown in Table 1, the weight values of the athletes did not differ with respect to group or

226 measurement factors ($p > 0.05$). Additionally, the interaction effect of group and measurement

227 factors on weight values was not statistically significant ($p > 0.05$).



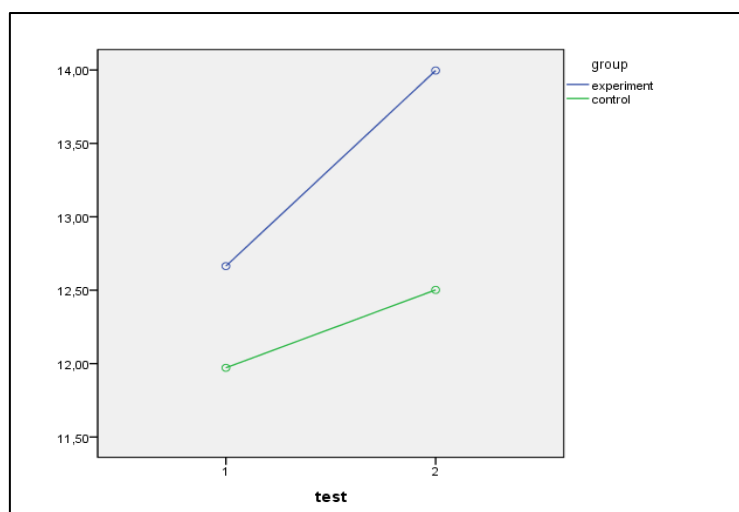
Graph 1. The Pre-test and Post-test Weight Values of the Experimental and Control Groups

Table 2. Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-test Anaerobic Power Values of Athletes

	Group	n	$\bar{x}$ (watt/kg)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	14	12.66	1.01	11.20	14.46	Group (Experiment/Control)	5.800	0.023*
	Control	14	11.97	1.44	8.85	14.51			
	Total	28	12.32	1.27	8.85	14.51	Measurement (Pre-test/Post-test)	18.048	0.000*
Post-test	Experiment	14	13.99	1.22	11.42	16.52	Group*Measurement	3.340	0.079
	Control	14	12.50	1.59	9.11	15.00			
	Total	28	13.24	1.58	9.11	16.52			

*p<0.05

According to Table 2, the anaerobic power values of the athletes significantly differed with respect to group and measurement factors ($p<0.05$). Additionally, the interaction effect of group and measurement factors on anaerobic power values was not statistically significant ($p>0.05$).



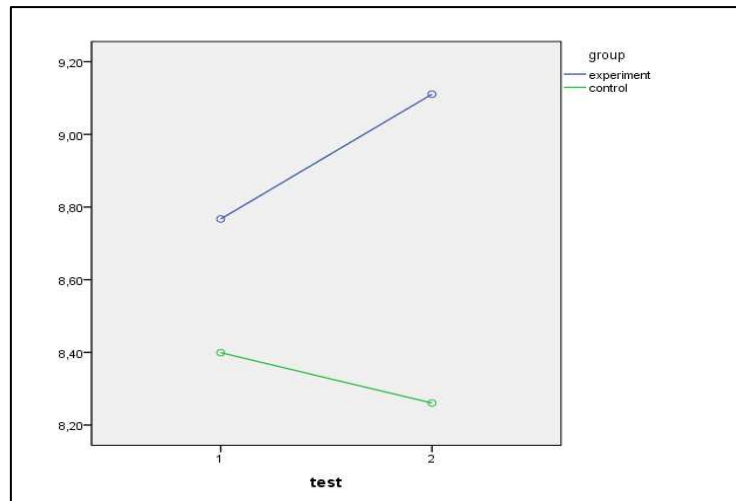
Graph 2. The Pre-test and Post-test Anaerobic Power Values of the Experimental and Control Groups

Table 3. Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-test Anaerobic Capacity Values of Athletes

	Group	n	$\bar{x}$ (watt/kg)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	14	8.77	0.36	8.29	9.49	Group (Experiment/Control)	12.677	0.001*
	Control	14	8.99	0.58	7.12	9.11			
	Total	28	8.58	0.51	7.12	9.49	Measurement (Pre-test/Post-test)	2.194	0.151
Post-test	Experiment	14	9.11	0.46	8.47	10.19	Group*Measurement	12.135	0.002*
	Control	14	8.26	0.53	7.20	8.89			
	Total	28	8.69	0.65	7.20	10.19			

*p<0.05

According to Table 3, it was seen that the anaerobic capacity values of the athletes significantly differed with respect to the group factor ($p<0.05$). However, there was no significant difference among the anaerobic capacity values of the athletes in terms of measurement factors ($p>0.05$). Additionally, the interaction effect of group and measurement factors on anaerobic capacity values was statistically significant ($p<0.05$).



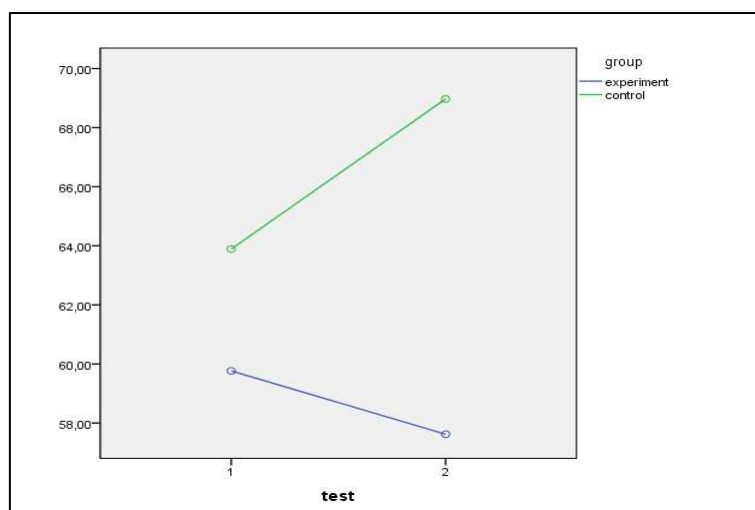
Graph 3. The Pre-test and Post-test Anaerobic Capacity Values of the Experimental and Control Groups

Table 4. Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-test Fatigue Index Values of Athletes

	Group	n	$\bar{x}$ (%)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	14	59.77	7.58	48.30	73.69	Group (Experiment/Control)	7.351	0.012*
	Control	14	63.89	12.77	40.15	90.30			
	Total	28	61.83	10.52	40.15	90.30	Measurement (Pre-test/Post-test)	0.454	0.506
Post-test	Experiment	14	57.62	7.12	47.00	67.50	Group*Measurement	2.746	0.109
	Control	14	68.97	9.48	57.20	86.70			
	Total	28	63.30	10.05	47.00	86.70			

*p<0.05

According to Table 4, the fatigue index values of the athletes significantly differed with respect to the group factor ($p < 0.05$). However, there was no significant difference among the fatigue indices of the athletes in terms of the measurement factors or the interaction between the group and measurement factors ($p > 0.05$).



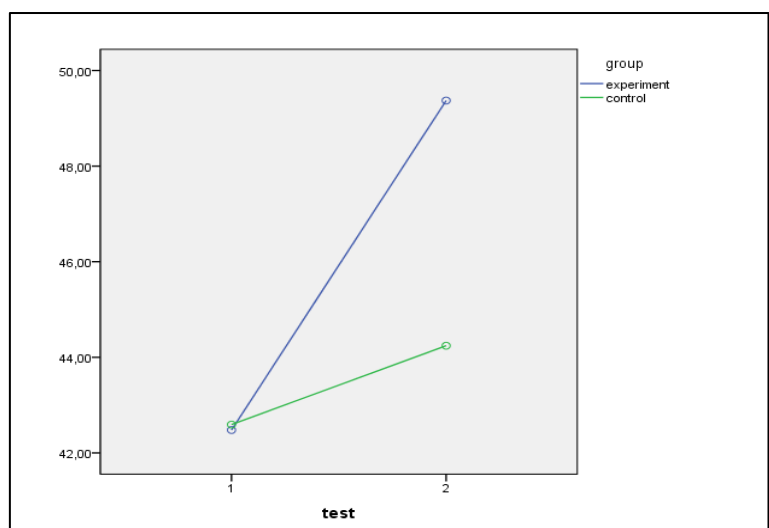
Graph 4. The Pre-test and Post-test Fatigue Index Values of the Experimental and Control Groups

Table 5. Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-test Max.VO₂ Values of Athletes

	Group	n	$\bar{x}$ (ml/kg/dk.)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	14	42.48	5.30	31.00	51.50	Group (Experiment/Control)	2.917	0.100
	Control	14	42.59	3.90	34.20	49.80			
	Total	28	42.54	4.57	31.00	51.50	Measurement (Pre-test/Post-test)	27.210	0.000*
Post-test	Experiment	14	49.37	5.08	40.80	63.20	Group*Measurement	10.248	0.004*
	Control	14	44.24	3.15	39.90	49.90			
	Total	28	46.81	4.90	39.90	63.20			

*p<0.05

Table 5 shows that the maximum oxygen uptake (Max.VO₂) values of the athletes were significantly different with respect to the measurement factors and the interaction between the group and measurement factors (p<0.05). However, there was no significant difference among the maximum oxygen uptake (Max.VO₂) values of the athletes in terms of the group factor (p>0.05).

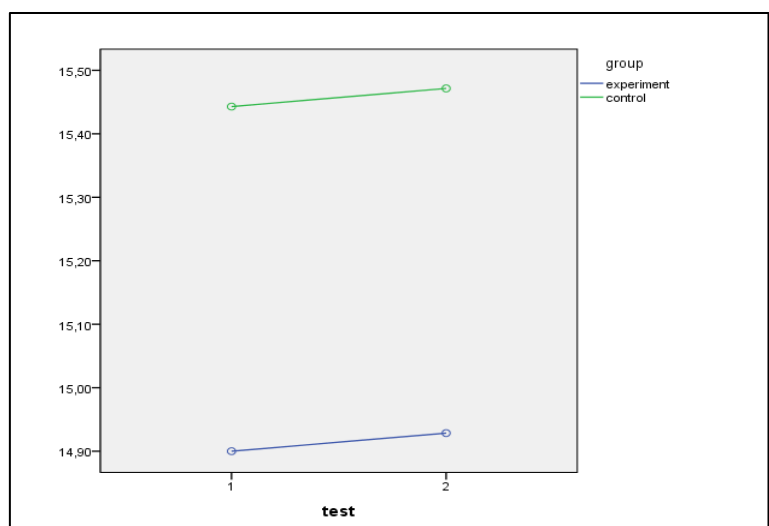


Graph 5. The Pre-test and Post-test Max.VO₂ values of the experimental and control groups

Table 6. Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-test HGB Concentration Values of Athletes

	Group	n	$\bar{x}$ (g/100 ml.)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	1 4	14.90	0.74	13.50	15.90	Group (Experiment/Control)	2.397	0.134
	Control	1 4	15.44	1.25	14.00	18.00			
	Total	2 8	15.17	1.04	13.50	18.00	Measurement (Pre-test/Post-test)	0.046	0.831
Post-test	Experiment	1 4	14.93	0.95	13.40	17.00	Group*Measurement	0.000	1.000
	Control	1 4	15.47	0.97	13.80	17.00			
	Total	2 8	15.20	0.98	13.40	17.00			

According to Table 6, there was no significant difference among the HGB concentrations of the athletes in terms of group and measurement factors ($p > 0.05$). Additionally, the interaction effect of group and measurement factors on HGB concentrations in athletes was not statistically significant ($p > 0.05$).

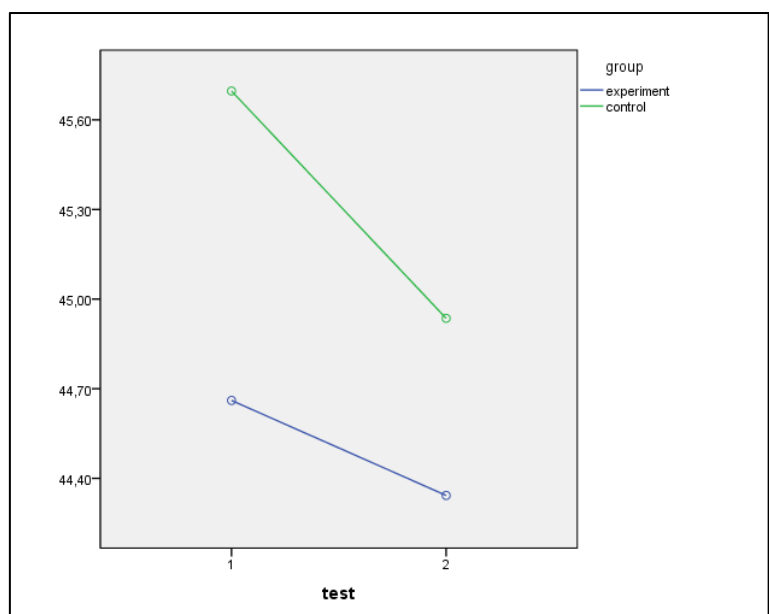


Graph 6. Pre- test and Post-test HGB concentrations in the experimental and control groups.

Table 7. Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-test HCT Values of Athletes

	Group	n	$\bar{x}$ (%)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	14	44.66	2.37	41.30	48.25	Group (Experiment/Control)	0.627	0.436
	Control	14	45.70	3.53	40.70	54.10			
	Total	28	45.18	2.99	40.70	54.10	Measurement (Pre-test/Post-test)	1.905	0.179
Post-test	Experiment	14	44.34	3.03	40.80	51.00	Group*Measurement	0.321	0.576
	Control	14	44.94	2.57	40.60	48.50			
	Total	28	44.64	2.77	40.60	51.00			

According to Table 7, there was no significant difference among the HCT values of the athletes in terms of group or measurement factors ($p>0.05$). Additionally, the interaction effect of group and measurement factors on the HCT values of the athletes was not statistically significant ($p>0.05$).

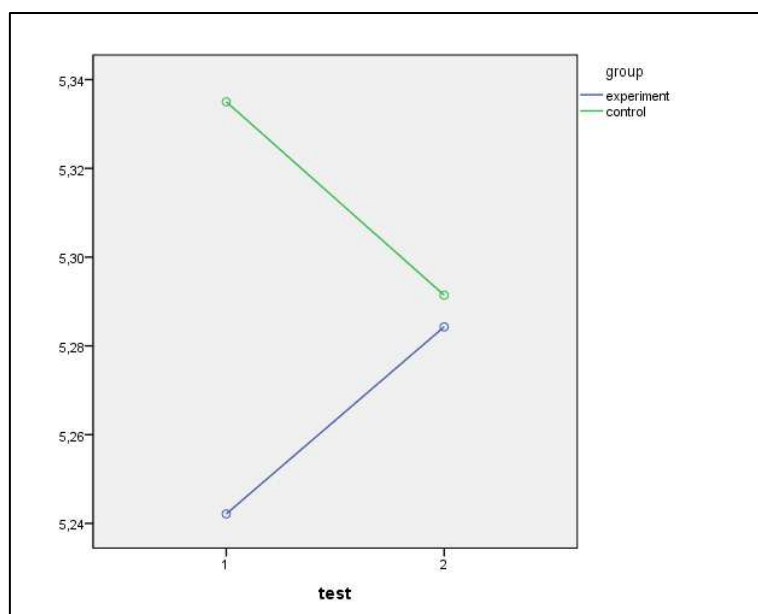


Graph 7. The Pre-test and Post-test HCT values of the experimental and control groups

Table 8. Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-test RBC Counts of Athletes

	Group	n	$\bar{x}$ (million/ μ L)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	14	5.24	0.36	4.72	5.98	Group (Experiment/Control)	0.118	0.734
	Control	14	5.34	0.44	4.65	6.07			
	Total	28	5.29	0.40	4.65	6.07	Measurement (Pre-test/Post-test)	0.000	0.989
Post-test	Experiment	14	5.28	0.46	4.56	6.39	Group*Measurement	0.749	0.395
	Control	14	5.29	0.35	4.71	5.94			
	Total	28	5.29	0.40	4.56	6.39			

As shown in Table 8, there was no significant difference among the RBC counts of the athletes in terms of group or measurement factors ($p>0.05$). Additionally, the interaction effect of group and measurement factors on the RBC counts of the athletes was not statistically significant ($p>0.05$).



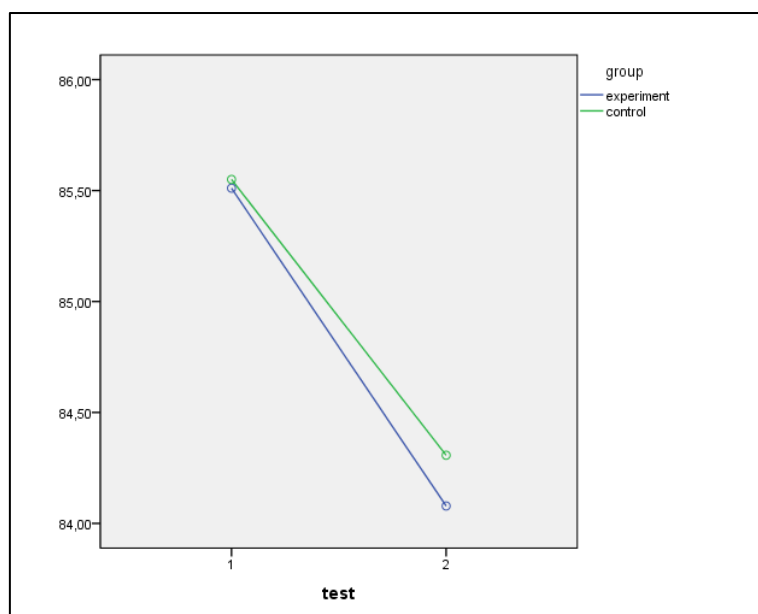
Graph 8. The Pre-test and Post-test RBC counts of the experimental and control groups

Table 9. Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-test MCV Values of Athletes

	Group	n	$\bar{x}$ (fL)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	14	85.51	3.24	79.90	91.30	Group (Experiment/Control)	0.012	0.912
	Control	14	85.55	3.71	79.70	92.30			
	Total	28	85.53	3.42	79.70	92.30	Measurement (Pre-test/Post-test)	9.091	0.006*
Post-test	Experiment	14	84.08	3.14	79.30	89.70	Group*Measurement	0.046	0.833
	Control	14	84.31	3.46	79.50	90.50			
	Total	28	84.19	3.24	79.30	90.50			

*p<0.05

As shown in Table 9, there was no significant difference in the MCV values of the athletes in terms of the group factor or the interaction between the group and measurement factors ($p>0.05$). However, there was a significant difference among the MCV values of the athlete students in terms of the measurement factor ($p<0.05$).



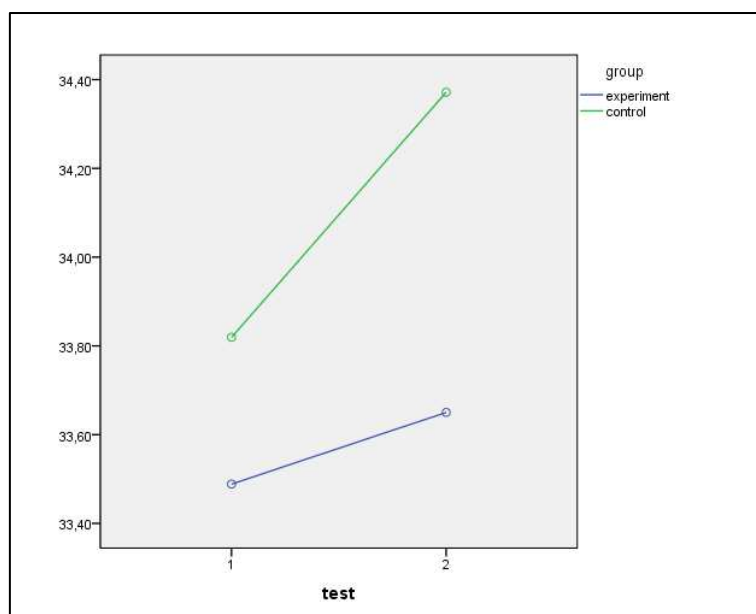
Graph 9. The Pre-test and Post-test MCV of experiment and control groups

Table 10. Two-way ANOVA for Mixed Measures to Analyze the Results of Pre-test and Post-test MCHC Values of Athletes

	Group	n	$\bar{x}$ (gr/100 ml)	SD	Min.	Max.	Factor	F	p
Pre-test	Experiment	1 4	33.49	0.64	32.70	34.54	Group (Experiment/Control)	4.449	0.045*
	Control	1 4	33.82	0.79	32.80	35.67			
	Total	2 8	33.65	0.72	32.70	35.67	Measurement (Pre-test/Post-test)	10.643	0.003*
Post-test	Experiment	1 4	33.65	0.58	32.70	34.70	Group*Measurement	3.191	0.086
	Control	1 4	34.37	0.85	33.20	36.00			
	Total	2 8	34.01	0.80	32.70	36.00			

*p<0.05

According to Table 10, there was a significant difference among the MCHC values of the athletes in terms of group and measurement factors ($p<0.05$). However, there was no significant difference among the mean MCHC values of the athletes in terms of the interaction of group and measurement factors ($p>0.05$).



Graph 10. Pretest and posttest MCHCs of the experimental and control groups.

Discussion

The main purpose of this study was to examine the effects of a sea-level IHT protocol on anaerobic performance, aerobic capacity, and hematological parameters among athletes. These findings indicate that IHT significantly enhanced anaerobic power, anaerobic capacity, and VO₂max, with no significant short-term changes in body mass or key hematological variables (HGB, HCT, RBC).

No significant changes in body mass were observed following short-term hypoxic exposure, suggesting that short-term hypoxic exposure may be insufficient to induce substantial alterations in the energy balance or body composition. This finding is consistent with previous studies reporting that short-duration hypoxic training does not markedly alter body mass [1,14,15].

The significant increase in anaerobic power in both groups and measurement effects indicates that repeated sprint training performed under hypoxic conditions positively influences

neuromuscular adaptations and the glycolytic energy system. High-intensity interval training conducted under hypoxia has been shown to improve phosphocreatine (PCr) resynthesis and intramuscular buffering capacity, thus improving anaerobic power output [6,16–18]. The nonsignificant results for the group $\times$ time interaction suggest that both groups improved with time, but the experimental group appeared to improve at a higher magnitude than the control group.

A significant main effect of group and the group $\times$ time interaction for anaerobic mean power indicates that the IHT protocol had a greater effect on anaerobic performance than normoxic training protocols [6,9,19,20]. This finding is supported by prior research reporting that repeated sprint training conducted under hypoxic conditions increases lactate tolerance and glycolytic enzyme activity [6,21].

A significant main effect of group on the fatigue index was observed, suggesting that the experimental group developed a more fatigue-resistant physiological profile. The absence of significant effects for time and the group $\times$ time interaction indicates that this adaptation may reflect structural differences between groups rather than progressive development over time. Previous studies have reported that hypoxia-based training can increase lactate accumulation and stimulate intracellular buffering systems, leading to improved metabolic endurance and thus a lower fatigue index [6,8]. However, these effects depend on the intensity and duration of training [22–24].

One of the key findings of the current study was the significant effect of time and the group $\times$ time interaction on maximal oxygen uptake ($\text{VO}_{2\text{max}}$), which suggested that the IHT protocol elicited a stronger physiological stimulus for improving aerobic capacity than normoxic training. The use of interval training under hypoxic conditions has been shown to improve peripheral adaptations, such as increases in capillary density and mitochondrial efficiency, leading to an increase in cellular oxygen utilization [25, 26]. Numerous studies have reported

greater gains in aerobic performance with IHT under hypoxic conditions [27-31]. However, similar to other hypoxic methods, the results were inconsistent. Some researchers have reported no significant differences in postintervention $\text{VO}_{2\text{max}}$ under normoxic conditions compared with sea level training [32-34]. These inconsistencies are most likely due to the variability in the combination of hypoxic dose, training intensity, and duration. The exercise volume, intensity, and degree of hypoxic exposure directly influence the magnitude of improvement in aerobic performance. Nevertheless, recent studies suggest that normobaric IHT can elicit faster adaptations in $\text{VO}_{2\text{max}}$ than similar protocols performed under normoxic conditions [6, 22, 35, 36]. The absence of a significant main effect of group in the present study may be explained by the homogeneity of baseline aerobic performance of the participants.

There were no significant differences in some key hematologic parameters (HGB, HCT, RBC), indicating that the duration of hypoxic exposure in this study was below the threshold required to elicit an erythropoietic response. Among recent studies, Meeusen et al. [16] reported that a 10-day IHT protocol resulted in a significant increase in HGB and HCT in elite triathletes. However, given that the erythropoietic process is time-consuming, several studies examining IHT protocols have reported no significant changes in hematological parameters. Indeed, 3–5-week protocols conducted at simulated altitudes of 2,500–4,000 m, involving three weekly sessions of 45–60 min or totaling less than 200 h of hypoxic exposure, have not resulted in significant changes in HCT or HGB [37–39]. A significant increase in red blood cell mass is generally observed following daily hypoxic exposure for 12–16 h for 2–4 weeks [40]. These findings indicate that the duration, intensity, and total hypoxic dose are key determinants of the erythropoietin (EPO) response [5,41].

In contrast, significant changes in the MCV and MCHC across measurement time points and between groups suggest that microlevel adaptations in erythrocyte function may have been initiated.

Conclusion

The results of this study indicate that a four-week hypoxic interval sprint training protocol at sea level using hypoxia devices significantly improved anaerobic power, anaerobic capacity, and $\text{VO}_{2\text{max}}$ in student athletes, whereas short-term high-intensity sprint training under normobaric hypoxia did not elicit significant changes in body mass or key hematological parameters (HGB, HCT, RBC).

In light of our results, short-term high-intensity interval training coupled with hypoxic technology is a potentially viable training method for enhancing performance-specific physiological adaptations in the context of performance, particularly in sports that target these adaptations. However, further research involving extended training periods and varying hypoxic doses is needed to induce hematological adaptations. Future investigations comparing different age groups, sports disciplines, and hypoxic protocols could help fully elucidate the mechanisms underlying the effects of hypoxic training.

Limitations of the Study

"This study has some limitations that should be acknowledged. First, the sample size was relatively small ($n = 28$), although sufficient to detect statistical significance for the primary outcomes. Second, while double blinding was maintained, subtle physiological sensations related to hypoxia might have been perceived by some participants. Finally, the intervention was limited to 4 weeks; future studies with longer training periods and larger sample sizes are recommended to confirm these findings.

List of abbreviations

LHTL: Live High-Training Low

LHTH: Live High-Training High

417 IHT: Intermittent hypoxic training

418 HGB: Hemoglobin

419 HCT: Hematocrit

420 RBC: Red blood cell

421 MCV: Mean Corpuscular Volume

422 MCHC: Mean corpuscular hemoglobin concentration

423 EPO: Erythropoietin

424 **DECLARATIONS**

425 **Ethics Approval**

426 Ethical approval for this study was obtained from the Clinical Research Ethics Committee of
427 Ordu University (approval number: 2017/52) prior to the start of the study. All procedures were
428 conducted in accordance with the ethical standards laid down in the Declaration of Helsinki.

429 **Clinical Trials Registry**

430 The study was registered at the Australian New Zealand Clinical Trials Registry (ANZCTR)
431 ID: ACTRN12626000865314;(https://anzctr.org.au/ACTRN12626000865314.aspx) on July
432 15, 2026.

433 **Consent to Participate**

434 Written informed consent was obtained from all individual participants (and/or their legal
435 guardians where applicable) prior to their inclusion in the study.

436 **Consent to Publish**

437 Informed consent for the publication of anonymous performance and clinical data was obtained
438 from all individual participants prior to the study.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request; however, owing to ethical and privacy concerns regarding minor participants, the data are not publicly accessible.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conceptualization: E.E.; Y.K.; E.A.; A.İ. Methodology: E.E.; E.A.; Y.K. Validation: E.E.; A.D.; A.İ. Analysis: E.A.; E.E. Investigation: E.E.; Y.K.; Resources: E.E.; A.D.; Y.K. Data curation: E.E.; E.A.; A.D. Writing—original draft preparation: E.E.; E.A.; Y.K. Writing—review and editing: E.E. Visualization P. S. Supervision: E.A.; E.E. All the authors have read and approved the final version of the manuscript.

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References

1. Millet, G. P., Roels, B., Schmitt, L., Woorons, X., & Richalet, J. P. Combining hypoxic methods for peak performance. *Sports Medicine*. 2010;40(1): 1–25.

2. Faiss, R., Girard, O., & Millet, G. P. Advancing hypoxic training in team sports: From intermittent hypoxic training to repeated sprint training in hypoxia. *British Journal of Sports Medicine*. 2013;47(Suppl. 1): i45–i50.
3. Sinex, J. A., & Chapman, R. F. Hypoxic training methods for improving endurance exercise performance. *Journal of Sport and Health Science*. 2015;4(4):325-332.
4. Bärtsch, P., & Saltin, B. General introduction to altitude adaptation and mountain sickness. *Scandinavian Journal of Medicine & Science in Sports*. 2008;18(Suppl. 1): 1–10.
5. Płoszczyca K, Langfort J, Czuba M. The effects of altitude training on erythropoietic response and hematological variables in adult athletes: a narrative review. *Frontiers in physiology*. 2018; 11(9):375.
6. Faiss, R., Léger, B., & Millet, G. P. Significant molecular and systemic adaptations after repeated sprint training in hypoxia. *PLoS ONE*. 2013;8(2):e56522.
7. Girard, O., Brocherie, F., & Millet, G. P.. Effects of altitude/hypoxia on single- and multiple-sprint performance: A comprehensive review. *Sports Medicine*. 2017;47(10): 1931–1949.
8. Hamlin, M. J., Marshall, H. C., Hellemans, J., Ainslie, P. N., & Anglem, N. Effect of intermittent hypoxic training on 20 km time trial and 30 s anaerobic performance. *Scandinavian journal of medicine & science in sports*. 2010;20(4):651-661.
9. Brocherie F, Girard O, Faiss R, Millet GP. High-intensity intermittent training in hypoxia: a double-blinded, placebo-controlled field study in youth football players. *The Journal of Strength & Conditioning Research*. 2015;29(1):226-37.
10. Bonetti, D. L., & Hopkins, W. G. Sea-level exercise performance following adaptation to hypoxia: A meta-analysis. *Sports Medicine*. 2009;39(2):107–127.
11. Castañeda-Babarro, A. The wingate anaerobic test, a narrative review of the protocol variables that affect the results obtained. *Applied Sciences*. 2021;11(16):7417.

- 486 12. Leger, L. A., Mercier, D., Gadoury, C., ve Lambert, J. The multistage 20 meter shuttle
487 run test for aerobic fitness. *Journal of sports sciences*. 1988; 6(2):93-101.
- 488 13. Stickland, M. K., Petersen, S. R., ve Bouffard, M. Prediction of maximal aerobic power
489 from the 20-m multistage shuttle run test. *Canadian Journal of Applied Physiology*.
490 2003;28(2):272-282.
- 491 14. Kayser, B., & Verges, S. Hypoxia, energy balance, and obesity: An update. *Obesity*
492 *reviews*. 2021; 22: e13192.
- 493 15. Klügel S, Nolte S, Hacker S, Kastner T, Walter N, Fleckenstein D, Maier C, Gebhardt
494 K, Relogio A, Malhan D, Klemmer A. Biomarkers predicting the effectiveness of
495 normobaric altitude training. *European Journal of Applied Physiology*. 2025;Dec 6:1-
496 10.
- 497 16. Meeuwsen, T., Hendriksen, I. J., & Holewijn, M. Training-induced increases in sea-
498 level performance are enhanced by acute intermittent hypobaric hypoxia. *European*
499 *journal of applied physiology*. 2001;84(4):283-290.
- 500 17. Morton, J. P., & Cable, N. T. The effects of intermittent hypoxic training on aerobic and
501 anaerobic performance. *Ergonomics*. 2005;48(11-14):1535-1546.
- 502 18. Zoll, J., Ponsot, E., Dufour, S., Doutreleau, S., Ventura-Clapier, R., Vogt, M., ... &
503 Fluck, M. Exercise training in normobaric hypoxia in endurance runners. III. Muscular
504 adjustments of selected gene transcripts. *Journal of applied physiology*.
505 2006;100(4):1258-1266.
- 506 19. Lanfranchi C, Willis SJ, Laramée L, Conde Alonso S, Pialoux V, Kayser B, Place N,
507 Millet GP, Zanou N. Repeated sprint training in hypoxia induces specific skeletal
508 muscle adaptations through S100A protein signaling. *The FASEB Journal*.
509 2024;38(8):e23615.

20. Birol A, Aras D, Akalan C, Aldhahi MI, Gülu M. Three sessions of repeated sprint training in normobaric hypoxia improves sprinting performance. *Heliyon*. 2024;10(6):e27607.
21. Brocherie F, Girard O, Faiss R, Millet GP. Effects of repeated-sprint training in hypoxia on sea-level performance: a meta-analysis. *Sports Medicine*. 2017;47(8):1651-60.
22. Brocherie, F., Millet, G. P., & Girard, O. Psychophysiological responses to repeated-sprint training in normobaric hypoxia and normoxia. *International Journal of Sports Physiology and Performance*. 2017;12(1):115-123.
23. Casey, D. P. & Joyner, M. J. Compensatory vasodilatation during hypoxic exercise: mechanisms responsible for matching oxygen supply to demand. *J. Physiol.*, 2012;590(24):6321-6.
24. Lundby, C., Calbet, J. A., & Robach, P. The response of human skeletal muscle tissue to hypoxia. *Cellular and molecular life sciences*. 2009;66(22):3615-3623.
25. Chapman, R. F., Stray-Gundersen, J., & Levine, B. D. Individual variation in response to altitude training. *Journal of Applied Physiology*. 1998; 85(4):1448-1456.
26. MacInnis MJ, Gibala MJ. Physiological adaptations to interval training and the role of exercise intensity. *The Journal of physiology*. 2017;595(9):2915-30.
27. Kong Z, Lei OK, Sun S, Li L, Shi Q, Zhang H, Nie J. Hypoxic repeated sprint interval training improves cardiorespiratory fitness in sedentary young women. *Journal of Exercise Science and Fitness*. 2022;20(2):100.
28. Kasai, N., Mizuno, S., Ishimoto, S. et al. Effect of training in hypoxia on repeated sprint performance in female athletes. *Springer Plus*. 2015;4(1):310.
29. Roels, B., Bentley, D. J., Coste, O., Mercier, J., & Millet, G. P. Effects of intermittent hypoxic training on cycling performance in well-trained athletes. *European journal of applied physiology*. 2007;101(3):359-368.

- 535 **30.** Hamlin, M. J., Olsen, P. D., Marshall, H. C., Lizamore, C. A., & Elliot, C. A. Hypoxic
536 repeat sprint training improves Rugby player's repeated sprint but not endurance
537 performance. *Frontiers in Physiology*. 2017;8:24.
- 538 **31.** Shi Q, Tong TK, Nie J, Tao D, Zhang H, Tan X, Kong Z. Repeated-sprint training in
539 hypoxia boosts up team-sport-specific repeated-sprint ability: 2-week vs 5-week
540 training regimen. *European Journal of Applied Physiology*. 2023;123(12):2699-710.
- 541 **32.** Gatterer, H., Philippe, M., Menz, V., Mosbach, F., Faulhaber, M., & Burtcher, M.
542 Shuttle-run sprint training in hypoxia for youth elite soccer players: a pilot study.
543 *Journal of sports science & medicine*. 2014;13(4):731.
- 544 **33.** Gatterer H, Klarod K, Heinrich D, Schlemmer P, Dilitz S, Burtcher M. Effects of a 12-
545 day maximal shuttle-run shock microcycle in hypoxia on soccer specific performance
546 and oxidative stress. *Applied physiology, nutrition, and metabolism*. 2015;40(8):842-5.
- 547 **34.** Brechbuhl C, Brocherie F, Millet GP, Schmitt L. Effects of repeated-sprint training in
548 hypoxia on tennis-specific performance in well-trained players. *Sports medicine*
549 international open. 2018;2(05):e123-32.
- 550 **35.** Faiss, R., Willis, S., Born, D. P., Sperlich, B., Vesin, J. M., Holmberg, H. C., & Millet,
551 G. P. Repeated double-pole sprint training in hypoxia by competitive cross-country
552 skiers. *Medicine & Science in Sports & Exercise*. 2015;47(4):809-817.
- 553 **36.** Galvin, H. M., Cooke, K., Sumners, D. P., Mileva, K. N., & Bowtell, J. L. Repeated
554 sprint training in normobaric hypoxia. *British journal of sports medicine*. 2013;
555 47(Suppl 1):i74-i79.
- 556 **37.** Vallier, J. M., Chateau, P., & Guezennec, C. Y. Effects of physical training in a
557 hypobaric chamber on the physical performance of competitive triathletes. *European*
558 *journal of applied physiology and occupational physiology*. 1996;73(5):471-478.

- 559 **38.** Dehnert C, Hütler M, Liu Y, Menold E, Netzer C, Schick R, Kubanek B, Lehmann M,
560 Böning D, Steinacker JM. Erythropoiesis and performance after two weeks of living
561 high and training low in well trained triathletes. *Int J Sports Med.* 2002;23(8):561-6.
- 562 **39.** Robach, P., Schmitt, L., Brugniaux, J. V., Nicolet, G., Duvallet, A., Fouillot, J. P., ... &
563 Richalet, J. P. Living high–training low: effect on erythropoiesis and maximal aerobic
564 performance in elite Nordic skiers. *European journal of applied physiology.*
565 2006;97(6):695-705.
- 566 **40.** Neya, M., Enoki, T., Ohiwa, N., Kawahara, T., & Gore, C. J. Increased hemoglobin
567 mass and VO₂max with 10 h nightly simulated altitude at 3000 m. *International journal*
568 *of sports physiology and performance.* 2013;8(4):366-372.
- 569 **41.** Siebenmann, C., & Rasmussen, P. Altitude training adaptations: Physiology,
570 biomarkers, and performance. *Nature Reviews Endocrinology.* 2022;18(11):693–706.

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