

# Comparative Effects Of A Four-Week Mountaineering Training Program On Red Blood Cell Count At Medium And High Altitudes

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## Abstract

This study investigated the influence of a four-week mountaineering training program on red blood cell (RBC) count among selected trainees at two different altitudes: medium altitude (2050 m) and high altitude (2700 m). Twenty trainees from Himachal Pradesh of the age group 18-25 years, were selected, and exposed to four-week training at two different high altitude training centres namely; Atal Bihari Vajpayee Institute of Mountaineering and Allied sports, Manali (2050 m) and Atal Bihari Vajpayee Institute of Mountaineering and Allied sports, Narkanda (2700 m) in Himachal Pradesh. These trainees were divided equally into two groups and assessed at three intervals i.e. pre-test (Day 0), mid-test (Day 14), and post-test (Day 28). Descriptive statistics, repeated measures ANOVA, and trend analyses were employed to examine within-subject and between-group differences. The results revealed no statistically significant changes in RBC counts over time or between altitude groups. Linear and quadratic trends were also found to be non-significant. These findings suggest that altitude-related physiological adaptations in RBC count may require longer training durations or more extreme environmental stimuli. Future research should explore longer-duration interventions and include additional haematological markers.

**Keywords:** Mountaineering Training, Red Blood Cell, Medium Altitude and High Altitude.

## INTRODUCTION

Mountaineering training at altitude is a physiologically demanding activity that exposes individuals to hypoxic (low oxygen) environments, triggering a cascade of adaptive responses. One of the primary physiological adaptations to altitude exposure is an increase in red blood cell (RBC) production. Red blood cells are crucial for transporting oxygen from the lungs to tissues, and higher RBC counts are associated with enhanced aerobic capacity and physical endurance, both vital attributes for individuals engaged in high-altitude physical exertion (Levine & Stray-Gundersen, 1997; Wilber, 2004).

Previous studies have consistently reported that exposure to high altitudes stimulates erythropoiesis through the release of erythropoietin (EPO), a hormone secreted by the kidneys in response to hypoxia (Milledge, 1992; Gore et al., 1998). The classical "live high-train low" model has demonstrated significant increases in total hemoglobin mass, hematocrit, and RBC count following altitude exposure for durations of 3-4 weeks or longer at elevations above 2500 meters (Levine & Stray-Gundersen, 2005). Similarly, studies conducted by Chapman et al. (1998) and Heinicke et al. (2005) observed increased RBC concentrations after high-altitude acclimatization, especially in well-trained athletes.

However, other research findings suggest that the effects of altitude training on hematological markers may not be uniform or guaranteed, particularly when the exposure duration is short or the altitude is moderate. For instance, Gore et al. (2001) observed minimal hematological changes after 12 days at 2100 m. Schmidt and Prommer (2008) also emphasized that while high altitude can stimulate erythropoiesis, individual variation and short-term exposures may produce non-significant or transient changes. Moreover, moderate altitudes (<2700 m) may not elicit the same magnitude of erythropoietic response compared to higher elevations, especially when exposure duration is less than 4 weeks.

Despite the abundance of literature on high-altitude training, limited empirical research has examined the comparative effects of mountaineering training programs conducted at medium (2050 m) and high (2700 m) altitudes over a short fixed period like four weeks, particularly among non-elite, physically trained populations such as trainee mountaineers in India. Furthermore, many studies focus on elite athletes and use comprehensive hematological profiles, leaving a gap in understanding simpler, practical markers like RBC count in semi-trained populations.

The current study attempts to fill this research gap by evaluating and comparing changes in RBC count among two groups of selected mountaineering trainees undergoing a structured four-week training program at different altitude levels; medium altitude (2050 m) and high altitude (2700 m). By using a repeated measures design and trend analysis, this study aims to assess: Whether a four-week training duration is sufficient to induce significant erythropoietic adaptations; If the level of altitude plays a differentiating role in RBC count response; And whether changes over time follow a linear or curvilinear (quadratic) pattern.

This research is particularly relevant for mountaineering institutions, sports physiologists, and altitude training program designers in regions like the Indian Himalayas, where such altitudes are commonly accessed for training purposes. The findings will help in optimizing training duration, altitude exposure, and recovery strategies for performance enhancement and health safety of mountaineers.

## OBJECTIVE OF THE STUDY

The objective of study intended to evaluate and compare the effect of a four-week mountaineering training program on RBC count over time at medium and high altitudes; and to examine linear and quadratic trends in RBC count across the training duration. It was hypothesised that there would be no significant effect of a four-week mountaineering training programme on the haematological biomarker red blood cell (RBC), count of mountaineering trainees at two different altitudes i.e. medium altitude (2050 m) and high altitude (2700 m).

## METHODOLOGY

A total of 20 mountaineering trainees from Himachal Pradesh of the age group 18-25 years, were purposively selected and randomly assigned to two altitude-based training groups: Group I (Medium altitude, 2050 m) and Group II (High altitude, 2700 m) with each group having 10 participants each. These trainees were exposed to four-week training at two different high altitude training centres namely; Atal Bihari Vajpayee Institute of Mountaineering and Allied sports, Manali (2050 m) and Atal Bihari Vajpayee Institute of Mountaineering and Allied sports, Narkanda (2700 m) in Himachal Pradesh. A repeated measures design was used for assessments of RBC counts at three time points: Pre-Test: Day 0; Mid-Test: Day 14 and Post-Test: Day 28. RBC count (in million cells/ $\mu$ L) was measured using standard hematological procedures at accredited laboratories. Descriptive Statistics, Repeated Measures ANOVA, Trend Analysis (Within-subjects contrasts for linear and quadratic trends) and Between-Subjects ANOVA were used as statistical techniques for comparison of red blood cell counts among two altitude groups at three time intervals i.e. pre-test (Day 0), mid-test (Day 14), and post-test (Day 28).

## RESULTS

The descriptive statistics, results of the one-way repeated measures ANOVA, and pairwise comparisons for the haematological biomarker; red blood cell count among selected mountaineering trainees at two different altitudes, namely medium altitude (2050 m) and high altitude (2700 m), are accessible in Tables 1 to 8.

	<b>Training Group</b>	<b>Mean</b>	<b>Std. Deviation</b>	<b>N</b>
<b>Pre-Test (Day-0)</b>	Group-I Medium Altitude	5.462	.3132	10
	Group-II High Altitude	5.814	.2488	10
<b>Mid-Test (Day-14)</b>	Group-I Medium Altitude	5.545	.4783	10
	Group-II High Altitude	6.168	.3704	10
<b>Post-Test (Day-28)</b>	Group-I Medium Altitude	5.546	1.387	10
	Group-II High Altitude	5.829	.485	10

Table-1 presents the descriptive statistics, specifically the mean and standard deviation, of red blood cell (RBC) counts among mountaineering trainees assessed at two different altitudes i.e. medium altitude (2050 m) and high altitude (2700 m) across three time points: day-0 (pre-training), day-14 (mid-training), and day-28 (post-training). On day-0 (pre-test), the mean and standard deviation of RBC count for Group-I (medium altitude) were 5.462 and .3132, respectively, while Group-II (high altitude) recorded values of 5.814 and .2488.

On day-14 (mid-test), the RBC count for Group-I was  $5.545 \pm .4783$  and for Group-II,  $6.168 \pm .3704$ . By day-28 (post-test), Group-I showed a mean RBC count of 5.546 with a standard deviation of 1.387, whereas Group-II reported 5.829 with a standard deviation of .485.

## A. MULTIVARIATE TEST

The analysis of the stated objectives has been conducted using both multivariate and univariate statistical approaches, as provided by the software output. Initially, to interpret the multivariate results, Box's Test of Equality of Variance-Covariance Matrices was examined. This test was applied to verify the assumption that the variance-covariance matrices of scores across time points are equal between Group-I (medium altitude) and Group-II (high altitude). The results of this test are presented in Table 2 below.

Box's M	14.516
F	1.976
Df1	6
Df2	2347.472
Sig	.066

As shown in Table-2, the value of Box's M is 14.516 with  $F(6, 2347.472) = 1.976$  and a p-value greater than .01, indicating a non-significant result. This suggests that the assumption of equality of variance-covariance matrices holds true. Since the assumption is satisfied, it does not pose any concern for further analysis. Consequently, Pillai's Trace has been used to interpret the results of the multivariate tests.

Effect	Value	F	Hypothesis Df	Error Df	Sig.	Partial Eta Squared
Medium and High Altitude Training	.104	.987	2.000	17.00	.393	.104

The data presented in Table-3 indicates that the main effect of repeated measurements over time, following a four-week training program at two altitudes i.e. medium altitude (2050 m) and high altitude (2700 m) is statistically non-significant, as reflected by Pillai's Trace value of .104,  $F(2, 17) = .987$ ,  $p > 0.01$ . Therefore, the hypothesis stating, "There will be no significant effect of a four-week mountaineering training programme on the haematological biomarker red blood cell count of mountaineering trainees at two different altitudes, i.e., medium altitude (2050 m) and high altitude (2700 m)," is accepted.

## B. Univariate Tests (Within-Subjects)

Secondly, following the multivariate analysis, the hypothesis can also be interpreted through the univariate results presented in Table-4.

To validate the univariate findings, it is essential to examine the assumption of sphericity. This was assessed using Mauchly's Test of Sphericity, and the corresponding results are reported below to ensure the accuracy and validity of the hypothesis testing.

Within Subjects	Mauchly's	Approx.	Df	Sig.	Epsilon
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Effect	W	Chi-Square			Greenhouse Geisser	Huynh-Feldt	Lower Bound
Red Blood Cell Count	.263	22.730	2	.000	.576	.624	.500

Table-4 presents the results of Mauchly's Test of Sphericity for the red blood cell count scores. The test yielded a significant result,  $W = 0.263$ ,  $\chi^2(2) = 22.730$ ,  $p = .000$ , indicating that the assumption of sphericity has been violated. As a result, a correction to the degrees of freedom is necessary to adjust for this violation. Based on Girden's (1992) recommendation, the Greenhouse-Geisser correction will be applied, since the corresponding epsilon ( $\epsilon = 0.576$ ) is below the .75 threshold. This adjustment ensures more accurate F-ratios in the subsequent univariate analysis of red blood cell count scores. The following table reports the within-subjects effects after applying this correction to evaluate the impact of time (four-week mountaineering training program) and altitude on red blood cell counts.

Source		Type-III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Medium and High Altitude Training	Huynh-Feldt	.323	1.151	.281	.353	.589	.019

Table-5, which presents the test of within-subjects effects, reveals that the main effect of repeated measurements over time, attributable to the four-week mountaineering training program conducted at two altitude levels (medium altitude: 2050 m and high altitude: 2700 m) is statistically non-significant when analysed using the Huynh-Feldt correction,  $F(1.151, 0.281) = 0.353$ ,  $p > 0.01$ . The Partial Eta Squared value ( $\eta^2 = 0.019$ ) suggests a small effect size, as per the benchmarks provided by Cohen (1988), Pituch and Stevens (2016), and Field (2018).

### C. Within-Subjects Contrasts (Trending over Time)

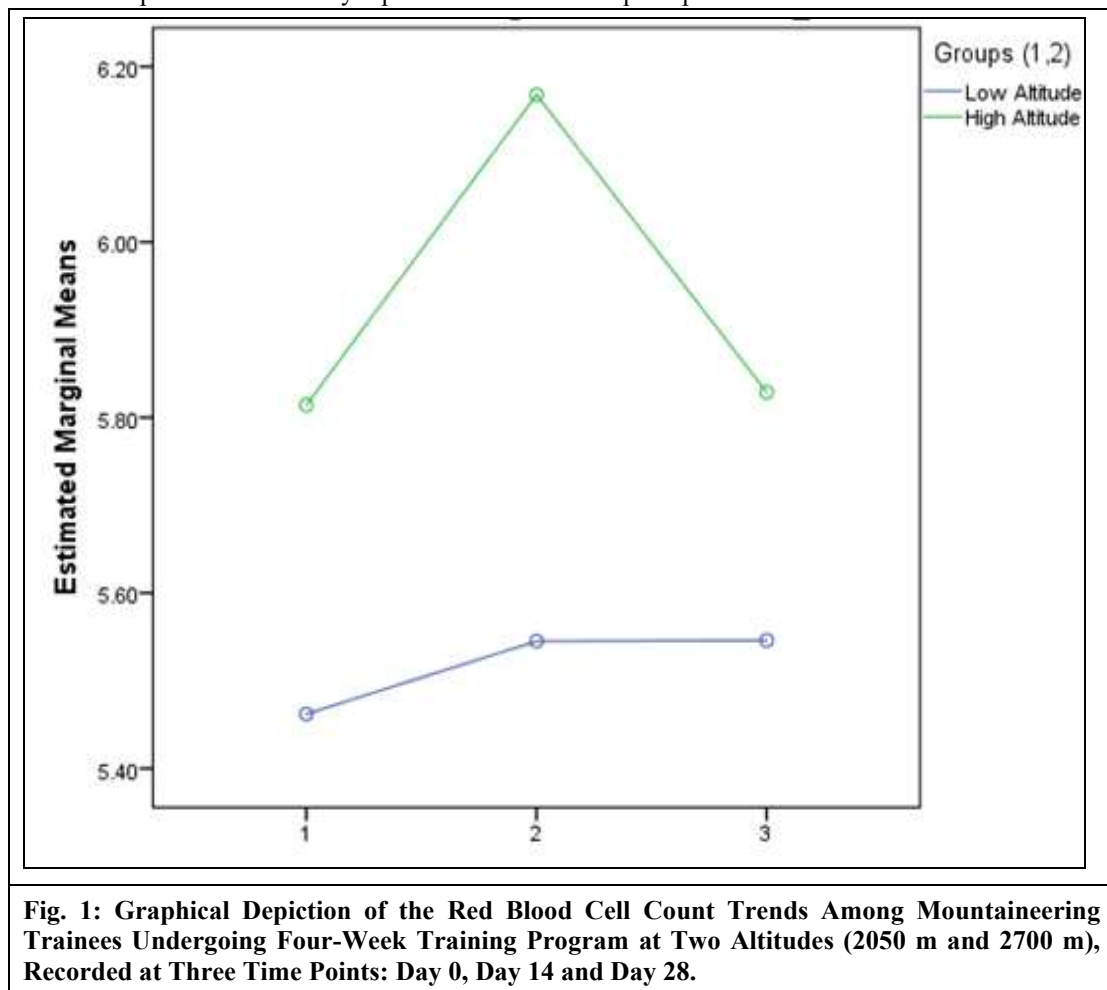
Furthermore, to examine nature of change over time resulting from the implementation of the four-week mountaineering training program at two altitude levels i.e. medium altitude (2050 m) and high altitude (2700 m) on red blood cell count, the results of the within-subjects contrasts are presented below. A linear trend indicates a consistent, straight-line progression, either an upward or downward shift in means across time points. In contrast, a quadratic trend reflects a curved trajectory, characterised by a notable acceleration or deceleration in mean values, suggesting more complex changes across the repeated measurements.

Source	Combined Red Blood Cell Count	Type-III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Medium and High Altitude Training	Linear	.012	1	.012	.023	.880	.001
	Quadratic	.311	1	.311	.761	.395	.041

Table-6 reveals that the trend in combined red blood cell count over the four-week mountaineering training program at two altitude levels i.e. medium altitude (2050 m) and high altitude (2700 m) is statistically non-significant for both the linear  $F(1, 18) = 0.023$ ,  $p > .01$  and the quadratic  $F(1, 18) = 0.761$ ,  $p > .01$ . This indicates that the changes in mean red blood cell counts do not follow a consistent linear or curvilinear (quadratic) pattern over time as a result of the training intervention.

The trend analysis further shows that in the medium altitude group, the RBC count shows a gradual upward trend across the training duration. There is a slight increase from Day 0 to Day 14, followed by a continued mild increase from Day 14 to Day 28. In contrast, the high altitude group demonstrates a different trend. The RBC

count shows a noticeable dip from Day 0 to Day 14, however, from Day 14 to Day 28, a marked increase is observed. These patterns are visually represented in the subsequent plot.



**Fig. 1: Graphical Depiction of the Red Blood Cell Count Trends Among Mountaineering Trainees Undergoing Four-Week Training Program at Two Altitudes (2050 m and 2700 m), Recorded at Three Time Points: Day 0, Day 14 and Day 28.**

#### D. Univariate Test (Between-Subjects Effects)

Furthermore, the researcher computed a univariate ANOVA to examine the between-subjects effects, focusing on the main and interaction effects of the grouping variables namely, the four-week mountaineering training program and the two trainee groups (medium altitude and high altitude) across three time points: Day 0, Day 14, and Day 28. The results of this analysis, including Levene’s Test of Equality of Error Variances, are presented in Table-7 to assess the assumption of homogeneity of variances among groups.

	F	Df1	Df2	Sig.
<b>Pre-Test (Day-0)</b> <b>Red Blood Cell Count Score</b>	1.921	1	18	.183
<b>Mid-Test (Day-14)</b> <b>Red Blood Cell Count Score</b>	.054	1	18	.819
<b>Post-Test (Day-28)</b> <b>Red Blood Cell Count Score</b>	1.317	1	18	.266

Table-7, presenting the results of Levene’s Test for Equality of Error Variances, examines the interaction effects of the mountaineering training program and the two trainee groups (medium and high altitude). The p-values for the combined red blood cell count at Day 0, Day 14 and Day 28 exceeds .05, indicating that the assumption of homogeneity of variances is met at these time points. Nevertheless, the assumption's violation is not a concern because the ratio between the largest and smallest group sizes remains below the critical threshold of 1.5 (i.e., 10/10 = 1.0). According to Petuch and Stevens (2016), under such conditions, the results of the between-subjects ANOVA remain reasonably robust and reliable.

**Table 8: Summary of Between-Subjects ANOVA on Red Blood Cell Count Scores Following a Four-Week Mountaineering Training Program at Two Altitude Levels (Medium and High Altitude)**

Source	Type-III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1968.141	1	1968.141	4601.586	.000	.996
Groups (1,2)	2.638	1	2.638	6.167	.023	.255
Error	7.699	18	.428			

As presented in Table-8, the computed F-ratio for the mean red blood cell count scores across the three time points (Day 0, Day 14, and Day 28) for Group I (medium altitude) and Group II (high altitude) is 6.167, which is statistically non-significant at the 0.01 level of confidence. This result indicates that there is no significant difference in the overall red blood cell count scores between the two trainee groups when averaged across all measurement occasions. Moreover, as the between-group comparison revealed no statistically significant difference across time points ( $p > .01$ ), no post hoc analysis was required.

## Discussion

The findings revealed no statistically significant changes in RBC count over time within each group, nor significant differences between the two altitude groups across the three measurement points (Day 0, Day 14, and Day 28). Furthermore, trend analyses for both linear and quadratic changes also yielded non-significant results.

These findings align with earlier research suggesting that short-term exposure to moderate or high altitudes may not be sufficient to induce robust erythropoietic responses, particularly in non-elite or semi-trained populations (Gore et al., 2001; Schmidt & Prommer, 2008). Although there was a slight upward trend in RBC count in the medium-altitude group and a recovery pattern in the high-altitude group after an initial dip, these variations did not reach statistical significance. This may be attributed to individual variability in physiological adaptation, limited exposure duration, or insufficient hypoxic stimulus.

In contrast, studies involving elite athletes exposed to higher altitudes (>3000 m) for extended periods (typically 3–4 weeks or more) have reported significant increases in hematological parameters, including RBC count and total hemoglobin mass (Heinicke et al., 2005; Levine & Stray-Gundersen, 2005). The relatively lower altitude levels used in the present study (2050 m and 2700 m) may have produced milder hypoxic stress, insufficient to strongly activate erythropoietin release and red cell production.

The lack of significant between-group differences further suggests that a 650-meter difference in training altitude may not produce distinct hematological outcomes in a four-week period. Additionally, the small sample size ( $n=10$  per group) and the homogeneity of the training population may have limited the study's statistical power.

In summary, while the theoretical rationale for altitude-induced hematological adaptations remains valid, the present findings highlight the importance of altitude intensity, training duration, and individual variability in determining actual physiological outcomes.

## Conclusion

The four-week mountaineering training program did not yield significant changes in red blood cell count in either medium or high altitude training groups. The expected erythropoietic response to altitude exposure may require more extended periods or more substantial hypoxic stimuli. The lack of statistically significant trends over time and between groups suggests that short-duration exposure to moderate or high altitude is insufficient to elicit measurable haematological changes in RBC concentration.

## Future Research Scope

Subsequent works should focus on longer-term studies (e.g., 8–12 weeks) to assess the cumulative effects of altitude training on haematological biomarkers, including additional variables such as haemoglobin concentration, hematocrit, and erythropoietin levels and use a larger and more diverse sample size to enhance generalizability.

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