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Effects Of A Four-Week Mountaineering Training Regimen On White Blood Cell Count: A Comparison Between Medium And High Altitudes

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Abstract

This study aimed to examine the effects of a four-week mountaineering training program on white blood cell (WBC) count among selected trainees at two distinct altitudes i.e. medium altitude (2050 meters) and high altitude (2700 meters). A total of 20 male trainees, aged between 18 and 25 years and residing in Himachal Pradesh, were purposively selected and equally divided into two groups. The participants underwent identical training protocols at two different high-altitude training centres: The Atal Bihari Vajpayee Institute of Mountaineering and Allied Sports in Manali (2050 m) and Narkanda (2700 m). WBC counts were recorded at three time points: baseline (Day 0), mid-point (Day 14), and post-training (Day 28). Data were analysed using descriptive statistics, repeated measures ANOVA, and trend analysis to identify within-group changes and between-group differences. The findings indicated no statistically significant variations in WBC count over time or between the two altitude groups. Additionally, both linear and quadratic trends in WBC levels were found to be non-significant. These results suggest that a four-week training duration may be insufficient to elicit measurable haematological adaptations in WBC count due to altitude exposure. Future studies should consider extending the training duration and including a broader range of haematological biomarkers to better understand altitude-induced physiological responses.

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

Introduction

High-altitude training has long been recognized as a powerful stimulus for inducing physiological adaptations in athletes and physically active individuals. Exposure to reduced oxygen availability at higher altitudes (hypoxia) triggers various hematological and cardiopulmonary responses aimed at enhancing oxygen transport and utilization (Fulco, Rock, & Cymerman, 2000). Among these adaptations, changes in haematological biomarkers, particularly red and white blood cell counts have drawn considerable interest in exercise physiology and sports science research. While the erythropoietic response to altitude is well-documented, the influence of altitude on immune function and white blood cell (WBC) dynamics remains comparatively underexplored.

White blood cells play a critical role in the body's immune defense system. Their response to physical stressors such as intense training, environmental changes, or hypoxic conditions can provide valuable insights into immune adaptation, inflammation, and overall physiological resilience (Nieman, 2000). Some studies suggest that moderate to high altitude exposure may initially suppress immune function, followed by a compensatory adjustment depending on the duration and intensity of exposure (Mazzeo, 2008). However, findings remain inconsistent due to variations in altitude levels, training protocols, participant profiles, and assessment timelines.

Mountaineering is a physically and psychologically demanding activity that combines prolonged endurance effort with environmental stressors, including cold temperatures, reduced oxygen pressure, and rugged terrain. These stressors can influence not only cardiovascular and muscular systems but also hematological and immunological profiles. Although previous research has predominantly focused on endurance athletes or elite mountaineers, there is a growing need to examine the physiological responses among recreational trainees and those undergoing formal mountaineering instruction, particularly in the Indian Himalayan context.

The Atal Bihari Vajpayee Institute of Mountaineering and Allied Sports (ABVIMAS) in Himachal Pradesh provides structured mountaineering training programs at varying altitudes. These programs offer a unique opportunity to examine altitude-induced hematological responses in a controlled yet ecologically valid setting. While studies have reported significant changes in hemoglobin concentration, hematocrit levels, and red blood cell counts after high-altitude training (Stray-Gundersen, Chapman, & Levine, 2001), evidence on white blood cell dynamics remains limited and inconclusive.

The present study addresses this research gap by investigating the effect of a four-week mountaineering training program on white blood cell count among selected male trainees at two distinct altitude levels viz. medium altitude (2050 meters, Manali) and high altitude (2700 meters, Narkanda). By assessing WBC count at three time points i.e. pre-test (Day 0), mid-test (Day 14), and post-test (Day 28), this study seeks to determine whether short-term exposure to moderate and high-altitude environments leads to significant hematological adaptations. Furthermore, this research contributes to understanding how altitude training might influence immune function in non-elite populations undergoing structured mountaineering training.

Despite the growing body of literature on altitude training, few studies have systematically compared WBC responses across different altitudes with consistent training interventions. The current study, therefore, fills an important void by focusing on both within-subject changes and between-group comparisons using rigorous statistical techniques such as repeated measures ANOVA and trend analysis. The outcomes may inform training protocols, altitude acclimatization strategies, and health monitoring practices in mountaineering education and related fields.

Objective of the Study

The primary objective of the study was to assess and compare the effects of a four-week mountaineering training program on white blood cell (WBC) count among trainees at two altitude levels i.e. medium altitude (2050 meters) and high altitude (2700 meters) across three time points. Additionally, the study aimed to explore both linear and quadratic trends in WBC count over the training duration to identify potential patterns of physiological adaptation.

It was hypothesised that the four-week mountaineering training program would not produce any statistically significant changes in WBC count among the trainees at either altitude. In other words, no significant differences were expected in the WBC responses over time or between the medium and high-altitude training groups.

Methodology

A total of 20 mountaineering trainees, aged between 18 and 25 years and residing in Himachal Pradesh, were purposively selected for the study. Participants were randomly assigned to two altitude-based training groups: Group I (Medium Altitude – 2050 meters) and Group II (High Altitude – 2700 meters), with 10 trainees in each group. The training intervention was conducted over a four-week period at two distinct high-altitude centers operated by the Atal Bihari Vajpayee Institute of Mountaineering and Allied Sports, Manali (2050 m) for Group I and Narkanda (2700 m) for Group II.

A repeated measures design was employed to evaluate changes in white blood cell (WBC) count across three time points: Pre-test (Day 0), Mid-test (Day 14), and Post-test (Day 28). WBC count, expressed in million cells per microliter (million cells/µL), was determined using standardized hematological procedures conducted at certified diagnostic laboratories.

For statistical analysis, descriptive statistics were used to summarize the data, while repeated measures ANOVA was applied to assess within-subject changes in WBC count over time. Trend analyses (within-subjects contrasts) were performed to evaluate both linear and quadratic patterns in WBC count progression. Additionally, between-subjects ANOVA was conducted to compare WBC levels between the two altitude-based groups across the three assessment points.

Results

The descriptive statistics, results of the one-way repeated measures ANOVA, and pairwise comparisons for the haematological biomarker; white 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.

Table 1: Descriptive Statistics of White Blood Cell Count Among Mountaineering Trainees Measured at Two Altitudes (2050 m and 2700 m) Across Three Time Points (Day-0, Day-14, and Day-28) During a Four-Week Training Program

	Training Group	Mean	Std. Deviation	N
Pre-Test (Day-0)	Group-I Medium Altitude	9.375	1.338	10
	Group-II High Altitude	9.761	.666	10
Mid-Test (Day-14)	Group-I Medium Altitude	8.688	1.794	10
	Group-II High Altitude	9.453	1.049	10
Post-Test (Day-28)	Group-I Medium Altitude	8.989	2.097	10
	Group-II High Altitude	9.909	1.027	10

Table-1 presents the descriptive statistics, specifically the mean and standard deviation, of white blood cell (WBC) 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 WBC count for Group-I (medium altitude) were 9.375 and 1.338, respectively, while Group-II (high altitude) recorded values of 9.761 and 0.666.

On day-14 (mid-test), the WBC count for Group-I was 8.688 ± 1.794 and for Group-II, 9.453 ± 1.049. By day-28 (post-test), Group-I showed a mean WBC count of 8.989 with a standard deviation of 2.097, whereas Group-II reported 9.909 with a standard deviation of 1.027.

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.

Table 2: Summary of Box's Test of Equality of Variance-Covariance Matrics w.r.t. Four-Week Training Program at Two Altitudes (2050 m and 2700 m)

Box's M	9.779
F	1.331
Df1	6
Df2	2347.472
Sig	.239

As shown in Table-2, the value of Box's M is 9.779 with F (6, 2347.472) = 1.331 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.

Table 3: Summary of Multivariate Test (Pillai's Trace) for White Blood Cell Count of Mountaineering Trainees Following a Four-Week Training Program at Two Altitudes (2050 m and 2700 m)

Effect	Value	F	Hypothesis Df	Error Df	Sig.	Partial Eta Squared
Medium and High Altitude Training	.033	.294	2.000	17.000	.749	.033

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 .033, $F(2, 17) = .294$, $p > 0.01$. Therefore, the hypothesis stating, "There will be no significant effect of a four-week mountaineering training programme on the haematological biomarker white 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.

Table 4: Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	Df	Sig.	Epsilon		
					Greenhouse Geisser	Huynh-Feldt	Lower Bound
White Blood Cell Count	.869	2.388	2	.303	.884	1.000	.500

Table-4 indicates that the result of Mauchly's Test of Sphericity is non-significant, suggesting that the assumption of sphericity is met. This implies that the variances of the differences between all pairs of related groups across the time intervals of the four-week mountaineering training program, conducted at medium and high altitudes are statistically equal. Although no correction is required due to the non-significant outcome, in borderline or precautionary circumstances, the Huynh-Feldt correction is preferred, as recommended by Girden (1992). This is supported by the Greenhouse-Geisser epsilon ($\varepsilon = 0.884$), which exceeds the threshold of 0.75, justifying the use of Huynh-Feldt adjustment for the univariate analysis of mean differences in white blood cell count scores. This result may be attributed to the equal time intervals between measurement occasions. The subsequent table presents the within-subjects effects to examine the main and interaction effects of time (four-week mountaineering training program) and altitude on white blood cell count.

Table 5: Summary of Repeated Measures ANOVA Examining the Effects of a Four-Week Training Program on White Blood Cell Count at Two Altitude Levels (2050 m and 2700 m)

Source		Type-III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Medium and High Altitude Training	Huynh-Feldt	.755	2.000	.377	.400	.673	.022

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, $F(2.000, 0.377) = 0.400$, $p > 0.01$. The Partial Eta Squared value ($\eta^2 = 0.022$) 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 white 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.

Table 6: Within-Subjects Contrasts Analysis of Combined White Blood Cell Count Scores for Two Mountaineering Trainee Groups

Source	Combined White Blood Cell Count	Type-III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Medium and High Altitude Training	Linear	.713	1	.713	.555	.466	.030
	Quadratic	.042	1	.042	.069	.795	.004

Table-6 reveals that the trend in combined white 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 $F(1, 18) = 0.555$, $p>.01$ and the quadratic $F(1, 18) = 0.069$, $p>.01$. This indicates that the changes in mean white 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 Group I (medium altitude trainees), there was a slight decline in white blood cell count from pre-test (Day 0) to mid-test (Day 14), followed by a mild increase from mid-test to post-test (Day 28). A similar pattern was observed in Group II (high altitude trainees), with a minor reduction from pre-test to mid-test and a more noticeable increase from mid-test to post-test. These patterns are visually represented in the subsequent plot.

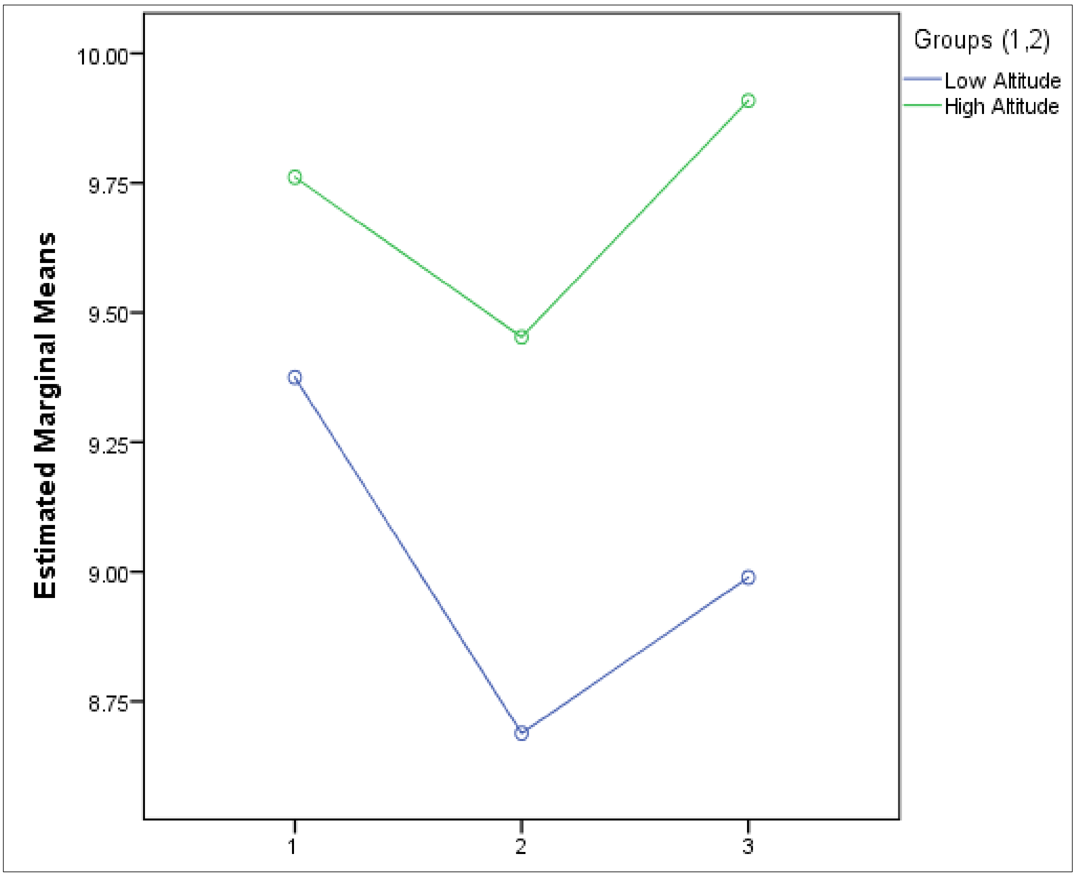

Fig. 1: Graphical Depiction of the White Blood Cell Count Trends Among Mountaineering Trainees Undergoing Four-Week Training Program at Two Altitudes (2050 m and 2700 m), Recorded at Three Time Points: Day 0, Day 14 and Day 28.

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.

Table 7: Results of Levene's Test for Assessing the Equality of Error Variances

	F	Df1	Df2	Sig.
Pre-Test (Day-0) **White Blood Cell Count Score**	1.339	1	18	.262
Mid-Test (Day-14) **White Blood Cell Count Score**	5.348	1	18	.033
Post-Test (Day-28) **White Blood Cell Count Score**	5.488	1	18	.031

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-value for the combined white blood cell count at Day 0 exceeds .05, indicating that the assumption of homogeneity of variances is met at this time point. However, for Day 14 and Day 28, the p-values fall below .05, specifying a violation of the assumption at these time points.

Despite this, the violation it is not considered critical, as 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 White 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	5259.384	1	5259.384	1276.407	.000	.986
Groups (1,2)	7.148	1	7.148	1.735	.204	.088
Error	74.168	18	4.120			

As presented in Table-8, the computed F-ratio for the mean white 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 1.735, which is statistically non-significant at the 0.01 level of confidence. This result indicates that there is no significant difference in the overall white 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 on the Findings

The present study aimed to evaluate the effects of a four-week mountaineering training program on white blood cell (WBC) count among trainees exposed to two different altitudes i.e. medium (2050 m) and high (2700 m). The analysis revealed no statistically significant changes in WBC count across the three time points (Day 0, Day 14, and Day 28) within either group. Moreover, no significant differences were observed between the two altitude groups at any of the measurement intervals. Both linear and quadratic trend analyses also yielded non-significant results, indicating a lack of directional change in WBC count over time.

These findings suggest that short-term exposure to moderate or high-altitude mountaineering training may not be sufficient to elicit measurable alterations in white blood cell count. This aligns with previous research indicating that hematological responses, particularly in WBC count, are more likely to occur with prolonged exposure to hypoxic conditions or more intense training stimuli (Mazzeo, 2008; Gleeson, 2007). The immune system may require a longer adaptation period to reflect significant changes in leukocyte dynamics, especially in individuals who are not elite athletes.

Additionally, the absence of significant trends in WBC count may indicate a stable immune response among the trainees, potentially reflecting effective acclimatization or a moderate training load that did not induce excessive physiological stress. This is a positive indicator from a health and safety perspective, as it suggests that the four-week program did not suppress immune function in either group.

Conclusion

The findings of this study indicate that a four-week mountaineering training program conducted at medium (2050 m) and high (2700 m) altitudes did not result in significant changes in white blood cell (WBC) count among the selected trainees. Neither altitude nor the duration of training produced notable within-group or between-group differences, and no significant linear or quadratic trends were observed over time. These results suggest that short-term altitude exposure may be insufficient to induce measurable haematological adaptations in WBC count. Further research with longer training durations and a broader range of immune markers is recommended to better understand the physiological impact of altitude training on immune function.

Future Research Scope

Future research should consider longer training durations, higher altitudes, or inclusion of additional biomarkers such as differential leukocyte counts, C-reactive protein, and cytokine levels to provide a more comprehensive picture of immune and hematological adaptations to altitude training.

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