RESEARCH ARTICLE

Effects of temporary stay at high altitude (Darjeeling) on physiological health parameters among college-going girls in Murshidabad District of West Bengal, India

Smritiratan Tripathy[1*], Dwipayan Dasgupta[1], Baishali Basak[1] and Sovan Samanta[2]

ABSTRACT

Background: Short-term exposure to high altitude (acute exposure) causes the body to experience hypoxia, or a reduced supply of oxygen. In response, the cardio-respiratory system undergoes several immediate changes to try to maintain adequate oxygen delivery to the tissues. The present study was undertaken to examine and compare the physiological parameters of young college girls residing at sea level and high altitude. The investigation aimed to evaluate the influence of altitude-related environmental conditions on various physiological responses, including cardiovascular and respiratory functions. *Methods:* About 48 college girls aged 19–22 years voluntarily participated in the study. Anthropometric measurements, including height, body weight, and body mass index, were recorded for all participants. Physiological parameters such as systolic and diastolic blood pressure, peak expiratory flow rate, oxygen saturation, etc., were measured under both sea level and high altitude conditions. The sea-level assessments were conducted in Berhampore, West Bengal, India, whereas the high-altitude measurements were carried out in Darjeeling, West Bengal, India, at two time points: 1 hour after arrival and 24 hours after arrival, to examine physiological adaptations associated with acute exposure to high altitude. *Results*: Anthropometric measurements showed that the mean BMI value of these girls is 21.30 ± 3.08 kg/m^2. About 75% of the students had a healthy weight, while about 16.67% were underweight. Moreover, acute exposure to high altitude (1 hour after arrival in Darjeeling) resulted in significant changes in physiological parameters, including blood pressure, heart rate, respiratory rate, and peak expiratory flow rate, when compared with the values recorded at sea level. However, after 24 hours at high altitude, these altered physiological parameters tended to return to levels observed at sea level. *Conclusion*: The study found that acute exposure to high altitude, assessed 1 hour after arrival in Darjeeling, produced significant alterations in physiological parameters. The reduced air density and decreased airway resistance at high altitude, which can facilitate expiratory airflow and influence cardiorespiratory function. Furthermore, after 24 hours of exposure, the altered parameters tended to approach values recorded at sea level, suggesting the onset of early physiological acclimatization and adaptive responses to the high-altitude environment.

Keywords: High altitude, Body mass index, Blood pressure, Peak expiratory flow rate (PEFR), Handgrip Strength, Oxygen saturation, Girl student.

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INTRODUCTION

Temporary stays at high-altitude regions have become increasingly common due to travel, tourism, and recreational activities in mountainous areas. Exposure to high altitude subjects individuals to distinct environmental conditions, particularly reduced atmospheric pressure and lower temperatures, which can markedly influence normal physiological functions and impose significant stress on the human body.

At high altitudes, air density and atmospheric pressure are lower. The gas composition remains unchanged at sea level despite this drop in air pressure. As altitude rises, only partial gas pressures decrease. Human performance is also impacted by this decrease in partial pressure of oxygen at high altitudes, which mostly results in a loss in oxygen absorption by cells[1]. The combined effects of reduced atmospheric pressure, low temperature, decreased humidity, increased solar radiation, and strong winds at high altitude impose considerable physiological stress on the human body, necessitating adaptive responses primarily involving the cardiovascular and respiratory systems. As a compensatory mechanism to reduced oxygen availability, both respiratory rate and heart rate increase at high altitude to maintain adequate oxygen delivery to body tissues.

Darjeeling, situated in the northernmost part of the Indian state of West Bengal within the Eastern Himalayas, is located at an average elevation of approximately 2,045 meters (6,709 ft) above sea level. At such high altitudes, reduced

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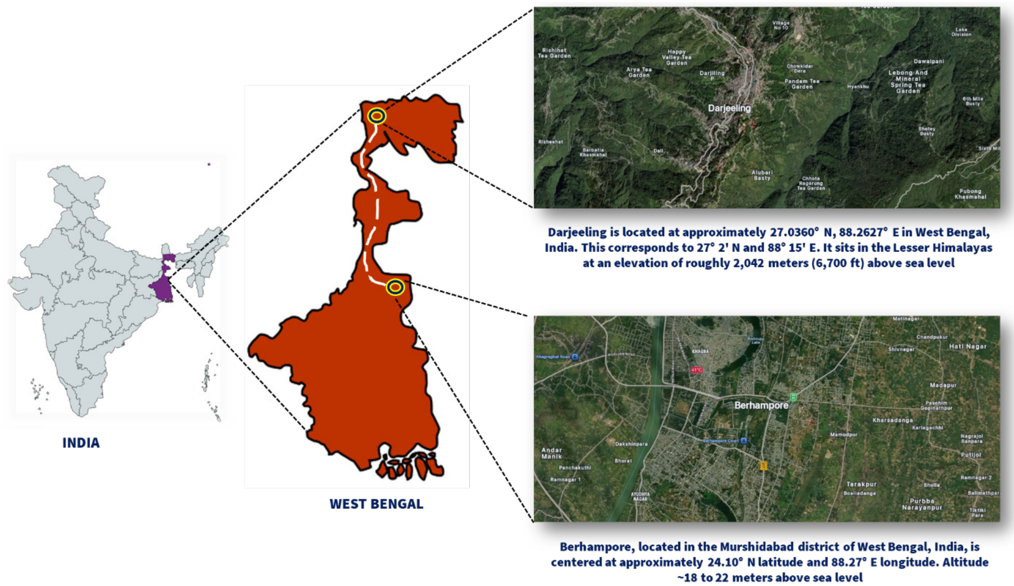

Figure 1: The schematic elastration of two geographically diverse areas in the state of West Bengal, India where the study was conducted

atmospheric pressure reduces oxygen availability, leading to hypoxemia that elicits a series of integrated physiological adaptations to maintain adequate tissue oxygenation. These adaptive responses primarily involve the pulmonary and cardiovascular systems. In the cardiovascular system, compensatory mechanisms include elevations in heart rate, myocardial contractility, and cardiac output, all of which contribute to improved oxygen transport under hypoxic conditions[2-4].

Although the physiological effects of high-altitude exposure have been widely investigated, there is a paucity of data specifically addressing cardiopulmonary and related physiological alterations in young female populations residing in or exposed to the Darjeeling region. In this context, the present study was undertaken to systematically evaluate and compare key physiological parameters between young women residing at sea level and those acutely exposed to high altitude in Darjeeling, with the aim of elucidating altitude-induced physiological variations and early adaptive responses.

METHODS

This study was conducted in April 2025 at two geographically distinct locations in the state of West Bengal, India: Berhampore Girls' College and Darjeeling in the Eastern Himalayas. According to the study design, baseline observations of sea-level environmental conditions were conducted at Berhampore, Murshidabad, at an altitude of approximately 18 to 20 meters above mean sea level, with an average barometric pressure of 756 mm Hg. Subsequently, all remaining phases of the investigation were conducted in Darjeeling, a high-altitude region of the Eastern Himalayas, to evaluate physiological responses under differing altitudinal conditions (Figure 1).

A total of 48 female students (n = 48), aged 19 to 22 years, from the Department of Physiology at Berhampore Girls' College, voluntarily participated in the study. Prior to enrolment, written informed consent was obtained from all participants in accordance with ethical research guidelines. The chronological age of each participant was verified from the official date of birth records maintained in the college register and was subsequently expressed in completed years by rounding to the nearest whole number[5].

Participants with a medical history of bronchial asthma, chronic bronchitis, pneumonia, thoracic injury or surgery, persistent cough, chest wheezing, or any other clinically significant respiratory disorder were excluded from the study. Individuals who had undergone recent treatment for respiratory illnesses, as well as smokers and individuals with a history of alcohol consumption, were also excluded to minimize potential confounding factors affecting pulmonary function. Ethical approval for the study was obtained from the Institutional Human Ethics Committee, and written informed consent was secured from each participant prior to data collection. Furthermore, the complete study protocol and experimental procedures were comprehensively explained to the participants by the supervising faculty members, followed by practical demonstrations to ensure proper understanding, compliance, and active cooperation throughout the investigation.

Figure 2 illustrates the overall study design adopted for the present investigation. A comprehensive assessment of anthropometric and physiological parameters was conducted among participants at both sea level and high altitude to evaluate the acute effects of altitude exposure. The anthropometric measurements included height, body weight, and body mass index (BMI), while the physiological assessments comprised systolic blood pressure (SBP),

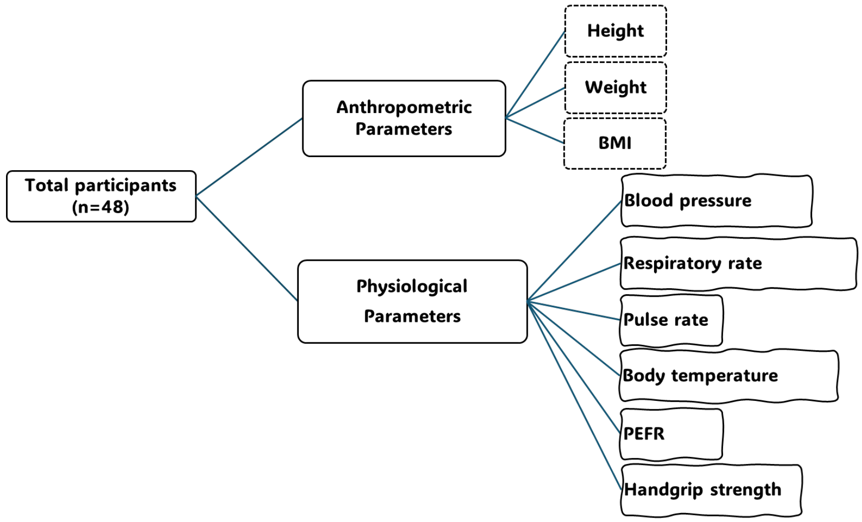

Figure 2: The study design facilitated a comparative evaluation of alterations in anthropometric and physiological parameters resulting from exposure to high altitude conditions following ascent from sea level.

diastolic blood pressure (DBP), pulse rate, body temperature, respiration rate, peak expiratory flow rate (PEFR), and handgrip strength. Baseline measurements were initially recorded at sea level at Berhampore Girls' College. Subsequently, the same parameters were reassessed following ascent to the high-altitude environment of Darjeeling at two distinct time points: first, approximately 1 hour after arrival to evaluate the immediate physiological responses to acute altitude exposure, and second, after 24 hours of stay to examine short-term acclimatization effects. This study design enabled a comparative analysis of the changes in anthropometric and physiological variables associated with the rapid transition from sea level to high altitude.

Height and body weight were recorded with the participants barefoot and dressed in light clothing using a standard stadiometer and a calibrated weighing machine (Crown). Systolic and diastolic blood pressures were measured using a standard mercury sphygmomanometer in conjunction with a stethoscope (Right Care), following established clinical guidelines and standardized measurement procedures to ensure accuracy and reliability. Blood pressure measurements were obtained with participants seated after a minimum 15-minute rest period to ensure hemodynamic stabilization. A second reading was subsequently recorded at least 10 minutes after the initial measurement. Peak expiratory flow rate (PEFR) was assessed using a Wright's peak flow meter with participants in a standing position. A nasal clip was applied to prevent air leakage through the nasal passages, and all readings were expressed under body temperature and pressure-saturated with water vapor (BTPS) conditions to ensure physiological standardization. Prior to data collection, two practice trials were performed to familiarize the participants with the procedure. Subsequently, three maximal forced expiratory maneuvers were recorded, with a 3–5-minute rest interval between attempts to minimize fatigue. The highest value among the three valid efforts was used for analysis. Handgrip strength was assessed using a standard handgrip dynamometer for both the dominant and non-dominant hands, following established testing protocols. Arterial oxygen saturation (SpO_2) was measured non-invasively using a pulse oximeter to evaluate peripheral oxygenation status[5].

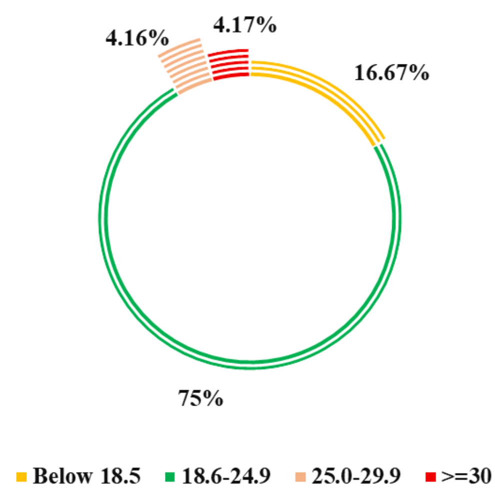

Figure 3: Distribution of BMI of participants

During their stay in Darjeeling, participants were instructed to remain within their accommodation units and not engage in any strenuous or unusual physical activity. They were advised to maintain a regular sleep schedule and adhere to a relatively standardized diet throughout the study period to minimize potential confounding factors related to lifestyle variation. None of the participants reported any symptoms suggestive of discomfort or acute mountain sickness, and no medication was consumed during the study. To ensure methodological consistency and reduce inter-observer variability, all measurements were performed by the same team of trained investigators using identical equipment at both sea-level and high-altitude study sites[1].

All collected data were systematically organized and tabulated prior to statistical analysis. The distribution of the variables was examined for normality, and the results were presented as mean ± standard deviation (SD). For inferential statistics, comparisons between groups or conditions were performed using Student's t-test, while associations between variables were evaluated using Pearson's correlation coefficient.

RESULTS

A total of 48 female college students voluntarily participated in this study. The participants were assessed for selected anthropometric and physical characteristics, including height, weight, and handgrip strength, which were measured individually using standard procedures (Table 1). The mean height of the participants was 155.33 ± 4.81 cm, indicating relatively low inter-individual variability around the mean stature. The mean body weight was 51.66 ± 8.18 kg, reflecting moderate variation among the study population. Based on the recorded height and weight values, the body mass index (BMI) of each participant was calculated using the standard formula (kg/m^2). The analysis revealed a mean BMI of 21.30 ± 3.08 kg/m^2 (Figure 3). Overall, these baseline anthropometric variables provide a clear descriptive overview of the study population and serve as essential reference data for evaluating physical performance parameters, including handgrip strength. The results indicated that mean handgrip strength was lower in the non-dominant hand (17.79 ± 3.16 kg) than in the dominant hand (20.91 ± 3.43 kg), demonstrating greater strength in the dominant upper limb among participants.

From Table 2, it was observed that the mean SBP and DBP levels of the participants increased 1 hour after arrival in Darjeeling compared with sea-level measurements recorded at Berhampore. Although SBP declined after 24 hours at high altitude, it remained slightly elevated relative to baseline sea-level values, indicating that participants' SBP had not yet fully returned to baseline levels. A similar pattern was also observed in the participants' pulse rate. Regarding participants' breathing rate, a marked immediate increase was observed from 21.29 ± 2.82 breaths/min at sea level to 28.62 ± 2.15 breaths/min 1 hour after arrival in Darjeeling. However, this elevated breathing rate returned to baseline levels after 24 hours of stay in Darjeeling. A significant change ($p<0.0001$) in SpO_2 levels was observed in participants compared to sea level. An immediate 1.93% reduction was noted upon exposure to high altitude. Furthermore, SpO_2 levels increased after 24 hours of exposure to high altitude, although they remained below sea-level values. The examined PEFR levels increased significantly upon sudden exposure to high altitude, and this elevated level did not change substantially after 24 hours of high-altitude stay.

Table 1: Physical characteristics of the studied participants (n=48)

Parameters		*Mean ± SD*	*Max*	*Min*
Height (cm)		155.33 ± 4.81	164	146
Weight (kg)		51.66 ± 8.18	75	35
BMI (kg/m^2)		21.30 ± 3.08	30.81	16.19
Handgrip strength (kg)	Dominant	20.91 ± 3.43	29	15
	Non-dominant	17.79 ± 3.16	26	12

DISCUSSION

This study aimed to systematically evaluate and compare key physiological parameters in young women (college students) at sea level and following acute exposure to high altitude in Darjeeling to elucidate altitude-induced physiological changes and early adaptive responses. In recent years, travel to high-altitude regions and mountain tourism in India have increased considerably, especially among young adults. Although a substantial proportion of travelers are male, recent trends indicate that young women are also increasingly participating in high-altitude travel[6]. Although several studies have reported changes in physiological parameters following high-altitude residence, the physiological responses to acute high-altitude exposure among young college girls, especially compared with sea-level conditions, remain poorly documented. Furthermore, whether the transition from sea level to high altitude and subsequent stay at high altitude induce alterations in physiological and anthropometric parameters among the young girl population of West Bengal, India, is still inadequately explored.

A total of 48 female college students voluntarily participated in the present study. Table 1 shows that the participants' mean height and body weight exhibited low to moderate inter-individual variation. The relatively limited variability in these anthropometric characteristics indicates that the study population was homogeneous with respect to physical attributes. This homogeneity may have minimized the potential confounding influence of anthropometric differences on physiological responses, thereby improving the reliability and consistency of the findings associated with high-altitude exposure[7]. According to standard BMI classification criteria, the individuals' mean BMI of 21.30 ± 3.08 kg/m^2 is within the normal healthy range (Figure 3). Most participants appeared to have similar dietary and body composition profiles, as indicated by the relatively small range in BMI values. Such consistency in BMI is crucial for physiological research because drastic changes in body composition can affect metabolic and cardiovascular responses to high-altitude exposure.[9,10] The observed physiological adaptations to high altitude may therefore be more reliable and interpretable because of the rather uniform BMI distribution among the subjects, which may have reduced the possible misleading effects of dietary or obesity-related factors.

Table 2: Tabular representation of the physiological parameters of the studied participants.

Parameters	*Sea Level*	*1 hour after arriving in Darjeeling*	*24 hours after arriving in Darjeeling*
SBP (mmHg)	109.66 ± 8.07	119.58 ± 5.34	111.91 ± 6.40
DBP (mmHg)	72.16 ± 5.77	78.5 ± 4.41	73.25 ± 5.49
Pulse Rate (beats/min)	94.95 ± 12.49	101.54 ± 9.78	98.04 ± 13.88
Breathing Rate (breaths/min)	21.29 ± 2.82	28.62 ± 2.15	21.37 ± 3.36
SpO_2 (%)	98.91 ± 0.40	96.75 ± 0.72	97.00 ± 1.16
PEFR (L/min)	278.33 ± 53.68	322.91 ± 48.59	315.83 ± 51.60

Within an hour after arrival, acute exposure to the moderate altitude of Darjeeling caused a significant increase in both SBP and DBP when compared to baseline sea level readings obtained in Berhampore (Table 2). Hypobaric hypoxia stimulates the sympathetic nervous system, raising catecholamine levels and increasing peripheral vascular resistance to maintain oxygen delivery, which are most likely the causes of this sharp rise.[11,12] Increased vascular tone during the early stages of altitude exposure is shown by the concurrent rise in diastolic pressure.[13] SBP began to decline after a day at high altitude, signifying the beginning of physiological acclimatization. SBP, however, remained marginally elevated above baseline levels, indicating insufficient cardiovascular adaptation during the first 24 hours. This prolonged rise could be the result of delayed vascular homeostasis restoration during early acclimatization and prolonged sympathetic activity.[14,15] Even after 24 hours, the pulse rate remained somewhat higher than baseline, suggesting that the autonomic and cardiovascular systems had not fully adapted. These results imply that even brief exposure to moderate altitude induces considerable hemodynamic stress and triggers early adaptive cardiovascular responses aimed at preserving oxygen balance in hypoxic environments.

The initial increase in breathing rate is probably caused by peripheral chemoreceptors being activated by hypobaric hypoxia, which increases ventilatory drive to maximize arterial oxygenation under low ambient oxygen pressure. After 24 hours, the respiratory rate returns to near baseline values, indicating early respiratory acclimatization, characterized by stabilized chemoreceptor sensitivity and increased ventilatory efficiency. These findings suggest that during the early stages of hypoxic exposure, respiratory adaptation to moderate altitude happens quickly[16-18]. Increased ventilatory drive, improved alveolar gas exchange efficiency, and early cardiac and hematological changes that assist oxygen transport under hypobaric hypoxic circumstances may all contribute to the partial improvement in SpO_2. Incomplete physiological acclimatization within 24 hours of exposure was indicated by SpO_2 readings remaining below the sea-level baseline, despite this recovery. These findings highlight the dynamic, time-dependent nature of oxygen saturation regulation at high altitude and imply that extended exposure and incremental adaptive responses to protracted hypoxic stress are necessary for the complete restoration of arterial oxygenation[11,19,20].

After rush elevation to a high altitude, PEFR spiked significantly and remained elevated for 24 hours, suggesting an instantaneous respiratory adaptation that stabilizes within the first day of exposure. Increased sympathetic stimulation, reflex-mediated bronchodilation, and increased respiratory effort to counteract decreased ambient oxygen availability and maintain efficient alveolar ventilation may be responsible for this rapid escalation. This compensatory response achieves an early steady state, indicating maintenance rather than advancement of ventilatory adaptation, as evidenced by the lack of additional notable change after 24 hours. These results suggest that acute hypoxic exposure mostly improved expiratory performance in the current cohort, in contrast to evidence of altitude-related bronchoconstriction in certain vulnerable populations. To clarify the underlying mechanisms and response variability, more research, including ventilatory dynamics, airway resistance, and inflammatory biomarkers, is necessary.[21-24]

CONCLUSION

The current study demonstrates that within an hour, acute exposure to a moderately high altitude in Darjeeling elicits notable physiological changes, largely due to hypobaric hypoxia, lower air density, and decreased atmospheric pressure. Reduced airway resistance also affects expiratory airflow, and these alterations represent quick compensatory reactions in the cardiorespiratory system to preserve oxygen delivery and functional balance. Early acclimatization was indicated by the tendency of most parameters to revert toward sea-level values after 24 hours. This partial normalization indicates coordinated changes in the respiratory, cardiovascular, and autonomic systems that enhance oxygen consumption and maintain physiological function during prolonged high-altitude exposure.

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PEER-REVIEWED CERTIFICATION

During the review of this manuscript, a double-blind peer-review policy has been followed. The author(s) of this manuscript received review comments from a minimum of two peer-reviewers. Author(s) submitted revised manuscript as per the comments of the assigned reviewers. On the basis of revision(s) done by the author(s) and compliance to the Reviewers' comments on the manuscript, Editor(s) has approved the revised manuscript for final publication.