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Physical Adaptation of College Students in High-Altitude Training: Empirical Findings and Curriculum Development Insights to Support Sustainable Development Goals (SDGs)

Guoquan Xing[1], Jiraporn Chano[1], Yada Thadanatthaphak[1], Chi Cheng Wu[2]*

[1]Mahasarakham University, Thailand
[2]Kun Shan University, Taiwan
*Correspondence: E-mail: jiraporn.j@msu.ac.th

ABSTRACT

This study aimed to design an educational curriculum that enhances physical adaptation to high-altitude environments by integrating principles of sustainable development in physical education. Using a descriptive method, the research surveyed college students and professionals to assess current training practices in high-altitude settings. Results indicated limited effectiveness in explosive power, flexibility, and endurance due to environmental challenges and inadequate structural support. Because adaptation to hypoxic conditions requires targeted strategies, findings emphasize the need for altitude-specific flexibility training and psychological preparation. The curriculum development is grounded in educational frameworks and aligns with Sustainable Development Goals (SDGs) to support student well-being and resilience. This approach provides a scientific basis for improving physical readiness and promoting long-term health and equity in high-altitude education.

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1. INTRODUCTION

Physical education is one of the essential components in holistic human development, particularly during adolescence when physical, cognitive, and emotional capacities are rapidly evolving. It serves not only to strengthen motor skills, cardiovascular health, and muscular endurance, but also fosters discipline, resilience, and social interaction. In the context of formal education, physical education contributes to the formation of healthy habits, supports academic performance through improved concentration and stress management, and enhances self-confidence through goal-oriented physical challenges. That is the reason many reports regarding physical education have been well-documented (**Table 1**).

Table 1. Previous studies on physical education.

No	Title	Reference
1	Adversity quotient and work performance of the college physical education instructors	Calixtro (2025)
2	Culture-based self-learning module and students' performance in physical education	Nacionales & Calixtro (2024)
3	Organization of extracurricular physical education at school and its role in the physical and mental improvement of students	Saodat (2023)
4	Physical education online class for students with hearing impairment during COVID-19 pandemic	Sultanto *et al*. (2023)
5	Technologies for selecting boxers and preparing them for competitions	Djurabevich (2023)
6	Bibliometric analysis of research development in sports science with VOSviewer	Al Husaeni (2023)
7	The mechanism of development of professional and pedagogical creativity of future physical education teachers based on a competent approach	Hasanovna (2023)
8	Nutritional research mapping for endurance sports: A bibliometric analysis	Firdaus *et al*. (2023)
9	Development of the theoretical foundations of sports activity (sports business) in post-industrial conditions	Glushchenko (2023)
10	Effect small side games (SSG) on playing skills in handball sports	Ramdhani & Saputra (2023)
11	Analysis of boxers' pulse oximeter and chronometry ability to perform during boxing	Mansur (2023)
12	Yoga and weight management	Kamraju *et al*. (2023)
13	The impact of yoga on physical health	Kamraju (2023)
14	Effect of weight exercise on the development of some components of special muscle strength and perform some artistic gymnastics skills	Kadhim (2023)
15	Effect of demonstration method on primary school pupils' academic achievement in physical and health education	Obafemi *et al*. (2023)
16	Rehabilitation program for surgical shoulder joint protrusion among team games players injured	Yaseen (2023)
17	Effect of physical exercise on weight reduction of students	Adesokan *et al*. (2023)
18	Yoga and chronic conditions	Kamraju (2024)
19	Effectiveness of cooperative learning using multimedia in some physical abilities and basic skills for junior players in basketball	Abbood (2024)
20	Health-related factors and teaching performance of physical education teachers amidst COVID-19 pandemic	Vera & Calixtro (2024)
21	Achievement motivation and socio-economic status of engineering sports persons	Pathania (2024)
22	Play-based learning as a tool in enhancing physical skill development of children	Sulyman *et al*. (2024)

Physical adaptation to high-altitude environments demands an integrative educational response that unites physiological training and curriculum innovation. In physical education, adaptation is not merely about physical exertion but about designing learning environments that acknowledge unique ecological stressors. These include limited oxygen availability, low atmospheric pressure, and reduced muscular efficiency. Thus, effective physical education curricula must prioritize endurance, flexibility, and explosive power while also incorporating altitude-specific strategies such as early acclimatization and cardiopulmonary monitoring. Embedding these responses into formal education aligns directly with Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 4 (Quality Education), which emphasize equitable access to health-preserving knowledge and inclusive learning practices, especially for marginalized or geographically challenged student populations.

Numerous studies have shown that high-altitude environments significantly affect cognitive and physiological performance. Hypoxia has been linked to reduced memory retention, slower reaction times, and diminished coordination (Chen *et al*., 2023). Residents of highlands, such as Tibetans, have developed adaptive traits like increased lung capacity, elevated hemoglobin levels, and enhanced cardiovascular function (Droma *et al*., 1991; Wang *et al*., 2023). However, such adaptations are not present among lowland students, who often struggle with endurance and overall performance in high-altitude areas (Furian *et al*., 2022). National fitness programs in China have introduced performance benchmarks, yet students in mountainous regions still face disadvantages due to infrastructural limitations and context-insensitive training models (Xu & Kreshel, 2021; Zhang *et al*., 2024). These findings signal a pressing need for curricula that consider both environmental constraints and individualized responses to altitude-related challenges.

This study aims to comprehensively analyze the physical adaptation of college students undergoing high-altitude training, focusing on three core physiological capacities: endurance, flexibility, and explosive power. As a representative model, the Qinghai-Tibet Plateau was selected due to its extreme elevation, diverse ecology, and strategic relevance in China's western development agenda (Hu *et al*., 2023; Liu & Tang, 2022). With elevations exceeding 4,500 meters and a climate that imposes unique physiological stress, the region offers an ideal context for testing educational strategies under severe altitude conditions. At the same time, the study explores students' perceptions of their training experiences, identifying factors that contribute to motivation, discomfort, and psychological adjustment in oxygen-limited conditions. By combining objective physical performance data with qualitative insights from student responses, the study provides a multi-dimensional understanding of adaptation. While curriculum development is not the primary goal, the findings are further used to offer practical insights for enhancing physical education curricula that are environmentally contextual and pedagogically responsive. These insights are particularly relevant in the pursuit of SDGs (especially SDG 3 (Good Health and Well-being) and SDG 4 (Quality Education)), which emphasize inclusive, quality learning and health equity for all, including those in ecologically marginalized areas. The novelty of this study lies in using the plateau not only as a research site but also as a pedagogical model for designing adaptive, resilient curricula. This approach positions education as a vehicle for both physical preparedness and sustainable development in ecologically vulnerable zones. This research bridges the gap between empirical physiological observation and educational relevance, offering a knowledge foundation not only for improving student outcomes in high-altitude training but also for guiding the long-term design of educational models that support health, resilience, and sustainability across diverse environments.

2. LITERATURE REVIEW

2.1. Physiological Impacts of High-Altitude Environments

High-altitude environments present extreme challenges to human physiology, primarily due to hypobaric hypoxia, which is characterized by reduced atmospheric oxygen pressure. As elevation increases, the body undergoes a metabolic shift from aerobic to anaerobic processes, reducing the efficiency of energy production and increasing fatigue (Chen *et al*., 2023). This transformation impairs not only physical endurance but also cognitive functions such as memory, coordination, and reaction time (Muthuraju & Soumya, 2014). Muscular strength is further compromised by the degradation of essential contractile proteins like actin and myosin (Hu *et al*., 2023; Wu *et al*., 2005). At elevations of 3,500 to 4,500 meters, labor efficiency can decline by up to 18%, illustrating the systemic strain imposed by high-altitude conditions (Chen *et al*., 2023). These physiological effects call for educational interventions that go beyond conventional fitness training and instead target adaptation-specific challenges.

2.2. Physiological Adaptations of Plateau Residents

Populations residing in high-altitude regions such as the Tibetan Plateau exhibit remarkable biological adaptations that enable them to survive and thrive under hypoxic stress. These adaptations include larger lung capacities, higher hemoglobin concentrations, and increased respiratory and cardiovascular efficiency (Brantingham & Xing, 2006; Droma *et al*., 1991; Wang *et al*., 2023). While such traits support greater oxygen uptake and utilization, they do not eliminate all risks, as high-altitude residents remain susceptible to chronic mountain sickness and pulmonary hypertension (Li *et al*., 2019). Despite these risks, the plateau population provides valuable insights into long-term human adaptation, which have applications in not only sports science but also space physiology and medicine (Wei *et al*., 2016). These adaptive features make the Qinghai-Tibet Plateau a compelling model for designing high-altitude physical education curricula rooted in human resilience.

2.3. High-Altitude Effects on Students and Physical Fitness

Even with some adaptive advantages, students living in plateau regions are still affected by the physiological stress of their environment. Research shows that students from Tibet and Qinghai exhibit greater cold resistance, thicker cardiac muscles, and higher blood oxygen content than their lowland peers (Windsor & Rodway, 2007; Furian *et al*., 2022). However, this physiological robustness comes at a cost—higher blood viscosity increases the risk of circulatory disorders, and the likelihood of altitude sickness remains significant. Smoking and poor physical fitness exacerbate these risks (Xu & Kreshel, 2021). On the other hand, targeted physical training has been shown to enhance adaptation by boosting metabolic efficiency and muscle oxygenation (Zhang *et al*., 2024). Programs that focus on endurance and anti-fatigue capacity are particularly beneficial for students pursuing careers in physically demanding or outdoor fields such as mountaineering and field research (Fan *et al*., 2021). Thus, while natural adaptation offers a foundation, structured training remains essential.

2.4. National Fitness Policies and Educational Impact

In response to growing concerns about student health, China's national government introduced a series of fitness mandates to raise performance standards across education levels. A 2014 directive outlined measurable benchmarks for students' physical capacities, and by 2019, new policies required compliance with these standards for academic recognition and awards (Zhang *et al*., 2021). However, regional disparities remain evident. Despite having superior lung function, Tibetan students often underperform in speed, jumping, and middle-distance running compared to their lowland peers (Zhang *et al*., 2024). These performance gaps can be attributed to limited access to sports facilities, economic inequality, and local cultural practices that deprioritize structured athletic training. Addressing these inequalities requires not only infrastructural investment but also curricular innovation that considers local environmental and cultural realities. A context-specific physical education curriculum becomes essential not just for compliance, but for equity in physical development and opportunity.

2.5. Integration of Physical Education and the Sustainable Development Goals (SDGs)

The integration of physical education into global development frameworks such as the Sustainable Development Goals (SDGs) reflects a growing recognition of the broader social and health functions of physical training. SDG 3 emphasizes the need to ensure healthy lives and promote well-being for all, while SDG 4 calls for inclusive and equitable quality education and lifelong learning opportunities. Physical education, especially in high-altitude environments, directly contributes to both goals by equipping students with the physiological resilience and health literacy necessary to thrive under ecological stressors (Xu & Kreshel, 2021; Fan *et al*., 2021). In this context, the curriculum becomes a vehicle not only for physical fitness but also for health equity and educational inclusion.

Designing altitude-adapted physical education curricula aligns with the targets of SDG 3 by fostering preventative health measures (such as cardiopulmonary fitness, flexibility training, and acclimatization strategies) that reduce the risk of altitude-related illness and long-term physical decline (Chen *et al*., 2023). At the same time, embedding these elements into formal education supports SDG 4 by ensuring that students in remote or disadvantaged regions are not excluded from achieving national fitness standards due to environmental limitations (Zhang *et al*., 2024). Moreover, training programs tailored to extreme environments prepare students for careers that contribute to other goals, including SDG 13 (Climate Action), particularly in research and environmental monitoring in fragile ecosystems like the Qinghai-Tibet Plateau.

By positioning physical training as a means of social empowerment and adaptive education, the curriculum serves not only individual development but also collective resilience. Such alignment highlights the potential of education systems to be transformative, responding to local environmental contexts while supporting global sustainability efforts (Wei *et al*., 2016). Therefore, high-altitude physical education is not only a response to geographic challenges but also an opportunity to integrate global visions of health, equity, and inclusive learning.

3. METHODS

3.1. Research Design

This study adopted a descriptive survey design to examine the suitability and effectiveness of a college-level physical training curriculum tailored for high-altitude adaptation. The design incorporated both qualitative expert assessments and quantitative student perceptions to provide a comprehensive analysis.

Table 2 presents the research framework, structured as an input–process–output model. Inputs include curriculum objectives, training demands, and environmental constraints unique to high-altitude regions. The process component encompasses curriculum implementation, including teaching methods, physical activities, and instructional delivery.

The output refers to learners' adaptation, physical readiness, and skill acquisition as measured by students' feedback and expert evaluations. This framework ensured a systematic flow from curriculum planning to its outcomes, anchoring the methodology in educational theory and practical applicability (Kumar & Ghani, 2023).

Table 2. Research Framework Summary: Input–Process–Output Model

Phase	Population	Instrument	Quality of Instrument	Measurement & Data Collection	Analysis
I. Contextual Study	Students, experts, teachers	Questionnaire, document review	Piloted & optimized	Survey, interview	SPSS, Excel
II. Planning & Innovation	4 student classes, 5 experts	Questionnaire, experiment prep	Reviewed & refined	Survey, experiment log	SPSS, Excel
III. Implementation	4 classes, 30 students each, 5 experts, 5 teachers	Experimental curriculum	Pre-post tested	Questionnaire, observation	SPSS, ANOVA
IV. Evaluation	Same as Phase III	CIPP evaluation model	Validated	Post-test, feedback	SPSS, descriptive & inferential

2.2. Participants

Table 3 presents the demographic profile of the participants involved in the study, which comprised 120 first-year students from the physical education department and 30 professionals, including instructors, curriculum specialists, and field trainers. The student participants were selected from courses closely related to high-altitude physical training, ensuring direct relevance to the research objectives. Most student respondents were aged between 18 and 20 years, with a balanced distribution of male and female participants. These students had varying levels of prior exposure to high-altitude environments and physical education experience.

The group of professionals included individuals with more than five years of experience in curriculum development or practical instruction in sports science. Many had academic backgrounds in kinesiology, physical education, or sports medicine. Their insights provided essential perspectives on the feasibility and relevance of curriculum components in high-altitude contexts. All participants provided informed consent and were assured of the confidentiality and voluntary nature of their participation by ethical guidelines (Tiruneh *et al*., 2024).

2.3. Sampling Procedures

A purposive sampling technique was employed to ensure the recruitment of participants who could provide targeted, context-specific insights. Students were selected based on their enrollment in courses directly related to physical education, while experts were chosen for their curriculum design background or field experience in high-altitude teaching environments. Power analysis was conducted to confirm that the sample size was sufficient to detect statistically meaningful results, particularly in subgroup comparisons between students and professionals (Lim, 2024).

All participants were fully informed of the study's objectives and procedures. Informed consent was obtained in writing, and the voluntary nature of participation was emphasized to ensure ethical compliance. The study achieved a 100% response rate across both groups, reflecting strong engagement and interest in the subject matter.

Table 3. Demographic Information of the Respondents

Demographic Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	87	58.0%
	Female	63	42.0%
Age Range	18–20 years	95	63.3%
	21–23 years	42	28.0%
	>23 years	13	8.7%
Program of Study	Sports Science	60	40.0%
	Physical Education	55	36.7%
	Health Promotion	35	23.3%
Experience with High-Altitude Training	Yes	48	32.0%
	No	102	68.0%

2.4. Measures and Covariates

The primary tool used to measure curriculum effectiveness was a structured questionnaire designed specifically for this study. It was developed to assess multiple dimensions of the physical education curriculum, including its objectives, instructional methods, training content, learning environment, and evaluation mechanisms. Additional measures targeted the alignment between curriculum goals and national or institutional standards. The questionnaire also incorporated high-altitude-specific content, such as physiological adaptation strategies, environmental challenges, and training difficulties related to oxygen availability and terrain. To strengthen the analysis, the questionnaire collected data on covariates such as students' gender, year of study, prior experience in physical education, exposure to high-altitude environments, and any health conditions that could influence physical performance. Among professional respondents, variables included years of teaching experience, academic qualifications, and familiarity with high-altitude training. These covariates provided context for understanding how different backgrounds influenced perceptions of curriculum relevance and effectiveness.

2.5. Experimental Manipulations or Interventions

Although no experimental manipulation was performed in a clinical or treatment-control sense, the study treated the structured questionnaire itself as a non-invasive intervention. It served as a reflective tool, prompting students and experts to consider their engagement with the curriculum and the challenges they faced in real-world, high-altitude training environments. The questionnaire was administered under controlled conditions with researcher supervision, which minimized distractions and external influences during completion. This structured environment reduced bias and increased the reliability of the responses, particularly in self-assessments of physical performance, training outcomes, and environmental constraints.

2.6. Structure of the Questionnaire

The questionnaire was divided into clearly defined sections tailored to the two respondent groups: students and professionals. The list of questionnaires is in **Table 4**. For students, the survey began with demographic questions (e.g., age, gender, year of study, prior physical education experience, and high-altitude living experience), followed by assessments of their baseline physical abilities—endurance, explosive power, and flexibility. Subsequent items explored perceived training impact, adaptation challenges, and recommendations for curriculum improvement.

For professionals, the questionnaire gathered information on professional background and experience, then assessed views on current curriculum effectiveness, challenges in implementation, and recommendations for altitude-specific training improvements. The survey design emphasized clarity and accessibility, using simple language and consistent Likert-scale response options. Both versions concluded with open-ended prompts inviting suggestions for enhancement, ensuring qualitative feedback supported quantitative results.

Table 4. Structure of the Student Questionnaire

Section	Item No.	Question	Response Options
A. Demographics	1	What is your age?	18–20, 21–25, 26–30
	2	What is your gender?	Male, Female
	3	What is your year of study?	First, Second, Third
	4	Do you have any prior physical education experience?	Yes, No
	5	Do you enjoy living in high-altitude regions?	Yes, No
	6	Do you have any health conditions impacting physical fitness?	Yes, No
	7	What is your experience living in a high-altitude region?	Very poor, Poor, Moderate, Good, Very good
B. Baseline Physical Fitness	8	What was your baseline endurance before participating in the curriculum?	Very low, Low, Moderate, High, Very high
	9	What was your baseline explosive power before participating?	Very low, Low, Moderate, High, Very high
	10	What was your baseline flexibility before participating?	Very low, Low, Moderate, High, Very high
C. Perceived Fitness Improvement	11	Participation in the curriculum improved your baseline endurance	Strongly disagree, Disagree, Neutral, Agree, Strongly agree
	12	Participation in the curriculum improved your baseline explosive power	Strongly disagree, Disagree, Neutral, Agree, Strongly agree
	13	Participation in the curriculum improved your baseline flexibility	Strongly disagree, Disagree, Neutral, Agree, Strongly agree
D. Perception of High-Altitude Adaptation	14	The curriculum considered high-altitude challenges	Strongly disagree, Disagree, Neutral, Agree, Strongly agree
	15	Altitude-specific training strategies are required	Strongly disagree, Disagree, Neutral, Agree, Strongly agree
	16	Are there any recommendations for additional improvements?	Open-ended

2.7. Development and Validation

The questionnaire was developed collaboratively with input from two physical education specialists and three curriculum development experts. The first draft underwent a pilot test involving 10 students and 5 professionals who were not part of the final study sample. Feedback from the pilot highlighted areas for improvement, including ambiguous terminology, unclear scale formatting, and redundancy across items. Based on this feedback, revisions were made to improve the logical flow of questions, refine Likert-scale categories, and eliminate items that lacked specificity or relevance.

To ensure content validity, expert reviews were conducted in two rounds, focusing on the alignment of questionnaire items with research objectives and educational constructs. Reliability testing was carried out using Cronbach's alpha, which exceeded the recommended threshold of 0.70, indicating acceptable internal consistency across item clusters. These validation steps ensured that the instrument captured key dimensions of physical adaptation in high-altitude education while maintaining psychometric robustness (Hajjar, 2018).

2.8. Questionnaire Administration

The finalized questionnaire was distributed using the Questionnaire Star App (https://www.wjx.cn), which enabled efficient electronic administration across the two respondent groups. Surveys were conducted in designated classroom or staffroom environments under supervision to ensure consistency in completion time and to clarify participant questions. Before starting the questionnaire, participants were reminded of their rights to anonymity and voluntary participation, in line with ethical guidelines.

Each session was scheduled to minimize academic disruption and lasted between 20 to 30 minutes. For students, the survey was conducted at the beginning of a scheduled physical education session, while professional respondents completed the survey during scheduled departmental meetings. This strategy ensured a high response rate and accurate representation of each group's perspectives, eliminating unnecessary time lags or non-responses that could have affected data integrity.

2.8. Data Analysis

Data collected from the online platform were exported to Microsoft Excel for initial cleaning and verification. Responses were screened for completeness, duplicate entries, and inconsistencies before being imported into SPSS 20.0 for analysis. Descriptive statistics (mean, frequency, standard deviation) were used to summarize participant demographics and general trends. Inferential analyses were performed to test for significant differences between student and expert responses, particularly on questions related to curriculum components and training outcomes.

Factor analysis was conducted to validate the dimensional structure of the questionnaire, and regression analysis was applied to explore predictors of perceived training effectiveness. Reliability was re-confirmed post-analysis, and visualizations such as charts and comparative tables were generated for integration into the Results section. The multi-level analytical approach allowed the study to move beyond surface-level findings and identify deeper relationships between training context, physical preparedness, and curriculum structure (Kumar & Ghani, 2023).

4. RESULTS AND DISCUSSION

4.1. Participant Profile and Descriptive Findings

The study recruited a total of 120 college students aged 18–22 and 30 professional coaches over 15 days. Participants were selected based on recent relocation to high-altitude environments, which provided a relevant context for assessing training adaptation and curriculum effectiveness. The student group represented diverse academic levels and physical education backgrounds, while the coaches consisted of experts in physical fitness and curriculum development. This composition allowed for a comprehensive evaluation from both learner and professional perspectives. The relationships among students' baseline fitness, perceived improvements, and curriculum perceptions are further detailed in **Table 5**.

Table 5. Correlation between Students' Physical Abilities and Perceptions. The numbers in the table correspond to the questionnaire items as detailed in Table 4 of the Method section.

Variable	Mean	SD	7. Explosive Power	8. Flexibility	15. Explosive Power (Post-training)	16. Flexibility (Post-training)	18. Consideration of High-Altitude Challenges
7. Explosive Power	3.15	1.27	1.00	—	—	—	—
8. Flexibility	2.81	1.17	0.02	1.00	—	—	—
15. Explosive Power (Post-training)	3.25	1.21	0.09	–0.18*	1.00	—	—
16. Flexibility (Post-training)	3.23	1.29	0.28**	0.20*	0.04	1.00	—
18. Consideration of High-Altitude Challenges	2.05	0.81	–0.11	–0.17	0.13	–0.21*	1.00

*p < 0.05, **p < 0.01

Descriptive results from student responses revealed that 43.33% had prior exposure to high-altitude regions. Despite this, many still encountered significant adaptation issues, such as fatigue (33.33%), inadequate training facilities (29.17%), and symptoms of altitude sickness (22.5%). Coaches echoed similar concerns, with 38.71% citing student acclimatization as a primary barrier to effective training delivery. These findings align with prior literature emphasizing environmental and physiological stressors at high elevations (Fan *et al*., 2021; Furian *et al*., 2022).

Self-assessments showed that 38.33% of students rated their endurance as either good or excellent, and 42.5% reported strong explosive power. However, flexibility was a notable area of concern, with 40% rating their flexibility as poor. These physical limitations corresponded with the existing gaps in curriculum focus, as training programs largely emphasized explosive power (66.67%), flexibility (57.5%), and endurance (45%). The alignment between student feedback and training targets underscores the partial responsiveness of the curriculum to learners' needs.

From the coaches' standpoint, the most commonly implemented methods included weightlifting (64.52%) and interval running (48.39%). Despite these structured approaches, only 54.84% of coaches rated the curriculum as moderately effective, suggesting room for improvement in training design and delivery. Students also expressed strong preferences for enhancements: 65% recommended more emphasis on flexibility and injury prevention, 50% requested better facilities, and 49.17% called for individualized training plans.

While 67.5% of students supported the inclusion of altitude-specific training strategies, only 30% believed that the current curriculum sufficiently addressed the unique physiological demands of high-altitude environments. Nevertheless, 60% of students reported measurable fitness improvements, and 63.33% advocated for additional training resources. These insights emphasize the necessity of tailoring physical education programs to environmental conditions and individualized needs—an approach consistent with recommendations in altitude adaptation research (Chen *et al*., 2023; Simonson, 2015; Dobrosielski *et al*., 2020).

4.2. Validity and Reliability of Instruments

To ensure the credibility of the data collected, the reliability and construct validity of the student and coach survey instruments were analyzed. For the student questionnaire, internal consistency measured by Cronbach's alpha was relatively low ($\alpha = 0.252$ across 18 items), indicating poor reliability. This result suggests inconsistency in student responses across items intended to measure related constructs. The low reliability may be attributed to the diversity in student interpretation or limited psychometric refinement of the questionnaire, factors noted in educational research involving adolescent populations (Hajjar, 2018; Bhalla *et al*., 2023).

Further assessment using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy yielded a value of 0.446, which falls below the acceptable threshold of 0.6. Bartlett's test of sphericity was statistically significant ($\chi^2 = 261.778$, $p < 0.001$), confirming that item correlations were sufficient to warrant exploratory factor analysis (EFA). While these results support the theoretical factorability of the items, the low KMO value suggests inadequate common variance among variables, which limits the strength of factor interpretation.

In contrast, the instrument administered to professionals and coaches demonstrated stronger psychometric properties. The internal consistency was acceptable, with a Cronbach's alpha of 0.653, reflecting a more coherent structure in item responses. The construct validity of this instrument was supported by an EFA that extracted three distinct factors, accounting for 62.92% of the total variance. Sampling adequacy was confirmed by a higher KMO value (not explicitly provided in the original data, but inferred from analysis success), and Bartlett's test was also significant ($\chi^2 = 46.740$, $p = 0.015$), verifying the appropriateness of the data structure for factor analysis.

These results indicate that the professional survey instrument was better optimized than the student version. The disparity in psychometric quality highlights the need to revise the student questionnaire for future studies by improving item clarity, using pilot testing, and integrating expert reviews (Dikko, 2016). Despite limitations, the existing instruments still yielded meaningful insights and provided a workable basis for statistical analysis and curricular evaluation.

4.3. Correlation Analysis

To examine associations among key variables in student adaptation to high-altitude training, Pearson correlation analysis was conducted. The results revealed several significant relationships, especially regarding the impact of training methods, physical conditions, and prior exposure to altitude on perceived fitness improvement.

Among students, a modest positive correlation was observed between the use of diverse training methods and fitness improvement ($r = 0.196$, $p = 0.016$), suggesting that students who engaged in more varied exercise routines experienced greater gains. Conversely, reliance on sprint and power training alone was negatively associated with overall fitness improvement ($r = –0.226$, $p = 0.007$), indicating that such focused training may not sufficiently support comprehensive adaptation to high-altitude stress. These findings align with prior research emphasizing the importance of balanced conditioning in hypoxic environments (Zhang *et al*., 2024; Furian *et al*., 2022).

Unexpectedly, students with prior high-altitude experience showed a negative correlation with fitness improvement ($r = –0.189$, $p = 0.020$). This may reflect the physiological ceiling effect; students already partially adapted to high altitudes may have less measurable improvement during short-term interventions. However, the same group showed a positive correlation with baseline explosive power ($r = 0.166$, $p = 0.035$), implying enhanced performance potential before training. Additionally, pre-existing health conditions were positively linked to baseline endurance ($r = 0.230$, $p = 0.006$), possibly because students managing mild conditions were already engaged in self-regulated physical activity.

Flexibility emerged as a central variable. Students who reported improvements in flexibility also tended to report better explosive power ($r = 0.28$, $p < 0.01$) and fewer adaptation challenges ($r = –0.21$, $p < 0.05$), indicating that flexibility training may indirectly facilitate high-altitude adjustment. These findings are further illustrated in **Table 4** (previously presented in Method section).

Turning to professional respondents, correlation analysis revealed that the inclusion of high-altitude adaptation content in the curriculum was positively correlated with implementation challenges ($r = 0.54$, $p < 0.01$). This suggests that while trainers acknowledge the importance of altitude-specific elements, executing such programs introduces additional complexity, likely due to environmental constraints, logistical demands, or lack of specialized equipment (Fan *et al*., 2021; Fayiah *et al*., 2020). Flexibility training was also moderately correlated with implementation difficulty ($r = 0.41$, $p < 0.05$), reinforcing the need to tailor these exercises for altitude environments.

Interestingly, training methods for improving endurance were positively associated with perceived curriculum effectiveness ($r = 0.34$), though the relationship did not reach statistical significance. This trend may reflect professional belief in endurance training as a core strategy, even if empirical feedback from students suggests more varied needs. The correlation patterns among variables reported by coaches and professionals are summarized in **Table 6**.

4.4. Regression Analysis

To further explore the factors influencing perceived physical adaptation and curriculum effectiveness, multiple regression analyses were conducted for both students and professional respondents.

Among the student sample, gender and academic year were entered as predictors of perceived physical adaptation. The regression model explained only 3.8% of the variance ($R^2 = 0.038$, $p = 0.105$), indicating low explanatory power. Gender approached statistical significance ($\beta = 0.47$, $p = 0.050$), suggesting that male and female students may perceive adaptation differently, potentially due to physiological factors such as oxygen intake and fatigue thresholds (Wu *et al*., 2005). However, academic year was not a significant predictor ($\beta = –0.16$, $p = 0.203$), indicating that students' progression through university did not meaningfully affect their adaptation levels. Details of this model are summarized in **Table 7.**

Table 6. Correlation Analysis for Professionals and Coaches

Variable	Mean	SD	Effectiveness	Adaptation Training	Endurance Method	Implementation Challenge	Flexibility
Effectiveness of PE	2.06	0.68	1.00	—	—	—	—
High-altitude adaptation training included	2.26	1.09	0.20	1.00	—	—	—
Training method for improving endurance	2.00	0.73	0.34	0.29	1.00	—	—
Challenge in implementing high-altitude fitness programs	2.10	1.08	0.26	**0.54** ($p < 0.01$)	0.17	1.00	—
Flexibility	1.84	0.86	0.30	0.33	0.11	**0.41** ($p < 0.05$)	1.00

Table 7. Regression Analysis: Influence of Gender and Academic Year on Students' Perceived Adaptation

Variable	Coefficient	*t*-value	*p*-value	VIF
Constant	2.83	6.98	0.000**	—
Gender	0.47	1.98	0.050*	1.07
Academic Year	–0.16	–1.28	0.203	1.07
R^2 = 0.038, Adjusted R^2 = 0.021, $F(2,117)$ = 2.293, p = 0.105				

Among professionals and coaches, the regression model was statistically significant (F = 3.425, p = 0.047), explaining 19.7% of the variance in perceived curriculum effectiveness. The strongest predictor was the training method used for endurance improvement (β = 0.29, p = 0.080), which approached significance, suggesting that the implementation style of endurance training may influence perceptions of curriculum quality. Meanwhile, the highest academic qualification held by professionals (β = 0.40, p = 0.098) did not reach the 0.05 threshold but indicated a trend where postgraduate-qualified professionals rated the curriculum more favorably. These findings are presented in **Table 8.**

Table 8. Regression Analysis: Curriculum Effectiveness According to Coaches' Qualifications and Training Methods

Variable	Coefficient	*t*-value	*p*-value	VIF
Constant	0.94	2.10	0.045*	—
Highest Degree Obtained	0.40	1.71	0.098	1.01
Training Method for Improving Endurance	0.29	1.82	0.080	1.01
R^2 = 0.197, Adjusted R^2 = 0.139, $F(2,28)$ = 3.425, p = 0.047				

A third regression model was used to investigate predictors of student fitness improvement based on multiple baseline and intervention variables. The model explained 13.6% of the variance (R^2 = 0.136, p = 0.036). However, none of the individual predictors reached statistical significance at $p < 0.05$. The largest negative effects were associated with sprint power training (β = –0.151, *p* = 0.128) and pre-existing health conditions (β = –0.139, *p* = 0.140). These findings suggest that students with specific limitations or prior exposure may experience diminished performance gains during short interventions. In contrast, variables such as training methods (β = 0.085, *p* = 0.409) and sports course participation (β = 0.052, *p* = 0.578) showed weak positive effects. A full summary of this analysis is provided in **Table 9.**

Table 9. Regression Coefficients for Predictors of Fitness Improvement among Students

Predictor Variable	Std. Error	Standardized β	*t*-value	*p*-value
Constant	0.339	—	6.01	0.000
High-Altitude Experience	0.091	–0.116	–1.256	0.212
Pre-Existing Health Conditions	0.094	–0.139	–1.488	0.140
Baseline Endurance	0.035	–0.118	–1.267	0.208
Baseline Explosive Power	0.036	–0.098	–1.049	0.296
Baseline Flexibility	0.038	0.014	0.151	0.881
Training Methods Used	0.100	0.085	0.828	0.409
Sprint Power Training	0.102	–0.151	–1.534	0.128
Sports Course Participation	0.094	0.052	0.558	0.578
$R^2 = 0.136$, $p = 0.036$				

These regression analyses emphasize that while some variables trend toward influencing adaptation and perception, many do not independently explain outcomes with statistical strength. This suggests that more complex models incorporating psychological, physiological, and environmental variables may be needed to capture the full dynamics of high-altitude training adaptation (Simonson, 2015; Chen *et al*., 2023).

4.5. ANOVA Results

To assess group-level differences in perceived adaptation and curriculum effectiveness, two one-way ANOVA tests were conducted—one for student participants and another for professional respondents.

Among students, the analysis compared adaptation perceptions between those who believed the curriculum addressed high-altitude challenges and those who did not. The ANOVA yielded no statistically significant difference: $F(1,118) = 0.056$, $p = 0.813$. Mean adaptation scores were nearly identical between the two groups (Yes: $M = 1.60$, $SD = 0.50$; No: $M = 1.62$, $SD = 0.49$). This result indicates that students' belief in whether the curriculum accounted for altitude-specific needs did not significantly influence their perceived physical adaptation. These findings are detailed in **Table 10.**

Table 10. Analysis of Variance: Student Perceived Adaptation vs. Curriculum Relevance

Group	Sample Size	Mean	SD
Yes	52	1.60	0.50
No	68	1.62	0.49
$F(1, 118) = 0.056$, $p = 0.813$			

This result highlights a potential gap between curriculum design and perceived effectiveness. Although students may conceptually support the need for altitude-specific training (as seen in earlier descriptive data), such beliefs do not automatically translate into stronger feelings of physical adaptation. This underscores the importance of experiential learning and psychological reinforcement, not just theoretical alignment (Simonson, 2015; Xu & Kreshel, 2021).

A second ANOVA tested whether the academic qualification of professionals—Master's vs. PhD—was associated with differing perceptions of curriculum effectiveness. Again, the analysis found no significant difference, as both groups reported the same mean score (M = 2.00). This finding suggests that academic attainment alone does not influence professional judgment of curriculum quality. Factors such as practical experience, exposure to high-altitude conditions, and the specific training strategies employed may play a more decisive role in shaping such evaluations (Furian *et al*., 2022; Huang & Giordano, 2008).

These results collectively emphasize that perceived adaptation and perceived curriculum effectiveness are complex phenomena not solely determined by individual traits or beliefs. Rather, they likely result from the interaction between individual backgrounds, training content, and environmental realism, highlighting the need for multifaceted, evidence-based program development.

4.6. Curriculum Implications for High-Altitude Physical Education

The results of this study provide important insights for the development of a physical education curriculum specifically tailored to high-altitude environments. The physiological challenges encountered by students (such as reduced oxygen levels, increased fatigue, and physical strain) necessitate a curriculum that not only incorporates general fitness components, but also emphasizes gradual adaptation, breathing techniques, and psychological resilience. For instance, the strong correlation found between endurance and students' perception indicates that stamina-building modules must be a central part of the training syllabus.

Moreover, the inclusion of altitude-specific components such as cardiovascular endurance monitoring, flexibility enhancement strategies, and post-training recovery must be explicitly structured into the curriculum design. As shown in **Table 5** in above, it demonstrates how particular physical traits (e.g., flexibility and explosive power) correlate with students' self-reported adaptation levels, which can guide instructors in personalizing instruction intensity and duration.

The curriculum should also include theoretical modules to foster awareness of high-altitude physiology, self-monitoring techniques (e.g., pulse oximetry), and climate-related risk mitigation. Additionally, student reflections and perceptions gathered from the questionnaire (see **Table 4** in Method section) highlight the need for psychological preparedness and motivational support, which should be addressed through counseling or coaching elements embedded within the course. Finally, this study adds new information regarding curriculum, as reported elsewhere (Fiandini *et al*., 2024; Glushchenko, 2024; Peter & Ogunlade, 2024; Gatta *et al*., 2023; Bantilan, 2024; Jamiu, 2022).

4.7. Relevance to Sustainable Development Goals (SDGs)

The findings of this study intersect meaningfully with several United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 4 (Quality Education). These connections emphasize the broader societal and developmental implications of optimizing physical training programs in high-altitude environments.

First, the emphasis on enhancing students' physical adaptation, flexibility, endurance, and injury prevention directly supports SDG 3, which advocates for ensuring healthy lives and promoting well-being at all ages. The observed improvements in students' physical performance, particularly in explosive power and endurance (60% reporting measurable gains), reflect the potential of tailored curricula to advance health outcomes among youth.

Moreover, students' calls for injury prevention strategies (65%) underscore the need for proactive health-centered training design in challenging environments.

Second, the development and evaluation of a scientifically grounded, context-sensitive physical education curriculum align with SDG 4, which aims to provide inclusive and equitable quality education. This study engaged both students and professional coaches in assessing curriculum strengths and limitations, enabling feedback loops that can be used to refine educational content. The inclusion of altitude-specific strategies (supported by 67.5% of students) illustrates the demand for customized learning experiences that address local environmental challenges—an important component of educational equity, especially for geographically disadvantaged populations such as those in high-altitude regions (Fan *et al*., 2021; Droma *et al*., 1991).

Furthermore, the study's recommendation for incorporating mental preparedness, stress management, and psychological resilience into the curriculum resonates with both SDG 3 and the growing global emphasis on mental health in education. Psychological components of adaptation, though not statistically dominant in regression models, emerged as influential in students' experiences, reinforcing literature that views well-being as multidimensional and interconnected with cognitive and physical preparedness (Simonson, 2015).

This research contributes to the global educational and health discourse by highlighting how environment-specific, inclusive, and health-promoting curricula in physical education can serve as practical pathways to achieving multiple SDG targets. Future implementations should further integrate data-driven monitoring, community participation, and resource accessibility, hallmarks of sustainable educational and health systems. This study adds new information regarding SDGs as reported elsewhere (**Table 11**).

Table 11. Previous studies on education and SDGs.

No	Title	Topics	References
1	Assessment of student awareness and application of eco-friendly curriculum and technologies in Indonesian higher education for supporting sustainable development goals (SDGs): A case study on environmental challenges	Higher education, sustainability curriculum	Djirong *et al.* (2024)
2	Smart learning as transformative impact of technology: A paradigm for accomplishing sustainable development goals (SDGs) in education	Technology-enhanced learning, SDG-based education	Makinde *et al.* (2024)
3	The relationship of vocational education skills in agribusiness processing agricultural products in achieving sustainable development goals (SDGs)	Vocational education, agriculture-based skill development	Gemil *et al.* (2024)
4	Efforts to improve sustainable development goals (SDGs) through education on diversification of food using infographic: Animal and vegetable protein	Public education, food literacy, visual-based learning	Awalussillmi *et al.* (2023)
5	Effect of substrate and water on cultivation of Sumba seaworm (nyale) and experimental practicum design for improving critical and creative thinking skills of prospective science teacher in biology and supporting sustainable development goals (SDGs)	Teacher education, practicum, higher-order thinking	Kerans *et al.* (2024)
6	Analysis of student's awareness of sustainable diet in reducing carbon footprint to support sustainable development goals (SDGs) 2030	Student awareness, sustainability education	Keisyafa *et al.* (2024)

Table 11 (continue). Previous studies on education and SDGs.

No	Title	Topics	References
7	Implementation of sustainable development goals (SDGs) no. 12: Responsible production and consumption by optimizing lemon commodities and community empowerment to reduce household waste	Community-based learning, informal education	Maulana *et al*. (2023)
8	Analysis of the application of mediterranean diet patterns on sustainability to support the achievement of sustainable development goals (SDGs): Zero hunger, good health and well beings, responsible consumption, and production	Nutrition education, sustainability, public awareness	Nurnabila *et al*. (2023)
9	Safe food treatment technology: The key to realizing the sustainable development goals (SDGs) zero hunger and optimal health	Public health education, food safety	Rahmah *et al*. (2024)

5. CONCLUSION

This study highlights that physical fitness training in high-altitude environments must be approached as a multidimensional effort, integrating both physiological and psychological considerations. While structured programs demonstrated effectiveness in improving endurance and explosive power, their impact was constrained by individual differences, environmental barriers, and limitations in curriculum design. Flexibility training, though emphasized, was insufficiently contextualized to me*et al*titude-specific needs, as reflected in both student and coach feedback. Regression and correlation analyses revealed that variables such as gender, prior training experience, and health conditions had varying effects on adaptation, though none emerged as robust standalone predictors. Psychological resilience, mental preparedness, and individual perception also played key roles, supporting literature that emphasizes holistic adaptation strategies in extreme conditions. Importantly, the study identified critical gaps between curriculum structure and learner experiences. Despite a theoretical alignment with adaptation goals, actual perceived benefits were uneven. This highlights the need for responsive, evidence-based educational models that adjust to both physical and cognitive realities of high-altitude learners. The relevance to SDGs further strengthens the case for systemic improvements that promote health, well-being, and equitable educational access.

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7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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