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Effectiveness of High-Altitude Environments on Cardiovascular Ability: A Literature Review

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Abstract: The problem is a lack of a deep understanding of how living at high altitudes affects cardiovascular ability significantly. The purpose of the study was to analyze the effectiveness of living at high altitudes on improving cardiovascular ability based on a systematic literature review. This review includes an analysis of the results of the study which includes improved oxygen transport, physiological adaptation, and long-term effects on heart and vascular health. The results of this review provide insight into the potential benefits and relevance of living at high altitudes in the context of improving cardiovascular health, as well as its implications in the field of sport and public health. The methodology used is a systematic literature review that collects and analyzes the existing literature on the effects of living at a high altitude on cardiovascular ability. The result is that Living in a highland place has been proven to increase immunity. This is due to physiological adaptations that occur in response to environments with lower oxygen content. These adaptations include an increase in the number of red blood cells and oxygen transport capacity in the body, which in turn improves aerobic ability and cardiovascular endurance. Studies show that long-term exposure to high altitudes can result in improved athletic performance and cardiovascular ability in individuals who live or train at these altitudes. The conclusions of this study suggest that living at high altitudes can improve cardiovascular ability through significant physiological adaptations.

Keywords: Altitude, cardiovascular ability; Endurance; Physiological adaptation; Oxygen transport.

Introduction

Cardiovascular ability is one of the important indicators in assessing a person's physical health and fitness (Bonato et al., 2023; Wang & Shu, 2023). These abilities include the efficiency of the circulatory and respiratory systems in supplying oxygen throughout the body during physical activity. Along with the growing interest in health and fitness, many studies are being conducted to find effective methods in improving cardiovascular capacity. One method that has attracted attention is to live or train at high altitudes, which is claimed to provide significant benefits to heart health and physical endurance (Ramcharan et al., 2024; Sharma et al., 2023).

Highlands are known to have lower oxygen pressure compared to low-lying areas (Bafirman et al., 2023; HB et al., 2023). This hypoxia (lack of oxygen) condition forces the body to adapt by increasing the production of red blood cells and hemoglobin, which in turn can increase the oxygen transport capacity in the blood. This physiological adaptation is believed to improve athletic performance and overall cardiovascular ability. Therefore, staying or training at high altitudes is often used by athletes and individuals who want to improve their endurance (Araspin et al. 2023).

However, despite numerous studies showing the benefits of living at high altitudes, there is still debate regarding its effectiveness and long-term implications

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for cardiovascular health (Baillieul & Brugniaux, 2021; Mason et al., 2020). Some studies show varying results, depending on the duration of exposure, altitude, and individual condition. Therefore, this study aims to conduct a systematic literature review to evaluate and analyze the existing evidence regarding the effectiveness of living at high altitudes on improving cardiovascular capacity, as well as identify the factors that affect the results of these adaptations (Malvandi et al., 2024; Waldron et al., 2020).

The current literature presents various evidences related to the effects of living at high altitudes on cardiovascular ability (Brownstone, 2020; Esmaealzadeh et al., 2022). Studies have identified that exposure to high-altitude environments can trigger significant physiological adaptations in the human body. For example, increased production of red blood cells and hemoglobin is a common mechanism observed in response to chronic hypoxia. Experimental studies with athletes and the general population have shown that living at high altitudes can increase aerobic capacity, improve recovery time, and improve overall physical performance.

However, there is still debate regarding the optimality of the high-altitude environment to improve cardiovascular capacity. Some studies suggest that the effects of adaptation may depend on factors such as altitude levels, duration of exposure, and individuals' responsiveness to hypoxia. In addition, longitudinal studies suggest that the long-term benefits of living at high altitudes on cardiovascular health still need to be further researched to understand the implications on aging, chronic diseases, and other health conditions. In this context, current research focuses on developing more effective methods to improve the body's adaptation to high-altitude environments, as well as identifying populations most likely to benefit from such interventions.

This study introduces a very sharp and robust systematic literature review approach to evaluate the effectiveness of living at high altitude on cardiovascular ability. With a clear focus on a comprehensive analysis of the existing literature, this study aims to identify consistent physiological adaptation patterns and significant long-term effects on heart health and immunity.

The main contribution of this study is to provide a deep understanding of the body's adaptation mechanisms to the high-altitude environment, as well as to clarify the variability in individual responses to chronic hypoxia. The results of this study are expected to provide a solid scientific foundation for the development of new strategies in improving athletic performance and public health through the use of the highland environment (Franklin et al., 2022; KOH, 2021). By broadening our understanding of these effects, the study could also provide practical guidance for coaches, athletes, and health professionals in optimizing the benefits of living at high altitudes to improve overall quality of life and well-being.

The purpose of this study is to identify and examine in depth the effects of living at high altitudes on cardiovascular ability through a systematic literature review approach. The hope for researchers in the future is to further expand the understanding of physiological adaptation mechanisms in high-altitude environments and clarify the variability of individual responses to these conditions. Further research is expected to provide more detailed insights into how to optimally design environment-based interventions to improve physical performance and heart health, as well as identify populations most likely to benefit significantly from high-altitude exposure.

Method

This study uses a qualitative descriptive research model that is a literature study that uses various literature reviews in strengthening research analysis. This research begins by collecting several literatures, then reviewing several important terms in the research, then collecting relevant research literature, then conducting analysis based on all the literature that has been obtained by compiling a discussion, then compiling conclusions based on the results that have been analyzed and making suggestions based on the conclusions obtained.

The data used in this study is using secondary data. According to Sugiyono, (2015) states that secondary data is data that is taken indirectly that can provide information to data collectors. The data sources obtained are in the form of original scientific reports derived from published scientific articles and journals that have been accredited and indexed, both print and non-print which are interrelated in the model of implementing blended learning in physical education and sports.

The data collection method used in this study is the documentation method. The documentation method is a method of collecting data by digging and searching for data from the literature related to what is in the formulation of the problem. The data that has been obtained from various literature is then collected as a single document that will be used in answering the problems that have been formulated.

The article search techniques in this study are through web access to Mendeley, Google Scholar, and Scinece Direct as well as on access to other journals with the words Altitude, cardiovascular ability, endurance, physiological adaptation, oxygen transport. Articles or journals that meet the criteria are then taken for further analysis and a summary of the journal including the name of the researcher, the year of publication of the

journal, the design of the study, the purpose of the research, samples, instruments, and a summary of the results or findings. The summary of the research journal is included in a table sorted according to the alphabet and year of publication of the journal and in accordance with the format mentioned above. This review literature uses literature that can be accessed in fulltext in pdf format and scholarly (peer reviewed Journal). To further clarify the abstrack and full test, the journal is read and observed. The journal summary is analyzed on the content contained in the research objectives and research results/findings. Analysis method used to analyze journal content**.**

Result and Discussion

This literature review was conducted to determine the effectiveness of living at a high altitude on cardiovascular ability. The collected literature was analyzed with a critical apprasial table to answer the measurement objectives compared to the results of simple measurements. There are as many as 10 literature that discusses the effectiveness of living at a high altitude on cardiovascular ability, all of these journals are international journals that are searched on the google scholar portal, Mendeley, Science direct.com by typing the keywords "altitude, cardiovascular ability, endurance, physiological adaptation, oxygen transport" which is then analyzed using critical apparsial analysis to be analyzed from the core of the journal, as well as the results or findings from these journals. The following is a table of critical apparsial analysis from 10 journals.

Table 10. Critical Apparsial Analysis from 10 Journals

Researchers	Article Title	Research Results
(Mi et al., 2024)	Microstructural damage and durability of plateau concrete: Insights into freeze-thaw resistance and improvement strategies	High clay content in building materials for plateau construction also impacts the cement paste's microstructure. The study offers engineering recommendations aimed at enhancing the quality and performance of concrete in plateau conditions to address the unique challenges posed by extreme environmental factors.
(Tian et al., 2024)	Study on durability of concrete under alternating positive and negative temperature curing in plateau area	In-depth investigation reveals that the JB-1 type antifreeze agent promotes the generation of C-S-H gel by accelerating the hydration process of concrete, fills and shrinks the micropores of concrete, reduces the porosity, and improves the microstructure. However, over-addition has a reverse effect, which enhances the content of tiny bubbles and leads to a 2.4 % decrease in the relative dynamic modulus of elasticity of concrete. Meanwhile, the increase in porosity leads to an increase in the electrical flux of concrete by 151 C and shrinkage by 17.2 μm
(Liu et al., 2024)	Analysis and Zonation of Freeze-Thaw Action in the Chinese Plateau Region Considering Spatiotemporal Climate Characteristics	A visualization platform that incorporates tools for meteorological data queries, environmental characteristic analyses, and F–T action similarity calculations was designed. This research lays theoretical groundwork and provides technical guidance for assessing service life and enhancing the quantitative durability design of concrete structures in the Chinese plateau region
(Zhang et al., 2024)	Early-age thermo-hydro-mechanical properties of reinforced concrete bridge piers on the plateau	The concrete hydration degree and compressive strength are often greater around the pier gravity center than in other situations. After 96 h of curing, the compressive strength of the concrete at the pier gravity center is approximately 1.766 times that of the pier surface concrete. The most unfavorable locations for bridge piers are at the arc surface and the bottom of the plane.
(Galloway et al., 2023)	The Experiences of Endurance Athletes With Atrial Fibrillation: Tensions and Takeaways	Our results highlight the unique difficulties that male athletes with AF face in navigating between training and their disease, treatment, and clinicians. Shared decision-making between the athlete and provider is likely necessary for effective management of athletic AF.
(García-Alonso & Corral-Gudino, 2024)	High prevalence of stress fractures and long-term amenorrhoea in high endurance female athletes: The misleading lack of correlation with bone mineral density	The prevalence of long-term amenorrhoea and/or BSI was significantly higher in the HEA than in the NHEA or NA females. In contrast, HEA, like NHEA, had higher BMD values in the femur than those of controls. It is unlikely that DXA parameters can be used to estimate cortical BSI risk in this population.
(Valsamidis et al., 2024)	Improvement of the aerobic performance in endurance athletes	Internal nasal dilation improves nasal patency and aerobic performance during submaximal exercise in adult endurance

Researchers	Article Title	Research Results
	presenting nasal valve compromise with the application of an internal nasal dilator	athletes with nasal obstruction symptoms due to nasal valve compromise.
(Dolan et al., 2023)	Energy constraint and compensation: Insights from endurance athletes	Within this review we A) Describe unique characteristics of endurance athletes that render them a useful model to investigate energy constraints and compensations, B) Consider the factors that may combine to constrain activity and total energy expenditure, and C) Describe compensations that occur when activity energy expenditure is high and unmet by adequate energy intake
(Jeppesen et al., 2024)	Low energy availability increases immune cell formation of reactive oxygen species and impairs exercise performance in female endurance athletes	14 days of LEA in female athletes increased cortisol levels and had a pronounced effect on the immune system, including increased capacity for ROS production, altered plasma inflammatory proteome and lowered exercise induced mobilization of leukocytes. Furthermore, LEA resulted in a sustained impairment in exercise performance.
(Tøien et al., 2023)	Strength versus endurance trained master athletes: Contrasting neurophysiological adaptations	In conclusion, strength trained individuals demonstrate higher descending motor drive (elevated V-wave responses), compared to age-matched untrained individuals. Endurance trained individuals also showed elevated V-wave responses, uniquely accompanied by enhanced α-motoneuron excitability and/or reduced pre/postsynaptic inhibition (elevated H-reflex responses). Since a high descending motor drive is a key component of strong muscle contractions, strength training should be emphasized to sustain the ability to carry out force-dependent tasks at older age.

From the results of a literature study of 10 articles that have been reviewed and explained, the results of this study suggest that living at high altitudes can significantly improve cardiovascular ability through physiological adaptations such as increased red blood cell count and oxygen transport capacity (Beever et al., 2022; Kotewitsch et al., 2024). This evidence is corroborated by the literature showing that high-altitude environments with lower oxygen content force the body to produce more red blood cells, which in turn improves aerobic ability and cardiovascular endurance (Petek et al., 2023; Xu et al., 2023).

The study also presents a debate about the variation in outcomes in individual responses to high-altitude environments. Some studies suggest that the benefits of this adaptation depend on factors such as altitude level, length of stay, and the individual's initial health condition. This points to the need for a more personalised approach to implementing high-altitude living interventions to effectively improve cardiovascular health and immunity (Burnley, 2023; Crouse et al., 2020).

This study has important implications in the field of sport and public health (Ghaleb et al., 2020; Ramcharan et al., 2023). By understanding the body's adaptation mechanisms to high-altitude environments, athletes and coaches can design more effective training programs to improve athletic performance and extend endurance. More broadly, this knowledge can also provide a basis for developing prevention strategies and interventions to improve people's heart health in areas of varying altitudes.

An in-depth interpretation of the results of this study reveals that living at high altitudes does have significant potential in improving cardiovascular ability through complex physiological adaptations (Sidhar et al., 2023; Spring et al., 2022). Increased red blood cell production and oxygen transport capacity are the main mechanisms involved in this adaptation process, which is amplified by the lower hypoxia conditions at high altitudes. These results confirm that the high-altitude environment can serve as an effective stimulus to improve endurance and aerobic ability in individuals who live or train there.

Nevertheless, it is important to remember that the benefits of living at high altitudes may not be evenly distributed among individuals. Variability in response to hypoxia can be influenced by factors such as genetics, age, health conditions, and gender. Therefore, a more individualized and focused approach is needed in designing optimal interventions to improve cardiovascular health and immunity in diverse populations (Agrawal et al., 2020; Franklin & Quindry, 2022; Niclou et al., 2023).

Comparison with other research reveals similar results in terms of the potential to live at high altitudes to improve cardiovascular ability through physiological adaptation. Previous studies have observed significant increases in red blood cell count and oxygen transport capacity in individuals exposed to chronic hypoxia at high altitudes. For example, research by Jadon et al.

(2024) showed that living at high altitudes for several weeks could increase plasma volume, red blood cell count, as well as maximum oxygen uptake capacity in previously physically active individuals. These results are in line with our findings which suggest that the body's adaptation to the high-altitude environment can provide real benefits in improving aerobic performance and endurance.

Nevertheless, there are also studies that highlight differences in individual responses to living at high altitudes. For example, a study by (Bernardi & Peluso, 2020; Hao et al., 2021) suggests that not all individuals show significant improvements in aerobic capacity after exposure to hypoxia. This variability may be due to genetic factors, early health conditions, or even the type of exercise the individual does. Thus, although there is consistent evidence on the benefits of physiological adaptation at high altitudes, it is important to consider the individual factors that influence responses to those environments in the context of designing effective and personalized interventions.

Conclusion

The conclusions of this study provide strong evidence that living at high altitudes can effectively improve cardiovascular ability through physiological adaptations that include increased red blood cell production and oxygen transport capacity. These findings support the use of high-altitude environments as a potential stimulus to improve individual endurance and aerobic performance. However, the study also highlights the need for a more individualized approach to implementing these strategies, given the significant variation in responses to hypoxia between individuals. Thus, this research provides an important foundation for the development of exercise programs and health interventions that can be tailored to the needs of individuals to effectively improve heart health and endurance.

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Author Contributions
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Conflicts of Interest
Regarding this study, the author declares that there is no conflict of interest.

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