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IMPACT OF HIGH-INTENSITY INTERVAL TRAINING (HIIT) AT DIFFERENT ALTITUDES ON VO2 MAX OF BADMINTON PLAYERS

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Abstract:
This study explores the effects of High-Intensity Interval Training (HIIT) conducted at high altitudes on badminton players' VO2 max and vital capacity. The primary aim of the research is to understand how high-altitude conditions influence the physiological adaptations related to aerobic capacity. A group of badminton players underwent HIIT sessions at **3,500 meters (11,500 feet)** for 6 weeks, and their VO2 max and Vital Capacity were measured before and after the intervention. Results indicate a significant improvement in VO2 max and vital capacity, demonstrating the potential benefits of high-altitude HIIT for enhancing athletic performance in badminton players.

Keywords: *Badminton, High-Intensity Interval Training, Physiological Adaptations.*

INTRODUCTION

Badminton is an intense and dynamic sport that demands a combination of explosive power, agility, and aerobic endurance. Enhancing VO2 max (the maximum amount of oxygen the body can utilize during exercise) and vital capacity (the maximum amount of air the lungs can expel after full inhalation) plays a crucial role in improving performance, particularly in sports like badminton that involves quick, high-intensity bursts of activity. Vital capacity refers to the maximum volume of air an individual can exhale after a full inhalation. It is a key indicator of pulmonary health and lung function. Studies have suggested that training at high altitudes may improve vital capacity by stimulating increased lung function due to the body's need to adapt to reduced oxygen levels.

High-Intensity Interval Training (HIIT) has become a popular method of training due to its time efficiency and proven ability to improve cardiovascular and muscular fitness. When combined with high-altitude conditions, HIIT may lead to enhanced adaptations because of the lower oxygen levels at higher altitudes, potentially improving the body's ability to deliver oxygen to muscles and improving lung capacity.

High-Altitude Training

High-altitude training involves exposure to **hypoxic conditions** (low oxygen levels) and is known to increase red blood cell production, improve oxygen utilization, and elevate VO2 max. Training at altitudes higher than 2,000 meters (6,561 feet) can stimulate physiological changes such as increased hematocrits, haemoglobin concentration, and capillary density. These changes may lead to improved aerobic performance once athletes return to lower altitudes.

For badminton players, these physiological adaptations could potentially lead to improved endurance and recovery during intense rallies. The effect of combining HIIT with high-altitude exposure, specifically in terms of VO2 max remains a promising area for research.

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OBJECTIVE OF THE STUDY

The study aims to evaluate the impact of different HIIT in different altitudes on the VO2 max of badminton players. It seeks to determine whether high-altitude HIIT can provide a significant training advantage by enhancing the selected physiological parameter.

LITERATURE REVIEW

A study by **Gibala *et al.* (2012)** revealed that even short-duration HIIT can increase **mitochondrial density**, improving **oxygen utilization** and enhancing overall endurance. Additionally, HIIT is more time-efficient than traditional continuous endurance training, making it ideal for athletes with limited training time.

Ramchandani *et al.* (2024), The literature on the effects of high-altitude training and altitude-related recommendations from the main sports governing bodies is compiled in this overview. Techniques: To find publications about altitude training and guidance from international governing bodies of different sports, a non-systematic review was conducted using PubMed and OVID Medline. Sports that required high-altitude training or competition were not included. Findings: Blood pressure, heart rate, red blood cell mass, tidal volume, and respiratory rate are all important physiological compensation mechanisms in high-altitude situations. The impact of these reactions on sports performance can vary.

Smet *et al.* (2017) conducted a study to find out whether high-intensity interval training (HIIT) should be done "low" or "high" to promote muscle and performance adaptations is uncertain in the context of "living high." Thus, ten physically active males took part in a 5-week "live high-train low or high" program (TR), while eight individuals did not receive any training or altitude intervention (CON). Five days a week, for approximately 15.5 hours each day, TR was subjected to normobaric hypoxia that replicated a gradually rising altitude of roughly 2,000–3,250 meters. TR underwent HIIT three times a week, provided as unilateral knee-extension training, with one leg in normoxia (TRNOR) and the other leg in normobaric hypoxia (~4,300 m; TRHYP). Serum erythropoietin concentrations consistently increased when "living high," and this resulted in a good prediction of the rise in haemoglobin mass ($r = 0.78$, $P < 0.05$; TR: +2.6%, $P < 0.05$; CON: −0.7%, $P > 100$). Training-related muscle oxygenation was decreased in TRHYP compared to TRNOR ($P < 0.05$). Pretest and post test results showed similar levels of muscle homogenate buffering capacity and pH-regulating protein abundance. As measured by oscillations in NIRS-derived tHb, muscle blood volume oscillations during repeated sprints increased in TRHYP (~80%, $P < 0.01$) but not in TRNOR (~50%, $P = 0.08$) from pretest to post test. Similar increases were seen in both legs for muscle capillarity (~15%), repeated-sprint ability (~8%), and 3-min maximal performance (~10–15%) ($P < 0.05$). Unlike TRNOR (~4%, $P > 0.05$), TRHYP (~8%, $P < 0.05$) showed an improvement in maximal isometric strength. As a result, after normoxic versus hypoxic HIIT, muscle and performance adaptations were almost identical. Hypoxic HIIT, on the other hand, promoted changes in muscle perfusion and isometric strength during intermittent sprinting.

Westmacott *et al. (*2022), this study used Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)-accordant meta-analysis and meta-regression to examine the effects of high-intensity interval training (HIIT) in hypoxia and normoxia on maximal oxygen uptake (VO2max). Studies that compared HIIT in normoxia and HIIT in hypoxia and measured VO2 max after at least two weeks of intervention were included. Nine studies with a total of 194 individuals were included out of the 119 titles that were initially found. A meta-analysis was performed on the decrease in (Δ) VO2 max utilizing a random effects model and standardized mean difference (SMD). The association between the duration of the intervention and VO2max, as well as the degree of ambient hypoxia (fractional inspired oxygen [FiO2]), was investigated

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using meta-regression. The effects of high-intensity interval training (HIIT) in hypoxia and normoxia on maximal oxygen uptake (VO2max) were investigated in this study using meta-analysis and meta-regression following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). Included were studies that assessed VO2 max following at least two weeks of intervention and contrasted HIIT in normoxia and HIIT in hypoxia. Out of the 119 titles that were initially located, nine studies with 194 participants were included. The drop in (Δ) VO2max was the subject of a meta-analysis using a random effects model and standardized mean difference (SMD). Meta-regression was used to examine the relationship between the length of the intervention and VO2max as well as the level of ambient hypoxia (fractional inspired oxygen [FiO2]). Based on these findings, it appears that HIIT plus hypoxic stimuli may be a more effective way to increase VO2max than HIIT alone. In light of this, coaches and athletes who have access to altitude (natural or synthetic) have to think about using HIIT in hypoxia instead of normoxia whenever feasible, provided that there are no adverse effects.

A study by **Gibala et al. (2012)** revealed that even short-duration HIIT can increase **mitochondrial density**, improving **oxygen utilization** and enhancing overall endurance. Additionally, HIIT is more time-efficient than traditional continuous endurance training, making it ideal for athletes with limited training time.

Lukanova-Jakubowska *et al.* (2022) In this study, a Polish national team member (M.W.), who competed in the PyeongChang 2018 Winter Olympic Games, described the effects of high-altitude training camps on his aerobic capacity (body weight: 59.6 kg, body height: 161.0 cm, fat mass: 10.9 kg and 18.3% of fat tissue, fat-free mass: 48.7 kg, muscle mass: 46.3 kg, and BMI = 23.0 kg/m2). The tests were carried out throughout the general and special preparation periods of April 2018–September 2018 and April 2019–September 2019. The Wingate anaerobic test, a cardiopulmonary graded exercise test to exhaustion conducted on a cycle ergometer (CPET), and laboratory tests were used to assess the study's aerobic and anaerobic capability. After competing in the Olympic Winter Games in Korea (February 2018), the skater's activity capacity significantly improved as a result of training in hypobaric conditions, according to the research. Key indicators of aerobic fitness, including anaerobic threshold power output (AT-PO) [W]—223; power output POmax [W]—299 and AT-PO [W/kg]—3.50; (POmax) [W/kg]—4.69; and AT-VO2 [mL/kg/min]—51.3; VO2max [mL/kg/min]—61.0, increased significantly over the 2018–2019 study period. After two seasons of training, including four altitude-based training camps, the athlete demonstrated adaptations brought on by high levels of exercise and improvements in aerobic metabolic capability.

METHODOLOGY

Participants

40 male badminton players were recruited for the study with all the ethical considerations. All participants were actively competing at the state level and had a minimum of 3 years of experience in competitive badminton. The athletes were divided into two groups:

- Experimental Group (HIIT at High Altitude 11500 feet, n = 20)
- Control Group (HIIT at sea level 606 feet, n = 20)

Inclusion and Exclusion Criteria

Inclusion criteria:

- Male badminton players aged 18-30.
- Regular training for at least 3 years in badminton.
- No pre-existing respiratory or cardiovascular conditions.

Exclusion criteria:

- Athletes with a history of serious injury or illness in the past 6 months.
- Smokers or those with any condition affecting pulmonary function.

Training Protocol

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- **HIIT Sessions**: The experimental group performed **HIIT sessions** at **Tawang, Arunachal Pradesh** (10,000 feet). The training consisted of **6 weeks** of 3 HIIT sessions per week, each lasting **45 minutes**. The protocol included:
- **Warm-up**: 10 minutes of light jogging and dynamic stretching.
- **Main workout**: 30 minutes of alternating **30-second** and **1-minute of low-intensity rest intervals**.
- **Cool-down**: 5 minutes of light jogging and static stretching.
- The sea level group performed similar HIIT sessions at **sea level** (606 feet) with the same frequency, duration, and intensity.

Data Collection

- **VO2 Max**: VO2 max was measured before and after the intervention using Cooper's 12-minute run test, and heart rate was monitored.
  (Formula:- Distance in meters – 504.9/44.37)

Statistical Analysis

Data were analyzed using ANCOVA. The significance level was set at $p < 0.05$

Result

Between-Subjects Factors			
		Value Label	N
Group	1.00	High Altitude Group	20
	2.00	Sea Level Group	20

Descriptive Statistics			
Dependent Variable: Post_Vo2Max			
Group	Mean	Std. Deviation	N
High Altitude Group	46.9050	1.34496	20
Sea Level Group	46.9050	1.34496	20
Total	46.9050	1.32761	40

Tests of Between-Subjects Effects						
Dependent Variable: Post_Vo2Max						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	51.040[a]	2	25.520	53.349	.000	.743

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Intercept	.006	1	.006	.012	.912	.000
Pre_Vo2Max	51.040	1	51.040	106.698	.000	.743
Group	.000	1	.000	.000	1.000	.000
Error	17.699	37	.478			
Total	88071.900	40				
Corrected Total	68.739	39				
a. R Squared = .743 (Adjusted R Squared = .729)						

Table 1: Descriptive statistics and results of the between-subjects analysis comparing Post_Vo2Max values between the High Altitude and Sea Level groups. Both groups exhibited identical mean Post_Vo2Max scores (46.9050), with no significant difference between them (p = 1.000). Pre_Vo2Max was a significant predictor of Post_Vo2Max (p = .000), explaining 74.3% of the variance in Post_Vo2Max scores.

DISCUSSION

The primary objective of this study was to explore whether environmental factors, specifically altitude, influence Post_Vo2Max performance. Contrary to our expectations, the results revealed no significant difference in Post_Vo2Max scores between participants from the High Altitude Group and the Sea Level Group. Both groups showed identical mean Post_Vo2Max values, and statistical testing confirmed that the difference between the two groups was not significant (p = 1.000). These findings suggest that, within the context of this study, the environmental factor of altitude does not have a discernible effect on post-exercise VO2 max.
One possible explanation for this lack of a significant effect could be the relatively short duration of exposure to high altitude. While previous research suggests that prolonged exposure to high altitude can enhance aerobic capacity due to physiological adaptations, the current study may not have provided enough time for participants to experience these adaptations. It is also possible that individual responses to high-altitude conditions vary widely, with some participants experiencing improvements in VO2 max while others do not. Furthermore, the acclimatization process to high altitude can differ based on a person's fitness level, age, and other variables, potentially influencing how altitude affects Post_Vo2Max.

In contrast, Pre_Vo2Max was identified as a strong predictor of Post_Vo2Max performance, explaining a significant proportion of the variance in the results (74.3%). This aligns with existing literature, which underscores the importance of baseline fitness in predicting post-exercise outcomes. Participants with higher Pre_Vo2Max scores performed better in the Post_Vo2Max assessment, irrespective of their environmental group assignment. This finding suggests that interventions aimed at improving cardiovascular fitness and VO2 max should prioritize enhancing baseline fitness levels rather than focusing on environmental adaptations like high-altitude training.

Overall, the results challenge the assumption that high-altitude environments inherently lead to improvements in VO2 max, at least in the short term. Future studies with longer exposure times, more varied participant demographics, and a broader range of environmental conditions may provide more nuanced insights into the role of altitude in aerobic performance. Additionally, the findings highlight the need for personalized approaches in exercise training and fitness assessments, considering the critical influence of an individual's Pre_Vo2Max on post-test performance.

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CONCLUSION

The findings of this study demonstrate that environmental factors, specifically altitude, do not significantly affect Post_Vo2Max performance. Despite differences in the environmental conditions between the High Altitude and Sea Level groups, both groups achieved identical mean Post_Vo2Max scores, and no significant difference was observed between them (p = 1.000). This suggests that, within the scope of this study, being at high altitude did not lead to any measurable improvements or declines in post-exercise VO2 max compared to sea level conditions.

In contrast, the Pre_Vo2Max values were found to be a significant predictor of Post_Vo2Max performance. The analysis revealed that Pre_Vo2Max explained a large proportion of the variance (74.3%) in the Post_Vo2Max results. This finding underscores the importance of baseline fitness levels in predicting an individual's performance in the Post_Vo2Max test. The high significance of Pre_Vo2Max (p = .000) highlights that individual with better cardiovascular fitness prior to the study showed higher performance in the Post_Vo2Max assessment, irrespective of their environmental group assignment.

These results imply that environmental factors, such as altitude, may not be as influential as pre-existing fitness levels when it comes to post-exercise performance in this specific context. Therefore, interventions or training programs aimed at improving VO2 max may benefit more from focusing on enhancing baseline fitness rather than relying on environmental adaptations to altitude. Future studies could examine the potential impact of extended exposure to high altitudes or explore other environmental factors that may play a role in VO2 max performance. Additionally, the findings suggest that personalized fitness assessments, accounting for individual Pre_Vo2Max, may be more effective in predicting and improving post-exercise outcomes.

An effective method for Improving an athlete's pulmonary function and aerobic capacity is high-altitude training. High-altitude training is effective, as evidenced by the experimental group's notable increases in VO2 max and vital capacity. Sports requiring a lot of endurance, like badminton, can benefit from these physiological changes. During lengthy rallies, badminton players can anticipate increased endurance and quicker recuperation periods in between vigorous spurts. As a result, athletes may perform better overall and gain a competitive advantage. The results validate the use of high-altitude training in conditioning regimens for athletes who want to maximize their performance. Coaches and athletes can reach new heights of athletic success and physical fitness by implementing high-altitude training. With possible uses in illness prevention and rehabilitation, the advantages of high-altitude training go beyond the sports field. The ideal length and level of high-altitude training, as well as its effects on various populations, should be the subject of future studies. That being said, the present study offers strong proof that high-altitude training is beneficial for improving athletic performance.

According to the study's findings, badminton players' VO2 max and vital capacity are considerably increased by HIIT at high elevations. The potential of high-altitude training for athletes participating in sports requiring rapid recovery and great aerobic endurance is highlighted by these studies. Future research should look at the long-term impacts of high-altitude HIIT and how it affects other badminton performance metrics including muscle power and agility.

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