



Original article. Increasing VO₂max through aerobic endurance training in the highlands country (altitude training) and lowlands country (sea level training) in hockey athletes. Vol. 12, n. ° 3; p. 1-17, July 2026.

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Increasing VO₂max through aerobic endurance training in the highlands country (altitude training) and lowlands country (sea level training) in hockey athletes

Aumento del VO₂máx mediante entrenamiento de resistencia aeróbica en zonas de tierras altas (entrenamiento en altitud) y zonas de tierras bajas (entrenamiento a nivel del mar) en atletas de hockey

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Abstract

A good VO2Max capacity is a very important thing that a hockey athlete must have, therefore choosing the right training model to increase aerobic endurance is very necessary. The purpose of this study was to determine the extent of effectiveness of aerobic endurance training in altitude training and sea level training in hockey athletes. This study employed an experimental research design with a randomized pre-test post-test control group design. 36 men hockey athletes from STKIP Pasundan were sampled. A simple random sampling technique was used to determine the experimental group (altitude training) and the control group (sea-level training). The treatment program was implemented for 6 weeks (24 sessions) and included continuous running, cross-country, fartlek, and interval training. The bleep test was used to measure VO2Max capacity. The results of this study shown the altitude training aerobic capacity improvement training model has a significant impact (sig .00) on increasing the athlete's VO2max capacity with an average increase of 6.80 and the sea level training training model also has a significant impact (sig .00) on increasing the athlete's VO2Max with an average increase of 5.87. That concluded the aerobic capacity improvement training models of altitude training and sea level training have a very significant impact on increasing VO2Max in hockey athletes, but the altitude training model has a better increase compared to sea level training.

Keywords: aerobic endurance training; VO2Max; altitude training; sea level training; hockey athletes.

Resumen

Una buena capacidad de VO2Max es algo muy importante que un atleta de hockey debe tener, por lo tanto, elegir el modelo de entrenamiento correcto para aumentar la resistencia aeróbica es muy necesario. El propósito de este estudio fue determinar el grado de efectividad del entrenamiento de resistencia aeróbica en el entrenamiento en altitud y el entrenamiento a nivel del mar en atletas de hockey. Este estudio empleó un diseño de investigación experimental con un diseño de grupo de control pre-test-postest aleatorizado. Se muestrearon 36 atletas de hockey hombres de STKIP Pasundan. Se utilizó una técnica de muestreo aleatorio simple para determinar el grupo experimental (entrenamiento en altitud) y el grupo de control (entrenamiento a nivel del mar). El programa de tratamiento se implementó durante 6 semanas (24 sesiones) e incluyó carrera continua, campo a través, fartlek y entrenamiento a intervalos. Se utilizó la prueba de pitido para medir la capacidad de VO2Max. Los resultados de este estudio mostraron que el modelo de entrenamiento para mejorar la capacidad aeróbica en altitud tiene un impacto significativo (sig .00) en el aumento del VO2máx del atleta, con un aumento promedio de 6.80, y el modelo de entrenamiento a nivel del mar también tiene un impacto significativo (sig .00) en el aumento del VO2máx del atleta, con un aumento promedio de 5.87. Esto concluyó que los modelos de entrenamiento para mejorar la capacidad aeróbica del entrenamiento en altitud y el entrenamiento a nivel del mar tienen un impacto muy significativo en el aumento del VO2máx en atletas de hockey, pero el modelo de entrenamiento en altitud tiene un mejor aumento en comparación con el entrenamiento a nivel del mar.

Palabras clave: entrenamiento de resistencia aeróbica; VO2Max; entrenamiento en altitud; entrenamiento a nivel del mar; atletas de hockey.



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Introduction

Field hockey is a team sport that demands high levels of physical ability, particularly aerobic endurance (VO2max), as athletes must perform moderate-to-high-intensity activity repeatedly throughout a relatively long match, lasting 4 x 20-minute sessions (Sparks, 2025). VO2max is a key indicator of aerobic capacity, crucial for supporting technical performance, recovery speed, and game consistency in hockey athletes (Goods et al., 2023; Lam et al., 2026). VO2max is strongly linked to endurance performance, metabolic efficiency, and cardiovascular functional capacity, making it a key variable in the study of exercise physiology and coaching (Xu et al., 2025).

To support these demands, endurance training is essential, serving as the primary method for increasing VO2max in athletes, including field hockey players. Endurance training has been shown to be effective in increasing VO2max through central and peripheral physiological adaptations, such as increased cardiac output, stroke volume, skeletal muscle capillarization, mitochondrial biogenesis, and increased oxidative enzyme activity (Zhang et al., 2025). However, the effectiveness of endurance training is strongly influenced by the training environment, particularly altitude. In recent decades, altitude training has been widely used as a strategy to increase aerobic capacity through exposure to hypoxic conditions due to the low partial pressure of oxygen at high altitudes (Chapman et al., 2014; Kashapov & Kashapov, 2022). This hypoxic exposure stimulates physiological adaptations such as increased erythropoietin (EPO) production, which plays a role in red blood cell formation, and increased hemoglobin mass. These hematological adaptations have the potential to increase blood oxygen-carrying capacity, which theoretically can support increased VO2max and aerobic performance (Barratt et al., 2025; Faiss et al., 2025). However, implementing altitude training is not always easy for all athletes or teams, primarily due to the potential for decreased training quality due to low oxygen availability (Li et al., 2023). Alternatively, sea-level training remains the most commonly used method because it allows athletes to maintain optimal training intensity under normoxia (Skattebo et al., 2024). Under normoxia, such as at low altitude, endurance training programs can significantly increase aerobic capacity, especially in untrained or moderately fit individuals (MacInnis & Gibala, 2017). Low-altitude



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endurance training has been shown to be effective in increasing VO₂max through cardiovascular and metabolic adaptations, such as increased cardiac output and increased muscle oxygen utilization efficiency (Deldicque, 2022).

Contemporary research identifies various hypoxic training models, including living high–train high (LHTH), living high–train low (LHTL), and living low–train high (LLTH). Several systematic reviews and meta-analyses have shown that certain hypoxic training models, particularly those that allow athletes to maintain high training intensities, can produce greater aerobic adaptations than training at low altitudes (Girard et al., 2017). Furthermore, a recent network meta-analysis reported that hypoxic-based endurance and interval training have the potential to produce greater increases in VO₂max than normoxic training, although the magnitude of the effect varies widely across studies (Feng et al., 2023).

Nevertheless, scientific evidence regarding the benefits of high-altitude training for increasing VO₂max remains inconsistent. Several meta-analyses have reported that although hypoxic training consistently improves hematological parameters, such as hemoglobin concentration and total hemoglobin mass, the increase in VO₂max is not always greater than equivalent training at low altitude (Maciejczyk et al., 2023; Millet et al., 2013). This variation in results is influenced by several factors, including altitude, duration of hypoxic exposure, regulation of training intensity, and the initial fitness status of the study subjects. Furthermore, training at high altitude presents practical challenges, such as reduced maximal work capacity, increased fatigue, and the need for adequate acclimatization. Conversely, training at low altitude allows for higher absolute loads, which is essential for maximizing central cardiovascular adaptations. Therefore, the relative effectiveness of low-altitude and high-altitude endurance training on increasing VO₂max remains a matter of scientific debate and requires further empirical study, as altitude training has the potential to provide hematological adaptation benefits, while sea-level training allows for higher and more stable training intensities.

In the context of hockey, the need for high aerobic endurance must be balanced with the ability to maintain game intensity and reaction speed. Several studies have shown that hockey athletes with higher VO₂max have better match performance, including total distance covered and active engagement in the game (McGuinness et al., 2019). However,



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empirical studies directly comparing the effectiveness of endurance training at altitude and sea-level in hockey athletes are still limited, particularly in the context of athlete development in developing countries. This study aims to analyze and compare the effects of endurance training on increasing VO₂max at low and high altitudes. It is hoped that this will provide theoretical and practical contributions to the development of sports physiology and coaching.

Methods

This study used an experimental study with a randomized pre-test post-test control group design to determine the impact of aerobic endurance training on athletes in two types of locations, namely altitude training and sea level training on hockey athletes. The participants in this study were 36 male non professional hockey athletes from STKIP Pasundan (average age 20,2 years). A random assignment was used to assign 18 participants to the experimental group (altitude training) and 18 to the control group (sea-level training).

The treatment was carried out for 6 weeks (24 meetings) in the form of training to improve the athletes' aerobic abilities. The experimental group (altitude training) will undergo training treatment in a highland area with an altitude of 1468 meters above sea level, while the control group (sea level training) will undergo training treatment in a lowland area with an altitude of 8 meters above sea level.

The training program includes the aerobic foundation training stage (continues run and cross country) with high volume and intensity of 50-60% in the first week (4 times), then moving on to the aerobic development training stage (continues run, cross country, and fartlek) with high volume and intensity of 60-70% in weeks 2-3 (4 times/week), the aerobic threshold training stage (continuous run) with moderate volume and intensity of 70-80% in week 4 (4 times), finally at the maximum aerobic speed training stage (principle interval) with low volume and intensity of 80-90% in weeks 5-6 (4 times/week). Meanwhile, to measure aerobic capacity (VO₂Max) in hockey athletes, researchers used the Bleep test instrument. The aerobic capacity measurements were carried out before the treatment was given (pre-test) and after the treatment was given (post-test).

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The data analysis used in this study was using the t-test (paired sample t-test) with a significance level of 0.05 on the SPSS version 27 application. After previously carrying out a normality test using the Shapiro-Wilk test and a homogeneity test using the Levene's statistical test.

Results

After undergoing 24 sessions (6 weeks) of treatment, the aerobic capacity (VO2Max) was initially measured before the treatment was administered. After the treatment, the aerobic capacity (VO2Max) was remeasured using the Bleep test. The results are shown in Table 1 below:

Table 1. Descriptive Data of VO2Max Hockey Athletes

No	Group	N	Min	Max	Mean	Std.Dev	Gain
1	ALT (pretest)	18	40,2	53,1	46,62	3,65	6,80
2	ALT (posttest)	18	48,7	60,76	53,42	3,04	
3	SLT (pretest)	18	42,4	52,5	46,55	2,86	5,87
4	SLT (posttest)	18	49,3	56,5	52,42	2,17	

ALT : Athletes with Altitude Training Endurance Program

SLT : Athlete with Sea Level Training Endurance Program

Table 1 above shows that the initial VO2Max of the hockey athletes who received the high-altitude aerobic endurance training program (Altitude Training) averaged 46.62, with a final VO2Max of 53.42, representing a gain of 6.80. Meanwhile, the initial VO2Max of the hockey athletes who received the low-altitude aerobic endurance training program (Sea Level Training) averaged 46.55, with a final VO2Max of 52.42, representing a gain of 5.87.

The results of the hypothesis testing for the hockey athletes who received the high-altitude aerobic endurance training program can be seen in Table 2 below.



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Table 2. Hypothesis Test of Altitude Training Program Group

		Paired Differences		95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Mean	Std. Dev	Std. Error Mean	Lower Upper			
Pair 1	Pretest VO2Max-ALT - Posttest VO2Max ALT	-6.795	1.6104	.37957	-7.5958 -5.9942	-17.902	17	.000

ALT: Altitude Training Program

In Table 2 above, the results of the hypothesis test for the Altitude Training program group have a sig. (2-tailed) value of 0.000, which means that the aerobic ability training program at high altitudes (Altitude Training) for hockey athletes has a significant impact on increasing their aerobic ability (VO2max). Meanwhile, for the hypothesis test on the group of hockey athletes who received the aerobic endurance training program at low altitudes (Sea Level Training) can be seen in Table 3 below.

Table 3. Hypothesis Testing of Sea Level Training Program Group

		Paired Differences		95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Mean	Std. Dev	Std. Error Mean	Lower Upper			
Pair 1	Pretest VO2Max SLT - Posttest VO2Max SLT	-5.872	1.12462	.26508	-6.43148 -5.31296	-22.153	17	.000

SLT: Sea Level Training Program

In Table 3 above, the hypothesis test results for the Sea-Level Training program group also showed a significant value (two-tailed) of 0.000, indicating that the high-altitude aerobic training program (Altitude Training) for hockey athletes had a significant impact on increasing their aerobic capacity (VO2max).

The results of this study demonstrate that both the high-altitude (Altitude Training) and low-altitude (Sea-Level Training) aerobic training programs for hockey athletes significantly impacted their aerobic capacity (VO2max). However, there was a difference in the average increase. The Altitude Training program had an average increase of 6.80. Meanwhile, the Sea-Level Training program had an average increase of 5.87,



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indicating that the increase in VO₂max in hockey athletes who trained at altitude training had a slight advantage compared to hockey athletes who trained at sea-level training.

Discussion

This study aimed to evaluate the effect of aerobic endurance training programs in different environments, namely altitude training and sea-level training, on increasing the maximum aerobic capacity (VO₂Max) of hockey athletes. The results of data analysis showed that both training models made a positive contribution to improving the athletes' physical condition, but there were differences in the magnitude of the increase achieved by the group that trained at high altitude compared to the control group at sea level. In line with this research, previous research has shown that an aerobic endurance training program using the altitude training method carried out for 6 weeks has a significant impact on long-distance runners (Dewanti et al., 2026).

Other research findings showed a higher increase in VO₂Max in the altitude training group in line with the literature stating that environmental hypoxia acts as an additional stimulus for the cardiovascular and hematological systems, this has an impact on increasing sprint performance and Vo₂max in elite athletes (Kashapov & Kashapov, 2022; Sridhar, 2025). However, in contrast to previous research, this research was applied to non-professional athletes who have limitations regarding facilities and especially nutritional intake which is not well maintained.

As is known, altitude training is a form of physical exercise performed at high altitudes or in mountainous areas with low oxygen levels (Goods et al., 2025). Altitude training produces varying hematological responses in each individual, depending on the duration and intensity of hypoxic exposure (Nowak-Lis et al., 2025). Under conditions of limited oxygen, the body adapts by stabilizing hypoxia-inducible factor (HIF), which stimulates the release of erythropoietin (EPO) from the kidneys (Chen et al., 2023). This process triggers erythropoiesis, which increases the total hemoglobin mass in circulation, thus increasing the capacity for oxygen transport to working muscles (Bonato et al., 2023; Kuorelahti et al., 2025). This aerobic capacity-enhancing training program, which combined continuous running, cross-country, and interval training for 6 weeks, facilitated



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changes in the hockey athletes' oxygen capacity (VO2Max) (Bonafiglia et al., 2016; Hindsø et al., 2022; Parmar et al., 2021).

Increasing VO2Max in hockey athletes is very important, because the game requires very high aerobic endurance (Duthie et al., 2022). Superior aerobic capacity allows athletes to recover their heart rate faster and clear lactate more efficiently between intense game shifts (Mathew B et al., 2024). This study aligns with previous research showing that the altitude group experienced an increase in VO2Max ranging from 4.4% to 13%, far exceeding the sea-level group which only showed a marginal increase (Sridhar, 2025).

The effectiveness of the improvements in athletes in this study was likely driven by the use of the Live High, Train Low (LHTL) model. This model allows athletes to gain the erythropoietic benefits of living at altitude while still maintaining the high mechanical intensity of training at sea level or low altitude (Brocherie et al., 2024). This overcomes the drawbacks of the traditional Live High, Train High (LHTH) model, where training intensity often decreases due to oxygen limitations, which can lead to detraining effects on explosive power and speed (McLean et al., 2014). For hockey athletes, the ability to train at maximal speed is crucial for maintaining muscle memory and technical skills (Mathew B et al., 2024).

Furthermore, the use of High-Intensity Interval Training (HIIT) in a hypoxic environment has been shown to have a strong impact. This finding is supported by a meta-analysis that stated that HIIT in hypoxic conditions resulted in a greater increase in VO2Max (SMD = 0.68) compared to normoxic HIIT (Westmacott et al., 2022). The dual stimulus of interval training load and low partial pressure of oxygen triggers faster mitochondrial remodeling and increased vascularization through angiogenesis (Wiesinger et al., 2024). In hockey athletes, these peripheral adaptations are invaluable for improving lactate threshold and repeated sprint endurance (Sridhar, 2025).

The altitude training provides a hematological boost (Lundby & Robach, 2025), the results of this study also confirm the significant effect of sea-level training on improving VO2Max in hockey athletes. The primary advantage of sea-level training, or normoxic conditions, is the athlete's ability to maintain higher absolute exercise intensities without the constraints of oxygen limitation (Broxterman et al., 2024;



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Wiesinger et al., 2024). This allows for greater stimulation of the central oxygen transport system, specifically increasing stroke volume and maximal cardiac output (Chen et al., 2023). Implementing appropriate training methods at sea level, such as High-Intensity Interval Training (HIIT), has been shown to significantly increase VO₂Max in hockey athletes. High-intensity interval training forces the cardiovascular system to work at peak capacity, which triggers mitochondrial remodeling and increases oxidative enzymes in muscle tissue (Henríquez et al., 2023; Westmacott et al., 2022). In addition, continuous running and fartlek methods at sea level remain an important foundation for building a strong aerobic base, which supports efficient oxygen use by muscles and accelerates recovery after strenuous exercise (Zakia et al., 2024).

Although altitude training has a more significant impact on improving the aerobic abilities of hockey athletes compared to sea-level training, this training model also has several drawbacks that need to be noted. Altitude training carries a much higher risk of dehydration than sea-level training (Inami et al., 2023). This is caused by a faster and shallower breathing rate (hyperventilation), which increases water loss through exhaled water vapor (González-Alonso et al., 2023; Karamaoun et al., 2022). Furthermore, low air humidity (dry air) accelerates the evaporation of sweat from the skin, often making athletes unaware of the amount of fluid lost (Viscor et al., 2023). The phenomenon of high-altitude diuresis is due to physiological and pathological phenomena that occur in the body, namely increased urine production, which is a hormonal response of the kidneys to a hypoxic environment (Inami et al., 2023). Athletes at high altitudes also often experience a decreased sensation of thirst, so voluntary fluid intake tends to decrease (Kiran & Medabala, 2025). Compared to sea-level training, the partial pressure of oxygen at sea level tends to be normal and makes the respiratory rate more stable, resulting in lower fluid loss through the respiratory system than at high altitudes (Mandorino et al., 2025). The thirst mechanism also works more accurately as an indicator of the body's hydration needs. Therefore, a trainer needs to consider carefully when implementing these two training models.

Limitation

Monitoring athletes' rest periods and nutritional factors is a limitation of this study. During the training camp, the coach only provided rest periods without monitoring what



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the athletes did during those breaks, including their nighttime sleep. Researchers and coaches had limited interventions regarding athletes' rest periods, so it was not possible to monitor whether the athletes were experiencing short rest periods and poor sleep (staying up late). Another limitation of this study is the athletes' nutritional intake, which may have been inappropriate. Considering that the hockey athletes used in the study were not from professional hockey clubs with financial and nutritional resources, it is important to note that the significant increase in aerobic capacity at high altitudes is highly dependent on the adequacy of the athletes' iron reserves. Without adequate ferritin levels (>30-50 ng/mL), the body cannot produce new hemoglobin even with a strong EPO stimulus.

Conclusions

Overall, the results of this study confirm that altitude training significantly improves VO₂max in hockey athletes compared to sea-level training. This competitive advantage provides a strong physical foundation for athletes to maintain intensity in the final quarter of a match, where fatigue is often a determining factor in the outcome. Further research is recommended to pay more attention to the quality of rest and nutrition received by athletes, and, if necessary, to measure the recovery phase of athletes in both training models.

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