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Endurance training for judo athletes: Improving anaerobic and aerobic capacity in the high altitude

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ABSTRACT

Background Problems: Judo is a sport that requires aerobic and anaerobic abilities. This is because the scoring in judo matches is different from other martial arts, where athletes will look for absolute 'ippon' points in one match. Therefore, training is needed that can support increasing aerobic and anaerobic capacity in judo athletes. Endurance training at high altitudes is a training method that is believed to have benefits for athletes' aerobic and aerobic capacity. **Research Objectives:** The study aims to examine the effect of endurance training on increasing the anaerobic and aerobic capacity of judo athletes based on the Special Judo Fitness Test (SJFT), which is a specific test for the sport of judo that can describe anaerobic and aerobic fitness according to the needs of judo. **Methods:** This research was conducted in the Puncak area of West Java, which is included in the highlands. An experimental method was used in this research on twenty-four Indonesian elite judo athletes who are carrying out training camps to face the SEA Games in Vietnam in 2021. The t test using SPSS Version 24 was used for data analysis in this study. **Findings and Results:** The results showed that there was a significant increase in anaerobic and aerobic capacity at high altitudes in judo athletes, as seen from the SJFT. **Conclusion:** This study concluded that endurance training could increase the anaerobic and aerobic capacity of judo athletes in the highlands. Endurance training at high altitudes for judo athletes is highly recommended because it has been proven to have a significant effect on increasing anaerobic and aerobic capacity. We recommend that judo coaches carry out training at high altitudes because it has been proven to improve the aerobic and anaerobic abilities of judo athletes.

Keywords: Aerobic capacity; anaerobic capacity; elite athletes; judo



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INTRODUCTION

Judo is one of the toughest and most intense sports, where winning requires a wide range of technical skills and understanding. Judo matches can last from a few seconds to eight minutes, but typically last three minutes, with activity phases of 20-30 seconds and 5-10 second breaks (Santos et al., 2015). Effective judo techniques must be performed under extreme metabolic stress and high levels of peak strength and power (da Silva et al., 2022; Franchini et al., 2014). Elite judo athletes must maximise their conditioning training, concentrate on

developing strength as well as endurance, meet the specific anaerobic and aerobic metabolic demands of judo combat (Burns & Callan, 2017; Franchini et al., 2014; Ruddock et al., 2021). Martial arts performance involves a multifaceted interaction of open and complex skills, said to present irregular activity and periods of rest (Brito et al., 2017). Also in the sport of judo, aerobic excellence in competition and participation in high-lactic metabolism are required for actions that determine competitive success (Bartel et al., 2022).

Judo is a martial sport associated with explosive movements (Dopico et al., 2014; Wazir et al., 2017). The uniqueness of Judo is that victory can be achieved quickly and can also be achieved in a relatively long time (Kajmovic et al., 2022; Pierantozzi et al., 2022). This can be seen from the statistical results released by <https://www.judodata.com/statistics/>, which show that 62% of the matches ended before the match time ended, 15% of the matches ended according to the match time, and 24% of matches ended with a golden score. From these data, it can be seen that Judo is a sport that requires both anaerobic and aerobic capacities. To improve anaerobic and aerobic abilities, appropriate training is needed for judo athletes so that their aerobic and anaerobic capacities increase. Judo techniques, such as throws, arm locks, choking techniques, and immobilisation, require high-efficiency phosphogene processes-anaerobic non-lactic acid and lactic (glycolic) acid (Franchini, 2021; Francisco et al., 2023). Judo training and judo-specific exercises must be manipulated to maximise training response and competitive performance (Franchini et al., 2014). In addition, the use of instruments that are characteristics of the sport of judo is using the Special Judo Fitness Test, which is a test that can be used to determine the level of physical fitness according to the characteristics of the sport of judo, namely a sport that requires high physiological demands, although techniques and tactics seem to play a big influence on match performance. One of the supporting elements of achievement coaching is a good training programme (Bompa & Carrera, 2015; Purnamasari et al., 2022).

Since the 1968 Olympics, it was discovered that training at altitude affects endurance ability; training at moderate altitude (2000 to 3000 m) has become popular for enhancing competitive performance both at altitude and at sea level (Ramchandani et al., 2024; Robach & Lundby, 2020; Sharma, 2022). In this study, exercises were carried out in the highlands at an altitude of 1500 metres above sea level. Previous research revealed that the physical fitness of students at Manado State University who live in the highlands has a good level of fitness (Nurkadri & Hayati, 2020); therefore, this study wanted to see the effect of endurance training on judo athletes who were trained in the highlands as seen from the special judo fitness test.

Training the endurance component refers to all types of sports training aimed at increasing cardiovascular or muscular endurance (Bangsbo, 2015). Endurance training involves developing the body's breathing ability and muscle strength to strengthen physical activity with a lower risk of injury over a long period of time (Yang, 2019). In general, general endurance training refers to the aerobic system, which is often associated with cardiovascular endurance; in fact, endurance ability is much more complex. Endurance in sports is related to the appearance or performance of the technique they master. Athletes who are in good physical condition can be defined as athletes who perform techniques consistently and effectively with minimal effort, which leads to their success (Bompa & Carrera, 2015; Ulbricht et al., 2016).

Modifications for exercise with a hypoxic effect have been found, including with houses and tents at height, as well as special breathing apparatus (Serebrovskaya & Xi, 2016). In addition, an effect has been developed for hypoxic inspiration at rest and during exercise, and the term intermittent hypoxic training (IHT) has been coined (Ramos-Campo et al., 2016). In general, intermittent hypoxic training can be divided into two distinct strategies: (1) providing hypoxia at rest, with the primary goal of stimulating altitude acclimatisation; or (2) providing hypoxia during exercise, with the main goal of increasing the training stimulus (Álvarez-Herms et al., 2016; Li et al., 2020; McLean et al., 2014; Viscor et al., 2018; Wyatt, 2014).

In the last 20–30 years, athletes' maximal oxygen uptake (VO₂max) has increased, and world records for long-distance running have increased. One of the factors affecting the increase in VO₂max and the increase in world records is training at altitude, because athletes living in mountainous areas have won many Olympic and World Championship medals in long-distance running over the past decades (Wilber, 2022). A person's endurance can be described by his VO₂max ability. Factors that affect a person's VO₂max, including temperature (Castellani & Tipton, 2016). The effect of changes in temperature on VO₂max occurs indirectly;

this occurs when an increase in basal body temperature resulting from progesterone has a thermogenic effect that will affect cardiovascular performance; therefore, it will affect VO₂max (Gio et al., 2021).

Aerobic capacity is the ability to maintain high work output for a long time, known as aerobic capacity (Langeskov-Christensen et al., 2015), while anaerobic capacity is the ability to carry out high workloads repeatedly (Sumpena & Sidik, 2017). Interval training affects anaerobic endurance capacity (Faisal & Sepdanius, 2020); besides that, sprint interval training can affect the increase in aerobic capacity (Gist et al., 2014). A continuous run is a form of running training that is done continuously without rest (Bompa & Buzzichelli, 2019). This exercise is also often referred to as long-distance running. This exercise is a running exercise at a specified speed and distance, without rest time until the entire distance has been covered (Purnamasari et al., 2022). A shuttle run is a form of exercise that can be used to increase speed, agility, and endurance (Popović et al., 2020).

In athletes who engage in endurance sports, the capacity of the muscles to receive and use oxygen exceeds the capacity of the cardiovascular system to transport oxygen (Joyner & Dominelli, 2021). The main goal of high-altitude training is to increase the total red blood cell volume and haemoglobin mass in order to increase limiting binding (i.e., oxygen delivery) by increasing the oxygen-carrying capacity of arterial blood, thereby increasing VO₂max and improving performance (Gwotmut, 2023). One possible reason for the absence of a positive effect of altitude training is that even moderate hypoxia during exercise can substantially impair training speed and reduce mechanical and neuromuscular excitability, leading to the gradual attenuation of certain determinants of endurance performance (Dragos et al., 2022). Therefore, although VO₂max and oxygen transport play an important role in most endurance sports, attention should be paid to other factors, including neuromuscular and anaerobic characteristics (muscle strength factors), which influence endurance performance and training responses at high altitude.

Therefore, this needs to be done to determine the effect of resistance training on increasing the anaerobic and aerobic capacity of judo athletes based on the Special Judo Fitness Test (SJFT), which is a special test for the sport of judo that can describe anaerobic and aerobic fitness according to Judo's needs that occur to anaerobic and aerobic capacity in athletes. Even though we know that Indonesia is a country that has a very large territory and many highland areas are often used as training camps, such as the Puncak area, especially for Indonesian Judo athletes, this research needs to be carried out so that it can become a reference for academics and practitioners in the field regarding the benefits of training at altitude on anaerobic and aerobic capacity of Judo athletes, which so far has not been studied much or is limited. So, this study aims to examine the effect of endurance training on increasing the anaerobic and aerobic capacity of judo athletes based on the Special Judo Fitness Test (SJFT), which is a specific test for the sport of judo that can describe anaerobic and aerobic fitness according to the needs of judo.

METHOD

An eight-week experimental method (Fraenkel et al., 2022) was used in this study by providing treatment in the form of a combination of judo training and physical training arranged in an exercise programme (as can be seen in Table 1). The physical training programme provided includes an aerobic endurance training programme combined with technical training and is given on a scheduled basis to athletes with a total of 16 sessions per week (morning, afternoon, and evening). The forms of physical training provided are long-slow distance running (LSDR), intensive interval training (IIT), extensive interval training (EIT), and tempo running (TR). Meanwhile, the technical training provided is the drilling exercise of kumikata, nage waza, and ne waza. This training programme is given directly by professional trainers in the material domain, namely aerobic exercise. Twenty-four Indonesian elite judo athletes who are carrying out training camps to face the SEA Games XXX Vietnam 2021 are involved as research subjects. Before and after the treatment was given, the subjects took the Special Judo Fitness Test (Franchini et al., 2009) at the Padepokan Judo Indonesia (PJI). Data were analysed using SPSS version 24 with t-test analysis (Santoso, 2017) with reference to the SJFT norm classification (which can be seen in Table 2).

Table 1. Eight Week Combination Physical Training and Judo Program

Week	Item	Duration	Intensity	Interval
1	Kumikata Nage waza LSDR	150'	65% MHR	2-3'
2	Kumikata Nage waza LSDR	150'	65% MHR	2-3'
3	Kumikata Nage waza EIT	120'	75% MHR	3-4'
4	Kumikata Ne waza EIT	120'	75% MHR	3-4'
5	Kumikata TR	90'	85% MHR	4-5'
6	Kumikata Ne waza TR	90'	85% MHR	4-5'
7	Kumikata Nage waza Ne waza IIT	60'	95% MHR	5-6'
8	Kumikata Ne waza Nage waza IIT	60'	95% MHR	5-6'

LSDR: Long-Slow Distance Run; EIT: Extensive Interval Training; TR: Tempo Run; IIT: Intensive Interval Training; MHR: Maximum Heart Rate.

Table 2. Classificatory Norms in the Special Judo Fitness Test (SJFT)

Classification	Variables			
	Total of Throws	HR After (bpm)	HR 1 min After (bpm)	Index
Excellent	≥29	≤173	≤143	≤11.73
Good	27-28	174-184	144-161	11.74-13.03
Average	26	185-187	162-165	13.04-13.94
Poor	25	188-195	166-174	13.95-14.84
Very Poor	≤24	≥196	≥175	≥14.85

(Franchini et al., 2009)

Table 1 describes the classification of norms in the Special Judo Fitness Test (SJFT). For the Excellent category, athletes must get a total of 29 kicks for a heart rate below or equal to 173 bpm, below or equal to 143 bpm for a heart rate after 1 minute, and an index less than or equal to 11.73. For the good category, athletes must get a total of 27-28 slams after between 174 and 184 bpm and between 144 and 164 bpm for a heart rate after 1 minute with an index between 11.74 and 13.03. For the average category, athletes must get a total of 26 kicks after between 185 and 187 bpm and between 16 and 265 bpm for a heart rate after 1 minute with an index between 13.04 and 13.94. For the poor category, athletes must get a total of 25 kicks after between 188 and 195 bpm and between 166 and 174 bpm for a heart rate after 1 minute with an index between 13.95 and 14.84. Finally entered into the Very Poor category if the athlete gets a number of throws less than or equal to 24, for a heart rate above or equal to 196 bpm, above or equal to 175 bpm for a heart rate after 1 minute, with an index greater than or equal to 14.85.

RESULTS AND DISCUSSION

The data obtained was then processed and analysed, after which the data was presented in table form, which can be seen in Table 2.

Table 2. PreTest and PostTest Result of Special Judo Fitness Test (SJFT)

Variables (n=24)		PreTest Mean $\pm$ SD	PostTest Mean $\pm$ SD
Heart Rate (bpm)	15 s	166.67 $\pm$ 21.803	166.25 $\pm$ 9.696
	30 s	179.17 $\pm$ 18.396	177.92 $\pm$ 9.315
	30 s	190 $\pm$ 15.88	187.50 $\pm$ 12.247
	1 min after	139.58 $\pm$ 18.053	144.58 $\pm$ 13.507
Throws (number)	15 s	6.42 $\pm$ 0.654	6.79 $\pm$ 0.588
	30 s	11.29 $\pm$ 0.955	12.21 $\pm$ 1.179
	30 s	10.75 $\pm$ 0.989	12.08 $\pm$ 1.018
	Total Throw	27.32 $\pm$ 6.081	29.84 $\pm$ 6.719
Index (point)		11.69 $\pm$ 1.702	10.75 $\pm$ 1.098

Based on Table 2, it is explained that the number of samples that took part in the Special Judo Fitness Test (SJFT) in the study was 24 people, with the following results: The pretest average value for heart rate 15 s was 166.67 with a standard deviation of 21.803 and the average for posttest 166.25 with a standard deviation of 9.696, heart rate 30 s is known an average value of 179.17 with a standard deviation of 18.396 and the average posttest 177.92 with a standard deviation of 9.315, then the pretest average value for heart rate 30 s is 190 with a standard deviation of 15.88 and the average posttest score is 187.50 with a standard deviation of 12.247. Finally, the pretest value for heart rate 1 minute after obtained an average of 139.58 with a standard deviation of 18.053, and for the posttest, an average of 144.58 was obtained with a standard deviation of 13.507. Judging from the number of kicks, it is known that the average number of kicks in the pretest with a time of 15 s is 6.42 with a standard deviation of 0.654, while the average number of kicks in the posttest 6.79 with a standard deviation of 0.588, the average number of kicks in the pretest with a time 30 s is 11.29 with a standard deviation of 0.955, the average number of kicks in the posttest is 12.21 with a standard deviation of 1.179, the average number of kicks in the pre-test with a time of 30 s is 10.75 with a standard deviation of 0.989, and the average number of kicks in the post-test is 12.08 with a standard deviation of 1.018.

It is also known that the total number of kickbacks for all parts in the pretest has an average of 27.32 with a standard deviation of 6.081, and for the posttest, the number of kicks has an average total kickback of 29.84 with a standard deviation of 6.719. So it can be concluded that the index value of point heart rate and throws in the pretest has an average value of 11.69 with a standard deviation of 1.702, while for the posttest, it has an average index value of 10.75 with a standard deviation of 1.098. This means that the results obtained after the treatment (posttest) are better than the results obtained before the treatment (pretest). This means that the treatment that has been carried out so far has been able to have an effect in the form of an increase in the aerobic and anaerobic capacities of Judo athletes. In this study, an index (point) of 10.75 was obtained so that it was included in the "Excellent" classification. Furthermore, the t-test was carried out to determine the significance of the increase that occurred, which can be seen in Table 3.

Table 3. T-Test Result

Pair	Sig.	Assumption
Pretest-posttest	0.000	H ₀ rejected

Based on Table 3, it can be seen that if the sig. is $0.000 < 0.05$, then H₀ is rejected. Thus, it can be concluded that there is a significant increase in anaerobic and aerobic capacity at high altitudes in judo athletes, as seen from the Special Judo Fitness Test (SJFT). Next, we present an error bar graph containing the average value and standard deviation on the pretest and posttest, which can be seen in Figure 1.

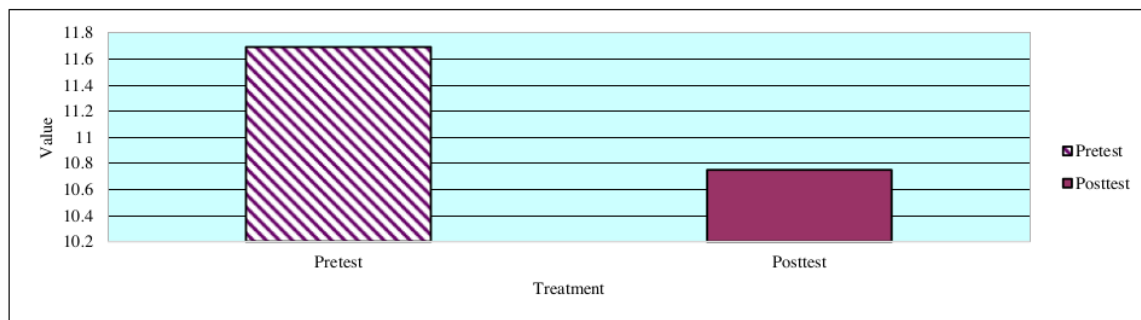


Figure 1. Error Bar Graph of the Average and Standard Deviation Index Value of Pretest and Posttest

Based on Figure 1, it can be seen that the pretest has a greater index value than the posttest, with a standard deviation that is also greater. This shows that after being given treatment, athletes have better abilities than before being given treatment.

Providing high-altitude training for 2-4 weeks is a viable strategy for elite athletes that allows for the benefits of explosive movement and aerobic and anaerobic metabolism (Tomazin et al., 2021). The implementation of training at this altitude has been a routine part of the preparation of several high-level athletes for a long time because it is believed to have various significant benefits (Khodae et al., 2016). Physiologically, the most important environmental factors at high altitudes are low atmospheric oxygen concentrations and low barometric pressure. The body's first response to high-altitude low oxygen concentrations (hypoxia) is an increased ventilation response triggered by carotid body receptors (Chawla & Saxena, 2014; Whayne, 2014; Khodae et al., 2016; Rozita et al., 2022). Altitude training can increase blood oxygen-carrying capacity to improve sea-level endurance performance in athletes. Increased production of erythropoietin (EPO) in hypoxia is a key factor in achieving an increase in haematological variables. The degree of EPO increase and accelerated erythropoiesis depends on the duration of exposure and the degree of hypoxia. Exposure to terrestrial or simulated hypoxic environments causes a decrease in PaO₂ as well as arterial oxygen saturation (SaO₂). In addition, many other factors can influence the haematological response to altitude training (Ploszczyca et al., 2018).

Athletes in Western countries rapidly adopted this form of altitude training to induce an elevation-acclimatisation-dependent increase in red blood cell volume (RCV) and, at the same time, apply additional training stimulus due to tissue hypoxia. High RCV in athletes is well documented and well correlated with overall training performance in elite athletes, and thus attempts to increase RCV to improve performance appear to be valid (Brocherie et al., 2015; Ploszczyca et al., 2018). In simple terms, studies show that performing high-altitude drills has emerged as a way to gain a tactical advantage over competitors. This requires breathing in a reduced percentage of oxygen (hypoxia), either natural or simulated, to improve athletic performance (Khodae et al., 2016). Therefore, training at altitude is a very positive strategy that can be applied in the training process for elite athletes.

Coaches who handle elite athletes will use various strategies and training methods to achieve the best performance for their athletes and get the highest performance. We know that achievement is the cumulative result of various aspects of training that are integrated (Novian & Noors, 2020). In the training process, the most common is to use traditional training by practicing at height (Tomazin et al., 2021). Studies show this strategy has significant benefits for athletes. The traditional training referred to in this study is converted into endurance training by combining physical training and technical training in Judo, which is applied in this study. This exercise has been proven to increase anaerobic and aerobic capacities in elite judo athletes. This is a good thing because in judo matches that use aerobic and anaerobic systems, it shows that the anaerobic system functions to expend short, fast, all-out maximum power during the match, while the use of the aerobic system contributes to maintaining effort during the duration of the match and recovering energy quickly during the game. At the time of competition, good anaerobic capacity and aerobic capacity are needed from a judo player. In addition, the characteristics of Judo are that it involves large and small muscles (Purnamasari et al.,

2021), so specific exercises are needed that can increase the athlete's anaerobic capacity and aerobic capacity judo elite. Endurance training at this altitude has been proven to be a solution to this problem.

The results of this study are in line with previous research which revealed that altitude training in the form of four camps under hypoxic hypobaric conditions provides several conclusions, including (1) The use of four altitude camps in two consecutive annual training cycles allows athletes to achieve high training adaptation and improve aerobic potential; (2) Significant increases in physiological parameters were found, some of which reached the highest levels in a professional skater's career so far: the anaerobic change threshold AT-VO₂ (mL/kg/min) of 51.3, and VO₂max (mL/kg/min) of 61.0; (3) The results show high economics and excellent aerobic potential of an athlete (Lukanova-Jakubowska et al., 2022). However, training at a height that has been carried out in various sports has yielded different results, and there has not been a consistent conclusion. Short-duration altitude training appears to result in significant increases in aerobic but not anaerobic power in trained adolescent endurance runners. An eleven-day altitude training camp at ~1850 m above sea level proved highly effective in improving cardiorespiratory fitness and running speed across a wide range of blood lactate levels, but not anaerobic performance, in trained adolescent runners.

These findings are comparable to what can be observed in adults and highlight the value of appropriately structured, short-duration altitude training for increasing fitness levels and possible sea-level race performance in this population (Bahenský et al., 2020). Four weeks of training at a moderate altitude positively affected the athlete's lactate threshold and upper body muscle mass. Maximum oxygen uptake is reduced in athletes tested at high altitudes compared to sea level due to being in a hypoxic environment. Indicators of aerobic capacity (maximum oxygen uptake, haemoglobin, and RBC count) did not improve significantly after athletes returned to sea level compared with pre-moderate altitude training, which may be related to altitude being too low, duration of exposure to a hypoxic environment, and design load. training. When imposing moderate-altitude training on athletes, exposure time, training load characteristics, and nutritional strategies must be carefully designed to optimise training outcomes (Yu et al., 2023). Studies implementing strategies to enhance the erythropoietic effects of chronic altitude exposure, which requires athletes to live higher than competition heights, suggest that 19 days of staying at altitude or more is recommended to minimise altitude-mediated performance reduction (Chapman et al., 2016).

In the sport of judo, which is very dominant with anaerobic and aerobic energy systems, training at this height has been proven to significantly improve performance abilities. Exercises carried out at high altitudes have an advantage because oxygen levels at high altitudes tend to be lower than oxygen levels at low altitudes. This is because the number of air particles is getting smaller compared to the height, which results in a small gravitational force so that the pressure in the air will be smaller, which causes the oxygen level to decrease. The effectiveness of exercise at altitude can improve aerobic ability because of the effects of hypoxic erythropoietic (Park et al., 2016; Ploszczyca et al., 2018), by exercising at altitude, the body is deprived of oxygen, and the body will automatically compensate by taking as much oxygen from the outside, so that red blood cells will produce more to bind oxygen. The advantage of training at altitude is that the body will get used to taking oxygen quickly, so when training or competing at lower altitudes, the body is used to taking oxygen quickly. An athlete's body that suddenly adapts to changes in altitude will increase their performance. This mechanism is associated with haematological, cardiovascular, or ventilatory effects (Townsend et al., 2016). Therefore, the performance improvement of elite judo athletes can be enhanced by adding aerobic routines to normal training to increase recovery capacity (Bonato et al., 2015).

Even though this research provides positive results for judo athletes, the authors need to highlight several things that may cause differences in the effects of endurance training at high altitudes. There are at least four important things that need to be considered, including: (1) The training programme provided: the training programme provided must be in accordance with the demands and needs of the athlete; the coach needs to prepare a training programme that is in accordance with these two things based on training principles (laws of pedagogy, physiology, and psychology), which should not be ignored; (2) Treatment provider or programme implementer: the treatment provider, in this case the coach, must have adequate skills and qualifications, lest the athlete not receive a good training programme due to the coach not understanding the training; (3) Athletes: the athletes themselves are one of the important things that need to be considered,

considering that this research uses elite judo athletes who can be said to be trained athletes and not athletes who are just training; (4) Conditions in the field: conditions in the field must be taken into account, such as the availability of areas for training, the extreme height of the facilities and infrastructure available, and also the height of the high ground used in carrying out the training. Therefore, this research still has several limitations, as previously stated. So it is important for practitioners to understand the entire context presented in this article. Apart from that, it is highly recommended that further research be tested on different categories or levels of plateaus and different categories of athletes so that it can complement the results of this research.

CONCLUSION

Based on the results of the research that has been done, this study provides the conclusion that endurance training can increase the anaerobic and aerobic capacity of judo athletes in the highlands. The author sees that the positive research results are very beneficial for the further training process. Endurance training at high altitudes for judo athletes is highly recommended because it has been proven to have a significant effect on increasing anaerobic and aerobic capacity. The results of this research can be said to be something new in Indonesia, especially in Judo sports training. Therefore, it is hoped that this research can be a reference for coaches who are working with judo athletes so that the training process can be more efficient and peak performance can be achieved more optimally. We recommend that judo coaches carry out training at high altitudes because it has been proven to improve the aerobic and anaerobic abilities of judo athletes.

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CONFLICT OF INTEREST

The author fully declares that there is no conflict of interest in this article.

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