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Effects of Altitude Training on Recovery Ability and Maximum Oxygen Consumption of Elite Male Taekwondo

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Abstract

Background and Aim: To investigate the effects of high-altitude training on the physical recovery capacity and maximal oxygen consumption (VO_{2max}) of elite male Taekwondo athletes.
Methods: The study employed a combination of literature review, mathematical statistics, and experimental methods, with a primary focus on experimental approaches. (1) Study Participants: The study participants were elite male Taekwondo athletes who resided in plain areas and had a minimum of 5 years of training and competitive experience. (2) Variables Measured: The variables measured included resting heart rate (morning pulse), blood oxygen saturation, exercise heart rate, and maximal oxygen consumption.
Results: (1) Five weeks of high-altitude training and exposure to a low-oxygen environment did not significantly affect the morning pulse of the athletes. (2) The 5-week high-altitude training resulted in a significant increase in blood oxygen saturation among the participants, with the most significant increase observed in the fourth week. On average, the blood oxygen saturation of the athletes increased by 3.51%. (3) Compared to the plain areas, the athletes showed no significant differences in resting heart rate and maximal heart rate before exercise. However, their heart rate exhibited a faster decline at the 3, 5, and 10-minute intervals of recovery. (4) The 5-week high-altitude training significantly improved the athletes' VO_{2max}, enhancing their cardiopulmonary function and overall performance.
Conclusion: High-altitude training can effectively enhance blood oxygen saturation, facilitate rapid post-exercise heart rate recovery, improve VO_{2max}, and subsequently impact the athletes' physical recovery capacity.

Keywords: Altitude Training; Taekwondo; Recovery Ability; Maximum Oxygen Consumption

Introduction

Taekwondo is a highly competitive and spectator sport that has been popularized in more than 100 countries around the world since the International Olympic Committee made it an international sport in 1980 (Gao et al., 2008). The sport combines strength, speed, endurance, tactics, and psychology, and hit points or knock out your opponent to determine the winner. In the official game, the offensive and defensive actions are completed in a very short period requiring athletes to have a high phosphate energy supply; the official game and rest time totaling 8 minutes, and 120 seconds of continuous exercise per round requires athletes to have good glycolytic and aerobic metabolic exercise capacity. However, in the 60 seconds of the interval the stronger aerobic capacity to replenish energy buffer blood lactic acid buildup to restore physical fitness. Intermittent hypoxic exposure was originally used as an adaptive training to prepare for competitions at high altitudes, but nowadays it is more often used as a training tool for high-level athletes to improve their sports performance and increase their overall athletic ability, and to give new stimuli in a hypoxic environment by changing the altitude of the training to further enhance physical functions (Hinckson et al., 2005; Chapman & Levine., 2007). Studies (Hobbins et al., 2021) have shown that the special environment of hypoxia in the altitudes plus a certain intensity of exercise load stimulation will lead to the body facing "double" hypoxic stimulation, resulting in changes in arterial oxygen content leading to immediate changes in convective oxygen delivery, coupled with hypoxic exercise brings more unique challenges to the body's cardiovascular system. Hypoxic training at altitude improves the body's cardiopulmonary function and enhances hematological indicators without correspondingly increasing the mechanical load on the muscles and bones (Hobbins et al., 2021).

Given the characteristics of the sport, elite Taekwondo athletes should possess the ability to perform high-intensity activities repeatedly. Historically, to achieve a proficient muscular buffering capability to handle repeated and high-intensity motions, high-intensity interval training methods have been employed. However, a study of significant reliability revealed that a continuous six-week regimen of high-intensity intermittent hypoxic training can enhance key performance parameters in elite

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Taekwondo athletes (Chacón et al., 2020). Multiple physiological mechanisms, predominantly influencing the athlete's hematological parameters such as erythrocyte deformability, red cell membrane fluidity, and increased hemoglobin concentration, underlie the performance improvement post-altitude training (Zhu et al., 2008). Four weeks of intermittent hypoxic exposure significantly elevated blood lactate levels in elite Muay Thai athletes, indicating enhanced anaerobic energy supply and acid resistance. However, a greater reduction was observed in the $PaCO_2$ and HCO_3^- levels in the altitude training group compared to sea-level controls, suggesting potential alkalosis risks (Teng, 2009). Moreover, altitude training not only augments the oxygen-carrying capacity of athletes and the ability of hemoglobin to release oxygen in tissues but also enhances the athlete's aerobic power output.

As training research on the sport of taekwondo deepened, workers in the field of sports science realized that it was difficult to improve the athletic performance of taekwondo athletes using conventional training methods when individual athletic performance reached a plateau, and began to think about how to improve the athletic ability of taekwondo athletes scientifically and effectively. Increasing the training load will improve the risk of injury while changing to a new training environment and using different training methods can increase the excitement of the athletes in the training process. Conventional training methods combined with a low oxygen environment will produce new stimuli to the body, which can break the original balance, and after training adapt to produce a new balance to improve sports performance. Although the theory of altitude training has been proposed and applied for more than half a century, it is not a new training method, according to the available data, it is very rare for taekwondo athletes to train at altitude, and there is a lack of experimental evidence on what changes in physiological functions occur after taekwondo athletes train at altitude. Therefore, this study was conducted to investigate the possible changes in the physiological functions of taekwondo athletes who train at high altitudes and to provide new ideas for the development of training programs.

Objective

Assessing whether altitude training can enhance the physiological functions of male elite Taekwondo athletes to improve their performance, determining the potential impact of altitude training on the recovery ability and VO_{2max} of elite Taekwondo athletes, to offer strategic references for future training plan formulation.

Literature Review

Altitude training started in the 1950s and has been around for more than half a century. Initially, it was proposed by the Soviet sports science that people from the plains could adapt to the hypoxic environment by going to the altitude, and the adaptation could be better stimulated by certain intensity of exercise, which could effectively strengthen the respiratory and cardiovascular systems of the human body and thus improve the aerobic metabolic capacity (Faulkner et al., 1967). After decades of development, altitude (hypoxic) training can be divided into five categories, mainly including Live High-Train High (LHTH), Live High-Train Low (LHTL), Live Low-Train High (LLTH), Intermittent Hypoxic Training (IHT), and Repeated Sprint Training in Hypoxia (RSH). Intermittent Hypoxic Training (IHT) and Repeated Sprint Training in Hypoxia (RSH), each of which has its advantages and disadvantages for improving athletes' performance. The training period at high altitude is divided into 3 phases; ① the adaptation phase, to facilitate the athlete's adaptation to high altitude, is 7-10 days at moderate altitude (1500m), depending on the total duration of the training cycle and the frequency of hypoxic exposure (Bigard et al., 1991); ② Low-intensity training phase, the main task of this period is to gradually increase the intensity of training, and eventually reach the same intensity as the horizontal altitude, usually lasting 21 days; ③ Recovery and Preparation for Return to Sea Level, this phase will last for 5 days to recover and gradually reduce the volume and intensity of training in preparation for returning to the plains for competition (Millet et al., 2010).

Taekwondo originated in the ancient Korean Peninsula and is an ancient competitive sport as well as one of the world's leading combat arts. It was originally learned for warfare, self-defense, and physical fitness. In 1988, Taekwondo was introduced as a performance sport at the Olympic Games in Seoul, Korea, and in 1992, it became an official sport at the 25th Barcelona Olympic Games (Serina

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and Lieu., 1991). Approximately 80% of the scoring moves in taekwondo are kicks, and the main targets of attacks include the head, chest, and abdomen, so participants must wear protective equipment during training and competition (Chuang, et al 1992). This sport is mainly powered by glycolytic and phosphagen energy supply systems, which require athletes to have not only short and fast explosive power but also good aerobic endurance (Little et al., 2011).

Altitude training, also known as intermittent hypoxic training, is a training method that enhances an athlete's ability to transport oxygen through the bloodstream by discontinuously using Normobaric or hypobaric hypoxic stimuli to achieve performance enhancement goals (Levine, 2002). Heart rate, Exercise heart rate refers to the number of times the heart beats during physical activity. It is commonly used to monitor exercise intensity and assess physical recovery capacity. Blood oxygen saturation, Blood oxygen saturation refers to the percentage of oxygen-bound hemoglobin in the blood compared to the total capacity of hemoglobin to bind oxygen. It represents the concentration of oxygen in the blood and is an important physiological parameter of the respiratory system. Monitoring blood oxygen saturation can provide an estimation of lung oxygenation and hemoglobin's ability to transport oxygen. Maximal oxygen consumption, Maximal oxygen consumption, also known as maximal aerobic capacity or Maximum oxygen uptake (VO_{2max}), refers to the maximum amount of oxygen that a person can utilize during intense exercise involving large muscle groups over an extended period. It represents the highest level of cardiovascular and muscular oxygen utilization. Maximal oxygen consumption is typically measured in terms of the amount of oxygen consumed per unit of time, usually expressed as milliliters of oxygen per kilogram of body weight per minute (ml/kg/min). It is an important indicator of aerobic fitness and the body's ability to perform sustained, oxygen-dependent activities.

Based on publicly available research both domestically and internationally, there is a lack of studies concerning altitude training for Taekwondo athletes. However, Taekwondo as a sport demands extremely high physiological capabilities, requiring athletes to possess a variety of comprehensive skills. Hence, enriching training methodologies to enhance the physical qualities of Taekwondo athletes holds significant practical value.

Conceptual Framework

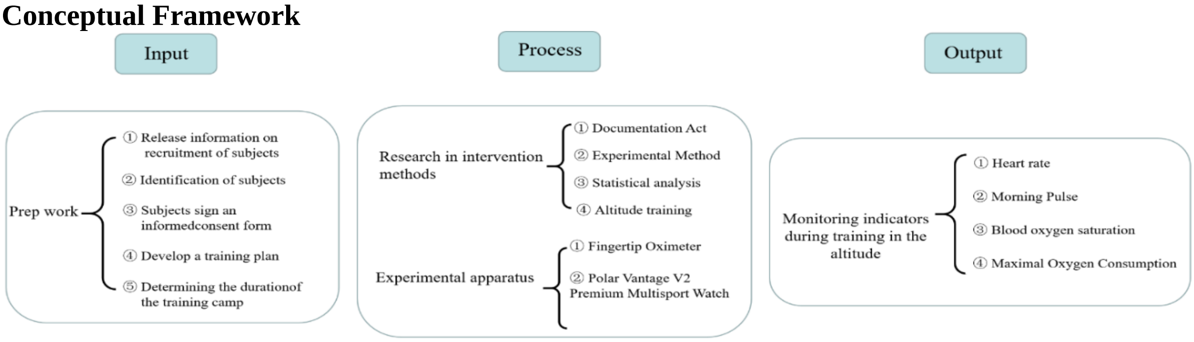

Figure 1. Conceptual framework

Methodology

The study employed a combination of literature review, mathematical statistics, and experimental methods, with a primary focus on experimental approaches. (1) Study Participants: The study participants were elite male Taekwondo athletes who resided in plain areas and had a minimum of 5 years of training and competitive experience. (2) Variables Measured: The variables measured included resting heart rate (morning pulse), blood oxygen saturation, exercise heart rate, and maximal oxygen consumption.

Population and sample

①Subjects recruitment: Subject recruitment information was released via the Internet and the G*Power software calculated that at least 19 subjects needed to be recruited for this study. The athletes tested were all from professional sports teams, and the subjects recruited were tested for athletic ability and interviewed and informed of possible risks before formal inclusion. As elite athletes are a special group, it was difficult to recruit enough subjects, and only 14 elite athletes who met the requirements

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were recruited for this study, which is a shortcoming of this study. Basic demographics of the 14 subject athletes: Mean age 19.30 ± 2.20; Mean height 174.62 ± 3.792; Mean body weights before and after training were; 61.78 ± 4.583, 60.29 ± 3.136.

②Inclusion criteria: The study population consisted of taekwondo athletes who were native to the plains. A total of 14 athletes were recruited to participate in plateau training, and all athletes had no plateau training experience in the last year and had ≥5 years of training and competition experience（demographic characteristics are shown in Table 1). Inclusion criteria: (1) all athletes were male; (2) no heavy training and no sports injury in the 48 hours before the test; (3) no history of smoking or alcohol consumption and no medication affecting cardiopulmonary function in the last six months; (4) all athletes agreed to the blood sample collection and signed the informed consent form for the test, and had the right to terminate the test if they felt unwell during the training period.

Research Tools

In this experiment, we observed the changes in heart rate, morning pulse, blood oxygen saturation, and maximum oxygen consumption of taekwondo athletes before, during, and after training. The equipment used includes the Yuwell Fingertip Oximeter, Polar Vantage V2 Premium Multisport Watch, and Bruce Max Aerobic Capacity Test Treadmills.

Training locations and training programs

The training site, DuoBa National Highland Sports Training Base in Qinghai Province, China, is at an altitude of 2,366 meters; its air density is only three-quarters of that of the plain, and the oxygen concentration is 20-40% lower than that of the plain. This training at high altitude will last for 5 weeks, see appendices 1-6 for a detailed training program.

Data Analysis

IBM SPSS Statistics 27 software was used to perform different statistics on the data collected in this study. Paired samples t-test to determine if the effects of maximal oxygen consumption, morning pulse, oxygen saturation, and heart rate were statistically significant after 5 weeks of plateau training, and the values obtained were expressed as mean ± standard deviation (□X ± S). When $p > 0.05$ indicates no significant difference, when $p < 0.05$ indicates a significant difference, and when $p < 0.01$ indicates a highly significant difference.

Results

1. Morning pulse

Figure 2A and Table 3 show the changes in morning heart rate before and after high-altitude training. It can be observed that during the 7-day training period at sea level (Week 1), the average morning heart rate was 59.65±3.04, remaining stable without significant fluctuations. After arriving at high-altitude areas (Week 2), the training intensity was lower than that at sea level during the first week of acclimatization. A slight downward trend in morning heart rate was observed on the 6th and 7th days. However, the average morning heart rate for the second week was 58.83±3.23, which was similar to that at sea level. The training intensity in the third and fourth weeks was comparable to that at sea level, with average morning heart rates of 58.39±3.28 and 58.28±3.51, respectively. The most significant decrease in morning heart rate occurred in the fifth week, with an average of 57.19±3.30, indicating a decrease of 2 beats per minute compared to sea level. A slight rebound was observed in the sixth week, with an average morning heart rate of 58.32±3.09. According to statistical analysis, the 5-week high-altitude training did not result in a statistically significant change in the morning heart rate of elite male Taekwondo athletes ($p>0.05$) compared to sea level. Throughout the entire training period, the changes in morning heart rate (Figure 2B) show a noticeable downward trend after 12 days of training. On the 35th day, the morning heart rate reaches its lowest point before experiencing a slight increase.

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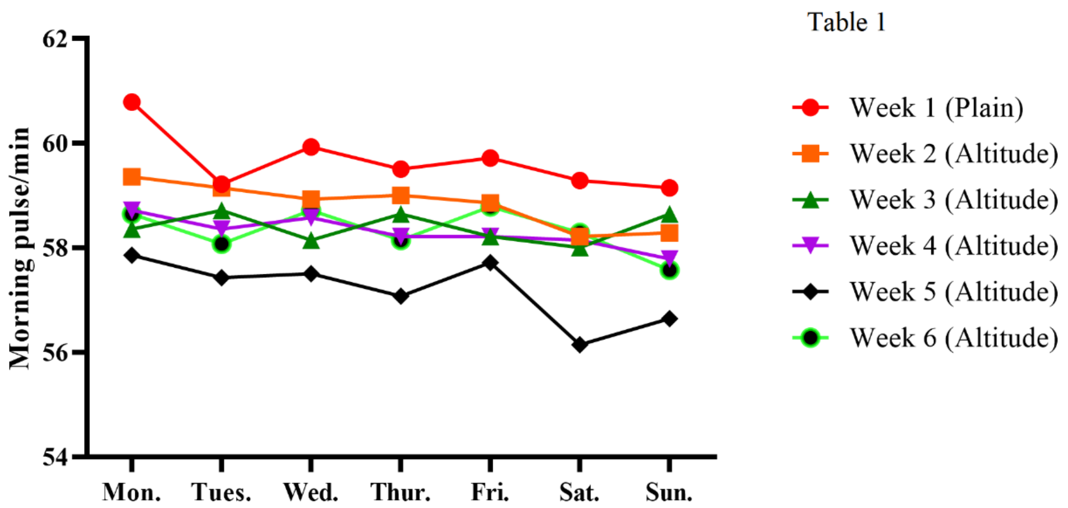

Figure 2 A. Morning pulse changes during altitude training

Note： Week 1 represents the baseline morning heart rate in the plain area. Week 2 shows the changes in morning heart rate after 1 week of adaptation to a high-altitude low-oxygen environment. Week 2 represents the changes in morning heart rate after 2 weeks of high-altitude training. Week 4 represents the changes in morning heart rate after 3 weeks of high-altitude training. Week 6 represents the changes in morning heart rate after 5 weeks of high-altitude training.

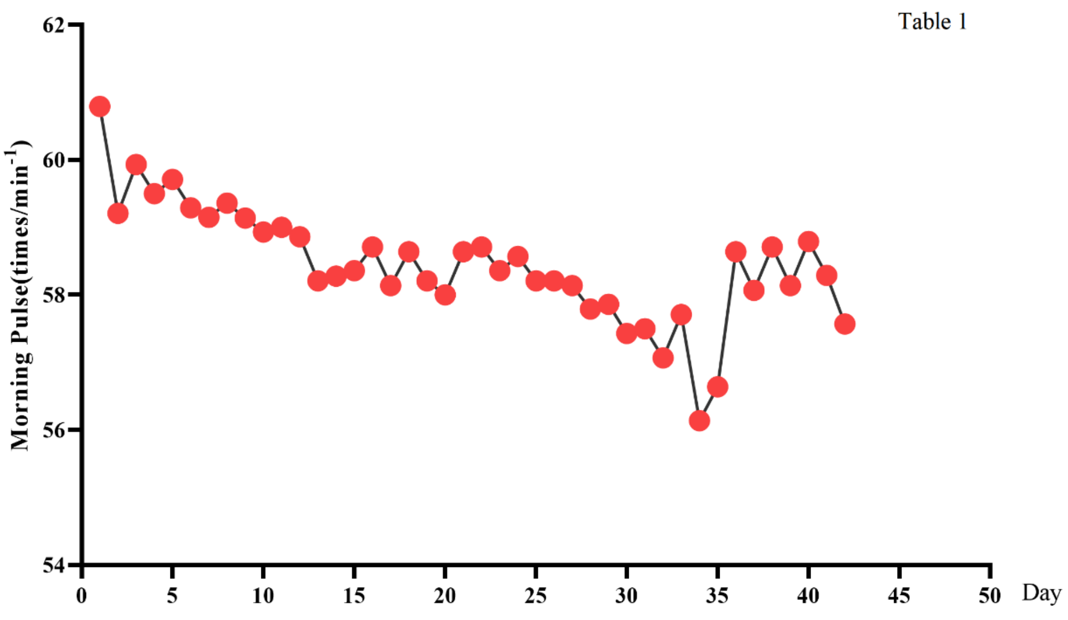

Figure 2 B. Changes in the morning heart rate of athletes during training in plain and high-altitude areas

Note： Changes in morning heart rate trend for elite male taekwondo athletes during the entire training period (42 days).

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Table 1. Morning pulse changes during altitude training

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Week 1	60.79±2.49	59.21±2.72	59.93±3.40	59.50±3.82	59.71±2.76	59.29±3.97	59.15±2.10
Week 2	59.36±3.00	59.14±4.01	58.93±3.39	59.00±3.23	58.86±2.74	58.21±3.07	58.28±3.20
Week 3	58.36±3.20	58.71±3.45	58.14±3.43	58.64±3.43	58.21±2.91	58.00±3.23	58.64±3.28
Week 4	58.71±4.49	58.36±2.73	58.57±3.96	58.21±3.07	58.21±3.87	58.14±2.98	57.79±3.49
Week 5	57.86±3.03	57.43±3.30	57.50±3.23	57.07±3.43	57.71±3.65	56.14±3.04	56.64±3.43
Week 6	58.64±3.25	58.07±2.81	58.71±2.73	58.14±3.04	58.79±3.04	58.29±3.54	57.57±3.23

Note： Data on morning pulse changes for the full training cycle, data presented as mean with standard deviation (mean ± sd).

2. SpO_2

Figure 3 and Table 2 show the changes in blood oxygen saturation before and after high-altitude training. According to statistical evidence, compared to the blood oxygen saturation at sea level, the 5-week high-altitude training increased the blood oxygen saturation of elite male Taekwondo athletes. Increases were observed in Week 2, Week 3, Week 4, and Week 6, but they were not statistically significant (p >0.05). In Week 5, there was a significant increase in blood oxygen saturation (p <0.0001). The average increase in blood oxygen saturation for athletes exposed to 4 weeks of low-oxygen stimulation was 3.51%.

Table 2

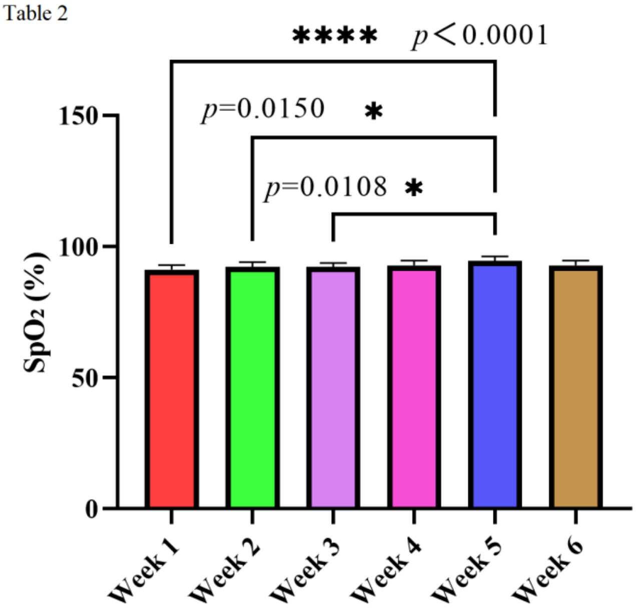

Figure 3. Changes in SpO_2 before and after training in the altitude

Note： Blood oxygen saturation changes before and after high-altitude training. Week 1 represents the baseline values in the plain area, Week 2 shows the blood oxygen saturation changes after 1 week of adaptation in the high-altitude low-oxygen environment, Week 2 displays the blood oxygen saturation changes after 2 weeks of high-altitude training, Week 4 presents the blood oxygen saturation changes after 3 weeks of high-altitude training, and Week 6 represents the blood oxygen saturation changes after 5 weeks of high-altitude training. *p < 0.05 indicates a statistically significant difference, **p < 0.01 indicates a significantly significant difference, and *p < 0.001 indicates an extremely

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significant statistical difference.

Table 2. Changes in SpO_2 before and after training in the altitude

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
SpO_2(%)	91.29±1.68	92.29±1.77	92.21±1.53	92.79±1.89	94.50±1.74****	92.86±1.83

Note： Data on SpO_2 changes for the full training cycle, data presented as mean with standard deviation (mean ± sd).

3. HR

Figure 4 and Table 3 show the changes in resting heart rate, maximum heart rate, and heart rate after 3, 5, and 10 minutes of recovery between training in the plain area and training in the high-altitude area. The resting heart rates before exercise for the first 10 minutes were 66.79±3.09, 66.79±3.19, 67.57±4.01, and 68.71±4.71, respectively, for both the plain and high-altitude conditions. There were no significant differences in resting heart rate between the plain and high-altitude conditions (p >0.05). The immediate post-exercise heart rates (maximum heart rates) were 178.86±2.35, 179.64±4.45, 180.43±3.06, and 179.57±3.18, respectively, for both the plain and high-altitude conditions. There were no significant changes in immediate post-exercise heart rate (maximum heart rate) between the plain and high-altitude conditions (p >0.05). The heart rates after 3 minutes of recovery were 120.79±5.58, 117.79±8.00, 110.57±8.90, and 110.57±7.85, respectively. In the fourth and sixth weeks, the heart rate recovery was significantly better compared to the first week in the plain area, and both the fourth and sixth weeks showed statistically significant differences (p <0.05). Compared to the plain area, the heart rate decreased by 8.46% after 3 minutes of recovery in the sixth week. The heart rates after 5 minutes of recovery were 110.36±6.03, 103.00±8.06, 101.00±9.07, and 97.71±8.09, respectively. Compared to the plain area, there was a slight decrease in heart rate in the second week, but it was not statistically significant (p >0.05). The fourth and sixth weeks showed statistically significant differences, and the heart rate decreased by 11.78% after 5 minutes of recovery in the sixth week. The heart rates after 10 minutes of recovery were 102.57±6.82, 91.64±6.96, 92.36±7.78, 89.50±6.21, respectively. The heart rate recovery after 10 minutes of recovery was better in the high-altitude area compared to the plain area, and all weeks showed statistically significant differences (p <0.05). Compared to the plain area, the heart rate decreased by 12.74% after 10 minutes of recovery in the sixth week.

Table 3

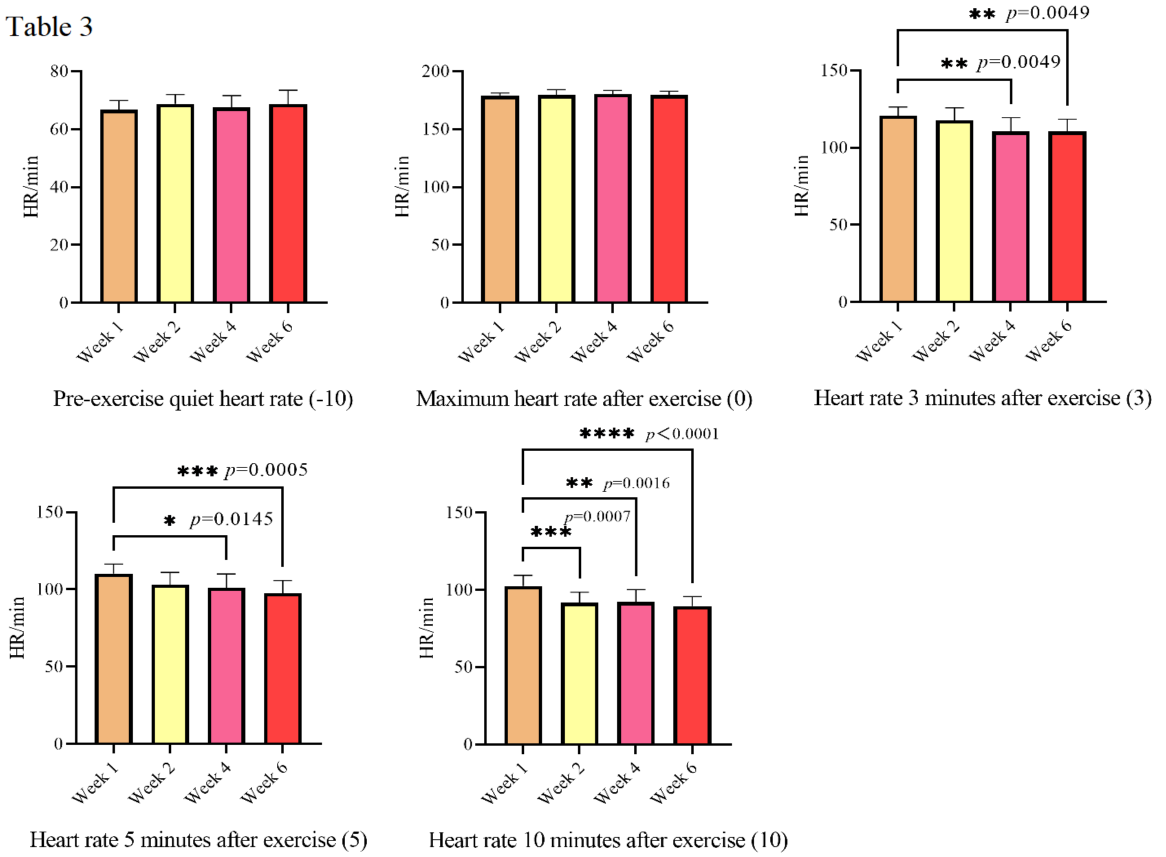

Fig 4. Heart rate changes before and after training in the altitude

Note: Heart rate changes before and after high-altitude training. Week 1 represents the baseline values in the plain area, Week 2 shows the heart rate changes after 1 week of adaptation in the high-altitude low-oxygen environment, Week 4 displays the heart rate changes after 3 weeks of high-altitude training, and Week 6 presents the heart rate changes after 5 weeks of high-altitude training. *$p < 0.05$ indicates a statistically significant difference, **$p < 0.01$ indicates a significantly significant difference, and *$p < 0.001$ indicates an extremely significant statistical difference.

Table 3. Heart rate changes before and after training in the altitude

	Week 1	Week 2	Week 4	Week 6
-10（min）	66.79±3.09	66.79±3.19	67.57±4.01	68.71±4.71
0（min）	178.86±2.35	179.64±4.45	180.43±3.06	179.57±3.18
3（min）	120.79±5.58	117.79±8.00	110.57±8.90**	110.57±7.85**
5（min）	110.36±6.03	103.00±8.06	101.00±9.07*	97.71±8.09***
10（min）	102.57±6.82	91.64±6.96***	92.36±7.78**	89.50±6.21****

Note： Data on HR changes for the full training cycle, data presented as mean with standard deviation (mean ± sd). -10 represents the resting heart rate during the first 10 minutes of training; 0 represents the immediate heart rate after training; 3 represents the heart rate 3 minutes after the end of training; 5 represents the heart rate 5 minutes after the end of training; 10 represents the heart rate 10 minutes after the end of training.

4. VO_{2max}

As shown in Figure 5 and Table 4, after 3 weeks of high-altitude training, the participants' maximum oxygen consumption (VO_{2max}) increased from 48.73±1.31 (ml/min/kg) to 50.43±1.26 (ml/min/kg), an increase of 3.49% with statistical significance (p <0.05). After 5 weeks of high-altitude

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training, the increase in VO2max was even more significant, with an increase from 48.73±1.31 (ml/min/kg) to 51.01±1.66 (ml/min/kg), representing a 4.68% increase and showing statistical significance (p <0.001).

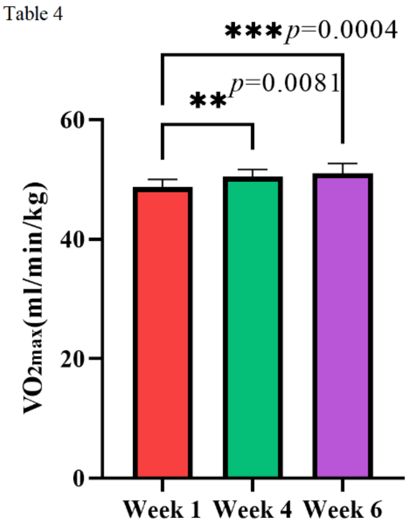

Fig 5. Changes in VO_{2max} before and after training in the altitude

Note： Changes in VO_{2max} before and after high-altitude training. Week 1 represents the baseline value in the plain area, Week 4 shows the VO_{2max} after 3 weeks of high-altitude training, and Week 6 represents the VO_{2max} after 5 weeks of high-altitude training. *p < 0.05 indicates a statistically significant difference, **p < 0.01 indicates a significantly significant difference, and *p < 0.001 indicates an extremely significant statistical difference.

Table 4. Changes in VO_{2max} before and after training in the altitude

	Week 1	Week 4	Week 6
VO_{2max}(ml/min/kg)	48.73±1.31	50.43±1.26**	51.01±1.66***

Note： Data on VO_{2max} changes for the full training cycle, data presented as mean with standard deviation (mean ± sd).

Discussion

The morning heart rate of athletes is an important physiological indicator that directly reflects their cardiovascular system function. A sudden increase in morning heart rate during the morning monitoring the day after training completion often indicates bodily fatigue. According to Kjaer's research, the morning heart rate of Danish elite male and female figure skaters was (53±2) times/min^{-1} and (58±3) times/min^{-1}, respectively (Kjaer & Larsson, 1992). In this study, the athletes' morning heart rate started to decrease after the fifth day of reaching the plateau, indicating an adaptive decline. Throughout the entire period of high-altitude training, the morning heart rate showed an overall downward trend, reaching its lowest point on the 35th day (56.14±3.04) times/min^{-1}, and the heart rate reserve correspondingly increased. Fifteen years ago, there was a publicly available study that found when athletes undergo high-intensity exercise stimulation in a high-altitude low-oxygen environment, their bodies undergo corresponding changes shortly after arriving at high altitude. Specifically, the increased heart rate leads to an increase in cardiac output at rest, while stroke volume shows no significant difference. This condition continues to occur in the following days (Battista et al., 2007). In this study, when the athletes arrived at the high-altitude region, the head coach did not implement the target training intensity for the first week but instead reduced the intensity of the training plan. This allowed the athletes seven days to adapt to the low-oxygen environment. As the athletes gradually adapted to the high-altitude hypoxic environment, the hypoxic condition within the body would be alleviated. This may be

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a reason why the athletes' morning heart rate continued to slowly decline in the later stages of training.

Blood oxygen saturation is an important physiological parameter that reflects respiratory function and the adequacy of oxygen in the body. It is known that blood oxygen saturation decreases with increasing altitude (Netzer et al., 2017). However, in this low-oxygen training process, the expected decrease in blood oxygen saturation did not occur. During the first three weeks of low-oxygen stimulation, the athletes' blood oxygen saturation remained similar to the measurements at sea level. It was in the fourth week of low-oxygen stimulation that a significant change in blood oxygen saturation was observed, which is consistent with the findings of a study by Saugy in 2016 (Saugy et al., 2016). Furthermore, a highly reliable study published by the American College of Sports Medicine also observed that exercise stimulation at moderate altitude increases the body's SpO2 (oxygen saturation), and the increase in blood oxygen saturation can significantly improve the quality of high-intensity training and potentially enhance adaptation to long-term training (Paradis-Deschênes et al., 2018). Finally, it should be emphasized that in this study, the first three weeks of "dual hypoxia" stimulation did not result in significant changes in blood oxygen saturation. A comparison between weeks revealed that the peak blood oxygen saturation occurred in the fourth week, which is consistent with the previous notion that 28 days is considered an optimal duration for high-altitude training (Millet et al., 2010).

During physical exercise, heart rate, as a fundamental and crucial physiological measurement, is frequently used to monitor the body's cardiovascular function. If the heart rate can quickly recover and reach the desired range, it holds long-term significance for an athlete's competitions or training plans (Mikus et al., 2009). Before starting exercise, determining the resting basal heart rate can not only assess whether the body is experiencing excessive fatigue at a certain stage but also evaluate the athlete's training level through monitoring. During exercise, the heart rate increases along with the metabolic level of the body. Within certain ranges, it reflects the intensity of the current exercise load and the extent to which the body's metabolism has reached. During the post-exercise recovery process, the regulation and recovery of heart rate are directly influenced by various recovery conditions. According to this study, there were no significant differences between the resting heart rate and the maximum heart rate during exercise. However, after completing exercise and resting for 3, 5, and 10 minutes, the athletes' heart rates significantly decreased, indicating a reduction in energy expenditure and enhanced cardiac pumping function (Schmitt et al., 2008). This indicates that the design of the training plan and the setting of exercise intensity in this study were reasonable, providing effective stimulation for the heart and lung functions and improving the body's recovery capacity (Katayama, 2004).

VO_{2max} is the most objective parameter for describing aerobic capacity, and genetics play a decisive role. In addition to innate genetic factors, changes in the external environment and systematic exercise training can significantly increase VO2max levels. Some researchers believe that the increase is unlikely to exceed 30% (Falgairette et al., 1993). The extent to which VO_{2max} can be improved varies depending on different training intensities, training frequencies, duration of each training session, training periods, initial activity levels, and even different muscle fiber types. However, this effect often diminishes when training is stopped. According to this study, there were individual differences in the increase of VO_{2max}, with the most significant change observed in athletes whose VO_{2max} increased from an initial value of 49.36 to 54.14, representing a 9.68% increase compared to the initial value. During exercise in a low-oxygen environment, the body faces external and internal hypoxia, leading to stress responses that enhance metabolism. Under the regulation of the nervous system, the respiratory system undergoes a series of changes. As exercise intensity increases, breathing becomes deeper and faster, and the ventilation capacity of the lungs gradually reaches its maximum limit. Periodic high-altitude training leads to favorable adaptations in lung function, resulting in improvements in cardiorespiratory function to varying degrees. Although this study observed significant improvements in VO_{2max} among elite male taekwondo athletes, other studies have shown that 4 weeks of high-altitude training does not affect VO_{2max} in endurance athletes (Julian et al., 2004). However, according to two highly reliable meta-analyses, high-altitude training or intermittent hypoxic stimulation does increase VO_{2max}, thereby influencing athletes' endurance performance and competition results (Bonetti & Hopkins, 2009; Brocherie et al., 2017). Looking at previous studies, training at moderate altitude has shown various benefits for athletes' physiological parameters and performance, with few negative reports of adverse effects. Therefore, it is recommended that elite male taekwondo athletes engage in periodic high-altitude training.

Conclusion

The author is required to compose a concise and coherent overview of the findings obtained from the investigation.

High-altitude training can effectively improve blood oxygen saturation, promote rapid post-exercise heart rate recovery, and enhance the maximum oxygen consumption of elite male taekwondo athletes, thus influencing their physical recovery ability.

	Pre-training	Post-training	Change（%）
VO_{2max}(ml/min/kg)	48.73±1.31	51.01±1.66***	4.68% ↑
SpO_2(%)	91.29±1.68	94.50±1.74****	3.52% ↑
Heart rate -10（min）	66.79±3.09	68.71±54.71	2.87% ↑
Heart rate 0（min）	178.86±2.35	179.57±3.18	0.39% ↑
Heart rate 3（min）	120.79±5.58	110.57±7.85**	-8.46% ↓
Heart rate 5（min）	110.36±6.03	97.71±8.09***	-11.46% ↓
Heart rate 10（min）	102.57±6.82	89.50±6.21****	-12.74% ↓

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