Effects of 6 weeks sub-plateau cold environment training on physical functional status and athletic ability in elite snowboarding parallel giant slalom athletes

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Objective: Either Hypoxic or cold environment has been shown to be useful in improving athletes' function and performance, while whether the combination of subalpine and cold circumstance was more effective is unclear. The present study aims to investigate the effects of 6 weeks of training in a sub-plateau cold environment on physical functional status and athletic ability among elite snowboarding parallel giant slalom athletes. **Methods:** Nine elite athletes (four males and five females) participated in the study. These All athletes underwent 6 weeks of high intensity ski-specific technical training (150min/session, 6-time/week) and medium-intensity physical training (120min/session, 6-time/week) prior to the Beijing 2021 Winter Olympic Games Test Competition. Physiological and biochemical parameters were collected from elbow venous blood after each two-week to assess the athletes' physical functional status. Athletes' athletic ability was evaluated by measuring maximal oxygen uptake, Wingate 30s anaerobic capacity, 30m sprint run and race performance before and after 6 weeks of training program. Repeated measures ANOVA was used to test the overall differences of blood physiological and biochemical indicators. For indicators with significant time main effects, post-hoc tests were conducted using the LSD method. A paired-samples t-test was used to analyse changes in athletic ability indicators before and after training. **Results:** (1) There was a significant overall time effect for red blood cell (RBC) and white blood cell (WBC) in males, as well as the percentage of lymphocytes (LY%), serum testosterone (T) and testosterone to cortisol ratio (T/C) in females ($p < 0.001$-0.015, $\eta_p^2 = 0.81$-0.99). In addition, significant time effect was also founding terms of blood urea (BU), serum creatine kinase (CK) and serum cortisol levels in both male and female athletes ($p = 0.001$-0.029, $\eta_p^2 = 0.52$-0.95). (2) BU and CK levels in males and LY% in females were all significantly higher at week 6 ($p = 0.001$-0.038), while WBC in males was significantly lower ($p = 0.030$). In addition, T and

T/C were significantly lower in females at week 2 compared to pre-training (*p* = 0.007, 0.008, respectively), while cortisol (C) was significantly higher in males and females at weeks 2 and 4 ($p_{(male)}$ = 0.015, 0.004, respectively; $p_{(female)}$ = 0.024, 0.030, respectively). (3) As for athletic ability, there was a noticeable increase in relative maximal oxygen uptake, Wingate 30s relative average anaerobic power, 30m sprint run performance and race performance in comparison to the pre-training (*p* < 0.001-0.027).**Conclusions:** 6 weeks of sub-plateau cold environment training could not only improve the physical functional status but also promote aerobic and anaerobic capacity for snowboarding parallel giant slalom athletes. Furthermore, male athletes gained more improvement of athletes' physical functional status and athletic ability when trained in sub-plateau cold environments.

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ABSTRACT

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Subject Exercise physiology; Environmental health; Kinesiology; Public Health; Sports Medicine

Keywords Sub-plateau training; Cold environment; Snowboarding; Athletes; Parallel giant slalom; Physical functional status; Athletic ability

INTRODUCTION

In general, trained in hypoxic environment of the plateau with the same training load is more stimulating to the organism and the results are more effective than the same condition in the plain area *(Gao et al., 2019; Park et al., 2020)*. Previous studies have confirmed that altitude or hypoxic training can increase the blood volume and hemoglobin (Hb) levels of athletes *(Bonne et al., 2014; Tannheimer et al., 2010; Wachsmuth et al., 2013)*, improve the body’s ability to buffer acids such as blood lactic acid (BLA) *(Ramos-Campo et al., 2018; Shaw et al., 2020)*, and increase the number of capillaries and mitochondria in skeletal muscle *(Hoppeler et al., 2003; Vogt et al., 2001)*. At present, studies concerning the effects of plateau or hypoxic training on athletes’ physical functional status and athletic ability mainly focused on summer physical events such as rowing, swimming, cycling, middle-distance running, boxing and sparring *(Gao, Gao & Meng, 2018; Garcia et al., 2020; Millet & Brocherie, 2020)*. Athletes in these events have improved their physical functional status and athletic ability through plateau or hypoxic training and have achieved excellent athletic results in major competitions at home and abroad *(Arezzolo et al., 2020; Gao et al., 2019; Gao, Gao & Meng, 2018; Viscor et al., 2018; Zhao, Li & Lu, 2008)*.

The snowboarding parallel giant slalom is a competitive event with a single race time of about 35-45 s. It is based on glycolytic metabolism for energy, and is most often trained and competed in high altitude mountains *(Li, Chen & He, 2018; Zebrowska et al., 2012)*. Normally, the training environment for snowboarding parallel giant slalom is extremely harsh and athletes are subjected to the lack of oxygen and cold at high altitudes. Compared to the plain environment, the athletes’ cardiopulmonary regulation *(Saltykova, 2016; Zafeiratou et al., 2021)*, thermoregulation

(Castellani et al., 2010; Castellani & Young, 2016), energy metabolism *(Lichtenbelt et al., 2014; Marino, Sockler & Fry, 1998)*, immune system *(LaVoy, McFarlin & Simpson, 2011)* and neuroendocrine system *(Cui et al., 2014; Makinen et al., 2008)* are significantly different in the hypoxic and cold environment. It has been shown that when exercising in cold environments, the body' s convective heat dissipation increases due to the thermal gradient of temperature conduction, energy expenditure increases, and the body' s heat production and dissipation become imbalanced, resulting in a drop in body temperature, increased muscle viscosity and reduced physical functional status *(Luo, 2005; Weng, Wang & Lin, 2019)*. Some studies have reported that athletes in winter sports experience greater heat and water loss during exhalation, with water loss of 32 mg/L during exercise at temperatures below -16 °C, proportional to the amount of ventilation *(Sue-Chu, 2012)*. Exercise in cold environments also causes the endocrine and immune systems to respond, leading to immunosuppression *(Cicchella, Stefanelli & Massaro, 2021; Mourtzoukou & Falagas, 2007)*. Prolonged and repeated cold exposure also increases the activity of the neuroendocrine system, releasing more neurotransmitters and causing reduced sympathetic activation and increased parasympathetic activation *(Dan et al., 2002; Makinen et al., 2008; Marino, Sockler & Fry, 1998)*. Therefore, based on the respective effect of hypoxia and cold, it can be assumed that the physiological responses of the body systems in combined settings will be more acute and complex.

At present, research on physical functional status and athletic ability in winter sports is mainly related to cross-country skiing, biathlon, Nordic biathlon and other long-distance physical events, while less research has been conducted on the physical functional status of athletes in skill-led or speed-led snowboarding sports such as snowboarding parallel giant slalom, snowboarding U-course tricks, snowboarding slopestyle tricks, snowboarding big jump and snowboarding obstacle chase. Numerous studies have found that altitude training significantly increases the red blood cell and haemoglobin levels of cross-country skiers and biathletes, which in turn promotes higher maximum oxygen uptake and improved performance *(Bădău et al., 2016; Christoulas, Karamouzis & Mandroukas, 2011; Sandbakk & Holmberg, 2017; Wehrlin, Marti & Hallen, 2016)*. In view of the specificity of the oxygen-deficient cold environment of the altitude in winter, it is unknown that how this form of circumstance affects physical functional status and athletic ability of athletes. Hence, this study aims to investigate the effect of 6 weeks cold sub-plateau cold environment on the physical functional status and athletic ability of elite snowboarding parallel giant slalom athletes in the cold sub-plateau environment. The results of the current study may provide theoretical and practical guidance for other snowboarding sub-sports and other winter skill-dominated speed sports.

MATERIALS AND METHODS

Participants and ethical principles

A total of 9 elite athletes from the Chinese snowboarding parallel giant slalom national team (4 males and 5 females) participated in this study. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Shanghai University of Sport

(Ethics number: 102772020127082; Date of approval: 27 October 2020). All athletes were clear about the content and process of the test and signed an informed consent form. Demographic information about the subjects is shown in Table 1.

Training arrangements

This training program was conducted 6 weeks before the Olympic Test Competition held in Chongli District (altitude: 1878-2031 m), Hebei Province, China. The athletes were trained six days per week (Monday to Saturday) from 9:00 am to 11:30 am in a cold outdoor sub-plateau environment (average temperature: -10 °C ~ -20 °C) with high intensity training in specialized skiing techniques. Each athlete made 8-10 skiing trips (around 560 m/trip) per morning. In the afternoon (15:00 to 17:00), the athletes underwent medium to high intensity physical training at 1500 m above sea level. The training programs of physical training consisted of low to medium intensity dynamic stretching, aerobic training, medium to high intensity explosive training in upper and lower body, and stability training. The training was followed by a conditioning break on Saturday afternoon and Sunday. The weekly schedule for athletes' specialized skiing techniques training and physical training is shown in Table 2.

Blood index test and procedure

Elbow venous blood was collected from athletes at 7:00 am in the morning at the following timepoints: pre-training, week 2, week 4 and post-training. Blood sample was collected from the elbow vein using an ethylene diamine tetraacetic acid antico-agulated vacuum blood collection tube for white blood cell (WBC), the percentage of lymphocytes (LY%), the percentage of mononuclear cells (MO%), the percentage of neutrophils (NE%), red blood cells (RBC) and haemoglobin (Hb) testing (Beckman Coulter AC Tdiff-2 haemocytometer, USA). 2.5 ml of elbow vein blood was collected using a sodium heparin anticoagulated vacuum blood collection tube for analyzing blood urea (BU), creatine kinase (CK), testosterone (T), cortisol (C) (Beckman Coulter Access 2 Immunosav System fully automated biochemistry analyzer, USA).

Athletic ability assessment

30 m sprint run test

The 30 m sprint run test was performed before and the second day after the 6 weeks of sub-plateau cold environment training. In the test, all athletes had a 15-minute warm up session, and then got ready for the 30 m sprint run test. When hearing the command "Run", all athletes ran across the 30 m finish line as fast as possible and the time taken for each athlete was recorded. Each athlete was tested twice with a five minutes interval and the fastest time was taken as the final test result.

Wingate 30-second anaerobic athletic ability test

The Wingate 30-second anaerobic athletic ability test was conducted 10 minutes after 30 m sprint run test. Before the test, the athletes warmed up on a power bike (Monark Ergomedic 894E, Sweden) with a 60 W load for 10 min and then rode as hard as they can for 30 seconds. During the test, the computer automatically recorded athletes' peak cycling power and relative peak cycling power, which was used as an indicator of the anaerobic capacity. The same procedure was conducted again two days after the 6 weeks of sub-plateau cold environment training.

Maximal oxygen uptake assessment

The athlete' s maximum oxygen uptake in the morning 3 days prior to winter sub-plateau training. Prior to the test, athletes wore a cardiorespiratory fitness tester mask (Cortex Metamax 3b, Germany) and then warm up on a power bike (Lode Corival Cept, Netherlands) for 10 minutes at a load of 60 W. The test was conducted with an initial load of 90 W for the males and 60 W for the females then the load was enhanced by 30 W every 2 minutes until athletes were too exhausted to continue. The same procedure was conducted again three days after the 6 weeks of sub-plateau cold environment training.

Race performance

A snowboarding parallel giant slalom competition was held in the morning 1 day prior to sub-plateau cold training. Before the formal competition, each athlete performed two warm-up skis. In the official test, all athletes stood in the front of the start line and crossed the finish line as fast as they could. And the time taken by each athlete was recorded as the final result. On the 5th day after the 6 weeks of sub-plateau cold environment training, the athletes were tested again in the same way.

Statistical analysis

All data were processed and analyzed using IBM SPSS Statistics 26.0 software (SPSS Inc., Chicago, USA). Data normality was verified using the Shapiro-Wilk test. Repeated measures ANOVA was used to test the overall differences of blood physiological and biochemical indicators during the 6 weeks of sub-plateau cold environment training. Post hoc pairwise comparisons of differences between different time points of the same physiological and biochemical index were performed using the LSD method. A paired-samples t-test was used to analyze the variability of athletic ability indicators before and after training in a sub-plateau cold environment. Independent samples t-test was used to compare the differences between groups for the same indicators. Effects sizes (ES) in the form of partial eta squared (η_p^2) were used from ANOVA output. Data are presented as means and standard deviations ("Mean ± SD"), and "$p < 0.05$" was considered as a significant difference, "$p < 0.01$" was considered as a very significant difference.

RESULTS

Physical functional status

RBC and Hb

As shown in Table 3, there was a significant time effect in the male' s RBC throughout the 6 weeks of training in the sub-plateau cold environment ($p < 0.001$, $\eta_p^2 = 0.99$), while no significant changes were found in Hb of both sexes and RBC of female athletes ($p = 0.096$, 0.377, 0.685, respectively; $\eta_p^2 = 0.99$, 0.22, 0.11, respectively). Compared to pre-training, male' s RBC was only higher at week 4 ($p = 0.05$), while there was no significant difference at week 2 and 6 ($p = 0.632$, 0.774, respectively). In addition, female' s RBC and Hb were significantly lower than level of males at week 2, 4 and 6 (all $p_{\text{week 2}} = 0.001$; $p_{\text{week 4}} = 0.001$, 0.003, respectively; all $p_{\text{week 6}} < 0.001$).

WBCs and WBC subpopulation cells

In Table 4, there was a significant overall time effect for male' s WBC and female's LY (%) throughout the six weeks of training in the sub-plateau cold environment ($p = 0.005$, 0.015, respectively; $\eta_p^2 = 0.95$, 0.81, respectively), while no significant changes were seen in LY (%) for male and WBC for female ($p = 0.489$, 0.511, respectively; $\eta_p^2 = 0.23$, 0.17, respectively). Similarly, the insignificance was also found in MO (%) and NE (%) for both sexes ($p_{\text{male}} = 0.575$, 0.703, $\eta_p^2 = 0.19$, 0.14; $p_{\text{female}} = 0.145$, 0.920, $\eta_p^2 = 0.90$, 0.04). Compared to the pre-training, male' s WBC decreased significantly at week 2 and week 6 ($p = 0.021$, 0.030, respectively), while there was no significant difference at week 4 ($p = 0.420$). In addition, female LY (%) increased throughout the training period, with LY (%) increasing significantly at week 4 and 6 in comparison to level of pre-training ($p = 0.030$, 0.038, respectively), and significantly higher at week 6 compared to week 2 ($p = 0.001$). As for the difference between the gender, female's NE (%) was significantly higher than that of the male at week 6 ($p = 0.007$), while no significant differences were observed between groups for other indicators ($p = 0.073$-0.688).

BU and CK

As can be seen in Table 5, there was a significant time effect on BU and CK of both male and female throughout the 6 weeks of training ($p_{\text{male}} = 0.013$, 0.029, $\eta_p^2 = 0.68$, 0.52; $p_{\text{female}} = 0.006$, 0.001, $\eta_p^2 = 0.94$, 0.95). In the paired comparisons within the group, CK was significantly lower of female at week 2 compared to pre-training ($p = 0.023$), and BU and CK levels were significantly higher at week 6 in both male and female compared to pre-training, week 2 and week 4 ($p_{\text{Bu(male)}} = 0.001$, 0.001, 0.012, respectively; $p_{\text{CK(male)}} =0.017$, 0.015, 0.003, respectively; $p_{\text{Bu(female)}} = 0.007$, 0.009, 0.003, respectively; $p_{\text{CK(female)}} =0.009$, 0.003, 0.043, respectively). However, male and female's BU and CK were not significantly differ at other time points within the group ($p = 0.136$-1.000). In addition, among the differences between the gender, BU was significantly lower in female than in male at week 4 ($p = 0.049$), and CK was significantly lower in female at week 2 and 6 ($p = 0.029$, 0.026, respectively). However, there were no significant differences in BU and CK for female compared to male at other time points ($p = 0.203$-0.624).

T, C and T/C

It is clear from Table 6 that there was a significant temporal effect on C for both male and female as well as T and T/C for female throughout the 6 weeks of training in the sub-plateau cold environment ($p_{C(male)} = 0.002$, $\eta_p^2 = 0.98$; $p_{C(female)} = 0.001$, $\eta_p^2 = 0.98$; $p_{T(female)} < 0.001$, $\eta_p^2 = 0.98$; $p_{T/C(female)} = 0.001$, $\eta_p^2 = 0.96$), whereas no significant changes were seen in T and T/C for male ($p_{T(male)} = 0.741$, $\eta_p^2 = 0.12$; $p_{T/C(male)} = 0.667$, $\eta_p^2 = 0.13$). Compared to pre-training, C was higher throughout the training for both male and female, with it being significantly higher at weeks 2 and 4 ($p_{(male)} = 0.015, 0.004$, respectively; $p_{(female)} = 0.024, 0.030$, respectively), but no significant difference was observed at week 6 ($p = 0.155$-0.823). In addition, female' s T and T/C decreased significantly at week 2 compared to the pre-training ($p = 0.007, 0.008$, respectively), then gradually increased at weeks 4 and 6 ($p = 0.369$-0.629), and were significantly higher at week 6 than at week 2 ($p < 0.001$, $p = 0.021$, respectively). Furthermore, for comparison between the gender, both T and T/C were significantly lower in female than in male throughout the training in the sub-plateau cold environment (all $p_{week2} = 0.002$; all $p_{week4} < 0.001$; $p_{week6} = 0.009, 0.002$, respectively).

Athletic ability

In Figure 1, after 6 weeks of intervention, the relative maximal oxygen uptake (Figure 1A) and snow race performance (Figure 1D) of both male and female, as well as the 30m sprint performance (Figure 1C) of the female were very considerably higher than pre-training ($p = 0.000$-0.007). In addition, Wingate 30s relative mean power for both male and female athletes (Figure 1B) and 30m sprint performance for male subjects (Figure 1C) were both noticeably higher than pre-training ($p = 0.013$-0.027). As for the gender comparisons, the male athletes were very significantly higher than the female athletes in all indicators of athletic ability ($p = 0.000$-0.001).

DISCUSSION

This study was the first to monitor blood physiological and biochemical parameters and athletic ability of snowboarding parallel slalom athletes during training in a sub-plateau cold environment over a 6-week period. And the aim of this study was to investigate the effects of sub-plateau cold environment training on the physical functional status and athletic ability of snowboarding parallel slalom athletes. This study shows that after 6 weeks of high intensity specialized skiing techniques training and medium to high intensity physical training in the sub-plateau cold environment, the elite parallel giant slalom athletes maintained a good functional state of their body systems in general. In addition, the study found that 6 weeks of sub-plateau hypoxic cold environment training not only improves the physical functional status of the elite parallel giant slalom athletes, but also promotes significant improvements in specific athletic ability and competition performance. Furthermore, this study found that training in the sub-plateau cold environment was more effective in improving physical functional status and athletic ability in male athletes than in female athletes.

Effects of 6 weeks of sub-plateau cold environment training on the oxygen transport system of elite parallel giant slalom athletes

Snowboarding parallel giant slalom, its competition single trip skiing time is about 35-45 s, is mainly based on glycolytic metabolism for energy supply, and is mostly training and competition in cold alpine environments. Compared to plains and ambient environments, there are significant differences in the physiological functions of the human body when exercising in altitude and cold environments *(Acosta et al., 2018; Brajkovic, Ducharme & Frim, 1998)*. Normally, when training in an altitude environment, the body is more deeply stimulated than in a plain environment due to the relatively low oxygen concentration of the altitude environment *(Ramos-Campo et al., 2018; Schmutz et al., 2010)*. RBC and Hb reflect the oxygen-carrying capacity of the blood and the body' s functional status, and their reserve levels in the body reflect the body' s aerobic metabolism. A number of studies have shown that plateau training can improve the aerobic metabolic capacity of athletes by increasing the density of skeletal muscle capillaries and the number of mitochondria, increasing blood volume and total Hb, enhancing the ability of skeletal muscle to buffer BLA, oxidize fatty acids and the efficiency of energy use during exercise *(Saunders et al., 2013; Tannheimer et al., 2010)*. In this study, the RBC and HB of both male and female athletes were higher than pre-training in the other weeks of the 6 weeks sub-plateau cold environment training, except for the female athletes whose RBC and HB were slightly lower at week 6, suggesting that the 6 weeks of training promoted the production of RBC and increased the body' s RBC reserve, thereby possibly contributing to the enhancement of maximum oxygen uptake. In addition, the changes in RBC and Hb of the athletes in this study, mean that the oxygen transfer capacity of the subjects has improved in contrast to the pre-training level, which is consistent with other' studies observing the increase of Hb level and oxygen-carrying capacity of the Hb after plateau training *(Bonne et al., 2014; Nummela et al., 2021; Wachsmuth et al., 2013)*. Furthermore, this study found that both RBC and HB were significantly lower in female athletes than in males throughout the 6 weeks of training in a sub-plateau cold environment, suggesting that there are significant gender differences in human RBC and HB production. Lastly, this study also found that RBC and Hb levels of athletes were significantly higher than those engaging in summer Olympic sports *(Ma, Gao & Li, 2019)*, which was probably attributed to the fact that cold hypoxic environment of the plateau stimulated the body' s erythropoietin (EPO) response *(Kasperska & Zembron-Lacny, 2020; Wisniewska, Ploszczyca & Czuba, 2020)*.

Effects of 6 weeks of sub-plateau cold environment training on the immune system of elite parallel giant slalom athletes

In general, the acute exposure to high altitude causes an inflammatory response in the body and reduces the immunity of the body, while long-term altitude training can improve the stability of the body's immune system *(Aksel, Corbacioglu & Ozen, 2019; Gallagher & Hackett, 2004; Hackett & Roach, 2001)*. Several studies have shown that short or intermittent plateau hypoxia exposure rapidly activated the sympatho-adrenal system to regulate the activity of immune cells and the secretion of related cytokines *(Jung, Kim & Park, 2020; Park et al., 2020; Svendsen, Hem & Gleeson, 2016)*, while longer plateau training or hypoxia exposure may affect the immune system by regulating the proliferation and differentiation of immune cells via the hypoxia-inducible factor (HIF) signalling pathway *(Domingo-Gonzalez et al., 2017; Taylor & Colgan, 2017; Wang, Huang & Gao, 2021)*. It has been shown that proliferative capacity of the body' s T lymphocytes and the activity of NK cells are suppressed at the beginning of plateau or hypoxia exposure *(Facco et al., 2005; Morabito et al., 2016)*, the activity of NE cells is increased *(Chouker et al., 2005; Wang et al., 2019)* and the body experienced a certain inflammatory response. In contrast, after prolonged hypoxia and plateau training, the expression of CD55 and CD59 on the surface of leukocytes and CD4/CD8 of T lymphocytes increases, which in turn improves the regulatory function of the body' s immune system *(Wang, Huang & Gao, 2021)*. Theoretically, when training in a hypoxic environment on the plateau, the lack of oxygen combined with the training load causes enough stimulation to the athlete' s organism, and if the cold is added to the stimulation, the organism will be subjected to a more serious burden, and the function of the organism' s systems will undergo more complex changes, but little research has been reported on these changes. Hence, it has been demonstrated that when training in hypoxic and cold environments at plateau, the body may experience a series of physiological stress responses similar to those seen when training at plateau or in hypoxic environments, such as a decrease in WBC and LY% reflecting immune function, and an increase in NE% reflecting inflammation during early training in cold environments on the plateau *(Thompson-Torgerson et al., 2007)*. In our study, WBC and LY% were lower at week 2 of training in a sub-plateau hypoxic cold environment prior to the Olympic Games Test Competition compared to pre-training, while MO% and NE% were higher than pre-training, indicating that the athletes' immune system function was somewhat suppressed and the body experienced a certain inflammatory response during the first 2 weeks of training. Moreover, from week 4 to 6, LY% level gradually increased and was higher than pre-training at the end of the sub-plateau hypoxic cold training, which suggested the body' s recovery process. On the other hand, WBC increased at week 4 and remained lower than pre-training at the end of the sub-plateau hypoxic cold training, while MO% and NE% gradually decreased from week 4 to the end of the training. This is generally consistent with Gao et al. *(Gao et al., 2018)* and wang *(Wang, Huang & Gao, 2021)* reported the changes in indicators such as WBC, LY%, MO% and NE% in rowers during hypoxic training. Therefore, in the training period, the elite parallel giant slalom athletes' bodies adapted to the hypoxic cold environment of the sub-plateau and the training load, the stability of the regulatory functions of the body systems was improved, the immunity of the body gradually recovered and the inflammatory response progressively reduced.

Effects of 6 weeks of sub-plateau cold environment training on the musculature of elite parallel giant slalom athletes

Previous studies have found that human body becomes more unadapted to training at the early stage of sub-plateau training, which was shown by increased protein and amino acid catabolism and BU and CK levels *(Wang, Gao & Gao, 2013; Yu et al., 2016)*. As the body adapts to the plateau training environment, the BU and CK levels gradually stabilize and change regularly with the training volume or intensity *(Li & Wang, 2017; Zhang, Gao & Zhu, 2017)*. In our study, CK for both genders and BU for male were lower at week 2 compared to pre-training, which is consistent with Wang et al. *(Wang, Gao & Gao, 2013)* who reported the same change of blood BU and CK levels in rowers when training at plateau for longer than 1 week. As for this phenomenon, this may be related to the adaptation of the athletes' body to the hypoxic environment of the plateau and the improved ability of the body to withstand the training load. In addition, the BU and CK levels of both male and female in this study were significantly higher at the end of week 6 compared to pre-training and week 4, which may be related to the greater stimulation of the athlete' s body caused by 6-week multiple competition-intensity specific skiing technique training. Further analysis revealed that although the BU and CK of the elite parallel giant slalom athletes were significantly higher at the end of week 6 of training, they were still in the normal range. Because of BU and CK did not significantly exceed the normal range during the last 2 weeks of high-intensity training, and the body remained stable in terms of the functional status and muscle fibers. This indicates that training adaptation ability of the athletes' body also improved during this process although the stimulation of the training load on the body gradually deepened with the increase of the training load. Previous studies have shown that prolonged hypoxic exposure can promote HIF-1 gene expression and induce adaptive changes in the body to the hypoxic environment and improve the body' s exercise performance *(Cimino et al., 2012; Rocco et al., 2014; Yeo, 2019)*. As a result, prolonged and repeated cold stimulation can promote the body' s adaptation through adrenergic and non-adrenergic mechanisms and reduce the physiological fluctuations of the body's physiological fluctuations during exercise in cold environments *(Castellani & Young, 2016; Saltykova, 2016; Young & Castellani, 2007)*.

Effects of 6 weeks of sub-plateau cold environment training on the endocrine system of elite parallel giant slalom athletes

T has the function of promoting anabolism in the body, inhibiting the breakdown of muscle glycogen and activating glycogen synthesis, increasing muscle glycogen and creatine phosphate reserves, and enhancing the body' s immunity and resistance to bacterial infection *(Chiu et al., 2015; Ouergui et al., 2016)*. In contrast, the main role of C is to accelerate the breakdown of fats and proteins into sugars, and accelerate the body's catabolism *(Ouergui et al., 2016; Pesce et al., 2015)*. T and C reflect the body's anabolism and catabolism from different perspectives, and can be used to assess the effect of training load on an athlete' s functional status. The training loads in different environments stimulate the body differently. When exercising in hypoxic or cold environments on the plateau, human body was not only stimulated by the training load, but also experienced the hypoxia and cold stimuli *(Ramos-Campo et al., 2018; Schmutz et al., 2010)*. One study by Wang *(Wang, 2020)* has showed that elite modern pentathletes had a high anabolic capacity and peak serum T levels during the sub-plateau adaptive training phase of moderate intensity training, while a certain decrease in serum T occurred during the increased sub-plateau training load phase, which suggested that changes in serum T in athletes were associated with training load during the subalpine period. *Zhao, Li & Lu (2008)* showed that serum T and C of male weightlifters decreased significantly at the beginning of sub-plateau training compared to the pre-training period, increased slightly at the middle of training period, and decreased slightly at the end of sub-plateau training, and that serum T and C were lower throughout the sub-plateau training period compared to the pre-training period. The study by *Zhao, Li & Lu (2008)* concluded that this was related to the greater maladjustment of the body to the training load and plateau environment during sub-plateau training in male weightlifters. In our study, serum T and T/C levels were significantly lower in both male and female during the first 2 weeks of training in a sub-plateau cold environment compared to the pre-training period, while serum C was significantly higher compared to the pre-training period. These results suggested that the training load at the beginning of training in a sub-plateau cold environment combined with the hypoxic and cold plateau environment caused some pressure to the participants' body. From 4 to 6 week, the athletes' serum T and T/C did not decrease significantly due to the increase in training load, but gradually increased. This suggested that as the training progressed, the body systems gradually adapted to the sub-plateau cold environment. Moreover, this further suggested that the anabolic levels of the elite parallel giant slalom athletes have improved and the physical function status was in a higher level after 6 weeks of training in a sub-plateau cold environment.

Effects of 6 weeks of sub-plateau cold training on the aerobic metabolic capacity of elite parallel giant slalom athletes

The existed studies concerning plateau or hypoxic training have demonstrated that plateau or hypoxic training lasting 3 weeks or more could increase the body' s RBC and Hb counts, improve the body' s oxygen transport capacity, enhance the body' s removal of BLA, thereby improving the body' s aerobic metabolic capacity *(Bonne et al., 2014; Saunders et al., 2013; Shaw et al., 2020; Tannheimer et al., 2010; Wachsmuth et al., 2013)*. It has been shown that plateau or hypoxic training not only improves indicators related to oxygen transport and oxygen utilization capacity (e.g. EPO, Hb, RBC, 2, 3-DPG), but also promotes maximal oxygen uptake and specific aerobic athletic ability *(Gao et al., 2018; Liu & Zhang, 2015; Wang, Gao & Gao, 2013)*. In our study, after 6 weeks of training in a sub-plateau cold environment, elite parallel slalom athletes showed a significant increase in their relative maximum oxygen uptake levels. The data suggested that 6 weeks of specialized skiing technique training and physical training in a sub-plateau cold environment could improve the aerobic metabolism capacity. Additionally, this trend was consistent with the changes of RBC and Hb levels. On the other hand, as athletes' blood RBC and Hb levels remained stable and high after 6 weeks of training in a sub-plateau hypoxic cold environment, as well as the significant increase in maximum oxygen uptake. This was also consistent with the findings of *Wang, Gao & Gao (2013)* that sub-plateau training could improve the rowers' RBC and Hb levels and improve their aerobic metabolism capacity. Therefore, it could be concluded that 6 weeks of sub-plateau cold environment training was effective in improving the aerobic metabolism capacity of athletes in snowboarding parallel giant slalom.

Effects of 6 weeks of sub-plateau cold environment training on anaerobic metabolic capacity in elite parallel giant slalom athletes

Some studies have shown that plateau or hypoxic training not only enhance the body' s aerobic metabolism capacity, but also promotes the body' s anaerobic metabolism capacity *(Bădău et al., 2016; Christoulas, Karamouzis & Mandroukas, 2011; Holmberg, 2015)*. Hypoxia can induce the expression of HIF-1 and HIF-1-related genes *(Cimino et al., 2012; Yeo, 2019)*. As a DNA-binding protein, HIF-1 induces an increase in the expression of several genes, including glycolytic metabolism enzymes, which in turn promotes adaptation to hypoxic environments *(Tang & Jiang, 2004)*. *Semenza & Wang (1992)* showed that both EPO-synthesizing Hep3B cells and non-EPO-synthesizing HeLa cells were induced by hypoxia to increase mRNA transcription of three key enzymes of glycolytic metabolism, aldolase A (AL-DA), phosphofructokinase (PFK) and pyruvate kinase (PK). Therefore, it can be suggested that hypoxia can promote an increase in glycolytic metabolic enzymes induced by hypoxia via the induction of HIF-1 expression. Studies by *Wang (2013)* and *Li (2014)* showed that hypoxic training stimulated the body more deeply and improved BLA levels of athletes compared to training in a normoxic environment. Both their studies confirmed that 3 and 4 weeks of hypoxic training can improve anaerobic power levels in boxing and sparring athletes who are mainly fed by anaerobic glycolytic metabolism and promote the improvement of athletes' specific athletic ability. In addition, some studies have shown that 4 weeks of hypoxic training can significantly improve the levels of all indicators of the Wingate 30 s anaerobic work test in aerobic and cycling athletes, and can promote the reduction of BLA and CK levels *(Li, 2020; Ma et al., 2013)*. In our study, subjects had significant improvements in anaerobic exercise capacity such as Wingate 30s anaerobic power levels and 30 m sprint runs, as well as significant improvements in competition performance, indicating that 6-week training was beneficial to improving anaerobic metabolism and increase competitive performance.

Conclusions

Six weeks of high intensity specialized skiing technique training and medium-to high-intensity physical training in a sub-plateau hypoxic cold environment can im-prove the physical functional status, aerobic and anaerobic capacity of elite snowboarding parallel giant slalom athletes. The decrease of the immunity and anabolism ability would appear at the early stages of training session. Furthermore, male athletes gained more improvement of athletes' physical functional status and athletic ability when training trained in sub-plateau cold environments.

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Table 1(on next page)

Basic information of athletes

Notes: Values are presented as Mean ± SD.

Table 1 Basic information of athletes.

Gender	Age (years)	Height (cm)	Weight (kg)	Training experience (years)
male	26.75 ± 4.03	178.75 ± 3.50	73.63 ± 2.87	12.25 ± 3.86
female	26.40 ± 3.85	168.80 ± 8.98	61.40 ± 4.93	14.00 ± 4.53

Notes:

Values are presented as Mean ± SD.

Table 2 (on next page)

The schedule of 6-week training program of elite snowboarding parallel giant slalom athletes in the sub-plateau cold environment prior to the Olympic Test Competition

Notes: Strength training mainly included explosive strength training for the upper and lower limbs, stability training for the lower limbs and core stability training for the trunk.

Table 2 The schedule of 6-week training program of elite snowboarding parallel giant slalom athletes in the sub-plateau cold environment prior to the Olympic Test Competition.

Week	Specialized skiing techniques training		Physical training							
	Total skiing distance (m)	**Training intensity**	**Aerobic warm-up (minutes)**	**Training intensity**	**Dynamic stretching (minutes)**	**Training intensity**	**Strength training (minutes)**	**Training intensity**	**Aerobic running (minutes)**	**Dynamic stretching (minutes)**
Week 1	26880	high	90	low	90	low to medium	270	low to medium	90	low
Week 2	26880	high	90	low	90	low to medium	360	low to medium	90	low
Week 3	33600	high	90	low	90	low to medium	360	low to medium	90	low
Week 4	33600	high	90	low	90	low to medium	360	low to medium	90	low
Week 5	22400	high	90	low	90	low to medium	300	high	90	low
Week 6	14000	Highest	90	low	150	low to medium	300	low to medium	90	low

Notes:

Strength training mainly included explosive strength training for the upper and lower limbs, stability training for the lower limbs and core stability training for the trunk.

Table 3(on next page)

The changes of RBC and Hb in peripheral blood during 6 weeks sub-plateau cold environment training

Notes: [a] significant changes compared to pre-training ($p < 0.05$), ** very significant changes compared to male ($p < 0.01$).

Table 3 The changes of RBC and Hb in peripheral blood during 6 weeks sub-plateau cold environment training.

Weeks	RBC ($\times10^{12}$/L)		Hb (g/L)	
	Male (n = 4)	Female (n = 5)	Male (n = 4)	Female (n = 5)
pre-training	5.42 ± 0.12	4.55 ± 0.33	167.00±5.89	144.20±7.95
Week 2	5.48 ± 0.14	4.59 ± 0.21**	167.50±5.07	146.00±6.67**
Week 4	5.54 ± 0.12[a]	4.61 ± 0.25**	168.75±4.86	147.40±8.41**
Week 6	5.46 ± 0.09	4.49 ± 0.16**	167.50±4.20	142.80±5.76**
Overall effect of *p*-value	< 0.001	0.685	0.096	0.377
ES (η_p^2)	0.99	0.11	0.99	0.22

Notes:

[a] significant changes compared to pre-training ($p < 0.05$), ** very significant changes compared to male ($p < 0.01$).

Table 4(on next page)

The changes in peripheral blood WBC and WBC subpopulations during 6 weeks sub-plateau cold environment training

Notes: [a] significant changes compared to pre-training ($p < 0.05$), [b] significant changes compared to week 2 ($p < 0.05$), [*] significant changes compared to male ($p < 0.05$).

Table 4 The changes in peripheral blood WBC and WBC subpopulations during 6 weeks sub-plateau cold environment training.

Weeks	WBC (×10⁹/L)		LY (%)		MO (%)		NE (%)	
	Male (n = 4)	Female (n = 5)	Male (n = 4)	Female (n = 5)	Male (n = 4)	Female (n = 5)	Male (n = 4)	Female (n = 5)
pre-training	5.96±0.81	6.41±2.38	47.58±4.71	32.39±7.81	5.18±0.78	5.66±0.65	45.33±4.31	52.92±10.55
Week 2	4.84±0.19[a]	6.34±1.81	44.43±8.48	37.40±5.65	6.05±1.82	5.66±0.94	47.40±6.73	53.68±5.46
Week 4	5.39±0.53	6.42±2.15	46.68±6.32	40.22±5.51[a]	5.10±0.29	5.34±0.93	45.98±5.91	51.48±7.45
Week 6	4.98±0.29[a]	5.80±1.27	48.53±4.52	47.02±2.61[ab]	5.08±0.55	5.46±0.72	44.70±5.05	51.46±4.80[*]
Overall effect of *p*-value	0.005	0.511	0.489	0.015	0.575	0.145	0.703	0.920
ES (η_p^2)	0.95	0.17	0.23	0.81	0.19	0.90	0.14	0.04

Notes:

[a] significant changes compared to pre-training ($p < 0.05$), [b] significant changes compared to week 2 ($p < 0.05$), [*] significant changes compared to male ($p < 0.05$).

Table 5 (on next page)

The changes of BU and CK in peripheral blood during 6 weeks sub-plateau cold environment training

Notes: [a] significant changes compared to pre-training ($p < 0.05$), [b] significant changes compared to week 2 ($p < 0.05$), [c] significant changes compared to week 4 ($p < 0.05$), * significant changes compared to male ($p < 0.05$).

Table 5 The changes of BU and CK in peripheral blood during 6 weeks sub-plateau cold environment training.

Weeks	BU (mmol/L)		CK (u/L)	
	Male (n=4)	Female (n=5)	Male (n=4)	Female (n=5)
pre-training	5.27±0.74	4.17±0.36	111.75±4.64	84.60±6.45
Week 2	5.10±0.92	4.32±0.33	108.50±12.29	72.00±6.83[a*]
Week 4	5.40±1.02	4.17±0.27[*]	115.75±13.56	97.00±30.47
Week 6	6.02±1.02[abc]	5.67±0.35[abc]	141.75±20.53[abc]	113.20±12.98[abc*]
Overall effect of *p*-value	0.013	0.029	0.006	0.001
ES (η_p^2)	0.68	0.52	0.94	0.95

Note:

[a] significant changes compared to pre-training ($p < 0.05$), [b] significant changes compared to week 2 ($p < 0.05$), [c] significant changes compared to week 4 ($p < 0.05$), [*] significant changes compared to male ($p < 0.05$).

Table 6(on next page)

The changes of T, C and T / C in peripheral blood during 6 weeks sub-plateau cold environment training

Notes: [a] significant changes compared to pre-training ($p < 0.05$), [b] significant changes compared to week 2 ($p < 0.05$), [*] significant changes compared to male ($p < 0.05$), [**] very significant changes compared to male ($p < 0.01$).

Table 6 The changes of T, C and T / C in peripheral blood during 6 weeks sub-plateau cold environment training.

Weeks	T (ng/dl)		C (ug/dl)		T/C	
	Male (n = 4)	Female (n = 5)	Male (n = 4)	Female (n = 5)	Male (n = 4)	Female (n = 5)
pre-training	753.75±252.34	42.20±2.69[**]	15.97±1.56	17.41±1.29	48.72±19.25	2.48±0.27[**]
Week 2	707.00±132.43	33.40±2.89[a**]	17.35±1.44[a]	20.02±1.67[a]	41.09±7.12	1.70±0.19[a**]
Week 4	764.50±222.11	38.80±6.11[**]	17.63±1.05[a]	19.40±0.89[a]	43.50±12.53	1.96±0.23[**]
Week 6	753.25±235.21	41.40±3.70[b**]	16.47±2.37	19.89±4.70	47.90±21.65	2.24±0.43[b**]
Overall effect of *p*-value	0.741	0.000	0.002	0.001	0.667	0.001
ES (η_p^2)	0.12	0.98	0.98	0.98	0.13	0.96

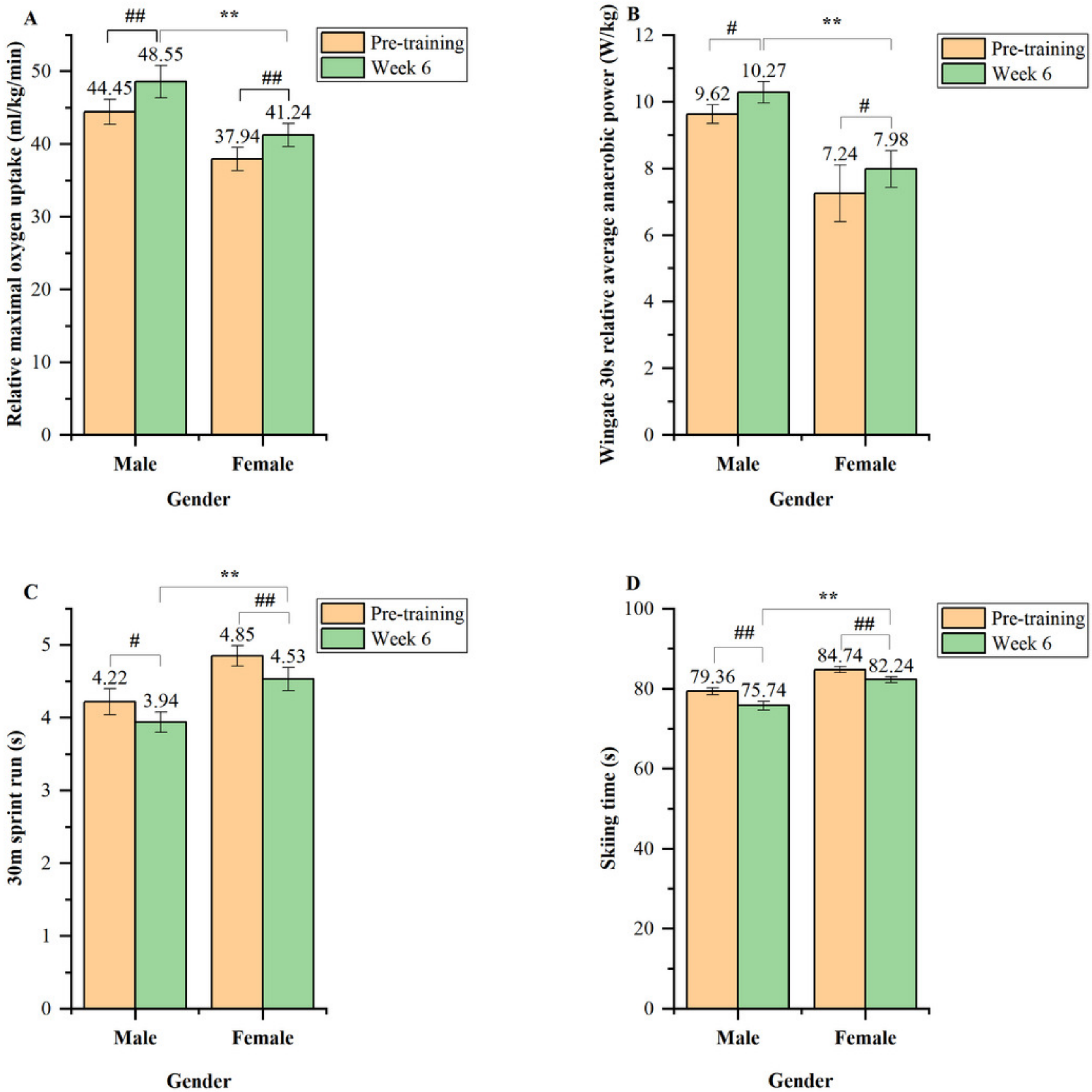
Notes:

[a] significant changes compared to pre-training ($p < 0.05$), [b] significant changes compared to week 2 ($p < 0.05$), [*] significant changes compared to male ($p < 0.05$), [**] very significant changes compared to male ($p < 0.01$).

Figure 1

Figure1. The changes of athletic ability involving relative maximal oxygen uptake (A), Wingate 30s relative average anaerobic power (B), 30m sprint run performance (C) and race performance (D) after 6 weeks of sub-plateau cold environment training.

Notes: $^{\#}$ Significant difference compared to pre-training (*P* < 0.05), $^{\#\#}$ very significant difference compared to pre-training (*P* < 0.01), ** very significant difference compared to male (*P* < 0.01).


A
Relative maximal oxygen uptake (ml/kg/min)
##
**
##
44.45
48.55
37.94
41.24
Pre-training
Week 6
Male
Female
Gender
B
Wingate 30s relative average anaerobic power (W/kg)
#
**
#
9.62
10.27
7.24
7.98
Pre-training
Week 6
Male
Female
Gender
C
30m sprint run (s)
**
##
#
4.22
3.94
4.85
4.53
Pre-training
Week 6
Male
Female
Gender
D
Skiing time (s)
**
##
##
79.36
75.74
84.74
82.24
Pre-training
Week 6
Male
Female
Gender