Performance and biological response of middle-power under hyperbaric hyperoxic conditions in judo athletes – pilot studies

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Authors' Contribution:
A Study Design
B Data Collection
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D Manuscript Preparation
E Funds Collection

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Abstract

Background and Study Aim: Judo athletes are required to compete at maximum performance for 4-5 min in most competitions. In addition, various energy supply mechanisms are used in judo because it requires a proper combination of complex and competition-specific muscle strength due to its competitive characteristic. However, considering the competition-time glycolysis, middle-power is thought to be the main mechanism that is utilized. In recent years, hyperbaric oxygen therapy (HBO), which is useful for recovering physical function, has been reported as a training device. Although no effect has been observed in high-power training, performance is shown to be significantly improved in 30-s middle-power training. Therefore, we set up 60-s middle-power training, similar to a judo match, under normobaric normoxia (NN) and hyperbaric hyperoxia (HH) environments. The purpose of this study is knowledge about the performance of judo athletes and them biological response of a normal pressure, normal oxygen environment (normobaric normoxia, NN) and hyperbaric high oxygen environment (hyperbaric hyperoxia, HH) while exerting middle-power for 60 seconds.

Material and Methods: This study targeted 10 participants. The measurement items were average work (watt) and peak rotation speed as performance indexes, and body weight, heart rate (HR), the blood lactate concentration, and peripheral oxygen saturation (SpO2) as physiological indexes.

Results: Performance exhibited under HH conditions was higher than that under NN conditions because the average total work amount was significantly higher in the HH group with no decrease in peak rotation speed.

Conclusions: Considering the suppression of the exercise-associated decrease in oxygen saturation, and the maintenance of the oxygen utilization capacity of the body at a high level under HH conditions, it is highly possible that HH contributes to higher performance.

Keywords: exercise load experiments • judo match • specific hypoxic chamber • training

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Performance – *noun* the level at which a player or athlete is carrying out their activity • either in relation to others or in relation to personal goals or standards [18].

Tactics – *plural noun* the art of finding and implementing means to achieve immediate or short-term aims [18].

Acid – *noun* a chemical substance that is able to dissolve metals [18].

Load – *noun* **1.** a weight or mass which is supported **2.** the force that a body part or structure is subjected to when it resists externally applied forces **3.** the amount of something • usually weight • that a body part can deal with at one time [18] – the **3** meaning in this article.

Training load – "A simple mathematical model of training load can be defined as the product of qualitative and quantitative factor. This reasoning may became unclear whenever the quantitative factor is called 'workload volume' or 'training volume' interchangeably with 'volume of physical activity'. Various units have been adopted as measures i.e. the number of repetitions • kilometres • tons • kilocalories • etc. as well as various units of time (seconds • minutes • hours) (...) As in the real world nothing happens beyond the time • the basic procedure of improvement of workload measurement should logically start with separation of the time factor from the set of phenomena so far classified together as '*workload volume*'. (...) Due to the fact that the heart rate (HR) is commonly accepted as the universal measure of workload intensity • the product of effort duration and HR seems to be the general indicator of *training load* defined as the amount of workload. It is useful in analyses with a high level of generality. (...) In current research and training practice the product of effort duration and HR was referred to as conventional units' or further calculations have been made to convert it into points." [19 • p. 238].

Placebo effect – *noun* the apparently beneficial effect of telling someone that he or she is having a treatment • even if this is not true • caused by the hope that the treatment will be effective [17].

INTRODUCTION

Currently, more than 200 countries are members of the International Judo Federation (IJF), and activities, such as games and dissemination are being carried out in various regions. Even though Jigoro Kano invented judo in 1882, today, it is well-known worldwide, and there are many people enthusiastic about learning judo.

In judo competitions, there are two kinds of rules: the *Kodokan Judo Match Referee Regulations*, and the *IJF Match Referee Regulations*. Since there are differences in the scoring of skills, penalties, and presence or absence of overtime between these two, it is necessary to change tactics depending on the tournament being held [1-5]. In addition, the Kodokan Judo match referee rules stipulate that the match time should be between 3 to 20 min [6].

On the other hand, various rule revisions have been made to develop competitive judo from a global perspective after the *IJF Refereeing Regulations* were enacted in 1967. The rules were revised for an appropriate match time, and from 2018-2020, match times were required to be 4 min for both men and women.

Today, with the internationalization of competition in judo, the IJF refereeing rules have become widespread in international competitions. The All-Japan Judo Championship, which is the highest-level major tournament in Japan, had applied the *Kodokan Judo Match Referee Regulations* until 2010. From 1948 to 1950, at the beginning of the tournament, the match time was set to 15 min, and the final match was set to 20 min [7]. However, since the acceptance of the IJF referee rules (common consent) in 2011, the match time is set to 5 min. It is important to consider time when organizing tactics in a match and it is no exaggeration to say that it greatly affects the outcome [8]. In other words, judo athletes need to perform at their best during the 4-5 minutes required by most current competitions.

According to the textbook of the Japan Sports Association, when exercising, the form of exercise is divided into high-power (≤30 s), middle-power (30 s to 3 min), and low-power (≥3 min), and there is a difference in the supply form of energy [9]. In middle-power, the subjective exercise intensity (RPE) is considered to be the highest because lactic acid accumulates as a metabolite using the glycolytic ATP supply mechanism. In judo, various energy supply mechanisms are used because it is necessary to exert appropriate complex muscle strength due to the characteristics of the competition, but considering the game-time glycolysis, middle-power is considered the most used.

To date, with the advancement of science, many training devices have been developed and new training methods have been established. Hyperbaric oxygen therapy (HBO), which has been used for the purpose of recovering physical function, has also been studied as a training equipment. According to a report by Takezawa et al. [10], there is no difference in performance during a 10-s high-power performance test in a 100% oxygen environment with a concentration of 1.3 atm, but there is at 1.5 atm. The high-pressure and high-oxygen environments have been shown to support higher exercise performance than a normal environment during middle-power performance for 30 s under a 100% oxygen-concentration environment [11].

Therefore, in this study, we considered the result [12] that the average match time for men and women including the "waiting" time during judo competitions is 5: 24.52 min. The purpose of this study is knowledge about the performance of judo athletes and them biological response of a normal pressure, normal oxygen environment (normobaric normoxia, NN) and hyperbaric high oxygen environment (hyperbaric hyperoxia, HH) while exerting middle-power for 60 seconds.

MATERIAL AND METHODS

Participants

The participants were 8 healthy male and 2 female university students (total: 10 participants) who practiced high-intensity judo on a daily basis (Table 1). They provided advance informed consent in writing after we fully explained the purpose of the study, details of the experiment and risks associated with it, protection of privacy, and freedom to refuse to participate and withdraw at any time.

Study design

Research design and experimental environment

In this study, conducted exercise load experiments on the same participant under two different environmental conditions. A single-blind method was used to eliminate the placebo effect. Exercise load experiments under both environmental conditions

Table 1. Physiological characteristics of the participants.

Variable	Mean & SD
Age (yrs.)	19.2 ±1.0
Height (cm)	170.1 ±10.1
Weight (kg)	81.0 ±18.9
Hart rate (beat/min)	61.4 ±6.1
Predict VO_2max (ml/kg/min)	49.5 ±4.7

Anaerobic power (or **capacity)** – *noun* the maximum amount of energy that can be produced by anaerobic metabolism [18].

Pyruvic acid – *noun* a chemical formed in living cells when carbohydrates and proteins are metabolized 18].

Lactic acid – *noun* a sugar that forms in cells and tissue • and also in sour milk • cheese and yoghurt [18].

were carried out with intervals of one week as a washout period. The participants were urged to get enough sleep and rest after avoiding vigorous exercise and alcohol intake the day before the exercise load experiment.

The two environmental conditions used in this study. All experiments were performed in the same chamber with two different conditions: NN, normobaric normoxia; HH, hyperbaric hyperoxia; FiO_2, inspired fraction of oxygen; PB, barometric pressure; PiO_2, inspired pressure of oxygen. The inspired fraction of oxygen (FiO2) was 20.9% under NN conditions and 100% under HH conditions. The atmospheric pressure (PB) was 754 mmHg under the NN condition and 1113 mmHg under the HH condition. As a result, the partial pressure of inspired oxygen was 147.8 mmHg under the NN condition and 1093 mmHg under the HH condition (Figure 1).

Each exercise load experiment was conducted under two environmental conditions in the same artificial chamber. The chamber was made of iron with a width of 1,500 mm, depth of 2,000 mm, and height of 1,900 mm. A chamber that could sufficiently handle pressurisation of 1131 mmHg was used. During the exercise load experiment, inspiratory gas was supplied from a gas cylinder whose composition had been adjusted in advance via a regulator (Cayman1180400259, Johnson Outdoor Inc., Wisconsin, U.S.A.), and exhaled gas was discharged into the chamber through a duct equipped with a backflow prevention device. Ventilation was through a scuba diving mask (GULL MANTIS FULLFACE GM-1582, Tokyo, Japan). The intake gas composition under the NN condition comprised of an oxygen concentration of 20.9%, carbon dioxide concentration of 0.06%, and nitrogen concentration of 79.04%; the HH condition comprised of only oxygen at 100% concentration. Under HH conditions, the air compressor outside the chamber (Rocking Piston Type Dry Pumps DOP-80SP, ULVAC Co. Ltd., Kanagawa, Japan) was pressurised by the airflow outside so that the target air pressure (1131 mmHg) was reached in approximately 10 min. The pressurisation speed was thus set. The barometric pressure during the exercise load experiment under HH conditions was maintained by continuous monitoring using a barometric pressure sensor (ZSE30AF-C & L-NM, SMC,Tokyo, Japan), and a constant value was obtained by the experimenter outside the chamber manually fine-tuning the air compressor. According to the High Pressure Occupational Safety and Health Regulations, it is obligatory to control the amount of oxygen exposure so that the pulmonary oxygen toxicity unit (UPTD) is ≤600 per day and ≤2500 per week [13]. The HH

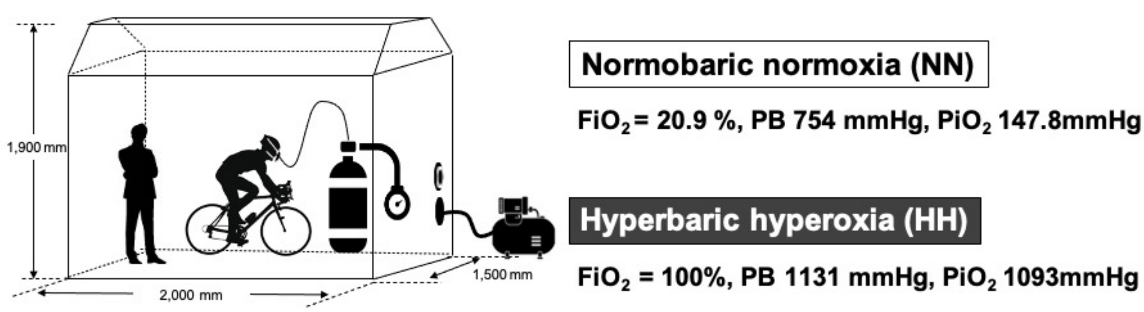

Figure 1. The chamber specification and experimental environment profiles.

condition used in this study exposed the participant to 1.5 atm 100% oxygen concentration for approximately 9 min. When these values are applied to the formula and calculated, it becomes 155.82, and there is no safety issue if the exposure is done only once.

$$UPTD = t \times [(PO_2 - 0.5) / 0.5]^{0.83}$$

The chamber temperature and relative humidity during the exercise load experiment were set to 24°C and 60%, respectively, using a room air conditioner (CU-225CF, Panasonic Co. Ltd., Osaka, Japan).

Exercise load experiment

The exercise load experiment was a pedalling exercise using a bicycle ergometer (POWERMAX-VII, Konami Sports Life Co., Ltd., Tokyo, Japan). The protocol for measuring performance required the participants to perform 3 sets of 60-s full-power pedalling exercises with a 2-min break between sets. The break between sets was done by sitting at rest on the saddle of the bicycle ergometer. The pedal load was set to 50% of the 'middle-power training load value' recommended from the results of the default program 'anaerobic power test' equipped with the bicycle ergometer, conducted in the preliminary experiment (Figure 2).

Measurement items

The measurement items were average work (watt) and peak rotation speed as performance indexes, and body weight, heart rate (HR), and peripheral oxygen saturation (SpO_2) as physiological indexes. A pulse oximeter (POD-3, Pacific Medico, Saitama, Japan) was used for measuring the HR and SpO2; Lactate ProTM2 (Lactate Pro 2, Arkray, Tokyo, Japan) was used to measure the blood lactate concentration, and blood samples were collected by fingertip puncture.

Statistical analysis

All the data obtained are shown as means and standard deviations (SD or ±). A paired t-test was used for analysis. In addition, the performance index was analysed using a paired two-way analysis of variance (ANOVA) with environmental conditions and the number of sets as factors. The statistical analysis software, JMP (ver.11.0, SAS Institute Inc.), was used for statistical analysis, and the significance level was set to $p<0.05$.

RESULTS

Performance index

Average workload

On the paired two-way ANOVA with environmental conditions and the number of sets as factors, no interaction was observed ($p = 0.896$), and no difference was observed in the overall main effect (Figure 3).

Figure 4 shows the results on calculating the total average work amount obtained from sets 1 to 3 under the NN and HH conditions. On t-testing the total average work between the two environments, the HH condition showed a significantly higher value than the NN condition ($p = 0.001$).

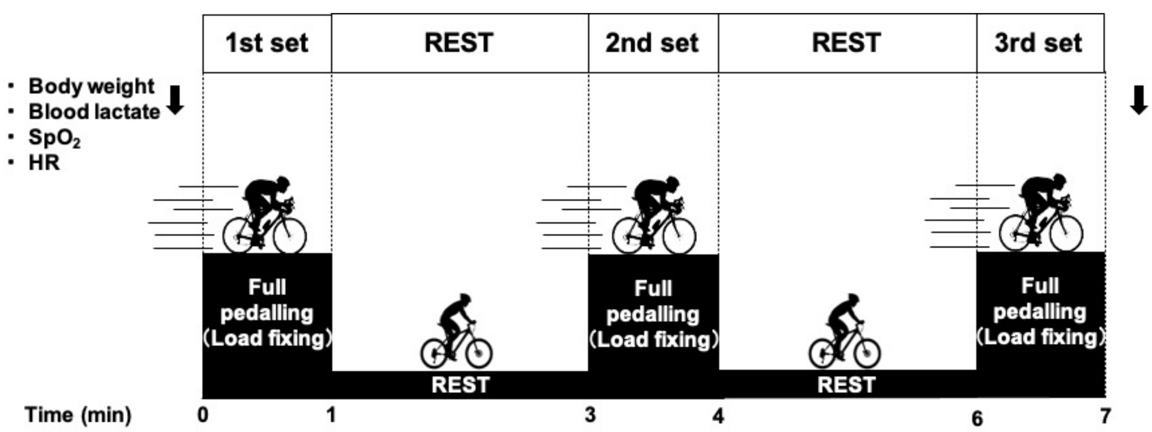

Figure.2. The experimental protocol. The black arrows indicate the timing of body weight, blood lactate, saturation pulse O_2 (SpO_2) and heart rate (HR) measurements.

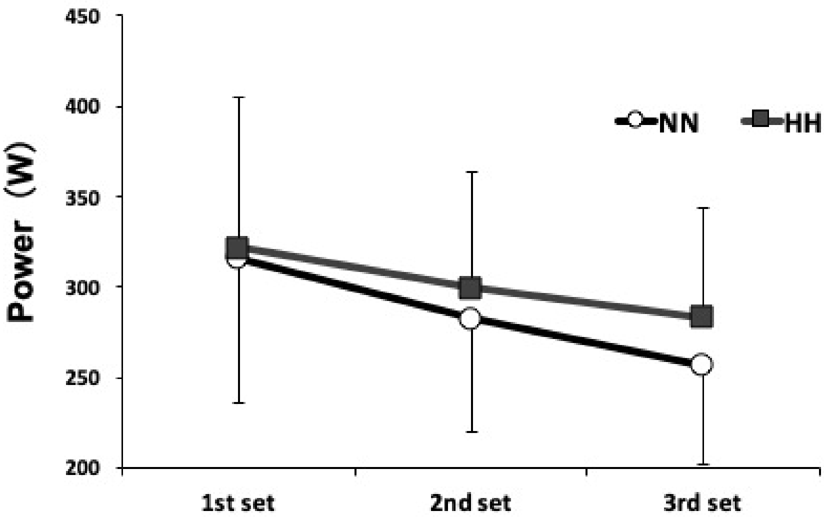

Figure 3. Changes in average power at normobaric normoxia (NN) and hyperbaric hyperoxia (HH).

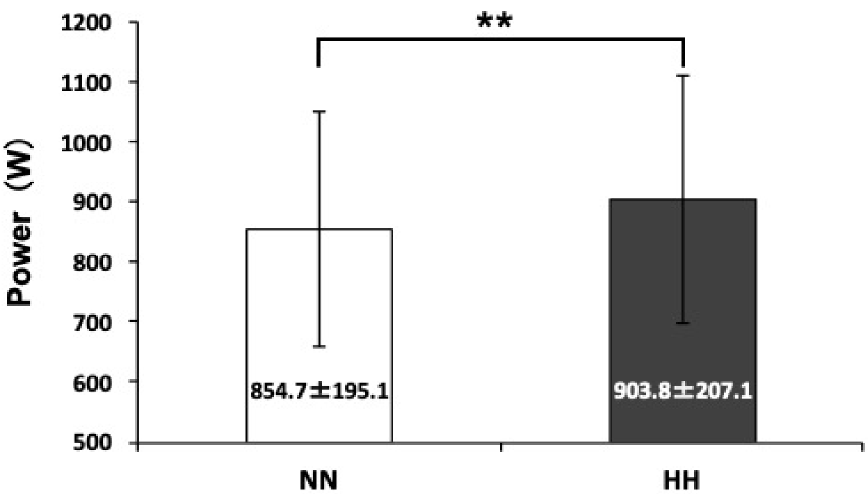

Figure 4. Total average power in normobaric normoxia (NN) and hyperbaric hyperoxia (HH) – values were summed from one to three sets; $^{**}p<0.01$

Peak rotation speed

The result of a paired two-way ANOVA with environmental conditions and the number of sets as factors revealed no interaction (p = 0.257), and a significant difference was observed between the number of sets in the main effect (p = 0.019). In the multiple comparison test, significant differences were obtained between the 1st set of NN conditions and the 3rd set of NN conditions (p = 0.025), and between the 1st set of HH conditions and the 3rd set of NN conditions (p = 0.028) (Figure 5).

Physiological index

The measured body weight before the exercise load experiments was 81.0 ±18.9 kg under the NN condition and 80.4 ±18.4 kg under the HH condition, and on the paired t-test, no significant difference was observed between the environmental conditions (p = 0.167) (Figure 6A). The HR immediately after the exercise load experiments was 152.1 ±15.6 bpm under the NN condition and 156.1 ±9.5 bpm under the HH condition (Figure 6B). On the paired t-test, no significant difference was observed

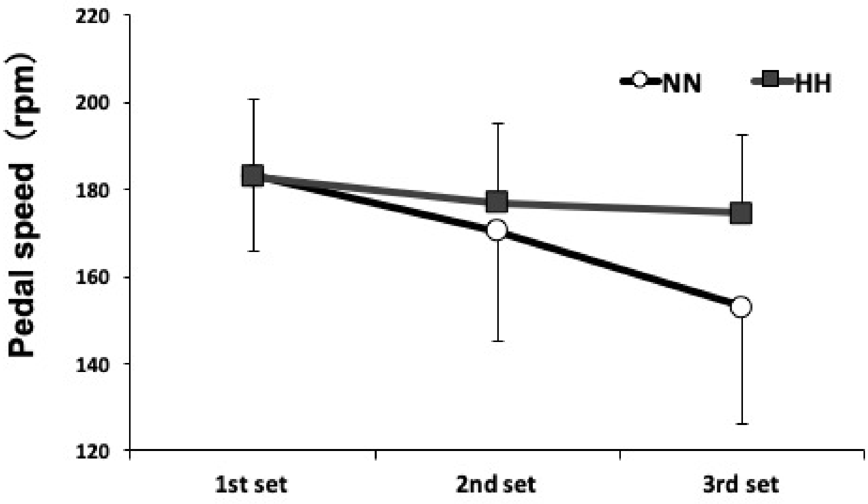

Figure 5. Changes in peak pedal speed at normobaric normoxia (NN) and hyperbaric hyperoxia (HH).

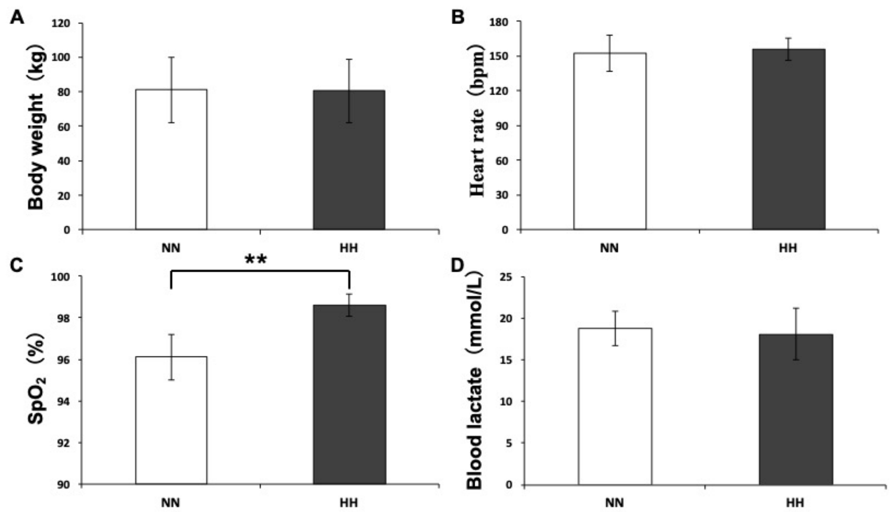

Figure 6. Physiological responses during exercise in normobaric normoxia (NN) and hyperbaric hyperoxia (HH). A) Body weight, B) Heart rate, C) saturation pulse O_2 (SpO_2), D) Blood lactate, ***p* < 0.01

between environmental conditions (p = 0.437). The SpO2 immediately after the exercise load experiments was 96.1 ±1.1% under the NN condition and 98.6 ±0.5% under the HH condition, and on the paired t-test, significantly higher values were obtained under the HH condition (p<0.0001) (Figure 6C). The blood lactate concentration immediately after the exercise load experiment was 18.8 ±2.1 mmol/L under the NN condition and 18.1 ±3.1 mmol/L under the HH condition (Figure 6D. No significant difference was found between environmental conditions (p = 0.608).

A significant difference of the peak rotation speed was observed under NN conditions (p = 0.027). On the multiple comparison test, the peak rotation speed of the 3rd set was significantly lower than that of the 1st set under NN conditions (p = 0.021) and the peak rotation speed was maintained from the 1st set to the 3rd set under HH conditions (Figure 7).

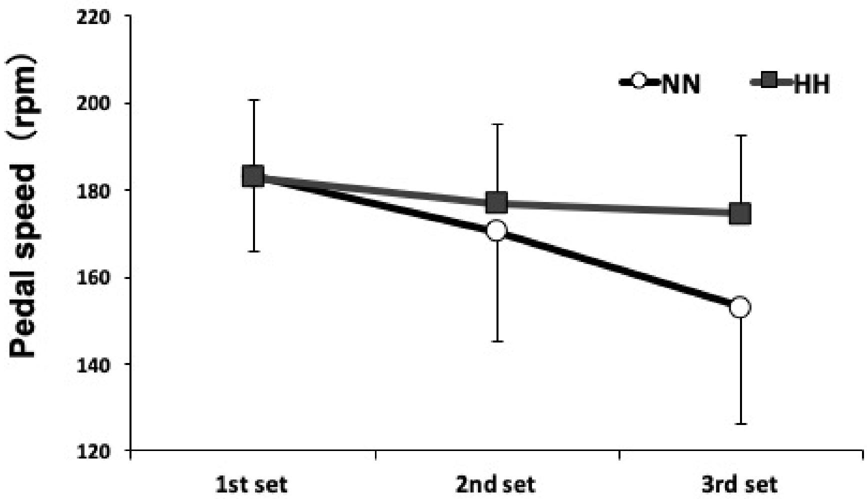

Figure 7. Changes in peak pedal speed at normobaric normoxia (NN) and hyperbaric hyperoxia (HH) *$p < 0.05$.

DISCUSSION

On summarising the results of this study, the total average workload under HH conditions was significantly larger than that under NN conditions (Figure 4). In addition, on the multiple comparison test, the peak rotation speed decreased significantly in the 3rd set under NN conditions, but no significant difference was observed in the peak rotation speed decrease under HH conditions (Figure 5). An additional analysis of the peak rotation speed, a one-way ANOVA with the number of sets as a factor, was performed for each environmental condition (Figure 7), and a significant difference was observed under NN conditions ($p = 0.027$). On the multiple comparison test, the peak rotation speed of the 3rd set was significantly lower than that of the 1st set under NN conditions ($p = 0.021$). In other words, the peak rotation speed decreased in the 3rd set under NN conditions, and the peak rotation speed was maintained from the 1st set to the 3rd set under HH conditions.

In the physiological responses, only SpO2 showed a significantly higher value under HH conditions (Figure 6C). In the human body, oxygen is supplied to the whole body by both bound oxygen and dissolved oxygen. Under NN conditions, most of the oxygen molecules bind to haemoglobin and are supplied to each tissue, but under HH conditions, the amount of dissolved oxygen increases exponentially because the amount of oxygen dissolved in the blood increases [14]. It is speculated that this is the reason higher performance can be achieved under HH conditions.

In this study, a 60-s full-power pedalling exercise was applied as an exercise task. When performing high-intensity exercise, the rate of carbohydrate catabolism greatly exceeds the rate of processing pyruvic acid in the aerobic system, resulting in the production of a large amount of lactic acid [15]. Since lactic acid is liberated with hydrogen ions in the body, it causes acidification in skeletal muscle and adversely affects muscle strength if produced in large amounts [16]. However, recent studies have also shown that when lactic acid produced by fast muscle fibres is released by monocarboxylic acid transporters, it is taken up by slow muscle fibres and the heart, and used as an energy source in the mitochondria [17]. This is called the lactate shuttle, and in this study, the increase in dissolved oxygen made the lactate shuttle more efficient and promoted the removal of lactate and synthesis of ATP.

The results of this study clearly showed the difference in the performance and physiological response when middle-power was exerted for 60 s under NN and HH conditions. Based on this, we would like to examine the long-term training effects and clarify the methodology of high-pressure and high-oxygen training on improving the competitiveness of judo.

CONCLUSIONS

In this study, 3 sets of 60-s full-power pedalling training were performed with a 2-min break under NN and HH conditions. The results suggested that higher performance was exhibited under HH conditions because the total average work amount was significantly higher than that under NN conditions, and because the peak rotation speed did not decrease. In addition, under HH conditions, the exercise-associated decrease in SpO2 is suppressed and the oxygen utilization capacity of the body is maintained at a high level, which contributes to high performance. These results may help find a new training method for improving the competitiveness of judo athletes in the future.

HIGHLIGHTS

60-s full-power pedalling training in under HH conditions may be used as a new training method to improve the competitiveness of judo athletes.

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