Effect of hyperbaric oxygen pretreatment on lower body negative pressure endurance of pilots with poor acceleration endurance

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Abstract

Background

Aiming at the problem of pilots with poor acceleration endurance, the effects of hyperbaric oxygen pretreatment (HBOP) on improving the lower body negative pressure endurance and centrifuge acceleration endurance of pilots with poor acceleration endurance were investigated.

Methods

Thirty pilots with poor acceleration endurance were subjected to multiple hyperbaric oxygen chambers and 3 oxygen exposures. The lower body negative pressure endurance, centrifuge acceleration endurance, blood pressure (BP), heart rate (HR),blood lactic acid (BLA), hydrogen ion concentration, partial pressure of carbon dioxide (PCO_2), partial pressure of oxygen (PO_2) and adrenal corticotropic hormone (ACTH) were measured before and after HBOP.

Results

The cumulative stress index increased after HBOP compared with before HBOP ($P < 0.05$), that is, lower body negative pressure endurance increased. 30 people underwent centrifuge reexamination, and the passing rate of 4.0 G 10 s reached 93.3%. After HBOP, diastolic blood pressure increased, heart rate slowed, lactic acid, hydrogen ion concentration, carbon dioxide partial pressure decreased, oxygen partial pressure increased compared with HBOP, and the changes were significant ($P < 0.05$)

Conclusion

HBOP can improve the lower body negative pressure endurance and centrifuge acceleration endurance of pilots with poor acceleration endurance.

1. Background

With the rapid replacement of our fighter jets and the continuous change of flight mode and combat style, the acceleration load continues to increase.The acceleration changes sharply in flight, up to the persistence of 9G or even higher G value + Gz [1-2].In recent years, the Air Force has increased the intensity and frequency of live-fire training drills, and further improved the technical standards of pilot training. The acceleration of gray vision, black vision and even G-LOC (G-induced loss of consciousness, G-LOC) occur from time to time, which are important factors threatening the flight safety of the Air Force.Therefore, how to more effectively improve the acceleration endurance of pilots is the current hot topic of military aviation medicine discussion [3].

At present, the centrifuge is not only the gold standard equipment to test the pilot acceleration endurance, but also has been recognized by the majority of scholars as the acceleration endurance training equipment.But the centrifuge equipment is huge, expensive, and difficult to promote.It has been shown that the biological effect of [4] LBNP is similar to the centrifuge + G_Z, that is, blood redistribution during LBNP, causing decreased blood pressure and insufficient blood supply to the head.. Negative body pressure at sitting -6.67 kPa can simulate the effect of + (2~3) G_Z on human cardiovascular function.Therefore, the lower body negative pressure endurance can reflect the acceleration endurance.The lower body negative pressure chamber equipment is small and easy to operate, which can be used for the preliminary detection of the acceleration endurance, but also for the acceleration endurance training [5].In this experiment, the lower body negative pressure endurance was tested by the lower body negative pressure chamber and the acceleration endurance was tested by centrifuge.

Sun Xiqing et al. [6] showed that Hyperbaric Oxygen Preconditioning (HBOP) can improve cardiovascular hemodynamics and enhance pilots' orthostatic endurance, which is closely related to acceleration endurance. Yang changbin et al. [7,8] found that HBOP can affect autonomic nervous function by changing heart rate variability under stress, thus improving the upright endurance of subjects, which suggests that HBOP may have a certain protective effect on unexplained syncope.Mahon et al. [9] showed that breathing hyperbaric oxygen during underwater infiltration may enhance the cardiovascular compensation response of postunderwater invasion of oppositions endurance. Exposure to inhaled hyperbaric oxygen may have had direct and indirect effects on the vasculature and autonomic nervous system, enhancing the cardiovascular compensatory response to orthostatic endurance after underwater infiltration. Ishihara et Al. [10] and Al-Waili et Al. [11] found that HBOP can significantly increase blood pressure and significantly decrease heart rate. Liu Hongjin et al. [12] showed that HBOP can effectively improve the lower body negative pressure endurance of normal pilots. With the increase of flight task intensity, the mental and physical load of flight personnel will also increase, and fatigue has also become A factor leading to flight accidents. In the fatigue state, visual acuity and Alomost loss of consciousness (A-LOC) and G-LOC are easy to occur [13].HBOP can promote the oxygen tension of tissues and cells of the body, facilitate the metabolic clearance of acidic products such as BLA, hydrogen ions and CO2, reduce fatigue, promote recovery and improve endurance of the body [14,15]. Body stress caused by hypoxia would produce a series of neuroendocrine reactions through HPA, thereby affecting the functions of all important organs [16]. HBOP can improve the expression levels of plasma dopamine, adrenaline, norepinephrine, and adrenocorticotropic hormone, thus accelerating the homeostasis of the body to establish a new balance to adapt to acute hypoxic environment [17].

This paper discusses the improvement of the lower body negative pressure endurance and acceleration endurance of pilots with poor acceleration endurance by hyperbaric oxygen pretreatment. The effects of hyperbaric oxygen preconditioning on human body were studied from blood pressure (BP), heart rate (HR), blood lactic acid (BLA), hydrogen ion concentration, partial pressure of carbon dioxide (PCO_2), partial pressure of oxygen (PO_2) and adrenal corticotropic hormone (ACTH).

2. Materials And Methods

Ethics approval and consent to participate

The experiment was approved by the Ethics Committee of the Air Force General Hospital, all methods were carried out in accordance with relevant guidelines and regulations, and all subjects were clearly informed of the specific research content, precautions and possible technical risks, and signed the informed consent of the experiment book.

2.1 Study subjects

A total of 30 male fighter pilots with poor acceleration endurance (+ Gz endurance <4.0G / 10s) were selected from February 2021 to July 2021 in the Air Force Special Medical Center , age (26.20±4.20), height (174.39 ± 2.40) cm, weight (67.84 ± 5.35) kg, flight time (650.19 ± 510.77) h, no various basic diseases and genetic history, and daily physical training.Physical and mental health was proved by blood drawing testing, plate exercise test, heart ultrasound, abdominal ultrasound, chest, whole spine X-ray, and psychological evaluation.The experiment was approved by the hospital ethics committee, and clearly informed all subjects of the specific research content, precautions and possible technical risks, and signed an informed consent form for the experiment.

2.2 Hyperbaric oxygen pretreatment

The experiment was conducted in the HYPERbaric oxygen chamber (Model yC3800J-X, Yantai Binglun Hyperbaric Oxygen Chamber Co., LTD.) of PLA General Hospital. The safety pressure window of HBOP is 1.5~3.0 Atmosphaera Absolutus (ATA), and 2.0 ATA and 2.5 ATA are more suitable pressure conditions, too low pressure will not produce HBOP effect [18].

HBOP scheme: using the multiplayer oxygen cabin, 3 times of oxygen inhalation HBOP scheme.After the subject enters the closed cabin door, the air is gradually pressurized to 2.5ATA for 10min, stabilized for 65min (30min 2, stop oxygen for 5min), and gradually to 1.3ATA within 10min and stay for 5min continue decompression for 5min and end exit..A total of 95min, once daily (fixed at 14:30-16:15 p. m.) for 3d continuously.

2.3 Lower body negative pressure endurance test

The lower body negative pressure endurance test can be used to check and predict a pilot's +GZ endurance. The subject will naturally sit in the lower body negative pressure chamber (XF-2008, Yantai Bingren Hyperbaric Oxygen Chamber Co., LTD.), place the subject's iliac spine line below the negative pressure chamber, and inflate the sealing ring to seal it with the edge of the inlet and outlet of the chamber to ensure the sealing of the lower body negative pressure chamber.Stepwise increasing scheme is adopted, that is, the LBNP load increases successively from -20 mmHg(1min) to→30mmHg(3min) to →40mmHg(5 min) to→50mmHg (7 min). It is not the limit value to reach -50mmHg. It can also continue to achieve -70mmHg (9min), -80mmHg (11min), etc.During the test, subjects' subjective feelings and physical signs were questioned and closely observed. Meanwhile, the heart rate, blood pressure and respiration of the subjects were monitored by PM-800Express Mindray monitor. When the end point of endurance was reached, the negative pressure in the lower body negative pressure instrument was quickly removed to end the experiment. The endpoints of endurance were either of the following: Blood pressure suddenly dropped below 90/60 mmHg, The heart rate suddenly dropped 15 times, or less than 60 times /min, The subjects complained of dizziness, palpitation, chest distress, nausea, pale face, cyanosis and other signs.

2.4 Acceleration endurance test

One of the most important factors affecting flight safety is the positive acceleration endurance of head and foot in centrifuge test, namely $+G_Z$ endurance. In this paper, acceleration endurance refers to $+G_Z$ endurance [19]. The centrifuge is amST-HC-4E human centrifuge of Air Force Special Medical Center (AMST Technology Company of Austria). The main arm length is 8.8m, and it can produce triaxial acceleration: longitudinal load is -5~$+15G_Z$, lateral load is -6~+6Gy, and forward and backward load is -10 ~+10Gx. The maximum $+G_Z$ growth rate is 10 G/s. The cockpit is equipped with 1 red central light and 2 white peripheral lights to determine visual changes of subjects. Anti-charge oxygen supply equipment of J-XXB aircraft is adopted, including: TK-X protective helmet, YM-X pressurized oxygen supply mask, KH-X anti-charge suit, KT-X anti-regulator, YX-X oxygen system. Oxygen source pressure is 1 MPa.

Acceleration endurance was tested before and after the HBOP. The tests of +2Gz, +3Gz and +4Gz were carried out on the centrifuge respectively (the experiments were carried out from 8:30 am to 11:00 am on the same day). The growth rate of G value was 3G /s and the loading duration was 10 s. The pilot's peripheral light loss (PLL) or more than 75% reduction in the amplitude of ear pulse wave or the pilot's inability to continue the experiment for various reasons were used as the index to judge the end point of endurance.

2.5 The indicators

The subjects' lower body negative pressure endurance, centrifuge acceleration endurance and blood indexes were measured before and after hbo pretreatment. Lower body negative pressure endurance index includes: lower body negative pressure endurance time and cumulative stress index, Hemodynamic indexes include blood pressure (BP), heart rate (HR), venous blood indexes:blood lactic acid (BLA), hydrogen ion concentration, partial pressure of carbon dioxide (PCO_2), partial pressure of oxygen (PO_2), adrenal corticotropic hormone (ACTH). Centrifuge pass rate = Number of people who pass centrifuge test (4.0G / 10s)/Total number of people who participate in centrifuge test.

Cumulative stress index CSI[20] is used to reflect LBNP level, and the calculation is shown in Equation (1) :

$$CSI = \sum_{i=1}^{N}(Pi \times ti) \qquad (1)$$

Among them, N is the total number of subjects in this experiment, 30 people, Pi is the negative pressure level (mmHg), ti is the tolerance time (min) of each negative pressure level, the negative pressure level range is -80~-20 mmHg, the negative pressure Pressure level tolerance time 0~11 min.

The secretion of normal ACTH was in circadian rhythm, which was higher in the morning and lower in the afternoon and evening. In this experiment, blood drawing time was uniformly set at 8:00 a.m. to control experimental variables. A total of 2 blood samples were collected: On the first day of the experiment, 2 mL of elbow venous blood was taken from each subject under basic condition (fixed at 8:00 a.m. on the day of the experiment) before oxygen inhalation, and serum was centrifuged for detection of BLA, hydrogen ion concentration, PCO_2, PO_2 and ACTH content before HBOP by the Clinical Laboratory of Air Force Special Medical Center. After the last oxygen inhalation, venous blood was taken again at 8:00 the next day to detect the corresponding physiological indicators.

2.6 Statistical analysis

SPSS25.0 was used for statistical analysis, and all experimental data were expressed as mean ± standard deviation, indicating that the experimental data were in line with normal distribution. Paired T test, $P<0.05$ was used to compare the experimental data of normality test. 0.05 considered that the difference was statistically significant.

3. Results

Table 1 Effects of HBOP on lower body negative pressure endurance, hemodynamics and blood parameters（$\bar{x}$±s，*n*=30）

Index	Pre-HBOP	Pro-HBOP	*t*	*P*
LBNP tolerance time min	15.37±3.73	20.48±4.61	7.75	0.001
Cumulative stress index(min·mmHg	-856.13±273.76	-1237.42±385.50	11.2	0.001
Systolic pressure/mmHg	110.84±8.77	109.19±6.94	0.93	0.36
Diastolic pressure/mm Hg	71.06±6.11	75.55±7.09	-3.252	0.003
Heart rate/ beat/min	64.97±8.68	56.74±7.61	5.493	0.032
Blood oxyen sat uration(%)	74.91±17.87	82.45±16.76	-3.08	0.005
Blood lactic acid/ mmol/L	2.66±1.38	2.13±0.70	2.186	0.037
Hydrogen ion concentration(nmol/L)	50.15±4.67	47.79±3.32	2.62	0.014
PCO_2 mmHg	56.59±7.02	53.77±5.93	2.188	0.037
PO_2 mmHg	51.69±24.40	63.06±28.08	-2.42	0.022
ACTH/ pmol/L	48.31±21.30	45.87±14.36	0.654	0.518

After 3 times of HBOP, the effects on the subject's lower body negative pressure tolerance, hemodynamics and blood indexes are shown in Table 1. It can be seen from Table 1 that the negative pressure level tolerance time was 15.37 min before HBOP, and increased by 5.11 min after HBOP, with a significant change. The cumulative stress index was -856.13 min·mmHg before HBOP, and decreased by -381 min after HBOP. ·mmHg, the cumulative stress index of subjects increased significantly after oxygen inhalation (P<0.001), indicating that the lower body negative pressure tolerance was significantly improved.

Before HBOP, 30 pilots with poor acceleration tolerance failed the centrifuge test (4.0 G/10 s). After HBOP, 28 pilots successfully passed the test. Of the remaining 2 pilots, 1 did not participate in the centrifuge test due to Achilles tendon injury. , 1 failed.

As can be seen from Table 1, the diastolic blood pressure of the subjects after 3 times of HBOP was significantly increased (P<0.01), and the heart rate was significantly slowed down (P<0.05), the experiment was statistically significant, there was no significant difference in systolic blood pressure before and after HBOP . After 3 times of HBOP, BLA, hydrogen ion concentration and PCO2 were significantly decreased, and PO2 was significantly increased (P<0.05). ACTH before HBOP was 48.31 mmol/L, and ACTH decreased by 2.44 mmol/L after HBOP, but it was not significant (P>0.5).

4. Discussion

The results of this paper show that after HBOP, the lower body negative pressure endurance of pilots with poor acceleration endurance is significantly improved, and verified by centrifuge test, 93.3% of the poor acceleration endurance (+Gz endurance <4.0G 10s) pilot qualified in centrifuge test.The pilot who did not pass the centrifuge test had a history of overheat shooting disease ten years ago. Although he is healthy now, his acceleration endurance is still not up to the standard. The training of acceleration endurance will be followed up.

HBOP can obviously improve the lower body negative pressure endurance and acceleration endurance of pilots with poor acceleration endurance

4.1 Effect of HBOP on hemodynamics of pilots with poor acceleration endurance

The results show that HBOP can improve the diastolic blood pressure, slow down the heart rate, improve the oxygen content and oxygen storage in the tissue of pilots with poor acceleration endurance, and play a very important role in protecting the tissue from hypoxia.

Lund et al. [21] have shown that hyperbaric oxygen (HBO) increases arterial pressure and lowers heart rate, which is consistent with this study. Hyperbaric oxygen can significantly improve hemodynamics and reduce blood viscosity, and its mechanism of action is as follows [22] : (1) Hyperbaric oxygen can increase oxygen penetration and treat local tissue hypoxia caused by cell edema, (2) Increase the oxygen reserve in tissues, thus improving the tolerance of the body to hypoxia, (3) Due to the local effect of carbon dioxide retention under hyperbaric oxygen, local cerebral vascular dilation is beneficial to increase cerebral blood flow in this area, (4) Hyperbaric oxygen can obviously improve the blood supply of ischemic hypoxia tissue and enhance the microcirculation function. After HBOP, the blood viscosity decreases, the surrounding resistance decreases, the effective blood volume increases, the oxygen supply status of the body is corrected, the heart function is increased and the blood circulation is improved.

Wu Xiaoyang [23], Li Ning et al. [24] believed that in healthy people, under 3 ATA oxygen pressure, total vascular resistance increased by more than 50%, leading to increased diastolic blood pressure. HBO treatment can slow down the heart rate, possibly because the chemoreceptors and baroreceptors of carotid sinus and aortic arch are stimulated by high concentration of blood oxygen and increased intravascular pressure, thus reflexively slowing the heart rate [25]. At the same time, in the course of HBO treatment, due to the obvious decrease of nitric oxide concentration in human body, it directly acts on the autonomic cells of the SINOatrial node, which also leads to the decrease of heart rate [26]. Pabla et al. [27] showed that HBO exposure increased the high-frequency power in the frequency domain index of heart rate variability, thus increasing vagus nerve activity, slowing heart rate, reducing its load on the heart wall and reducing cardiac oxygen consumption. HBOP can promote the heart to show signs of "functional saving", which is conducive to prolonging the duration of physical load, enhancing ontological motor ability and thus improving lower body negative pressure endurance [28].

4.2 HBOP can reduce human fatigue

Cui Jianhua et al. [29] showed that five HBOP sessions at altitude of 3700 m can effectively improve oxygen free radical metabolism for up to 8 days after exercise, and two HBOP sessions can last for 5 days. As HBOP can accelerate the clearance rate of BLA in the body at high altitude, so that the energy supply of the body changes from anaerobic glycolysis of sugar to aerobic oxidation of sugar, not only the BLA production is rapidly reduced, but also the oxygen tension in tissue cells and body fluids is significantly increased, which is conducive to the clearance of BLA and other acidic products [11]. Meanwhile, short-term HBOP can significantly and effectively improve the blood glucose level after physical stress, significantly reduce the activities of lactate dehydrogenase and Na+-K+ -ATPASE, and accelerate the clearance of BLA in the body, which can effectively slow down the occurrence of fatigue, reduce the severity of fatigue and effectively improve labor efficiency [30].

Under the condition of hypoxia, the process of glucose producing lactic acid is called anaerobic glycolysis of sugar. The final product of anaerobic glycolysis is lactic acid, and the released energy is accepted by ADP and then synthesized into ATP, which is the main energy source of the body under the condition of hypoxia [31]. The production of lactic acid depends on the O2 supply of the body during exercise and will increase due to the lack of O2 supply [29]. At the same time, the accumulation of various metabolites such as lactic acid, hydrogen ions, inorganic phosphoric acid and ammonia inhibits muscle contraction, so the accumulation of lactic acid and hydrogen ions can lead to fatigue, and the rapid elimination of fatigue can help improve exercise ability [32]. On the one hand, HBOP can improve the partial pressure of oxygen in the blood, make the physical oxygen dissolved in the blood increase rapidly, enhance the oxygen transport capacity of the body, improve the hypoxia state of the tissue, and promote the normal progress of aerobic metabolism. On the other hand, HBOP can improve the acidic environment in the body and improve the combination of hemoglobin and oxygen, thus promoting the fatigue recovery of the body [33].

The experimental results and mechanism of the above two aspects, after HBOP PO_2 are obviously higher than before, BLA, hydrogen ion concentration, PCO_2 reduced significantly than before, that HBOP may be involved in the acid produced by anaerobic respiration in the body metabolism, tissue oxygen tension rising at the same time, reduce the fatigue of the body, Extend the time of physical load, further improve the acceleration endurance.

4.3 HBOP affects the hypothalamic-pituitary-adrenal cortex axis (HPA axis)

When the human body is in a state of stress or stress, the HPA axis is continuously activated, and cortisol, adrenaline, ACTH and other hormones are at a high level, and the level of these hormones also reflects the intensity of stress response. Changes in hormone levels within a certain range can help the human body buffer and adapt to stress stimulation [34]. Casti et al. [35] showed that polyamines and ACTH in human body would change to varying degrees after HBOP, and ACTH was stimulated by HPA axis and opiate melanin, thus increasing its concentration. Li Yangyang et al. [17] showed that acute high-altitude exposure after HBOP can continuously increase both central neurotransmitters and ACTH. The mechanism may be that HBOP makes the HPA axis of the body continuously hyperactive during stress, so that the human body will produce enhanced stress response under various comprehensive stimuli of high altitude and low oxygen, insufficient oxygen supply under physical load and HBOP. HBOP can effectively regulate the secretion of a series of hormones such as norepinephrine and adrenocorticotropic hormone by HPA axis under stress state.

HPA axis is the neuroendocrine system sensitive to stress response in the body. Under the environment of acute stress, the human body will respond accordingly and gradually adapt to the new environment. In this study, the change of ACTH after HBOP was not statistically significant compared with that before. The pilots were in a quiet state before and after HBOP without acute stress reaction, and the changes of ACTH could not be monitored.

5. Conclusion

Thirty subjects with poor acceleration endurance were pretreated with hyperbaric oxygen. The lower body negative pressure endurance, centrifuge acceleration endurance and related blood indexes of subjects were tested before and after HBOP. The results show that HBOP can improve the hemodynamic indexes of pilots with poor acceleration endurance, reduce the fatigue degree, and improve the lower body negative pressure endurance and centrifuge acceleration endurance of pilots with poor acceleration endurance. Therefore, HBOP before high-load flight may be a fast and effective method to improve the acceleration endurance of pilots with poor acceleration endurance.

In the future, a comparative study of HBOP combined with lower body negative pressure training with HBOP alone and negative body pressure training alone can be carried out to explore an effective and convenient training method to improve pilots' acceleration endurance.

Abbreviations

HBOP
Hyperbaric oxygen preconditioning
HBO
Hyperbaric oxygen
G-LOC
G-induced loss of consciousness
LBNP
Lower body negative pressure
PLL
Peripheral light loss
SaO2
Blood oxygen saturation
BLA
Blood lactic acid
ACTH

Adrenocorticotropic hormone
CSI
Cumulative stress index

Declarations

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Author Contributions

All authors contributed to the study.Conception and design were performed by LH.Material preparation, data collection were performed bySN/ MM/FZ/ LQ.Analysis were performed by MM. The first draft of the manuscript was written by SN/ MM /LH, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Consent for publication

Not applicable.

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