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Observational Study

Impact of a 12-wk physical conditioning program on the aerobic capacity of aviation cadets

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Abstract

BACKGROUND

Flight cadets need to have good physical fitness to cope with the challenges of flying missions. The continuous development of science and technology has led to the constant upgrading of fighter jets and the improvement of their performance, which has resulted in new and higher requirements for the physical fitness of flight personnel. The traditional physical training mode, method, and assessment have been used for many years and do not meet current fitness needs.

AIM

To investigate the impact of a 12-wk comprehensive anti-G fitness training program on the aerobic capacity of aviation cadets and to evaluate its effectiveness.

METHODS

Fifty-five cadets were randomly assigned to control and experimental groups using a randomized, single-blind design. The control group maintained their existing training regimen, while the experimental group participated in a 12-wk comprehensive training intervention. The training program comprised strength training twice per week, high-intensity interval training three times per week, and supplemental nutritional and psychological support. Maximal oxygen uptake (VO_{2max}), lower limb strength, and hemoglobin levels were measured at baseline, at 6 wk and 12 wk post-intervention.

RESULTS

Repeated measures analysis of variance revealed significant differences of both VO_{2max} and relative VO_2 in both groups across time points ($P < 0.05$). However, no significant time-group interaction was observed ($P > 0.05$). Paired *t*-tests comparing baseline and 12-wk results showed that VO_{2max} and relative VO_2 were significantly higher in the experimental group than the control group ($P < 0.05$). This suggests that the training program effectively enhanced the aerobic capacity of the experimental group. Key indicators of aerobic capacity, bilateral lower limb strength and hemoglobin levels, were also significantly different over time and between groups ($P < 0.05$). No significant differences were noted in heart-rate metrics ($P > 0.05$).

CONCLUSION

A 12-wk comprehensive anti-G fitness training program significantly improved the aerobic capacity of aviation cadets, thereby enhancing their overall capacity and laying a physiological foundation for enduring high-G flights.

Key Words: Aviation cadets; Aerobic capacity; Physical training; High-intensity interval training, Anti-G fitness

Core Tip: This study employed a randomized, single-blind experimental design. Fifty-five cadets were randomly assigned to control and experimental groups. The control group maintained their existing training regimen, while the experimental group participated in a 12-wk comprehensive training intervention. The training program consisted of strength training twice per week, high-intensity interval training three times per week, and supplemental nutritional and psychological support. Maximal oxygen uptake, lower limb strength, and hemoglobin level were measured at baseline, 6 wk, and 12 wk post-intervention. The results showed that a 12-wk comprehensive anti-G fitness training program significantly improved the aerobic capacity of the aviation cadets, thereby enhancing their overall capacity and laying a physiological foundation for enduring high-G flights.

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INTRODUCTION

As aviation technology advances, aircraft capabilities continue to improve. High-difficulty and highly flexible flight maneuvers are increasingly frequent, characterized by high G-forces (+9 G) with high rates of increase (6 G/s), and prolonged duration (15-45 s) that recur multiple times during flight[1,2]. These demanding conditions require aviators to have robust anti-G fitness to combat anticipated loads. It is commonly accepted that physical qualities related to anti-G fitness include muscle strength and endurance. Endurance is crucial for long-duration, high-G flights and strength directly impacts the effectiveness of anti-G straining maneuvers.

Traditional physical training often involves moderate-intensity continuous exercise, which has limited effectiveness for improving endurance and may even hinder strength gains. Increasing evidence supports high-intensity interval training (HIIT) as an effective method for enhancing endurance. HIIT also maintains the number of type 2 muscle fibers[3], which is associated with the generation maximal force[4,5] and peak power output[6]. HIIT does not compromise gains in maximal strength and explosiveness.

This study aimed to address these issues by designing a foundational and efficient anti-G fitness training regimen including both strength training and HIIT and tailored for aviation cadets. The regimen was designed to improve both the cadets' strength and their aerobic capacity. Male cadets from a aviation academy participated in a 12-wk foundational, efficient anti-G fitness training program. Maximal oxygen uptake (VO_{2max}) and related blood and muscle indices were measured at baseline, 6, and 12 wk to explore the program's impact on aerobic capacity. The study aimed to provide a reliable training regimen to improving the anti-G fitness of pilots.

MATERIALS AND METHODS

Subjects

Fifty-five male cadets from the 2018 class of a certain aviation academy were randomly selected for this study. One cadet could not complete the training and post-test due to a fracture; hence, his data was excluded. The final sample size was 54 cadets, 26 in the experimental group and 28 in the control group. Baseline information about the research subjects can be seen in Table 1.

Table 1 Baseline characteristics of the study subjects

Group	Age in yr	Height in cm	Weight in kg	BMI in kg/m^2
Experimental group, n = 26	19.35 ± 0.69	174.64 ± 4.05	68.17 ± 4.88	22.37 ± 1.64
Control group, n = 28	19.39 ± 0.74	174.64 ± 4.32	67.44 ± 6.27	22.10 ± 1.85

Data are mean ± standard deviation. BMI: Body mass index.

Methods

Using a randomized control, single-blind method, the experimental group was assigned in a 12-wk foundational, efficient anti-G fitness training program. The control group followed the original curriculum, which included training for both strength and aerobic capacity. The testing and intervention period was from March to July. Indicators like height, weight, lower limb strength, VO_{2max}, and blood components were measured by professionally trained staff. To minimize measurement errors, all indicators were tested by the same personnel at the beginning, middle, and end of the study.

Effective training program of basic anti-G fitness: The training program included strength training (2 times/week, 90 min/session), HIIT (3 times/week, 10 min/session), psychological intervention (2 times/week, 14 min/session concurrent with strength training), and nutritional supplements. Strength training and HIIT were not scheduled on the same day. Details are shown in Table 2.

Test indicators

Direct measurement of VO_{2max}: The direct measurement of VO_{2max} was with professional gas exchange analyzers (Ergo-Fit, Germany) and an ergometer bike (MONARK, Sweden). The gas exchange analyzer was preheated and calibrated prior to testing. Subjects wore a cardiac monitor and a breathing mask and they warmed up for 3 min on the ergometer bike at 0 W. The test began at a 0 W load and increased by 25 W/min until exhaustion. The subjects were required to maintain a pedaling frequency of 55-60 r/min, and the test ended if they could not maintain at least 55 r/min. Post-exhaustion, they cooled down for 3 min at 0 W. Gas metabolism indicators were recorded during each breath throughout the test. The room temperature was maintained at 22-25 °C at a relative humidity of 40%-50%, with good air circulation.

Criteria for VO_{2max}: The criteria were: (1) Heart rate ≥ 180 bpm; (2) Respiratory quotient ≥ 1.15; (3) A plateau or slight decrease in VO_2 despite increasing workload; and (4) Subjective exhaustion despite encouragement, and determined by the good physical condition and regular training habits of the subjects. Reaching three of the above four criteria while closely monitoring heart rate and ECG confirmed VO_{2max}. The test was terminated when the subject could not maintain the pedaling frequency[7].

Isometric leg extension strength: Isometric leg extension strength was tested using Dr-Wolff (Germany) full-body isometric strength testing equipment.

Specific test method: (1) Test mode was used; (2) The seat back was in the vertical position; (3) The heels were aligned with the intersection of horizontal and vertical lines on the pedal; (4) The seat was adjusted so that the knee was flexed at 90°; (5) The subject exerted maximum force on the pedal, three times for 10 s each and could stop once maximum force was achieved; and (6) During the test, the subjects did not see the test data.

Hemoglobin test: Blood samples for hematological analysis were collected on an empty stomach at 6:30 am.

Data processing

The statistical analysis was performed with SPSS 22.0 software. Results with a normal distribution were reported as means ± SD. For normally distributed and homoscedastic variables, repeated measures analysis of variance (ANOVA) was used to compare data from the three tests. The main effect of time within groups and the interaction between the experimental and control group were examined. If an interaction existed, simple-effect analysis was conducted; and if not, covariance analysis and paired-sample t-tests were used. The significance level was $P < 0.05$.

RESULTS

Change of VO_{2max}

Changes in the VO_{2max} at each stage are shown in Table 3. ANOVA found significant differences in the VO_{2max} and relative VO_{2max} within both the experimental group and the control group over time ($P < 0.05$). However, there was no interaction between time and group ($P < 0.05$). As shown in Figures 1 and 2. When data from week 0 and week 12 were compared using the paired-sample t-test, the relative VO_{2max} of the experimental group was significantly higher than that of the control group ($P < 0.05$). This shows that the training program significantly increased the relative VO_{2max} of the experimental group.

Table 2 Effective basic anti-G fitness training program

Training item	Training method
Strength training	Mainly focused on squats, deadlifts (single-leg deadlifts), single-leg squats, bench presses, and bent-over rows. Core training was supplementary. Warm-up before and stretching after training are included. Intensity: First 6 wk focus on sub-80% 1RM for endurance, 5 sets of 8-15 reps; later 6 wk focus on above 85% 1RM for max strength, 4-6 sets of 6 reps; last two sessions were power sprints with high load, multiple sets, and fewer repetitions, 6-8 sets of 2-3 reps
HIIT	Full-effort cycling on a watt bike for 60 sec followed by relaxed cycling for 60 sec, with a 1:1 sprint-to-rest ratio. Total intervention duration was 10 min, three times a week. Cadets wore Polar monitors (TeamPro, Finland) to maintain training intensity, aiming for 85%-95% of their maximum heart rate

HIIT: High-intensity interval training.

Table 3 Change in VO_{2max} before and after intervention

Indicator	Group	Test time		
		Week 0	Week 6	Week 12
VO_{2max}	CG	2780 ± 347.19	2885.36 ± 352.64	2919 ± 382.48
	EG	2783.65 ± 245.43	2992.81 ± 275.11	3075.19 ± 331.96[a]
Relative VO_2	CG	41.51 ± 4.42	43.29 ± 4.46	43.78 ± 4.53
	EG	40.8 ± 4.25	44.29 ± 5.07	45.12 ± 6.63[a]

[a]$P < 0.05$.
Data are mean ± standard deviation. Experimental group compared with the control group.

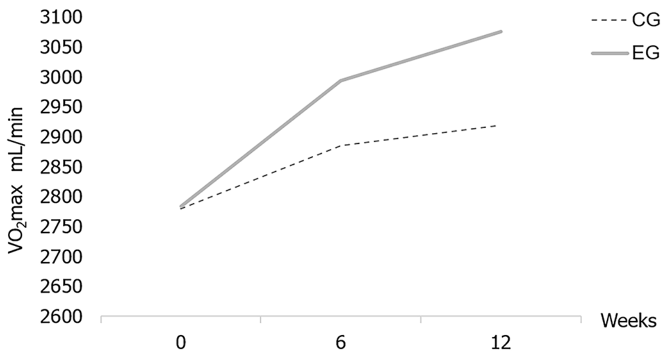

Figure 1 Change of maximal oxygen uptake. Experimental group (EG) compared with the control group (CG), $P < 0.05$. VO_{2max}: Maximal oxygen uptake.

Changes in indicators related to VO_{2max} before and after intervention

Changes of indicators related to VO_{2max} at each stage are shown in Table 4. Repeated measures ANOVA showed significant differences of both lower limb strength and hemoglobin level in both groups over time ($P < 0.05$). There was also an interaction between time and group ($P < 0.05$). Simple-effect analysis revealed that after 12 wk of intervention, lower limb strength and hemoglobin levels were significantly higher in the experimental group than in the control group ($P < 0.05$). This shows that the training program significantly improved these parameters, and subsequently impacted the VO_{2max}. However, no significant time-dependent changes or interactions were observed in heart-rate metrics ($P > 0.05$), showing that the training program did not have a notable effect on heart rate within the 12-wk test period.

DISCUSSION

Robust cardio-pulmonary function is beneficial for sustaining prolonged, high-intensity flight operations and facilitating physical recovery after high-G flights, making it an essential physical quality for pilots. Conventional training regimens are not optimal for improving cardio-pulmonary function, which may limit the anti-G fitness of pilots. Traditional physical training often relies on moderate-intensity continuous exercise, which has limited benefits for improving

Table 4 Change of indicators related to VO_{2max} before and after intervention

Indicator	Group	Test time		
		Week 0	Week 6	Week 12
Left-leg strength	CG	128.16 ± 24.54	127.57 ± 19.35	144.38 ± 28.8
	EG	131.04 ± 28.09	133.35 ± 27.62	177.73 ± 37.38[a]
Right-leg strength	CG	127.7 ± 25.41	123.86 ± 19.55	140.09 ± 28.14
	EG	130.87 ± 26.72	132.37 ± 25.26	171.79 ± 39.59[a]
Hemoglobin	CG	150.21 ± 7.93	151 ± 9.06	150.48 ± 8.38
	EG	152.81 ± 7.49	151.5 ± 8.12	155.08 ± 8.8[a]
Resting heart rate	CG	80.04 ± 11.57	76.43 ± 12.53	72.86 ± 11.62
	EG	77.19 ± 11.39	74.19 ± 8.85	73.5 ± 9.87
Max heart rate	CG	186.36 ± 13.57	190.11 ± 13	188.71 ± 13.3
	EG	188.77 ± 20.76	185.69 ± 8.77	191.19 ± 19.21

[a]P < 0.05.

Data are mean ± standard deviation. Experimental group compared with the control group.

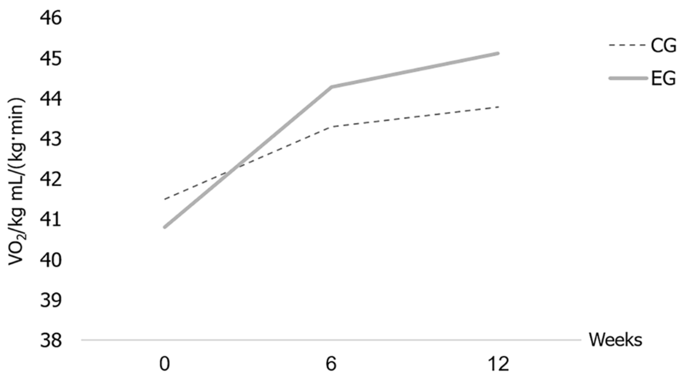

Figure 2 Change of relative maximal oxygen uptake. Experimental group (EG) compared with the control group (CG), P < 0.05. VO_{2max}: Maximal oxygen uptake.

endurance. Excessive aerobic training can reduce vagal tone, which impairs the compensatory heart-rate reflex mechanism under high-G loads. Conventional endurance training mainly increases type I muscle fibers but increased strength requires the development of type II fibers. Overemphasizing moderate-intensity, long-duration training can lead to a decline in strength. Competitive sports requiring high levels of both endurance and strength, such as kayaking, triathlons, and badminton, have promoted research interest in optimally combining strength and endurance training, selecting appropriate exercise repetition ranges, adopting suitable exercise modalities, and implementing reasonable rest intervals[8].

Endurance can be categorized as aerobic or anaerobic. High-G exposure during flights can last up to 45 s, requiring high anaerobic endurance, and recovery after high-G exposure requires aerobic endurance. Excessive low-intensity aerobic training in projects primarily focused on anaerobic activity can reduce performance, decrease the content of type 2 muscle fibers, and inhibit muscle growth. Current research suggests that low-intensity long-duration endurance training is only applicable for events relying on aerobic energy supply and is not suitable for those primarily relying on anaerobic energy and sports requiring high levels of strength generation, high rates of force production, and high power outputs. Studies have shown that HIIT significantly improves anaerobic endurance[8], and that strength training promotes the development of anaerobic endurance[9]. Nutritional supplements are used in competitive sports to ensure the material needs for strength and endurance training, and psychological guidance is crucial for training effects. Zou *et al*[10] have proposed a comprehensive training plan combining strength, HIIT, nutrition, and psychology designed to effectively improve strength and aerobic ability and enhance the anti-G fitness of flight cadets. They found that a 12-wk comprehensive intervention led to improvement of both lower limb strength and aerobic capacity.

Analysis of the effect on aerobic capacity

Figure 1 shows that the experimental group experienced a significant increase in VO_{2max} after just 6 wk of intervention.

The increase was substantially higher than that in the control group, aligning with the study objectives. Most literature reports indicate that detectable changes in VO_{2max} require a training period of more than 6 wk[11]. The significant change observed at 6 wk in this study can be attributed to the cumulative effect of the comprehensive training program. Both strength training and HIIT contributed to the improvement of VO_{2max}, and complemented by nutritional and psychological training components, resulted in evident enhancement of aerobic capacity within 6 wk.

Analysis of the effects of HIIT on aerobic capacity

Research shows that HIIT can effectively improve aerobic capacity[8,12-13]. This study included three HIIT sessions per week, each lasting only 10 min, and achieved a significant improvement in aerobic capacity, consistent with the existing literature. There is no consensus on the setting of exercise and interval times in HIIT, and different intensity settings yield inconsistent conclusions[14]. In this study, the HIIT exercise and interval time settings were related to the duration of high-G exposure during flight, which is 45 s. The exercise time was 60 sec, which was greater than the project's actual maximum time. As a result, the expected goals were met.

A meta-analysis by Cao *et al*[15] confirmed that HIIT as an effective way to improve cardiorespiratory fitness, especially for enhancing VO_{2max}. This advantage is particularly significant for male participants who are younger than 25 years of age, have training cycles longer than 6 wk, and have workload-to-rest ratios greater than 1.0. Previous studies indicate that HIIT three times a week significantly increase VO_{2max} for these groups of people. HIIT controls exercise intensity by heart rate monitoring, requiring the heart rate to reach 190 bpm during exercise and beginning the next set when the heart rate drops to 120 bpm. This can improve cardiac pump function and significantly enhance cardiorespiratory function. It is also an efficient training method for developing the lactic acid energy system and mixed phosphate and lactic acid metabolism. Most training methods use power bicycles to control intensity, and research shows that this method is more effective than running for improving endurance and interferes less with strength training[17].

Analysis of the effects of strength training on aerobic capacity

Many studies have shown that strength training helps to improve high-intensity exercise endurance[9,18-20]. This training program included two strength training sessions per week and focused on developing lower limb and core strength. The first 6 wk used light loads, multiple repetitions, and short intervals of exercises like squats and single-leg squats to increase muscle endurance. If the expected strength gains were small after 6 wk and the increase in VO_{2max} was more significant, the focus of the subsequent training shifted toward increasing aerobic endurance. The latter 6 wk focused on increased intensity, fewer repetitions, and longer rest intervals to maximize muscle strength. The results showed a significant increase in lower limb strength. During this phase, the emphasis was on anaerobic endurance, which aligns with the hypertrophy of type 2 muscle fibers required for anaerobic exercise.

Analysis of the effects of nutritional interventions on aerobic capacity

Table 3 shows that the hemoglobin content of the experimental group in significantly increased compared to the control group. The hemoglobin level affects the ability to absorb, transport, and release oxygen and the increase in hemoglobin content is a functional basis for the improvement of aerobic capacity. In this study, taking collagen extracted from donkey skin, astragalus, angelica, and iron capsules in combination with training intervention increased the hemoglobin content of the students in the experimental group. Improving the hemoglobin content can increase aerobic metabolism, thus improving the ability of the students to continue to resist loads in high-altitude flying maneuvers. HIIT induces mitochondrial proliferation in skeletal muscle cells by activating the PGC-1 α signaling pathway, leading to increases in the number of skeletal muscle capillaries and the hemoglobin levels. During high-altitude flight, acceleration and vibration can increase the tension of skeletal muscles and the activity of the cardiovascular system, thus increasing oxygen consumption. When the acceleration increases to 5-6 G, the oxygen consumption almost doubles. Because of the lack of oxygen during high-altitude flight, the metabolism of sugars, fats, and proteins is incomplete, resulting in accumulation of toxic substances, which seriously affects the function of organs such as the heart and brain. Mild cases can affect flight endurance and severe cases can endanger flight safety. Improving the hemoglobin content of pilots is of great significance for ensuring the safety of high-altitude flight[21].

Study limitations

The potential for improving aerobic capacity during aviation training is limited. However, this program showed a significant increase in VO_{2max} at 6 wk and the increase continued to increase through 12 wk. It is recommended to extend the intervention time to observe the maximum effect of the comprehensive anti-G fitness program on improving aerobic capacity.

CONCLUSION

This 12-wk comprehensive anti-G fitness training program significantly improved the aerobic capacity of aviation cadets thereby enhancing their comprehensive anti-G capacity and laying the physiological foundation for sustained high-G flights.

FOOTNOTES

Author contributions: Luo H contributed to the study conception and design, the literature review, and the manuscript drafting; Zhao DY acquired the data and figures; Li J revised the manuscript for important intellectual content; All authors read and approved the final version of the manuscript.

Institutional review board statement: This study was approved by the Ethics Committee of Beijing Sport University (No. 2019113H).

Informed consent statement: The data used in this study were not involved in the privacy information, so the informed consent was waived by the Ethics Committee of Beijing Sport University. All data obtained, recorded, and managed only used for this study, and all information are strictly confidential, without any harm to the participants.

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