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Research article

Evaluating the impact of a combined aerobic and strength training intervention on the physical performance of male Chinese People's Liberation Army air force pilots

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ABSTRACT

This study aimed to assess the impact of a 16-week combined training program on the physical performance of 20 male Air Force pilots, with an average age of 31.87 ± 2.75 years, body mass of 76.33 ± 0.79 kg, and height of 175.55 ± 3.65 cm. This intervention encompassed both aerobic and strength training, involving six weekly training sessions. The participants were categorized into two groups based on their initial physical performance levels to explore potential baseline influences on post-intervention adaptations. The study measured changes in estimated maximal oxygen uptake (VO_2 max), maximal strength, muscular endurance, and long jump performance before and after the training program. Repeated measures ANOVA revealed significant differences over time in the $\dot{V}O_2$ max ($F = 86.898$; $p < 0.001$; $\eta_p^2 = 0.821$), handgrip strength right hand ($F = 160.480$; $p < 0.001$; $\eta_p^2 = 0.894$), handgrip strength left hand ($F = 102.196$; $p < 0.001$; $\eta_p^2 = 0.843$), squat maximal strength ($F = 525.725$; $p < 0.001$; $\eta_p^2 = 0.965$), push-ups ($F = 337.197$; $p < 0.001$; $\eta_p^2 = 0.974$), sit up ($F = 252.500$; $p < 0.001$; $\eta_p^2 = 0.930$) and standing long jump ($F = 521.714$; $p < 0.001$; $\eta_p^2 = 0.965$). In conclusion, the 16-week combined training regimen significantly enhanced the physical performance of Air Force pilots, regardless of their initial performance levels.

1. Introduction

Physical fitness is crucial for military personnel in the Air Forces as it enhances operational readiness, combat performance, and mission success while promoting overall health and mental toughness [1]. Given its pivotal role among Air Force pilots, it is highly advisable to incorporate year-round physical conditioning into military practices [2,3]. This approach assists personnel in sustaining their capacity to execute various tasks [4,5] while maintaining optimal health conditions and reducing the risk of non-communicable diseases [6].

Physical fitness can be described as the capability to proficiently perform daily tasks and engage in physical activities with a high degree of functionality, typically attained through regular physical conditioning. Vital facets of physical fitness encompass body

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composition, strength, power, cardiorespiratory fitness, and flexibility [7], which collectively equip individuals to withstand the demanding physical challenges faced by air force pilots. Furthermore, a well-developed level of physical fitness is anticipated to reduce the risk of injuries linked to specific tasks carried out by air force pilots [5].

For instance, during training or missions, pilots frequently encounter substantial G-forces. Prolonged exposure to G-forces exceeding 7G can lead to musculoskeletal injuries, particularly affecting the cervical and lumbar vertebrae [8–10]. Research indicates that for each additional 100 h of flight time, the risk of spinal pain increases by 6.9 % [11]. Alarmingly, 20 % of high-performance aircraft pilots suffer from disabilities that impair their ability to carry out flight duties [12]. Simultaneously, musculoskeletal disorders rank as the predominant health issue among military pilots [13]. The prevalence of flight-induced musculoskeletal symptoms among active pilots varies from 32 % [12,14–16] to as high as 89 % [13,17].

Prior studies have highlighted that appropriate physical training can enhance the precision of tasks performed during military operations in isolation. Superior and healthier outcomes can thus be attained through effective physical training [18]. Consequently, physical training proves highly advantageous for Air Force pilots aiming to uphold both their occupational competence and overall health [19].

Among various physical fitness parameters, maintaining adequate aerobic fitness is paramount for air force pilots. As an illustration, different countries have established specific aerobic fitness requirements for their air force personnel, recognizing its critical role in their readiness. For instance, the Institute of Aviation Medicine mandates a minimum aerobic fitness level of ≥40 m·kg-1·min-1 for Norwegian Air Force personnel [20].

The significance of aerobic fitness for this population can be attributed to several factors. Firstly, it ensures an appropriate cardiorespiratory and cardiovascular status, which in turn improves the delivery of oxygen to the mitochondria and enhances the regulation of muscle metabolism [21]. Consequently, this contributes to the normalization of blood pressure, reduces the risk of stroke, and serves as a preventive and therapeutic measure against cardiometabolic conditions such as obesity, type 2 diabetes, and cardiovascular diseases.

In addition to aerobic fitness, muscular strength holds significant importance in both optimizing the performance of air force pilots and enhancing their overall health. For instance, past research has illuminated the substantial activation of neck muscles in pilots during flight, indicating a considerable burden on these muscle groups [22]. This heightened strain can set the stage for the prevalence of low back pain, which reportedly affects 36 % of air force pilots [23]. To mitigate low back pain and fortify the body's capacity to withstand these physical stresses, bolstering neck strength assumes paramount significance. Supporting this notion, Lange et al. have uncovered compelling evidence suggesting that specific neck strength exercises tailored for fighter pilots can effectively alleviate the severity of neck pain [24]. In a parallel context, a randomized controlled study revealed that the incidence of lower back pain is significantly lower among US Air Force pilots who incorporate specific core muscle exercises into their routines, compared to a control group that abstains from these exercises [25].

Acknowledging the paramount importance of physical fitness parameters, including aerobic and muscular strength, significant efforts have been directed towards crafting comprehensive strength and conditioning programs tailored for air force pilots. Nevertheless, existing programs often focus solely on one type of training [26,27], neglecting the benefits of a combined approach that encompasses both aerobic and strength training. Integrated training, which combines cardiorespiratory and strength exercises, is indeed recommended. In civilian and athletic populations, this holistic regimen concurrently enhances cardiovascular health, endurance, and muscular strength [28,29]. It bolsters overall performance by augmenting oxygen delivery to muscles, bolstering endurance for extended missions, and fortifying the body to withstand the rigorous physical demands inherent to air force duties [30]. Consequently, it emerges as a highly effective strategy for optimizing physical fitness in the demanding profession of air force service.

Despite its potential benefits, combined training has yet to be extensively studied in the context of air force pilots, presenting a noticeable gap in research. This gap is significant, as combined training holds promise as a supportive framework for daily practices within the air force, potentially improving physical fitness, overall health, and quality of life while reducing the risk of pain or injuries. Given the unique characteristics of this population, there is a pressing need to expand research on combined training to ascertain its impact, or lack thereof, on the physical fitness and health of air force pilots. With this gap and the importance of addressing it in mind, this study aims to investigate the effects of a combined aerobic fitness and strength training intervention on male Chinese People's Liberation Army Air Force pilots' physical fitness and overall health using a pre-post quasi-experimental design.

2. Methods

The present article followed the guidelines set forth in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement for reporting observational studies [31].

2.1. Study design

A pre-post quasi-experimental design was conducted to evaluate the effectiveness of a 16-week combined aerobic fitness and strength training intervention on subjective and objective health indicators of physical fitness and overall health among male pilots of the Chinese People's Liberation Army Air Force. The study received ethical approval from the Institutional Ethical Review Board of Chengdu Institute of Physical Education under the reference code 2023#145.

2.2. Setting

The study was carried out from 2023.5.29 to 2023.10.1 in the city of Chengdu. The recruitment process involved sending direct invitations to the Air Force Aviation Force of the Western Theater Command of China, which took place between 2023.5.10 and 2023.5.20.

2.3. Participants

The a priori sample size for this study was determined using G*Power 3.1 software (Düsseldorf, Germany) [32]. With a statistical power of 0.85 and a medium effect size of 0.35, considering two groups and three measures, a total sample size of 18 participants is recommended.

Convenience sampling was utilized. To be eligible for participation, pilots had to meet certain criteria: (a) age greater than 29 years, (b) flight time exceeding 1500 h, (c) previous international/domestic flight missions, and (d) a body mass index (BMI) of 23 or higher. Pilots who required special tasks during the intervention were excluded.

Participants were self-selected pilots recruited from the Air Force Aviation Force of the Western Theater Command of China. The author of this study also served as a professional physical trainer.

To account for potential dropouts and increase the ability to detect smaller differences, an initial total of 25 subjects were recruited. Ultimately, 20 participants (all males) with an average age of 31.87 ± 2.75 years, body mass of 76.33 ± 0.79 kg, and height of 175.55

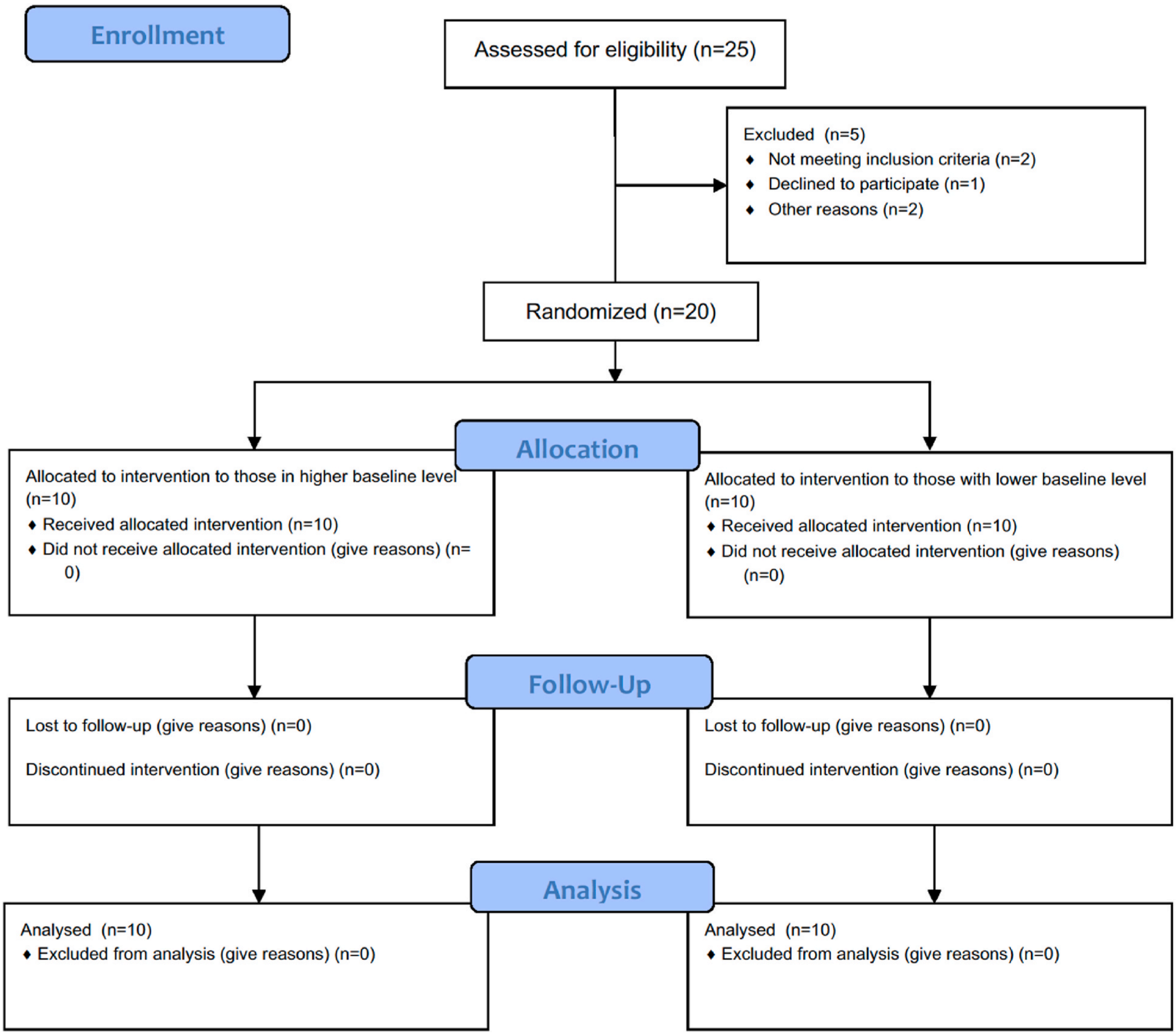

Fig. 1. Flowchart of participant selection.

± 3.65 cm met the inclusion criteria. On average, they have 1989.11 ± 419.5 flight hours.

Next, the participants were divided into two subgroups based on their baseline scores. One subgroup consisted of participants who scored below the median for each primary outcome, while the other subgroup included those who scored above the median. This categorization created two distinct groups and enabled a comprehensive discussion regarding the impact of individual adaptation in relation to both lower and higher baseline values. For a visual representation of participant enrollment and retention, please refer to Fig. 1.

Informed consent was obtained from all participants before their involvement in the study. Permission from the military was also secured, and pilots had the option to withdraw from the intervention at any time without providing a reason. To ensure data blinding and anonymity during data analysis, participants were assigned unique identification codes instead of using their names on the informed consent forms.

2.4. Assessment procedures

Anthropometric measurements, fitness assessments, and physiological evaluations were conducted at baseline, at the midpoint of the intervention (8th week), and following a 16-week intervention period. The following sequence of tests were made: (i) anthropometry; (ii) grip strength; (iii) maximum squat strength; (iv) standing long jump; (v) muscular endurance; (vi) 20-m shuttle running test. The assessment battery was made at the same day, and the tests were interspaced by 5 min of rest. In order to ensure the consistency of data comparisons, the baseline and post-intervention assessments were scheduled for the same day of the week, at the same time of day (approximately 1.5 h), and under identical environmental conditions (25 °C temperature and 53 % humidity). The assessments were conducted in both a laboratory and an in-field setting. To preserve the confidentiality of the military participants, all were instructed to assemble at the designated measurement site within the military installation for their evaluations, precisely at 3:00 p.m. as specified.

To ensure the privacy of the military personnel, the author did not directly participate in the assessment process (the assessment was blind to researchers). The hospital, arranged by the military, performed physical examinations on the participants, following the measurement values specified in the study regulations.

2.5. Anthropometry assessment

Anthropometric measurements of participants were conducted following standardized procedures. Height and body mass were measured using a Smart Health digital weighing scale and stadiometer (601, WJ-H, China), with a technical error of ±0.5 cm and ±0.1 kg, respectively. Measurements were taken with participants wearing a regular shirt and shorts, excluding shoes. To ensure accuracy, height and body mass were measured three times, and the average of the three measurements was used as the statistical data for each assessment moment. Body mass index (BMI) was subsequently calculated based on the obtained height and body mass values.

Waist circumference was measured by identifying the top of the hip bones and the bottom of the ribcage and taking the measurement at a level midway between these landmarks. Hip circumference as measured at the widest part of the hip, typically at the level of the greater trochanter of the femur. The measurements were conducted by researchers designated by the military district, who had expertise in anthropometric assessment (ISAK level). The reliability of the measurements was high, with a ±value of 0.5 cm. To ensure measurement accuracy, the researchers utilized measuring tape with waist to hip ratio calculator (203, seca, China) with a technical error of ±0.1 cm. The waist and hip circumferences were measured three times following standardized procedures, and the average value was used as statistical data. Subsequently, the waist-to-hip ratio was calculated based on the obtained waist and hip circumferences.

2.6. Handgrip strength

Participants' grip strength was assessed using the KDCS-3 Grip Strength Tester (KDCS-3, Beijing, China). This grip strength tester is known for its minimal systematic error (0.1 kg) and is considered a highly reliable tool for evaluating the grip strength of military personnel. To ensure the accuracy of measurements, participants were provided with instructions to fully extend their arms and exert maximum force on the dynamometer using their dominant hand. They were instructed to maintain this grip strength for at least 3 s and perform the task twice, with the peak force being recorded for analysis. Each participant completed 3 trials for each hand, with a rest period of 2 min between trials and 3 min between assessments of each hand. The best of trials was used as the main outcome.

2.7. Maximum squat strength

The Smith squat rack (MX-G9, MASSFIT, China) was employed to assess the participants' maximum squat strength. This particular rack is known for its effective safety features and its ability to provide precise measurements of a participant's maximum squat strength.

The testing protocol began with participants performing a warm-up with a self-selected load that allowed them to complete a minimum of 6–10 repetitions, which corresponds to approximately 50 % of their predicted 1RM (one-repetition maximum). Following this warm-up, participants rested for 5 min. They then selected a weight based on their previous effort, which allowed them to perform three repetitions. After an additional 3-min rest period, participants increased the load by 10 % and attempted to lift their 1RM.

The test continued until participants reached muscular failure, preventing them from completing a squat repetition. The 1RM was determined as the maximum load lifted in a successful manner.

2.8. Standing long jump

The standing long jump physical fitness test instrument (AI, Lingkang, China) was used to evaluate the standing long jump of the participants. This instrument features a high-definition camera with 8 million pixels or more and an error margin of 0 cm, making it the most reliable choice for assessing the standing long jump. Participants were instructed to stand on the starting line with their legs slightly apart and knees slightly bent, while leaning their bodies forward. They were then asked to swing their arms back and forth naturally twice, while flexing and extending their legs accordingly. To generate a powerful jump, participants were instructed to push off the ground quickly with the soles of their feet, fully extending their knee joints, and jumping forward with their hips extended. The distance covered upon landing was recorded. Each participant performed 3 trials, with a 1-min rest between trials. Statistical analysis was conducted by taking the highest value of the trials.

2.9. Muscular endurance

Muscular endurance was assessed using established methods, as previously documented [33,34]. Participants engaged in 1-min sessions of push-ups and sit-ups. During push-ups, participants were directed to place their hands vertically on the ground, maintaining proper alignment of the torso with shoulders, hips, knees, and ankles throughout the entire range of motion. They raised their hands off the ground between each push-up, with the push-up rhythm regulated by a metronome. Participants aimed to complete as many repetitions as possible within 1 min while ensuring correct form [33].

For the sit-up assessment, participants were instructed to lie supine on a floor mat, with knees flexed at approximately 90° and feet flat on the ground. With their hands raised, the task involved a swift transition from a lying position to a seated one. They flexed their upper body forward, reaching for their feet while lowering their head. Participants were then required to return to the seated position and repeat this sequence within a 1-min timeframe [34].

2.10. Estimated maximal oxygen uptake

The participants' estimated maximal oxygen uptake (VO_2 max) was determined through a 20-m shuttle running test, following the original protocol [35]. During this test, participants were instructed to shuttle run between two lines positioned 20 m apart while circling around a central point located between these lines. They were required to pivot without crossing the lines before each turnaround, maintaining their activity within these boundaries. The test concluded when a participant failed to reach a line after two consecutive beeps or if they did not await two consecutive beeps before proceeding. The total distance covered by each participant was measured and recorded as the primary outcome. Furthermore, the participant's VO_2 max was estimated based on the number of stages completed, using the following formula: VO_2 max = −24.4 + 6.0 final velocity achieved [35].

2.11. Training intervention

The combined aerobic fitness and strength training intervention spanned 16 weeks, with training sessions taking place 6 times a week. Each session had a duration of 120 min. For a detailed breakdown of the training sessions, please consider Table 1. During the training phase, sets were separated by 3-min rest intervals, and the intensity was adjusted to maximal exertion to complete the highest

Table 1
Description of the training intervention.

	Warm-up phase	Training phase	Relaxation phase
Session 1	Jogging (5min) barrel agility training (15 min)	Backhand pull-ups (3 × 15), static grip (3 × 15), static hang (3 × 15), alternate fingers gripping the barbell plates (3 × 15) sit-ups (3 × 15) (80min)	Foam roller massage (20min)
Session 2	Jogging (10min) pnf stretch activation (5min)	Freestyle kick training (6 × 15) (30min) Freestyle one-arm alternating training (6 × 15) (30min) Freestyle arm and breathing training (6 × 15) (25min)	3000 m running freestyle (20min)
Session 3	Jogging (5min) barrel agility training (15 min)	Wall handstand (3 × 15), hanging pull-ups (3 × 15), finger pull-ups (3 × 15), L-shaped pull-ups (3 × 15), rope/towel pull-ups (3 × 15), maximum weight pull-ups (3 × 15), elastic band-assisted pull-ups (3 × 15) (80min)	Yoga (20min)
Session 4	Jogging (10min) pnf stretch activation (5min)	Freestyle kick training (6 × 15) (30min) Freestyle one-arm alternating training (6 × 15) (30min) Freestyle arm and breathing training (6 × 15) (25min)	3000 m running freestyle (20min)
Session 5	Static stretching (10min) foam rolling activation (10min)	Finger-assisted one-arm pull-ups (3 × 15), towel/rope-assisted one-arm pull-ups (3 × 15), reverse pull-ups (3 × 15), static grip (3 × 15), standard pull-ups (3 × 15) (80min)	Massage by physiotherapist (20min)
Session 6	Jogging (10min) pnf stretch activation (5min)	Freestyle kick training (6 × 15) (30min) Freestyle one-arm alternating training (6 × 15) (30min) Freestyle arm and breathing training (6 × 15) (25min)	3000 m running freestyle (20min)

number of trials before reaching fatigue (closer to failure). Participants self-regulated the intensity using the weight of the equipment, the speed of contraction during the concentric phase, and/or the range of motion. Trainers introduced these variations, and a monitoring scale was employed to ensure consistency in the reported intensity by participants, thereby controlling the stimulus.

Participants were instructed not to engage in any military activities or other sports training during this period. At baseline, the group was divided into two subgroups. One subgroup included participants who scored below the median for each primary outcome, while the other subgroup included participants who scored above the median. Both subgroups underwent the same exercise intervention.

Aerobic fitness and strength training sessions are conducted at 3 p.m. at the designated training ground by the military region. Each session begins with a 20-min warm-up, followed by 80 min of combined aerobic fitness and strength training. Finally, a 20-min cool-down session is included. To enhance participants' comprehension of aerobic fitness and strength training and to achieve optimal training results, we have implemented a schedule alternating between 3 times aerobic fitness sessions and 3 times strength training sessions per week.

2.12. *Statistical procedures*

The descriptive statistics are depicted in the form of mean and standard deviation. Sub-groups were stratified based on the cumulative Z-scores computed for the average of each physical fitness component. To accomplish this, the Total score of athleticism (reference) was utilized: individuals with scores above 0.0 were categorized as the better fitness group (BFT), while those with scores below 0.0 were designated as the lower fitness group (LFT).

The normality of the sample was assessed using the Shapiro-Wilk test ($p > 0.05$), and homogeneity was verified using the Levene test ($p > 0.05$). Following the confirmation of these statistical assumptions, the mixed ANOVA test (group*time) was employed. Pairwise comparisons were conducted using the Bonferroni post hoc test, and effect size was assessed using Cohen's standardized measure. A repeated measures ANOVA was applied to the entire participant cohort, and post-hoc Bonferroni tests were employed to compare assessments at different time points.

All statistical analyses were carried out using SPSS software (version 28.0.0, IBM, USA) with a significance threshold set at $p < 0.05$.

3. Results

Body mass index varied from 23.9 ± 1.0 at baseline to 23.1 ± 0.8 kg/m^2 post-intervention. Waist circumference ranged from 80.5 ± 2.1 to 77.3 ± 1.4 cm, while hip circumference ranged from 89.4 ± 1.9 cm to 85.4 ± 1.9 cm. Fig. 2 illustrates the anthropometric variations observed for all participants throughout the study.

Descriptive statistics of the participants exposed to the intervention program can be observed in Table 2. Repeated measures ANOVA revealed significant differences over time in the VO_2 max ($F = 86.898$; $p < 0.001$; $\eta_p^2 = 0.821$), handgrip strength right hand ($F = 160.480$; $p < 0.001$; $\eta_p^2 = 0.894$), handgrip strength left hand ($F = 102.196$; $p < 0.001$; $\eta_p^2 = 0.843$), squat maximal strength ($F = 525.725$; $p < 0.001$; $\eta_p^2 = 0.965$), push-ups ($F = 337.197$; $p < 0.001$; $\eta_p^2 = 0.974$), sit up ($F = 252.500$; $p < 0.001$; $\eta_p^2 = 0.930$) and standing long jump ($F = 521.714$; $p < 0.001$; $\eta_p^2 = 0.965$).

Descriptive statistics pertaining to VO_2 max, handgrip strength, and maximal strength during squat exercises among distinct groups (comprising sub-groups categorized by their initial fitness status) are presented in Fig. 3. The results from a mixed analysis of variance (ANOVA) indicate that there is no statistically significant interaction effect (group*time) with respect to VO_2 max ($F = 1.045$; $p = 0.339$; $\eta_p^2 = 0.055$), handgrip strength right hand ($F = 0.328$; $p = 0.617$; $\eta_p^2 = 0.018$), handgrip strength left hand ($F = 0.408$; $p = 0.606$; $\eta_p^2 = 0.022$) and maximal strength during squat exercises ($F = 2.007$; $p = 0.149$; $\eta_p^2 = 0.100$)

Post hoc analysis revealed no significant differences between groups with respect to VO_2 max ($p = 0.289$; $\eta_p^2 = 0.062$), handgrip strength left hand ($p = 0.075$; $\eta_p^2 = 0.166$) and maximal strength during squat exercises ($p = 0.079$; $\eta_p^2 = 0.161$). However, significant differences between groups were found at handgrip strength right hand ($p = 0.022$; $\eta_p^2 = 0.258$).

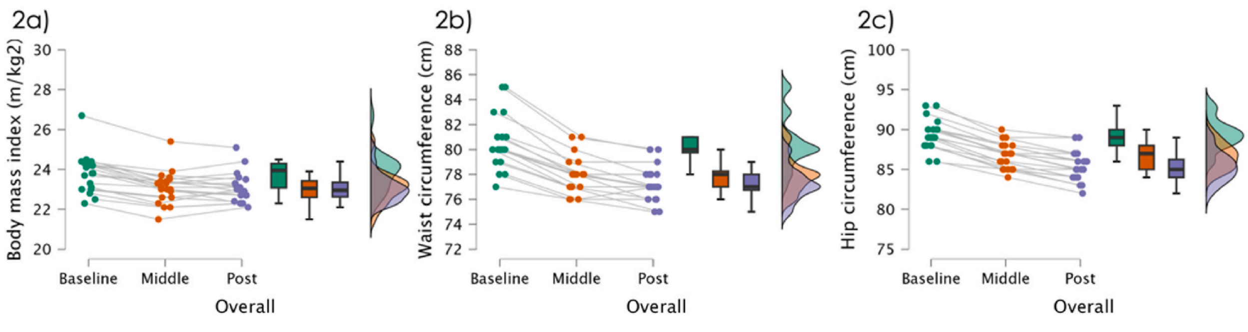

Fig. 2. Descriptive statistics of the anthropometric variations observed throughout the study. (a) body mass; (b) waist circumference; and (c) hip circumference.

Table 2
Descriptive statistics (mean ± standard deviation) of the physical fitness parameters measured over the time.

	Baseline (1)	Middle assessment (2)	Post-intervention (3)	Differences (2–1)	Differences (1–3)	Differences (2–3)
VO_2 max (ml/kg/min)	43.8 ± 1.3	46.4 ± 1.3	49.5 ± 2.4	+2.6 ml/kg/min |p < 0.001 |d = 2.0	+5.7 ml/kg/min |p < 0.001 |d = 3.1	+3.1 ml/kg/min |p < 0.001 |d = 1.7
Handgrip strength R (kg)	53.8 ± 5.9	55.8 ± 4.9	57.6 ± 4.6	+2.0 kg |p < 0.001 |d = 0.4	+3.8 kg |p < 0.001 |d = 0.7	+1.8 kg |p < 0.001 |d = 0.3
Handgrip strength L (kg)	52.7 ± 5.5	54.2 ± 4.8	55.7 ± 4.7	+1.8 kg |p < 0.001 |d = 0.4	+3.3 kg |p < 0.001 |d = 0.7	+1.5 kg |p < 0.001 |d = 0.3
Squat 1RM (kg)	74.7 ± 8.3	88.3 ± 8.2	101.9 ± 8.4	+13.6 kg |p < 0.001 |d = 1.6	+27.2 kg |p < 0.001 |d = 3.3	+13.6 kg |p < 0.001 |d = 1.6
Push-ups (n)	41.8 ± 6.8	47.9 ± 6.1	52.4 ± 5.8	+6.1 n |p < 0.001 |d = 0.9	+10.6 n |p < 0.001 |d = 1.7	+4.5 n |p < 0.001 |d = 0.8
Sit up (n)	55.5 ± 3.7	60.2 ± 4.1	63.7 ± 3.7	+4.7 n |p < 0.001 |d = 1.2	+8.2 n |p < 0.001 |d = 2.2	+3.5 n |p < 0.001 |d = 0.9
Standing long jump (m)	2.48 ± 0.08	2.59 ± 0.07	2.67 ± 0.07	+0.1 m |p < 0.001 |d = 1.6	+0.2 m |p < 0.001 |d = 2.7	+0.1 m |p < 0.001 |d = 1.1

R: right; L: left.

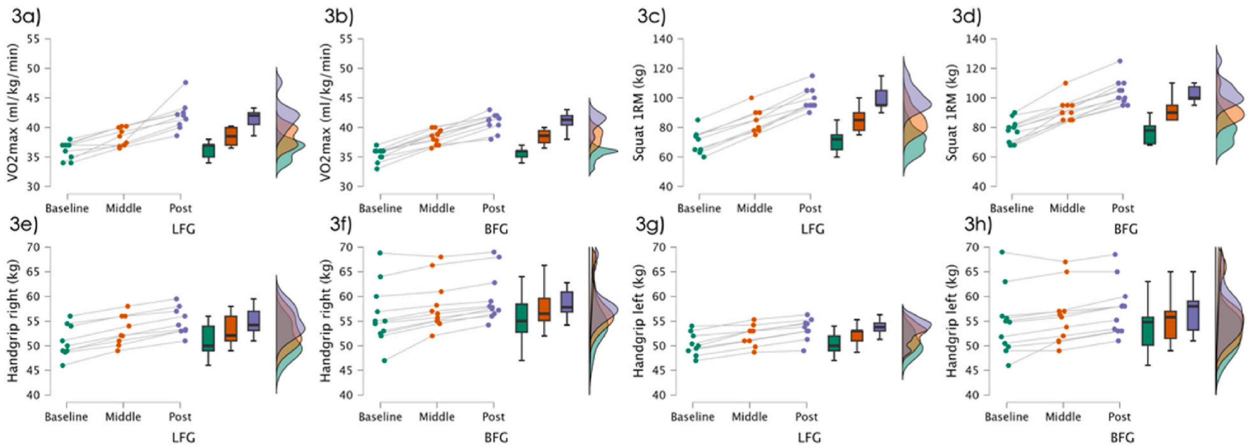

Fig. 3. Descriptive statistics for both the Lower Fitness Group (LFG) and the Better Fitness Group (BFG) include estimated maximal oxygen uptake (VO_2 max), handgrip strength, and maximal squat repetitions. (a) VO_2 max in LFG; b) VO_2 max in BFG; c) squat 1 maximum repetition (RM) in LFG; d) squat 1 maximum repetition (RM) in BFG; e) handgrip strength – right hand in LFG; f) handgrip strength – right hand in BFG; g) handgrip strength – left hand in LFG; h) handgrip strength – left hand in BFG.

Descriptive statistics pertaining to push ups, sit up and standing long jump (comprising sub-groups categorized by their initial fitness status) are presented in Fig. 4. The results from a mixed analysis of variance (ANOVA) indicate that there is no statistically significant interaction effect (group*time) with respect to push ups ($F = 3.105$; $p = 0.057$; $\eta_p^2 = 0.147$), sit up ($F = 2.082$; $p = 0.154$; $\eta_p^2 = 0.104$) and standing long jump ($F = 0.468$; $p = 0.581$; $\eta_p^2 = 0.025$).

Post hoc analysis revealed no significant differences between groups with respect to sit up ($p = 0.580$; $\eta_p^2 = 0.017$) and standing long jump ($p = 0.095$; $\eta_p^2 = 0.147$). However, significant differences between groups were found at push ups ($p = 0.025$; $\eta_p^2 = 0.248$).

4. Discussion

This study aimed to assess the effects of a 16-week comprehensive training program, combining aerobic fitness and strength training, on the health and physical fitness of male pilots within the Chinese People's Liberation Army Air Force. The results indicate substantial improvements in various key physical fitness parameters following the intervention, including VO2 max, handgrip strength, squat 1RM, push-ups, sit-ups, and standing long jump. Particularly noteworthy was the remarkable 36 % increase in squat 1RM performance. Although improvements in other metrics were relatively smaller, they remained statistically significant. These improvements can be attributed partially to the participants' initial baseline levels, as the amount of training during the initial stage was not extensive, allowing greater room for improvement.

Importantly, the intervention yielded significant enhancements in both higher and lower fitness level groups over the 16-week

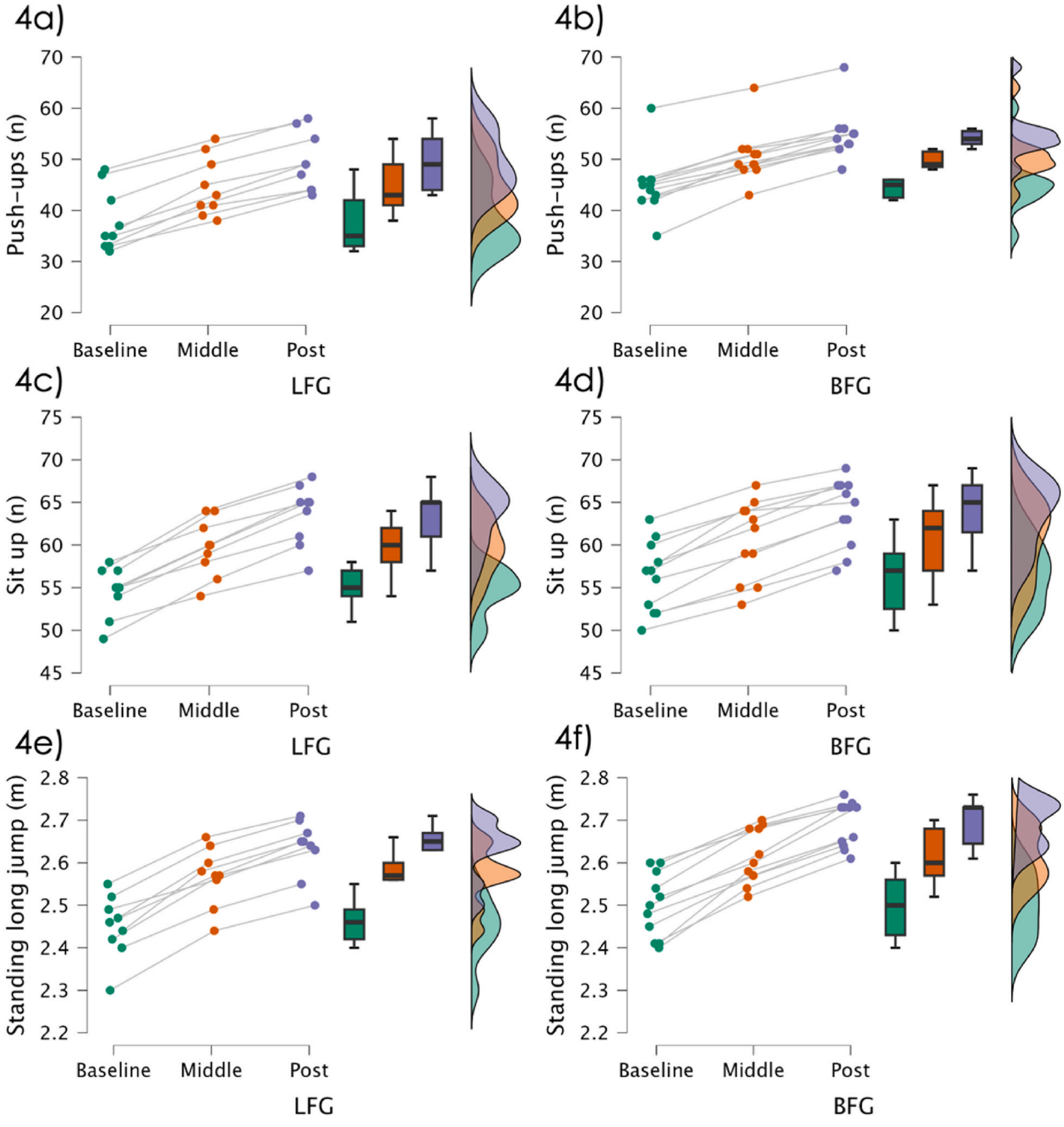

Fig. 4. Descriptive statistics for both the Lower Fitness Group (LFG) and the Better Fitness Group (BFG) include push up, sit up and standing long jump. a) push-ups in LFG; b) push-ups in BFG; c) sit up in LFG; d) sit up in BFG; e) standing long jump in LFG: f) standing long jump in BFG.

period, demonstrating consistent progress regardless of baseline fitness. This suggests that there is room for improvement regardless of initial fitness levels. Despite concerns about potential plateaus in progression, assessments conducted at various intervals revealed no such occurrence between the 8th and 16th weeks. Therefore, future research should consider extending the duration of the experiment to further explore the potential for improvement over time.

A significant aspect of this study was its evaluation of the training program's impact across a range of initial fitness levels among participants. Importantly, the intervention effectively enhanced physical fitness across individuals with differing baseline fitness levels, highlighting its broad applicability and value in improving the physical fitness of male pilots within the Chinese People's Liberation Army Air Force.

The significant improvements in maximal oxygen uptake observed in Air Force pilots after a 16-week period of combined strength and aerobic exercise can be comprehensively explained through physiological mechanisms. This dual approach harnesses the synergistic effects of both muscle strength and cardiovascular adaptations to enhance the pilots' overall physical performance [36–38]. Strength training (e.g., circuit training), for instance, induces neuromuscular adaptations and increases lean body mass, which, in turn, elevates the pilot's muscular endurance and favors cardiorespiratory improvement [39].

Simultaneously, aerobic exercise augments cardiovascular fitness, fostering a more efficient transport of oxygen to the muscles [40]. This leads to improved oxygen utilization and reduced reliance on anaerobic pathways, ultimately delaying the onset of fatigue during prolonged missions [41]. Furthermore, the enhanced cardiovascular capacity promotes increased stroke volume and cardiac output, ensuring a steady supply of oxygen to the working muscles [42]. This improved oxygen delivery, coupled with the heightened oxygen-carrying capacity due to aerobic training, results in a considerable enhancement in the pilots' maximal oxygen uptake. Integrating aerobic training with high-volume multi-joint resistance exercises for the legs and upper body enhances aerobic endurance and predictive VO_2 max [43]. Strength training, such as squat 1RM and push-ups, can improve oxygen distribution to mitochondria and muscle metabolism regulation, likely due to improvements in oxygen delivery and utilization in skeletal muscle [44].

Combined training over the course of 16 weeks has been shown to significantly enhance the maximum strength of Air Force pilots. After the intervention, there was a significant enhancement in the pilot's grip strength, showing a 7.1 % increase in the right hand and a 6.3 % increase in the left hand. However, the most remarkable effect witnessed was a substantial 36 % improvement in squat 1RM. Although significant, these gains are smaller than those performed in similar studies. For instance, Hickson [45] and Kraemer et al. [46] demonstrated significant disparities in strength gains from pre-training to post-training between the strength group and the combined training group, with improvements of 30 % and 19.5 %, and 35 % and 24 %, respectively.

Strength training is designed to target the development of muscle mass, power, and neuromuscular adaptations [47,48]. Resistance exercises, in particular, stimulate hypertrophy, or muscle growth [49], which directly contributes to increased maximum strength [50] Moreover, strength training improves the neural pathways and coordination necessary for maximal force production [51]. This not only results in the heightened recruitment of muscle fibers but also enhances the synchronization of motor units, ultimately leading to greater strength gains [52].

In addition, the increased circulation resulting from aerobic exercise is crucial for delivering oxygen and nutrients to muscles, thereby aiding in their recovery and growth [53]. Improved aerobic capacity also enables pilots to endure longer and more intense strength training sessions, which in turn leads to better gains in muscle strength [54]. The combination of aerobic and strength training within the context of Air Force pilot fitness promotes a synergistic effect. Aerobic conditioning provides the necessary endurance for pilots to withstand prolonged and high-intensity strength training sessions, which facilitates muscle growth and strength development [55]. This enhanced cardiovascular fitness also plays a pivotal role in the recovery process, allowing for more frequent and intense strength workouts [56].

The significant improvement in long jump performance following the combined training regimen can be attributed to several interconnected physiological mechanisms. First and foremost, the gains in maximal strength resulting from strength training are pivotal to enhancing long jump performance [57]. Increased maximal strength allows athletes to generate greater force during the take-off phase, enabling them to achieve a more explosive and powerful jump. This improved strength contributes to greater kinetic energy transfer from the athlete to the take-off board, propelling them further into the air [58]. Additionally, it is noteworthy that previous research findings have consistently highlighted the advantage of prioritizing resistance training over endurance training in the context of lower limb strength development, without any detrimental effects on aerobic capacity [59].This distinction in training emphasis must be underscored within the training process, as it elucidates the rationale behind our approach. In summary, the combined training approach promotes gains in maximal strength, which amplify the force generation during the take-off, leading to a more dynamic jump and greater kinetic energy transfer [60].

The results of our investigation revealed a significant enhancement in muscle endurance following the combined training regimen. Specifically, we observed a remarkable 25 % increase in push-up performance and a 15 % improvement in sit-up capabilities among the participating air force pilots. Notably, this improvement was more pronounced in upper body strength compared to core strength. However, it is crucial to acknowledge that prior research has not consistently identified associations between changes in muscular endurance assessments. These findings appear to diverge from our own, suggesting that while advancements in muscular endurance within core muscles might exist, improvements in upper body muscular endurance may not be readily apparent [61].

It is worth noting that endurance training typically does not lead to significant muscle fiber hypertrophy [62–66]. Instead, it induces various adaptations that optimize endurance performance. These adaptations encompass an augmentation in capillary density [62,63,65,67,68], an increase in mitochondrial volume density [69],and heightened oxidative enzyme activity [64,67]. Simultaneously, strength training enhances muscular strength and the ability to resist fatigue [70]. This combination promotes greater resistance to muscle fatigue by improving the oxidative capacity of muscle fibers, ultimately enhancing overall muscle endurance [71].

Despite the promising findings of the study, there are several limitations that should be considered. Firstly, the study focused exclusively on male pilots within the Chinese People's Liberation Army Air Force, which limits the generalizability of the results to other populations. Future research could benefit from including a more diverse sample, encompassing individuals from different military branches or even civilian populations. Additionally, while the 16-week intervention led to significant improvements in various physical fitness parameters, the absence of a control group makes it challenging to attribute these changes solely to the training program. Incorporating a control group receiving no intervention or a different type of intervention would allow for a better understanding of the specific effects of the combined training regimen. Finally, the study did not investigate the long-term sustainability of the observed improvements. Future research could explore the durability of the effects over an extended period to assess whether continued training is necessary to maintain the enhanced physical fitness levels. Despite these limitations, the study provides valuable insights into the effectiveness of combined strength and aerobic training interventions for improving the health and physical fitness of military personnel, laying the groundwork for further investigation in this field.

Practically, this study highlights the potential benefits of combined training for Air Force pilots, as it demonstrated improved physical performance, irrespective of baseline levels. This suggests that such training could be a valuable addition to their routine, contributing to their overall fitness and readiness for challenging missions. These findings could also have broader implications for enhancing the physical training programs for military personnel in general, offering opportunities to optimize their physical capabilities for the demands of their roles.

5. Conclusion

In conclusion, the findings of this study demonstrate the significant effectiveness of a 16-week comprehensive training intervention, which combines aerobic fitness and strength training, in enhancing the health and physical fitness of male pilots within the Chinese People's Liberation Army Air Force. Our results indicate substantial improvements in key parameters of physical fitness, including VO2 max, handgrip strength, squat 1RM, push-ups, sit-ups, and standing long jump. The intervention showed to be equally effective across individuals with varying baseline fitness levels, highlighting its broad-reaching benefits and equitable nature. These findings underscore the importance of implementing training programs that address the specific needs of military personnel, regardless of their initial physical fitness status. Moving forward, continued research in this area is warranted to further optimize training protocols and ensure the long-term sustainability of the observed improvements in physical fitness among Air Force pilots.

Ethical

The study received ethical approval from the Institutional Ethical Review Board of Chengdu Institute of Physical Education under the reference code 2023#145.

Financial conflicts

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

The data is available upon a reasonable request addressed to the corresponding author.

CRediT authorship contribution statement

DeSen Feng: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Li Li:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Qi Xu:** Writing – review & editing, Writing – original draft, Methodology. **TingYu Li:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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