Lower-Limb Explosive Power did not Improve during 8 Weeks of Integrative Military Physical Training

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Abstract

Objective: Military populations require a range of physical capabilities to meet the demands of the military profession. It is not known whether a specific within-session balance of the core components of physical fitness provides more effective training adaptations. The purpose of this research was to determine the effects of combinations of high-intensity endurance training, resistance training, anaerobic training and plyometric training.

Methods: Twenty-eight healthy young cadets participated in an 8-week training program. Training was performed 6 days per week. Testing occurred before and after the 8-week training regimen. The pre- and post-training measures included the basic physiological and performance levels.

Results: Physiological indices, such heart rate, heart rate variability, anaerobic power and maximal oxygen uptake, responded positively to training ($P < 0.05$). The components of physical fitness, such as muscle maximal strength and endurance, 600 all-out effort, 5000-m run time and 18-km military load carriage, were also significantly improved ($P > 0.05$). However, the jump capacity did not significantly increase.

Conclusion: The results of this study indicate that during short-term integrative training, the lower-limb muscle maximal power did not improve. Given that many military tasks demand explosive (power) abilities, a switch to integrative training may have far greater consequences for transferring the benefits of the training program to military human performance.

Background

Concurrent training (CT) is a mode of training that simultaneously develops various physical capacities [1, 2], such as aerobic capacity, muscle strength, and power, which is defined as the simultaneous training of strength and endurance within a periodized training regime. [1, 2]. Despite the potential additive benefits of combining these divergent exercise modes with regards to athletic and soldiers' physical performance, current evidence suggests that this approach may attenuate gains in muscle mass, strength, and power compared with resistance training alone [1-3]. This type of training has been variously described as the interference effect or concurrent training effect [4-6].

Military duties consist of physically demanding tasks, such as carrying or lifting heavy loads and materials, digging and shoveling actions and prolonged physical activity with additional loads of combat gear weighing 25-65 kg [7], i.e., activities that consist of similar demands to combined strength and endurance training. Optimal programming of training plays an important role when aiming for more specific responses after different types of military or physical training [8]. It is becoming common to design and implement periodization schemes aimed at minimizing the potential interference effects traditionally associated with concurrent training. A greater understanding of the interactions between strength and endurance training would provide useful insight for applied practitioners involved in common military tasks for which both capabilities need to be developed simultaneously to optimize performance[1, 2].

Previous studies have suggested that the varying modalities, intensities, frequencies, volumes and sequence of training, and between-mode recovery, may play roles in mediating the interference effect[3]. Although the responses of each variable to such programs remain controversial, several studies indicate that the degree of interference can be minimized or avoided, such as performing endurance training first and having short recovery periods (less than 3-8 hours) [9, 10]. These training variables may allow adequate recovery to improve the subsequent training adaptation.

Furthermore, given that several military duties consist of tasks for which high demands of anaerobic energy systems are also required, such as sprinting to and from cover, changing direction at speed, close-quarters combat, and quickly ascending stairwells and rigorous terrain, thus the anaerobic exercises (600-m all-out running) and plyometric training have been added to this integrative training model. Accordingly, the present study also aimed to integrate these components of military physical fitness. We hypothesized that the integration of these components of physical fitness would allow us to develop a gradual and progressive training program that incorporates the basic principles of exercise (regularity, progression, overload and recovery) to optimize military physical development.

Methods

Subjects

A total of 28 healthy male cadets from the college of basic education for commanding officers took part in this study. All participants underwent a complete physical examination and an electrocardiogram to determine their physical and mental condition, and all were diagnosed as healthy. Written informed consent was obtained from all of the participants. This study was carried out in accordance with the principles of the Basel Declaration and recommendations of the Declaration of Helsinki, the ethics committee of the Army Engineering University of PLA. The protocol was approved by the ethics committee of the Army Engineering University of PLA.

Experimental Protocol

This was a before-after controlled trial. An experimental design schedule is presented in Figure 1.

Before data collection and training intervention, all participants underwent a two-week familiarization period. During the familiarization period, subjects learned correct execution and proper form for the prescribed exercise tests, mainly regarding the various appropriate postures, utilization of constant range of motion, and movement speed. Physical and physiological evaluations were performed before and after the 8-week training intervention. All evaluations were conducted over 7 days with at least 12 hours of rest before each evaluation session. Before each test, there was a specific warm-up or cool-down.

Heart Rate and its Variability

The participant’s baseline HR was measured after a period of 10 min seated rest using a real-time HR monitor (Polar TEAM Heart Rate Monitor, Finland). HRV was analyzed at rest (5-10 min) using the Firstbeat SPORTS software program (version 4.4.0.2, Firstbeat Technologies Ltd., Jyväskylä, Finland). HRV variables included time and frequency domains. The time-domain measures were RR interval, the standard deviation of RR intervals (SD) and the square root of the mean squared successive differences of successive RR intervals (RMSSD). The frequency domain measures were low-frequency (LF, 0.04-0.15 Hz) and high-frequency (HF, 0.15-0.40 Hz) spectral components and the ratio between these components (LF/HF).

Maximal Oxygen Uptake

Maximal oxygen uptake (O_{2max}) was assessed with a Max IIa metabolic cart (AEI Technologies, Naperville, IL) using standard open-circuit spirometry techniques, followed by an incremental exercise test on a motor-driven treadmill (h/p/cosmos, quasar, Germany). Calibration procedures were performed before the test according to the manufacturer’s recommendations. The treadmill running test was performed using a modified Bruce protocol[11]. All subjects were encouraged to exercise to exhaustion. The highest 1-minute average of O_2 uptake was determined as O_{2max}. Exhaustion was ensured by respiratory exchange ratio >1.05.

30-s Wingate Anaerobic Test

The anaerobic power was measured on a mechanically braked stationary cycle ergometer (Monark Ergomedic 839E, Monark, Sweden) against a pre-determined force load of approximately 7.5% of the subject’s body weight in kilograms.

Muscular Strength and Endurance

Subjects completed a one-repetition maximum (1RM) test for bench press (upper-body muscular strength), deadlift (total-body muscular strength) and squat (lower-body muscular strength). Briefly, the 1RM should be accomplished in a maximum of 4 attempts, in which the load was gradually increased according to individual capacity. Each 1RM test began at a weight near the expected maximum by the subjects. After the participant had approximately 5 minutes of passive rest to feel recovered from the previous attempt, the weight was then increased to be somewhat more difficult (varying according to the exercise performed) [12]. Successive attempts with progressive loads were applied, until the 1RM value was found for each exercise. As the measure of upper-body muscular endurance, the maximal number of push-ups to exhaustion was assessed pre- and post-training.

Jump Capacity

Subjects performed lower-body explosive muscular strength tests (i.e., standing long jump) three times. The longest recorded distance was assessed as jump capacity.

Common Activities and Military Load Carriage Activity

The physical performance battery consisted of three tasks: 600-m all-out running, 5000-m running and 18-km military load carriage. The 600-m all-out effort and 5000-m run were tested on the formal track. The 18-km military load carriage activity was tested in the field.

Integrative Training Period

Experimental groups underwent an 8-week integrative training program. This training program was based on the pervious recommendations for optimizing the adaptations to integrative training, including performing high-intensity endurance training sessions first [10, 13] and at least 24 h of recovery between endurance and strength training.

However, given that physical training for military populations must address performance along an entire continuum to be able to perform a variety of mission tasks, this physical fitness training model mainly involved high levels of aerobic capacity (high-volume running, marching with load), fundamental strength and anaerobic activities. We attempted to properly balance between cardiorespiratory endurance, anaerobic activities, plyometric exercises and muscular strength based on training frequencies. Thus, the periodic, short-duration, high-intensity bursts of activities were interspersed between endurance and strength training (Table 1).

The training programs followed a periodized training plan to prepare the military populations to meet the specific physical needs. The frequency for each training component was 3 times per week. Before each training session, there was a specific warm-up or cool down.

Cardiorespiratory Exercise Training

The training mainly consisted of prolonged endurance training with or without a load. The endurance training lasted 100 min-120 min. The military load carriage activity under 27 kg was performed 1-2 times per week in the field environment.

Muscle Maximal Strength and Endurance Training

The training protocols consisted of mainly five exercises, which activated large or small muscle masses, performed in the following order: bench press, overhead press, half-squat, push-up, and pull-down. All exercises were executed using free weights or universal weight machines.

The training protocols were designed in accordance with a previous study [14]. In brief, the muscle strength protocol consisted of four to six sets of 6 repetitions at 90% of 1RM intensity with a 3-minute rest interval between exercises and sets. The muscle endurance protocol consisted of four to six sets of 16-20 repetitions at 40% of 1RM intensity with a 1-minute rest interval between exercises and sets. All subjects used a complete range of motion and a cadence of a 1- to 2-second positive phase and a 1- to 2-second negative phase. A muscle hypertrophy protocol was avoided. The muscle maximal strength and endurance training alternated in one-week cycles.

Plyometric Training

Plyometric training has been shown to improve muscle power, enhance sport performance, and reduce injury risk in young athletes. This method of training is based on the development of stretch-shortening cycle ability, which consists of a fast action of muscle stretching (eccentric action) followed by a fast shortening phase (concentric action). The training mode most representative of free play (e.g., jumping in multiple directions, skipping) was selected, including single- or double-leg frontward barrier hop, lateral barrier hop, skip and backward skip. The distance was 20 m, and the hurdle barrier height was 15-40 cm. Each exercise was performed in three to four sets with a 3-5-minute rest interval between exercises and sets. In addition, single-leg push-off and jump to box were also performed. Single-leg push-off was performed in three to four sets of 10-15 repetitions with a 3-5-minute rest interval between exercises. The plyometric box height was 15-40 cm. The jump to box was also performed in three to four sets of 2-6 repetitions with a 3-5-minute rest interval between exercises. The plyometric box height was 150-180 cm.

Anaerobic Exercise Training and Stability Training

The 600-m all-out run was selected to develop anaerobic ability. This exercise was performed three to four times with a 5-minute rest interval between exercises. The commonly used stabilization exercises were selected to develop core stability, including the bridge, unilateral bridge, side bridge and plank. Each exercise was performed three-four sets of 1.5-3 min duration with a 3-5-minute rest interval between exercises.

Statistical Analyses

All data presented in this study were calculated by the statistical package SPSS Version 17.0 The data are expressed as the mean ± SD. Differences from before to after the training period were assessed using the paired-samples t-test. $P < 0.05$ was considered statistically significant.

Results

HR and Heart Rate Variability

Heart rate variability parameters, before (Pre) and after (Post) the training period, are presented in Table 2 and Table 3, respectively. The average HR significantly decreased ($P < 0.05$), while the average RMSSD significantly increased ($P < 0.05$). No significant differences were found for SDNN, SDNN/HR, HF, LF or LF/HF (P values between 0.14 and 0.83).

General Physical Fitness

Anthropometric Measurements

No significant differences were found for body weight ($P > 0.05$) (Figure 2A) or BMI ($P > 0.05$) (Figure 2B).

Anaerobic or Aerobic Work Capacity

The average anaerobic power over 30 s significantly increased ($P < 0.05$) (Figure 3A). Similarly, the aerobic work capacity also significantly increased ($P < 0.05$) (Figure 3B).

Muscle Strength or Endurance

The muscle strength, represented by the bench press, deadlift and squat, significantly increased (all $P < 0.01$) (Figure 4A, B, C), and the muscle endurance, represented by the number of pull-ups, also significantly increased ($P < 0.01$) (Figure 4D).

Muscle Power

The muscle power of the lower extremities, represented by the standing long jump, did not show a significant difference ($P > 0.05$) (Figure 5).

Performance

The times in the common activities, such as 600-m all-out effort and 5000-m run, showed significant decreases (all $P < 0.05$) (Figure 6 A,B). The time in military load carriage activity (18 km, under 27 kg load condition) also showed a significant decrease ($P < 0.05$) (Figure 6 C).

Discussion

Military populations require a range of physical capabilities to meet the demands of the military profession, and physical training must address performance along an entire continuum that relies on three primary energy systems. For optimal performance, all training should be implemented in a gradual and progressive manner. Several strategies for CT have been adopted. Following an 8-week integrative training program, physiological and benign changes and improved performance were found, as expected. However, contrary to our hypothesis, the lower-limb explosive power did not change, likely suggesting that an interference occurred.

When designing training programs to enhance military basic fitness, there are a number of important factors to consider. Optimizing physical adaptation in various military environments is crucial for overall military readiness. It seems that an interference effect exists between aerobic training and resistance training if they are incorrectly manipulated. At present, many training variables have been suggested to reduce the interference phenomenon of CT [1-3, 5, 10, 13, 15, 16]. For example, previous studies have indicated that endurance athletes improve their performance significantly when they perform high-intensity strength training based on heavy resistance and plyometric exercises or a combination of both. Such improvements have also been observed in spite of a reduction of the sport-specific training volume [17, 18]. Moreover, high-intensity strength training favors greater muscle power, mainly via neural adaptations, with no or very little hypertrophic response[14], while resistance training with low loads (i.e., <60% of 1RM) might primarily augment the hypertrophy of type I muscle fibers, which have a higher oxidative capacity and a higher fatigue threshold[19]. Give that muscle hypertrophy could have a negative impact on weight-bearing endurance events, the muscle hypertrophy protocol was not adopted in our study. It is worth mentioning that 8 weeks of supplementation with these types of strength training failed to increase total body mass. During the CT, high-intensity endurance training sessions were performed early in the day [10, 13, 20]. In addition, give that many military tasks demand anaerobic or explosive (power) abilities, the anaerobic or plyometric training was added to this integrative training mode. In our attempt to induce more effective training adaptations, although heavy weight training or plyometric exercise is an effective way to improve muscle power in our study, the lower-extremity power did not improve. Given that many military tasks demands explosive (power) abilities, this change may have far greater consequences for the transfer of the benefits of the training program to military human performance and/or an improved capacity to perform activities of daily living.

Over the last several years, an understanding of the mechanisms of training adaptation in skeletal muscle has emerged, providing potential mechanistic insight into the CT effect, such as overtraining [4], residual fatigue [13], satellite cell response [21] and a molecular 'interference' effect [1-3, 5, 10, 22]. For example, mammalian target of rapamycin (mTOR, the key signaling molecule for protein synthesis) activity induced by RT can be maintained for at least 18 h [23], while AMP-activated protein kinase (the key signaling molecule for metabolic stress) induced by high-intensity endurance exercise can return to baseline levels by 3 h [24]. Moreover, other molecular events are activated by endurance exercise that could block mTOR [1]. Thus, it is likely that these potential mechanisms complementary simultaneously inhibit mTOR activation and limit skeletal muscle power during CT. Accordingly, the endurance training sessions should be placed before the strength sessions, or there should be a separation of at least 3 to 6 between the two types of training session [10, 25]. In our study, a period of recovery of at least 24h has been given, however, high-intensity anaerobic and plyometric exercise may have added complexity to these training adaptation responses. At present, the potential recovery mechanisms from these type training are unknown. In our study, the training frequency and volume were high, so it was likely overtraining that limited the muscle power development. Further work in this area is required to determine the specific plyometric training volume and/or frequency that will improve muscle power during integrative training. In addition, the residual fatigue may not allow for performing subsequent training sessions of higher quality. In this regard, it is worth mentioning that our training model induced greater rest bradycardia and higher RMSSD, which are adaptations associated with elite runners. In addition, there is an incompatibility and adaptation interference with concurrent training whereby endurance training attenuates hypertrophy or strength [1-3, 5, 10, 22], which may also have influenced the ability of lower-limb explosive power to improve.

The physical demands of military tasks are complex, and the key elements for success need to be identified based upon current combat loads [26].At present, it is still difficult to manipulate these program variables to effectively achieve a specific training outcome to meet all the occupational and operational demands and expectations [1, 2]. Furthermore, identifying the training variables and various molecular signaling responses should be investigated in the future, which may be able to identify different training strategies that can overcome any negative effects of this specific training mode.

Conclusion

Taken collectively, our data may provide further support that short-term integrative training does not improve lower-limb muscle maximal power. Future studies should identify the potential mechanisms responsible for the observed inhibition in power development after integrative training.

LIMITATIONS

This study has some limitations. There were no isolated control groups for short-term resistance training, endurance training, anaerobic training or plyometric training. Thus, the attenuated muscle muscular endurance or strength/power cannot be quantified.

Declarations

Ethics approval and consent to participate

This study was carried out in accordance with the principles of the Basel Declaration and recommendations of the Declaration of Helsinki, the ethics committee of the Army Engineering University of PLA. The protocol was approved by the ethics committee of the Army Engineering University of PLA. Written informed consent was obtained from all of the participants.

Consent for Publication

Availability of data and material

All data generated during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that this research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

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(2016JY374). The funders were not involved in the design of the experiments, nor were they involved in data collection, analysis, and writing of manuscripts.

Authors' contributions

JM and FH designed the study, performed the experiments, collected and analyzed the data, and revised the final version of the manuscript. QH, WJ, CD, XZ, SX and DT recruited participants, collected samples and performed the experiments. All authors read and approved the final version of the manuscript.

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Tables

Table 1

Summary of the training programs

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
A.m.	Endurance	Muscular strength or endurance	Endurance	Muscular strength or endurance	Endurance	Muscular strength or endurance	Rest
P.m.	Anaerobic activities	Plyometric exercises	Anaerobic activities	Plyometric exercises	Anaerobic activities	Plyometric exercises	

Table 2

Changes of HR and HRV time domain parameters (n=28)

	HR (beat/min)	RMSSD (ms)	SDNN (ms)	SDNN/HR (ms/beat)
Pre	63.36 ± 10.23	57.86 ± 28.65	74.50 ± 29.34	1.25 ± 0.64
Post	58.21 ± 7.16*	74.50 ± 28.64*	84.21 ± 20.06	1.49 ± 0.57

Average HR: Average heart rate; RMSSD: Root of the mean squared successive differences of in RR intervals; SDNN: The mean standard deviation of RR intervals; SDNN/HR: The mean standard deviation of RR intervals /heart rate

Table 3

Changes of HRV frequency domain parameters (n=28)

	HF (ms^2)	LF (ms^2)	LF/HF
Pre	4278.73 ± 2731.18	2948.45 ± 1604.72	122.44 ± 54.32
Post	5154.17 ± 2921.62	3657.70 ± 2745.64	140.17 ± 123.59

HF: High frequency; LF: Low frequency; LF/HF: The ratio between the low frequency and high frequency

* $P < 0.05$ *vs* rest

Figures

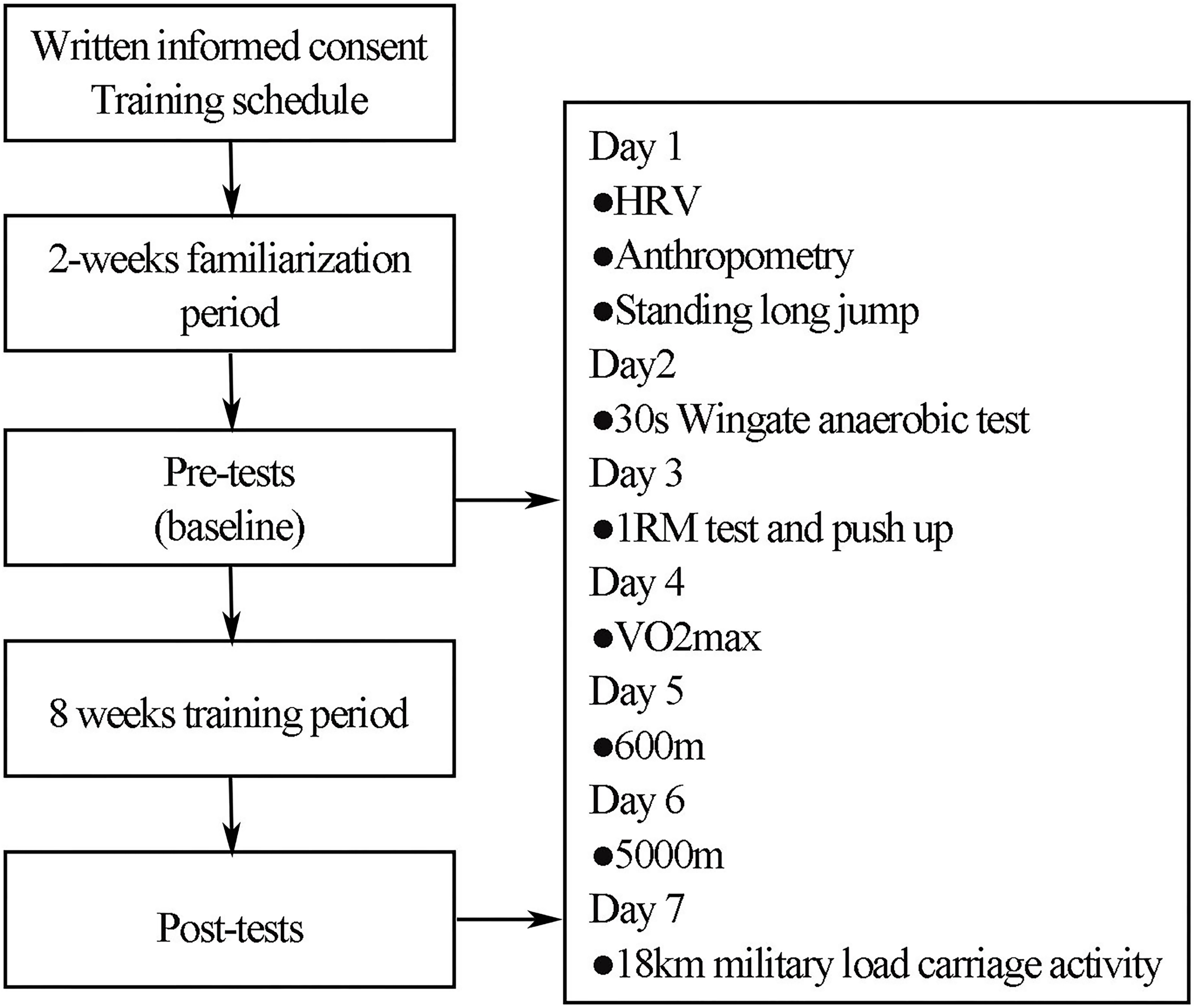

Figure 1

Experimental design schedule. HRV: heart rate variability; 1RM: one repetition maximum; V̇ O2max: maximum oxygen consumption.

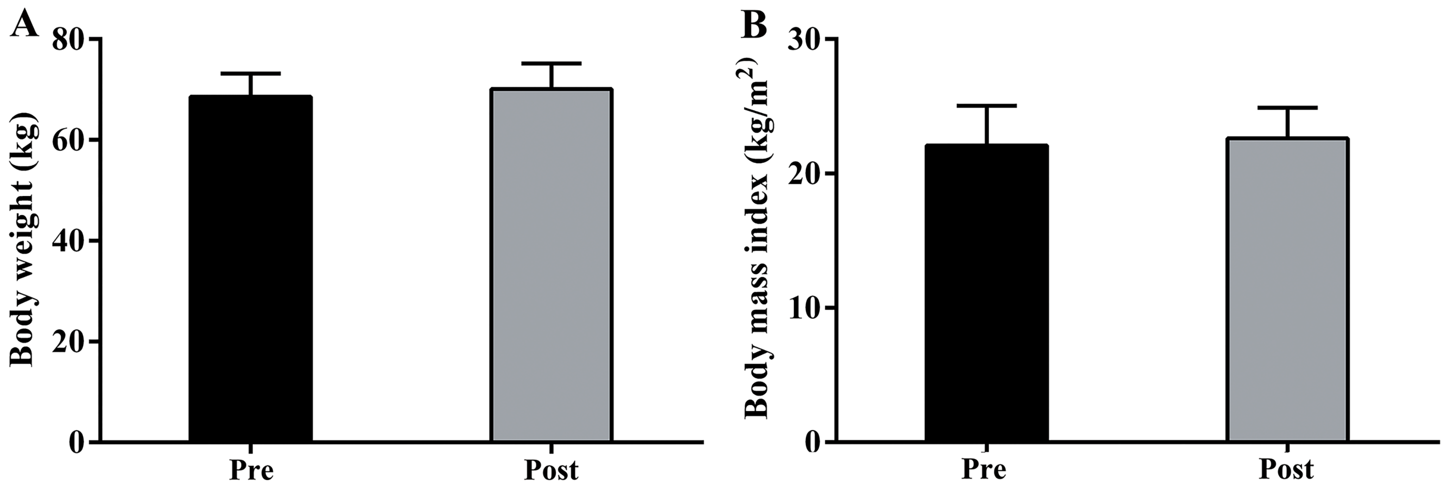

Figure 2

The changes in body weight (A) and BMI (B) from before (Pre) to after (Post) the training period (n=28). * indicates differences compared to Pre, P < 0.05. Values represent the mean ± SD.

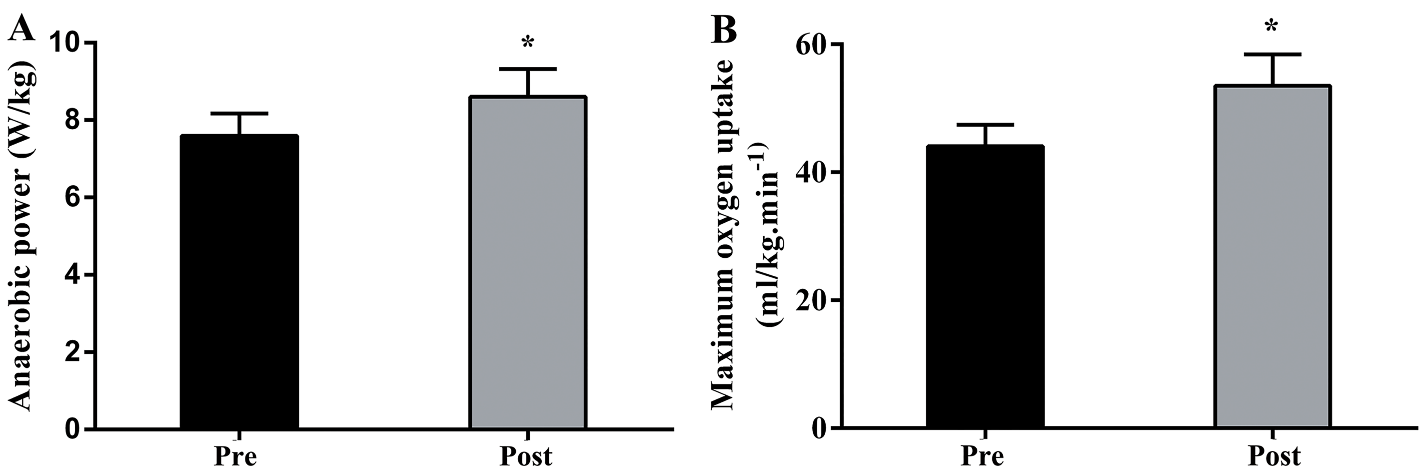

Figure 3

The changes in anaerobic power (A) and maximum oxygen uptake (B) from before (Pre) to after (Post) the training period (n=28). * indicates differences compared to Pre, P < 0.05. Values represent the mean ± SD.

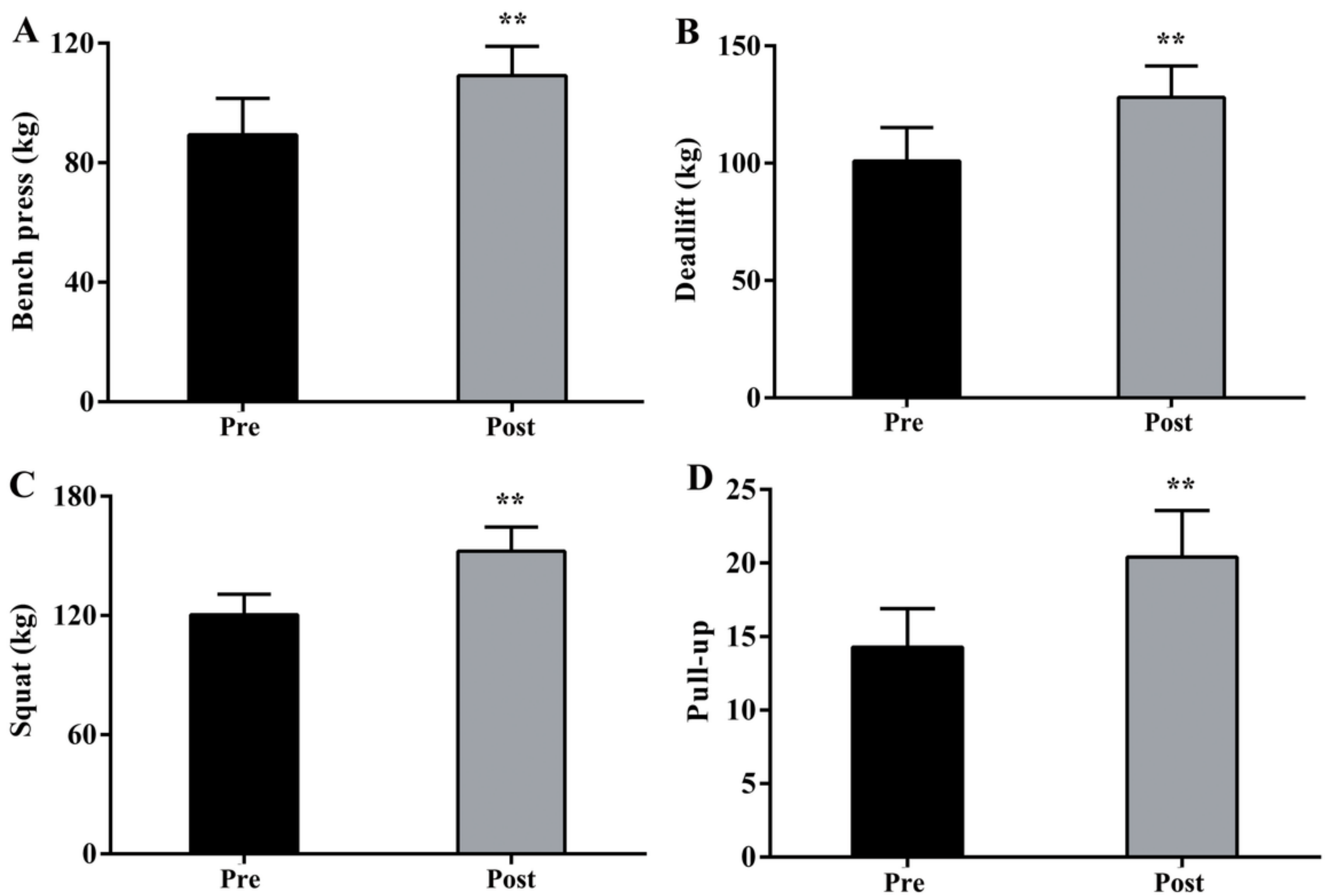

Figure 4

The changes in bench press (A), deadlift (B), squat (C) and pull-up (D) from before (Pre) to after (Post) the training period (n=28). **indicates differences compared to Pre, P < 0.01. Values represent the mean ± SD.

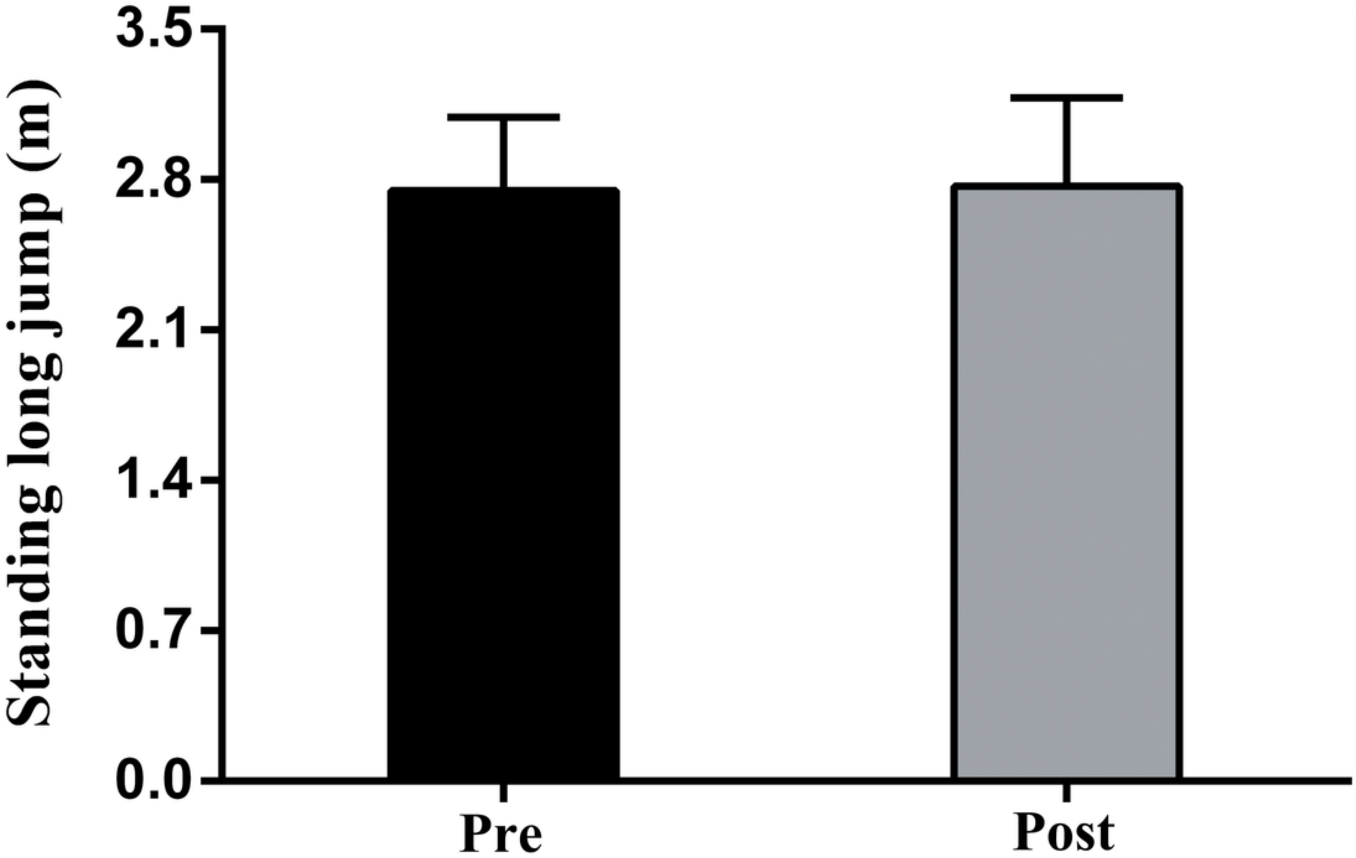

Figure 5

The changes in Muscle power (n=28). * indicates differences compared to Pre, P < 0.05. Values represent the mean ± SD.

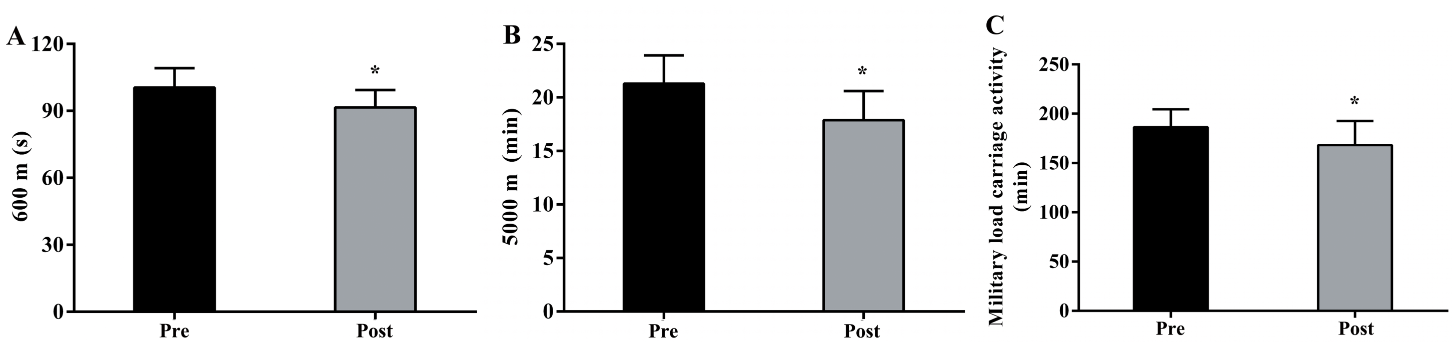

Figure 6

The changes in 600-m all-out run (A), 5000-m run (B) and 18-km military load carriage activity (C) from before (Pre) to after (Post) the training period (n = 28). * indicates differences compared to Pre, P < 0.05. Values represent the mean ± SD.