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Contact: Jani Vaara
Email: jani.vaara@mil.fi
Guarantor: Jani Vaara

Neuromuscular performance and hormonal profile during military training and subsequent recovery period

Capt Salonen Mika[1]

Huovinen Jukka, Msc.[2]

Kyröläinen Heikki, PhD[1,2]

Piirainen Jarmo M, PhD[2]

Vaara Jani P, PhD[1]

[1]Department of Leadership and Military Pedagogy,National Defense University, Santahamina, 00860, Helsinki, Finland

[2]Neuromuscular Research Center, Faculty of Sport and Health Sciences, University of Jyväskylä, Rautpohjankatu 8, 40700, Jyväskylä, Finland

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ABSTRACT

Introduction: Military training loads may induce different physiological responses in garrison and field training and only a little is known about how short-time recovery, lasting a few days, affects neuromuscular fitness and hormonal profile. This study aimed to investigate effects of garrison and field military service on neuromuscular performance and hormonal profile and to evaluate effects of a 3-day recovery on those factors.

Methods: Twenty healthy male soldiers (20±1 yrs.) participated in the study, which consisted of 4 days of garrison training [days (D) 1-4] and 7 days of military field training (Days 5-12) followed by a 3-day recovery period (Day 15). Serum hormone concentrations [testosterone (TES), cortisol (COR), sex-hormone binding globulin (SHBG), free thyroxine (T4)] were assessed at D1, D5, D8-D12 and D15. Hand grip strength was measured in 10 participants at D1, D5, D8, D12 and D15. Maximal isometric force (MVC), EMG and rate of force development (RFD) of the knee extensors and arm flexors were also measured at D5, D12 and D15.

Results: The maximal force of both the arm flexors and knee extensors were not affected by the garrison or field training, whereas the rate of force development (RFD) of the knee extensors was decreased during the field training (D5: 383 ± 130 vs. D12: 321 ± 120 N/s, $p<0.05$). In addition, hand grip strength was mostly no affected, although a significant difference was observed between D8 and D12 (531 ± 53 vs. 507 ± 43 N,$p<0.05$) during the field training. TES decreased already during the garrison training (D1: 18.2±3.9 vs. D5: 16.2±4.0 nmol/l, $p<0.05$) and decreased further during the field training compared to baseline (D8: 10.2±3.6 - D11: 11.4±5.4 nmol/l, $p<0.05$) exceeding the lowest concentration in the end of the field training (D12: 7.1±4.1 nmol/l, $p<0.05$). Similar changes were observed in free TES (D1: 72.2±31.4 vs. D12: 35.1±21.5 nmol/l,$p<0.001$).

The TES concentration recovered back to the baseline level and free TES increased after the recovery period compared to the baseline values (D15: 19.9±5.3 nmol/l, D15: 99.7±41.1 nmol/l, respectively). No changes were observed in the COR or SHBG concentrations during the garrison period. COR was decreased in the end of the field training (D12: 388±109 nmol/l) compared to baseline (D1: 536±113 nmol/l) ($p<0.05$-0.001) but recovered back to the baseline levels after the recovery period (D15: 495±58 nmol/l), whereas SHBG linearly increased towards the end of the field training ($p<0.05$-0.001).

Conclusions: The present findings demonstrate that neuromuscular performance can be relatively well maintained during short-term garrison and field training even when a clear decrease in hormonal profile is evident. In addition, hormonal responses during field training seems to be greater compared to garrison training, however, the recovery of 3-day in free living conditions seems to be sufficient for hormonal recovery. Therefore, a short-term recovery period lasting few days after the military field training may be required to maintain operational readiness after the field training.

INTRODUCTION

In military training, soldiers are exposed to physical and environmental stressors when preparing them to their demanding tasks. The challenge is to keep the balance between high physical loading combined with possible energy and sleep deficit, and sufficient recovery to maintain operational readiness. Although soldiers are intentionally pushed to their limits, recovery time and periods are needed to avoid overload[1,2]. In order to improve military training, the monitoring of fitness and hormonal profile may play an important role for the management and programming of military education. From anecdotal evidence, it has been argued that there may be differences in training load between garrison and military field conditions. The field training, typically lasting several days or weeks, is considered physiologically generally the most demanding period in soldiers' military training partly due to energy and sleep deficit. Previous studies have demonstrated multistressor environment including high physical activity, energy deficit and sleep restriction in military field training[3,4]. However, military training can contain high physiological and psychological stress sources also in garrison conditions[5,6,7]. Nevertheless, there are not yet many studies that have addressed the differences in physical loading between the garrison and field conditions.

Overtraining phenomenon is not widely used in military maybe due to its complex phenomenon and versatility of soldiers to overall stress sources. However, a severe overreaching and overtraining has previously been reported in soldiers. Chicharro et al. (1998) reported that 24 % of Spanish soldiers were in overtrained state after an 8-week basic training (BT) period[8]. Simultaneously, their physical performance (maximal isometric muscle strength, vertical jump and anaerobic capacity) decreased. In addition, Booth et al. (2006) concluded that 8 % of the studied Australian soldiers were in overtrained condition[1]. These studies underline the importance of balancing between sufficient recovery and physical loading during military training. Furthermore, the previous studies collectively show negative changes in neuroendocrine function and fitness parameters during military field training[8,9,10,11]. The previous studies have most consistently shown that neuromuscular function is decreased after arduous military field training when measured by vertical or horizontal jump test[9,10,12,13]. Nevertheless, the mechanisms of neuromuscular function, such as EMG activity, has yet been rarely measured during the military field training in soldiers[14].

In regard of recovery from physically challenging military training, one previous study showed that some components of physical fitness, however, may be recovered in young fit soldiers even during the military training[9]. Nevertheless, another study[13] reported that a 4- day recovery is insufficient for muscular endurance to recover back to the baseline levels. Furthermore, hormonal recovery can be seen after one or several weeks following the field training[3,15]. However, the information about shorter time-window for recovery has not been earlier assessed in soldiers. Despite the high physiological demands in soldiers during their training periods, to the best of our knowledge, there are no previous studies that have addressed the effect of recovery period lasting less than one week on physical fitness and hormonal profile parameters after military field training. Therefore, the present study aimed to investigate the effects of garrison and field services on neuromuscular physical fitness and endocrine profiles and further aimed to evaluate the effect of subsequent 3 days recovery. Lastly, this study adds to existing literature the novel assessment of EMG activity within military context during the military field training.

METHODS

Subjects

Twenty young (age 20 ± 1 yrs.) reconnaissance conscripts participated in the present study. The participants were healthy and fit men (mean±SD of 12-min running test: 2980±267 m) who were informed of the experimental protocol and the measurements, and they gave their written consent to participate in the present study. They were also free to withdraw from the studyat any time. The study protocol was approved by the National Defence Forces and the Ethics Committee of the local University.

Study procedures

Training period consisted of 4 days of garrison training (days 1-4) and 7 days of military field training (days 5-12) followed by a 3-day recovery period (days 13-15) (figure 1). The participants had normal typical garrison training before the initiation of the study and, therefore, the baseline values represent average physiological and physical conditions of the conscripts during garrison training. Body composition variables were assessed at days 1 (D1), 5 (D5), 8 (D8), 12 (D12) and day 15 (D15). Serum hormone concentrations [testosterone (TES), cortisol (COR), sex-hormone binding globulin (SHBG), free thyroxine (T4)] were assessed at D1, D5, D8-D12 and D15. Hand grip strength was measured in 10 participants at D1, D5, D8, D12 and D15. Maximal isometric force (MVC), EMG and rate of force development (RFD) of the knee extensors and arm flexors were also measured in 10 participants at D5, D12 and D15.

The garrison training included lectures, military skill training and physical training as well as the normal daily garrison routines such as preparing for the next training event, moving in formation and having meals. The mean estimated energy expenditure was 3500 kcal (range 2100-4900 kcal) based on heart rate, and the mean heart rate was 81 bpm/min during the garrison training. The military field training included military skill training (3 days) which focused on rehearsing the basic skills of a reconnaissance soldier followed by a 4 day rehearsal conducting reconnaissance during offensive operations. The ambient temperature varied between + 4 ja – 10 degrees during the field training and the mean estimated energy expenditure was 4100 kcal (range 1800-6400 kcal), and the mean heart rate was 88 bpm/min during the field training.

Body composition measurements

Body mass, fat mass and % body fat were measured in the morning using a bioelectrical impedance method (InBody 720, Biospace Co., Ltd., Seoul, South Korea). Body height was measured by using a commercial scale.

Physical fitness measurements and EMG recordings

Maximal aerobic capacity was measured one week before the training period by 12-min running test to evaluate baseline level of the participants. The maximal running distance was counted in meters. Hand grip strength was measured with Jamar-Saehan dynamometer (Masan, Seoul, Korea) separately from both hands. Result was calculated as a mean of best clenches of both hands. Maximal strength of the upper and lower extremities was measured with isometric dynamometers (University of Jyväskylä, Finland). The participants were instructed to produce maximal force as fast as possible and to maintain it for 2 - 3 seconds during three maximal trials, separated by 2-3 min recovery periods, for the upper and lower extremities. The testing personnel encouraged participants during the maximal effort. Knee extension and arm flexion were performed with the right leg and arm, respectively, in a sitting position where knee and elbow angle was set to 90°. The best performance was included for further analysis.

EMGs were recorded from the rectus femoris and biceps brachii muscles with bipolar surface electrodes (Beckman miniature skin electrodes, 650437, Illinois, USA) according to the guidelines of SENIAM[16]. The EMG signals amplification was 1000 times (Biotel 99, Glonner, Germany; bandwidth 20-640 Hz / -3 dB; CMRR 110 dB), and it was digitized and synchronized with the force records at a sampling frequency of 1 kHz. The EMG activities were full-wave rectified and integrated. The maximal force and EMG values were calculated for the periods of 500 ms when the force was kept on the maximal level. Maximal rate of force development (RFD) was defined as the average force produced during the first 500 ms of the maximal force production.

Serum hormone concentrations

Blood samples were drawn from the antecubital vein in the mornings to analyze testosterone (TES), cortisol (COR), sex-hormone binding globulin (SHBG) and free thyroxine (T4) (Immulite 1000, Siemens Healthcare Diagnostics Products Ltd., Gwynedd, UK). Sensitivity of the measurements were 0.5 nmol/l for TES, 5.5 nmol/l for COR, 0.2 nmol/l for SHBG and 3.9 pmol/l for T4. FreeTES was calculated with Anderson formula: FreeTES (pmol/l) = TES (nmol/l) x {2.28 – 1.38} x log [SHBG (nmol/l) x 0.1] x 10 (Stenman 2000, 30).

Statistical analyses

Statistical analyses were done by using IBM Statistics software (SPSS 21.0.0). Mean values and standard deviations (±SD) were calculated. Normality was tested with Shapiro-Wilk test. The normally distributed data was analyzed by using repeated measures ANOVA with Bonferroni post hoc for body composition, physical fitness and endocrine parameters. Friedman’s test was used when data was not normally distributed (T4, TES/SHBG-ratio and T4/COR-ratio). The level of significance was set at $p<0.05$.

RESULTS

Body composition

Body mass decreased during the field training (D8, D12) compared to the baseline values in the garrison conditions (D1, D5) ($p<0.001$), and did not fully increase back to the baseline level after the recovery period (D1 vs. D15) ($p<0.05$). Fat mass and body fat % decreased during the garrison period (D1 vs. D5, $p<0.001$) and were further decreased throughout the field training ($p<0.001$). Moreover, fat mass and body fat % remained at lower level after the recovery period compared to the garrison conditions ($p<0.05$). The detailed results of body mass and body composition are shown in table 1.

Neuromuscular performance

The hand grip strength was mostly no affected by the training, although a significant difference was observed between the days 8 and 12 during the field training ($p<0.05$). Similarly, the maximal force of both the arm flexors and knee extensors were not affected by the garrison or field training. Maximal EMG of the biceps brachii muscle was higher in the end of the field training (D12) than after the recovery period (D15) ($p<0.05$), while maximal EMG of the rectus femoris muscle was not affected. The rate of force development (RFD) of the knee extensors was decreased during the field training(D5 vs. 12) ($p<0.05$), whereas RFD of arm flexion was not affected (Table 2).

Hormonal profile

TES decreased already during the garrison training and decreased further during the field training, exceeding the lowest concentration in the end of the field training ($p<0.05-0.001$). However, TES concentration was recovered back to the baseline level after the recovery period (Figure 2). Similar changes were observed in free TES ($p<0.05-0.001$), and after the recovery period, free TES was increased to a higher level compared to its baseline value ($p<0.001$) (Table 3). COR decreased in the last days of the field training ($p<0.05-0.001$) but recovered back to the baseline levels after the recovery period (Figure 1). SHBG concentrations increased linearly towards the end of the field training ($p<0.05$-0.001), and it remained increased even after the recovery period compared to the baseline values ($p<0.001$) (Figure 1). The T4 concentrations were fluctuated during the whole two week period, exceedingits highest concentration in the end of the field training ($p<0.05$-0.001) (Table 3). Moreover, no change in T4 between the baseline and after the recovery values was observed (Table 3).

DISCUSSION

The main findings of the present study demonstrate that neuromuscular performance was not negatively affected to a great extent during the military field training. Secondly, substantial changes in hormonal profile during the military field training were observed. In addition, some of the changes already existed after the garrison training, and the 3-day recovery period in free-living conditions was sufficient to recover hormonal concentrations back to the baseline levels. Thirdly, body fat decreased during the field training and remained at the lower level after the 3-day recovery period.

Only small changes were noticed in the neuromuscular fitness during the study period. The maximal force of the upper extremities, measured by grip strength was not altered, except a difference between the day 8 and day 12, and similarly, isometric maximal arm flexor performance as well as rate of force development did not change during the study period. On the contrary, EMG of biceps brachii was increased after the field training, however, it decreased back to the baseline level after the recovery period. The present results conclude that the neuromuscular performance of the upper extremities can be well maintained, although great changes in the hormonal values were observed at the same time. On the other hand, the increased EMG of biceps brachii without changes in maximal force of the arm flexors after the field training may indicate minor decrement of the excitation-contraction coupling process at muscle level. However, this has not caused any major changes in the performance level of the neuromuscular system.. It may have seemed rational that some decrements would be observed in the lower extremities, because of a high amount of running and especially walking and standing typically occurs during the the field training. It seems that the neuromuscular level of the conscripts in the present study was high enough to tolerate the high physical activity during the field training. Previous studies have reported mixed results. A study by Nindl et al. (2002) showed that military field training lasting 72 hours did not effect on bench press power performance[9], whereas a study by Knapik et al. (1990) reported that the 5-day field military field training induced decreased upper body strength in most but not all upper body performance tests[17]. In addition, they reported decrements in upper body muscular endurance (push-ups). Similarly, a military field training lasting 21 days decreased upper body muscular endurance (push-ups), which did not recover after 4-days[13]. Thus, it may be speculated that longer field training may most potentially elicit greater changes in upper body performance than shorter ones. However, obviously the military tasks performed during the field training is of importance and therefore differences between studies are observed. The present study revealed that the level of neuromuscular fitness of the study participants was at sufficient level to tolerate the high psychological and physical demands set by the field training.

Although maximal knee extensor force and EMG of rectus femoris were unaffected during the study period, a decrease in RFD was observed in knee extension. This finding extends the previous studies, which have found either vertical or horizontal jump performance to decrease acutely after military field training[9,12,13] or during longer military training period lasting several weeks[10,18]. From physiological point of view, it may seem rational that some decrements are observed in the lower extremities, because of a high amount of running and especially walking and standing typically occurs during the military field training. The decrease in RFD together with previous findings with decreased jump performance indicates a fatiguing phenomenon of the lower extremities, which may originate from central and/or peripheral fatigue during the field training. The observed decrements in lower body performance in the present study may also partly relate to load carriage, which has been reported to decrease neuromuscular performance of lower extremities[19] and increase in ground reaction force[20].

Some changes in hormonal profile were detected even after the short garrison period evidenced for example by the subtle decrease in testosterone. Nevertheless, greater changes in serum hormone responses were observed in the field training and, especially, steep reduction was observed in the end of the training. As hypothesized, the field training thus affected greater changes in hormonal profile compared to the garrison training. Previous studies have shown, similar to the present study, changes in hormonal profile during military field training[3,4]. Previously, Alemany et al. (2008) reported reductions in IGF-1 and body weight after the 8-day military field training including high energy expenditure and sleep deficit[21]. Similarly, other studies have shown large reductions in anabolic hormonal concentrations and body weight after several weeks of military field training[21,22,23,24,25].

Testosterone is effecting as an anabolic signaling to, for example promoting muscle and bone mass. In turn, in the presence of high demands to either physical or psychological stress or combined, testosterone concentration has been shown to decrease often dramatically such as in the present study. In military field training, energy and sleep deficit attenuates further testosterone levels[21,22,23,24]. The decreased circulating testosterone levels are most likely, at least partly, related to higher testosterone uptake in the steroid receptors. The great reductions in TES with concomitant increase in SHBG in the end phase of the field training clearly indicate a reduction of anabolic potential of the conscripts. Moreover, SHBG is known to inhibit the function of testosterone and therefore bioavailability of testosterone is affected by the SHBG concentration.

Cortisol is typically released in response to psychological and/or physical stress and when increased it can be considered to represent a catabolic hormonal state as it mobilizes energy and inhibits anabolic actions by other hormones such as testosterone. In the present study, cortisol did not increase in concomitant with dramatic decrease in testosterone. It may speculative be discussed that there can be changes in proportion of bound cortisol and free cortisol. Unfortunately, the free cortisol was not measured in the present study. Nevertheless, as both forms of cortisol are biologically active this could explain in part of the decreased values despite of high energy demands experienced in the field training.

As thyroid hormones are responsible for metabolism regulation, a small increase in T4 in the present study might demonstrate a small negative energy balance at the first four days of military field training and adaptation, thereafter, to the end of the field training. However, no constant pattern of changes in T4 but rather fluctuation around the mean during the military training was observed. Together these results combined with a decrease in cortisol may speculatively be a sign of lesser requirement of facilitation of metabolism being indicative that the dramatic changes in TES and SHBG would be to some extent more due to sleep and energy deficit than increased physical load.

To the best of our knowledge, we are not aware of any previous studies comparing garrison and field training regarding hormonal responses and also acute recovery is not often studied before. A general conclusion from the present study results is that the 3 days recovery period in free-living conditions appeared to be mostly sufficient for hormonal recovery.

Military applications

In conclusion, the 12-day of continuous military training in garrison and field conditions decreases hormone concentrations, whereas neuromuscular performance could mostly be maintained in male soldiers. Moreover, a 3-day recovery period seemed to be sufficient to a full recovery of serum hormone concentrations. Based on the present study results, it can be concluded that in regard of hormonal profile, military field training is more strenuous than garrison training. Therefore, the present study findings emphasize the periodization of training and adequate recovery during both garrison and field training periods, but also emphasize a greater attention to be directed for optimal recovery straight after the military field training. Future studies are encouraged to investigate also female soldiers and mixed gender companies during garrison and in the field training.

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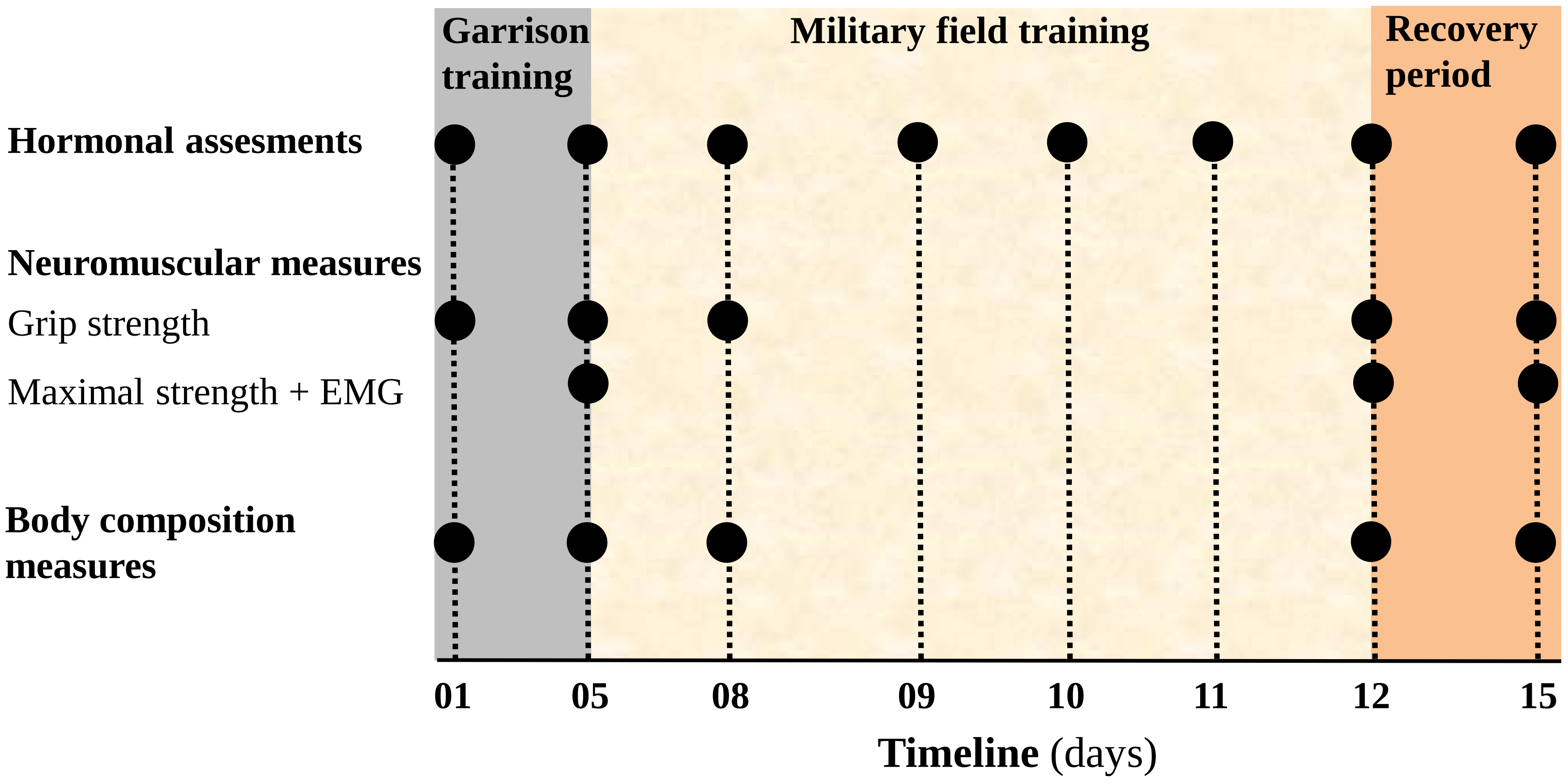
Figure 1. Timeline and measurements during the study period

Figure 2. Hormone profiles during the study period

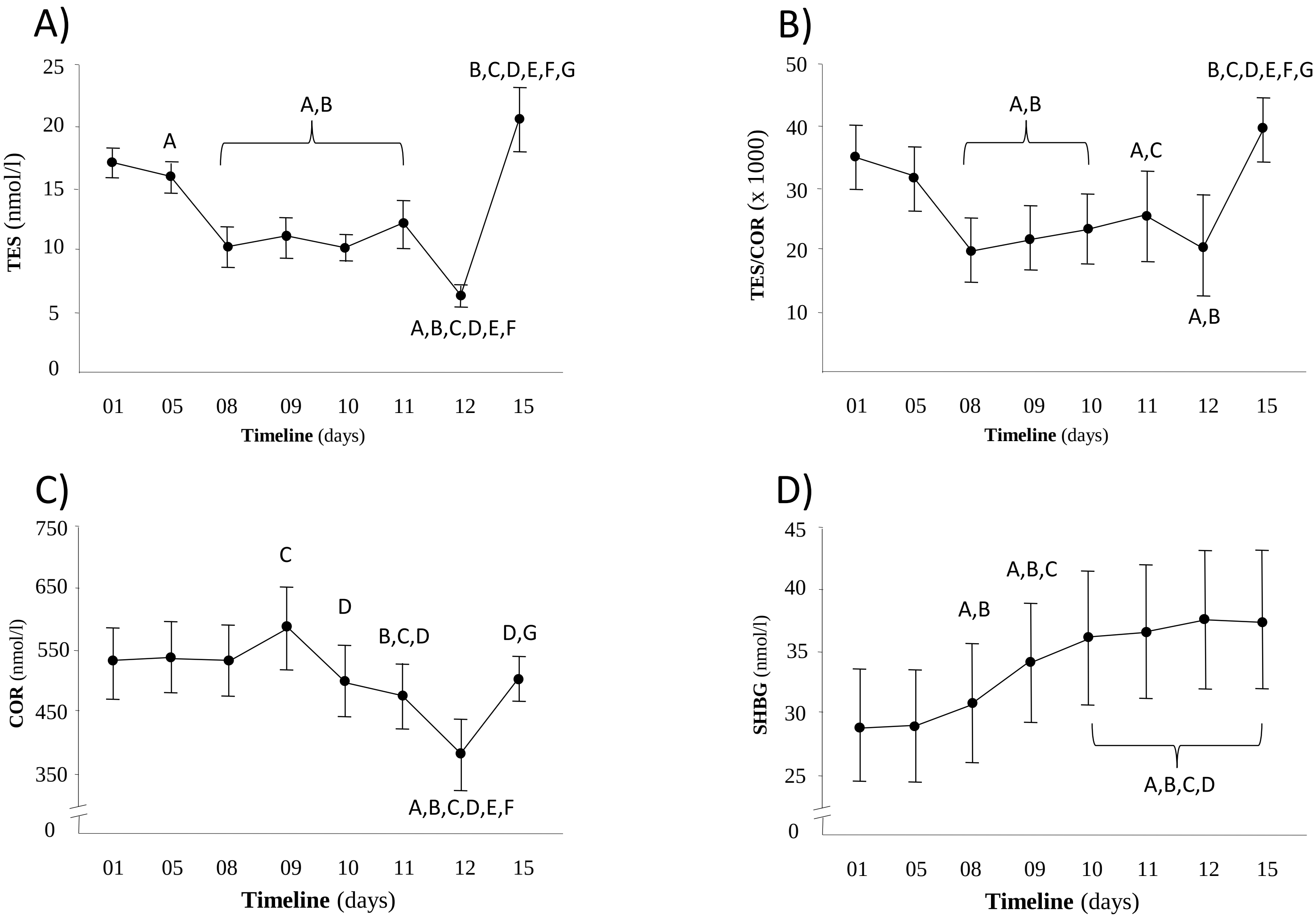
Table 1. The body composition values during the study period.

Table 2.The neuromuscular performanceand muscle activity (EMG) values during the study period.

Table 3.The concentrations of free testosterone and free thyroxine during the study period.



Garrison training
Military field training
Recovery period
Hormonal assesments
Neuromuscular measures
Grip strength
Maximal strength + EMG
Body composition measures
01
05
08
09
10
11
12
15
Timeline (days)



A $p<0.05$ compared to day 1, **B** $p<0.05$ compared to day 5, **C** $p<0.05$ compared to day 8, **D** $p<0.05$ compared to day 9, **E** $p<0.05$ compared to day 10, **F** $p<0.05$ compared to day 11, **G** $p<0.05$ compared to day 12

Table 1. The body composition values during the study period.

	D1 (garrison)	**D5** (aftergarrison)	**D8** (field training)	**D12** (field training)	**D15** (after recovery period)
Body mass (kg)	76.0± 7.1	75.7 ± 6.6	74.1± 6.7**aaa**, **bbb**	73.1± 6.4**aaa**, **bbb**, **ccc**	75.3± 7.1**a**, **c**, **ddd**
Fat mass (kg)	11.2± 4.1	10.1± 4.1**aaa**	9.0± 4.0**aaa**, **bbb**	8.9± 3.8**aaa**, **bbb**, **ccc**	9.2± 3.8**aaa**, **b**, **ccc**
Fat%	14.5± 4.4	13.2± 4.5**aaa**	11.9± 4.5**aaa**, **bbb**	12.0± 4.5**aaa**, **bbb**	12.1± 4.3**aaa**, **b**

ap<0.05, **aaa** p<0.001 compared to D1, **b**p<0.05, **bbb**p<0.001 compared to D5, **c**p<0.05**ccc**p<0.001 compared to D8,**ddd**p<0.001 compared to D12.

Table 2.The neuromuscular performanceand muscle activity (EMG) values during the study period.

	D1 (garrison)	**D5** (aftergarrison)	**D8** (field training)	**D12** (field training)	**D15** (after recovery period)
Handgripstrength (N)	502± 77	526± 49	531± 53	507±43**c**	502± 54
MVC of knee extension (N)	-	670± 219	-	590± 180	603± 240
MVC of arm flexors (N)	-	0.343± 0.051	-	0.354± 0.052	0.351± 0.050
RFD on knee extension(N/s)	-	383 ± 130	-	321 ±120 **b**	328 ± 120
RFD on arm flexion (N/s)	-	265 ±51	-	242 ±56	244 ±53
EMG of rectus femoris(μV)	-	0.169 ± 0.055	-	0.161 ± 0.045	0.167 ± 0.057
EMG of biceps brachii (μV)	-	567 ±231	-	647 ± 330	565 ±332**d**

b=p < 0.05 compared to D5, **c**=p < 0.05 compared to D8,**d**=p < 0.05 compared to D12,

Table 3.The concentrations of free testosterone and free thyroxine during the study period.

	D1 **(garrison)**	**D5** **(after garrison)**	**D8** **(field training)**	**D9** **(field training)**	**D10** **(field training)**	**D11** **(field training)**	**D12** **(field training)**	**D15** **(afterrecoveryperiod)**
FreeTES (pmol/l)	72.2 ±31.4	65.7±31.2	43.5±20.5aaa,bbb	53.0±28.9aaa, b, c	50.5±24.2aaa, b, c	55.6±30.8aaa	35.1±21.5aaa, bbb,ddd,eee,fff	99.7±41.1 aaa,bbb,c,dd,eee,fff,ggg
T4 (pmol/l)	15.8±2.1	16.5±1.7aaa	15.6±2.2 b	15.4±1.9bbb	15.4±2.0bbb	16.2±2.3c,d,ee	17.1±1.9 a,b,ccc,ddd,eee,f	15.4±2.0b,ggg

a/aaa=p < 0.05/0.001 compared to D1, b/bbb=p < 0.05/0.001 compared to D5, c/ccc=p < 0.05/0.001 compared to D8, d/ddd=p < 0.05/0.001 compared to D9, e/eee=p < 0.05/0.001 compared to D10, fff=p < 0.001 compared to D11, ggg=p <0.001 compared to D12.