



Sex differences in the physiological response to a demanding military field exercise

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Purpose: To investigate sex differences in the effect of a military field exercise on physical performance, body composition, and blood biomarkers.

Methods: Measurements were done in 23 male and 12 female conscripts before, and 0, 1, 3, 7, and 14 days after a 6-day military field exercise.

Results: During the field exercise, body mass decreased more in men (-6.5 ± 1.1 kg) than in women (-2.7 ± 0.7 kg), and muscle mass decreased only in men (-2.7 ± 1.0 kg). Body composition recovered within one week. Performance decreased, with no differences between men and women for countermovement jump (CMJ, -19 ± 8 vs. $-18 \pm 11\%$), medicine ball throw (MBT, -11 ± 7 vs. $-11 \pm 7\%$), and an anaerobic performance test (EVAC, -55 ± 22 vs. $-47 \pm 31\%$, men and women, respectively). MBT and EVAC performance recovered within two weeks, whereas CMJ performance was still reduced in men ($-17 \pm 6\%$) and women ($-9 \pm 8\%$) after two weeks recovery, with a larger reduction in men. Both men and women decreased [IGF-1] (-28 ± 9 vs. $-41 \pm 8\%$) and increased [cortisol] (26 ± 26 vs. $66 \pm 93\%$, men and women, respectively) during the exercise. Most biomarkers returned to baseline values within one week.

Conclusions: Men lost more body mass and muscle mass than women during a field exercise, but these differences did not lead to sex differences in changes in explosive strength and anaerobic performance. However, women recovered explosive strength in the legs faster than men.

KEYWORDS

body composition, cortisol, insulin-like growth factor 1, muscle damage, muscle strength, physical performance, recovery, testosterone

1 | INTRODUCTION

An important part of military training is simulated combat training and demanding field exercises. These field exercises often involve very high activity levels and energy expenditure combined with low energy intake and lack of sleep.¹⁻³ Previous

studies show that energy expenditure during field exercises can be 5000-10 000 kcal per day, with an energy deficit as high as 5000-6000 kcal per day over a three to seven days period.^{2,4-6} Such field exercises have been reported to lead to 3%-10% loss of body mass, 7%-28% loss of body fat, and 2%-6% loss of muscle mass,^{1,4,7,8} together with detrimental

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effects in many aspects of physical performance including reduced aerobic power,⁵ reduced anaerobic performance,⁹ reduced maximal and explosive muscle strength,^{1,2,7,8,10,11} and reduced performance in military-specific physical tasks.⁷ The large reduction in muscle mass might be related to decreases in anabolic hormones and increased catabolic hormones since studies report a large decrease in testosterone and insulin-like growth factor 1 (IGF-1), and increases in cortisol, after field exercises.^{1,4,8} The reduced physical performance has been speculated to be associated with these changes in body composition and hormones,^{1,5,8} but also to muscle damage⁴ as studies report large increases in the muscle damage marker creatine kinase (CK) after demanding field exercises.^{2,4}

Unfortunately, all the above-mentioned studies have only included male participants. In recent years, most Armed Forces have seen an increase in the number of women serving and enlisting. In fact, Norway introduced gender-neutral conscription in 2015, and the proportion of female conscripts in today's Norwegian Armed Forces is approximately 25%. Therefore, more knowledge on how demanding field exercises affect women's physiology and physical performance is needed. Notably, women have been reported to oxidize proportionally more fat and less carbohydrates at submaximal intensities than men,^{12,13} to be more resistant to muscle fatigue on a similar relative workload,^{12,14} and have a larger proportional area of type I fibers.¹⁵ On the other hand, women are under larger physiological stress during similar military activities compared to men due to lower aerobic fitness and lower maximal muscle strength.¹⁴ Women might therefore respond differently from men to demanding field exercises. To our knowledge, the only study investigating the physiological effects of a military field exercise in female soldiers reported that women oxidized more fat per kg lean body mass than men during a very strenuous one-week field exercise.⁶ The results also revealed that men lost more body mass, and that a larger proportion of the body mass loss was lean body mass in men compared with women. Because of their greater ability to burn fat, women may have a better ability to conserve muscle mass and muscle glycogen under these conditions. Since total muscle mass is an important factor for maximal strength, explosive strength and anaerobic capacity,¹⁶⁻¹⁸ and muscle glycogen is important for high-intensity performance,¹⁹ it may be speculated that women will have smaller decrements in performance following demanding field exercises. However, such sex-specific changes in physical performance have not yet been investigated.

The recovery process after demanding military field exercises has not received a lot of attention in the literature. This is surprising since knowledge of the recovery process is important for optimizing training, nutrition, and the long-term development of soldiers' physical performance. Nevertheless, Hamarsland et al⁴ investigated the recovery during the first days and weeks after an extremely demanding

field exercise in detail. They reported that even though body mass, muscle mass, and the hormonal system returned to baseline within one week of recovery, lower-body maximal strength needed two weeks to recover, and lower-body explosive strength was still about 15% depressed two weeks after the exercise. Importantly, none of the few studies investigating recovery after demanding field exercises have included female participants.

The aims of this study were twofold: Firstly, to investigate sex differences in the acute effects of an extremely demanding military field exercise on explosive strength and anaerobic performance, body composition and blood biomarkers related to body composition and physical performance; secondly, to examine the recovery in both men and women and investigate if there are any sex differences in the recovery process. We hypothesized that women would lose less muscle mass than men during the field exercise and that this would lead to smaller decrements in physical performance than in men. Furthermore, we hypothesized that women would be back to pre-exercise values faster than men.

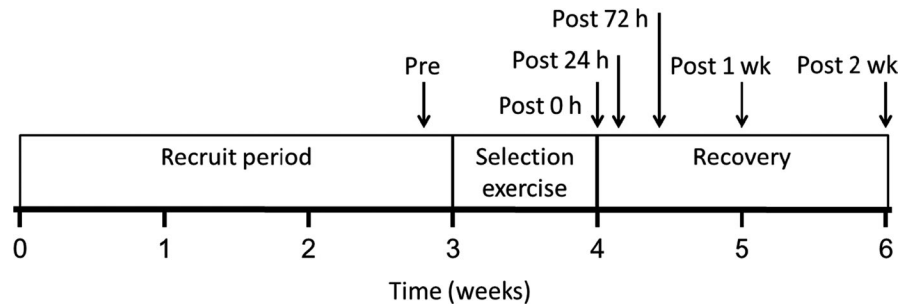
2 | METHODS

2.1 | Participants and experimental design

Participants were recruited from conscripts attending the annual selection process at the Armed Forces Special Command (FSK). The FSK conscript division consists of two troops: the Parachute Ranger Platoon and the Special Reconnaissance Platoon. The former is open for both sexes (but so far, only male conscripts have passed the selection process). The latter is only open for female conscripts. Thus, all men were recruited from the Parachute Ranger Platoon, while all women were recruited from the Special Reconnaissance Platoon.

The selection process consists of a three-week recruit period followed by a severely challenging five and a half day selection exercise. A total of 114 men and 26 women volunteered as potential participants in the study. All participants were over 18 years old and had completed a physical and medical examination before entering the selection process. They completed blood sampling and measurements of body composition and physical performance 2-3 days before the selection exercise. Most of the volunteers withdrew from the selection process or were taken out by the commanders at FSK during the selection exercise. A total of 23 men (age: 19.3 ± 1.8 years, body mass: 79.5 ± 6.3 kg, height: 183 ± 6 cm) and 12 women (age: 19.4 ± 1.5 years, body mass: 67.7 ± 5.5 kg, height: 172 ± 5 cm) from the volunteers managed to complete the selection exercise and were included in the study. They performed post-tests at the day they returned from the exercise (post 0h), and 24 hours (post 24 hours), 72 hours (post 72 hours), one week (post 1 week)

FIGURE 1 Timeline over the study. The arrows represent when tests were performed in respect to the selection exercise



and two weeks (post 2 weeks) after the exercise (Figure 1). During these 2 weeks, the service consisted mostly of classroom teaching with normal sleep and food intake, and easy physical activity.

Body composition measurements and blood sampling were carried out in the morning after an overnight fast (between 6 and 8 AM), while the physical tests were performed 2-4 hours after breakfast. An exception was on the day they returned from the selection exercise, where body composition was measured immediately after termination of the exercise (between 9 and 11 AM), and the physical tests were performed 3-5 hours later. No blood samples were collected at post 0 hour since it was not possible to standardize blood sampling (food, drink, activity, and time of day) at this time.

The project was evaluated by the Regional Committees for Medical and Health Research Ethics. Participation in the selection process and in the present study was voluntary and all participants were free to withdraw at any time. All participants provided a written informed consent, and the study was performed in compliance with the Declaration of Helsinki.

2.2 | Selection exercise

The selection exercise is an extremely demanding field exercise that lasts for approximately five and a half days. It is designed to test the candidates' physical and mental resilience in extreme situations in sub-optimal conditions and consists of large amounts of physical activity in addition to sleep and food restriction. The activities consisted mainly of loaded marching and various mentally and physically challenging tasks.

The selection exercise was performed simultaneously, but separately for male and female conscripts. The overall content of the selection exercise was similar, even though some differences between the specific activities for men and women were unavoidable. For example, the men had some longer marches and some more challenging activities. To objectively quantify differences between the exercises, we estimated activity energy expenditure by a wrist-worn accelerometer (ActiGraph wGT3X-BT, ActiGraph, Florida, USA) on the non-dominant hand in 8 male and 5 female

conscripts during the selection exercise. Energy expenditure was estimated with the Freedson VM3 Combination algorithm. Basal metabolic rate was calculated with the formula $BMR = 21.6 \times LBM(kg) + 370^{20}$ and added to the activity energy expenditure to calculate total energy expenditure. The men had a larger estimated average daily energy expenditure than the women ($7235 \pm 408 \text{ kcal day}^{-1}$ vs. $6041 \pm 357 \text{ kcal day}^{-1}$, respectively, $P < .001$). When normalized to body mass, there were no statistical differences between the sexes (men: $90.4 \pm 4.8 \text{ kcal kg}^{-1} \text{ day}^{-1}$, women: $88.9 \pm 3.9 \text{ kcal kg}^{-1} \text{ day}^{-1}$, $P = .555$). The accelerometer data also showed that there were no sex differences in the average daily sedentary time (men: $516 \pm 45 \text{ min day}^{-1}$, women: $536 \pm 31 \text{ min day}^{-1}$, $P = .495$) or time spent in light (men: $541 \pm 95 \text{ min day}^{-1}$, women: $480 \pm 71 \text{ min day}^{-1}$, $P = .257$) and moderate to vigorous (men: $365 \pm 75 \text{ min day}^{-1}$, women: $422 \pm 72 \text{ min day}^{-1}$, $P = .205$) intensity. The amount of sleep varied each day between 1 and 6 hours, with no sex differences. The weight of the backpack was similar for men and women and varied during the exercise between approximately 20-40 kg. The conscripts were given $575 \text{ kcal day}^{-1}$ in form of freeze-dried military rations (Drytech). An exception was for day 3, where the men only got 375 kcal. All the provided food was eaten.

2.3 | Body composition

Body composition and body mass were measured with bioelectrical impedance analysis (BIA) on an InBody 720 machine (Biospace Co.) according to the manufacturer's instructions. Participants were measured fasted in the morning between 6 and 8 AM. The participants were instructed not to shower or be physically active from the time they woke up until the test was completed and told to visit the toilet prior to measurements. The participants stood upright for the last 5 minutes before the test, and participants performed all measurements in their underwear. These rigid standardizations were not possible at the post 0 hour time point, when the candidates returned from the selection exercise. Because of a misunderstanding, the male participants had eaten breakfast before the measurement 72 hours after the exercise. The Inbody 720 device has been reported

to underestimate body fat percent by approximately 2 percentage points, compared to dual-energy X-ray absorptiometry measurements (DXA).²¹

2.4 | Blood sampling

Blood samples were collected in the morning (6-8 AM) after an overnight fast. The participants were instructed not to be physically active in the period between they woke up and the blood was collected. Because of logistical restraints, and since there was no way to standardize blood sampling the day the participants returned from the selection exercise, no blood samples were collected at this time. Whole blood was mixed before clotting in room temperature for 30 minutes and centrifuged at 1300 *g* for 10 minutes. Serum was transferred into tubes and stored frozen at -20°C until analyzed. Serum was analyzed for [cortisol] (analytic coefficient of variation: 6.8%), [testosterone] (6.7%) and [CK] (3.9%), at Fürst Medical Laboratory, while [IGF-1] (6.0%) was analyzed at The Hormone Laboratory.

2.5 | Physical performance tests

The physical tests started with a 10 minutes general warm-up that consisted of running at low to moderate intensity and exercises that targeted muscles and joints involved in the different tests. The warm-up finished with some higher intensity runs during the last 2 minutes.

The conscripts completed the physical tests in the following order: countermovement jump (CMJ), medicine ball throw (MBT), and an evacuation test for measuring anaerobic performance (EVAC). Because of logistical restraints, injuries and illness, not all participants were able to complete all physical tests after the selection exercise. Participants missing two or more test sessions for a specific test were excluded from the analyses for that test. Missing values were calculated for participants missing one test (see statistics). Therefore, the numbers of participants included are 17 men and 12 women in the CMJ data, 10 men and 11 women in the EVAC test data, and 18 men and 12 women in the MBT data. There were no significant differences in physical performance between the excluded and the included participants before the selection exercise.

2.5.1 | Countermovement jump

The CMJ test was performed on a force plate (HUR Labs, Tampere, Finland). The participants were instructed to stand on the platform with feet shoulder-width apart. Following a countdown from the test-administrator, the soldiers then

completed the jump. The jump was performed with a flexion of the knee and hip joint to about 90° in the knee joint, followed by a rapid countermovement and extension of the lower extremities. Hands were placed on their hips throughout the entire movement. Each participant was given 3 attempts, with a 30-second rest between each attempt. If the third attempt was highest, additional jumps were performed. The maximal power and jump height from the highest jump were used in the statistical analyses. The test-retest coefficient of variation (CV) for jump height in our laboratory is 4%.⁴

2.5.2 | Evacuation test

The EVAC test has been described in detail elsewhere.²² Briefly, the test was administered on a 10×20 m course. Cones were placed on the left-hand side at the 5 and 15 m mark, and at the right-hand side on the 10 m mark. The test started and ended at the same start line. A manikin (70 kg for men and 50 kg for women, Ruth Lee) was placed behind the start/finish line within a standardized area.

All participants performed a specific warm-up before conducting the test. The warm-up consisted of running one lap through the course at a moderate intensity and then pulling the manikin at high intensity through the first two turns of the course. To compensate for not being able to perform extensive familiarization, the participants practiced pulling the manikin during the general warm-up at pre-testing.

The test consisted of two maximal laps through the course. The first lap was completed without the manikin. When the conscripts passed the start/finish line after the first lap, the manikin was picked up by a handle on the side on the manikin's neck and pulled through the course on the second lap. The conscripts were instructed to perform both laps as quickly as possible and strong verbal encouragement was given throughout the test. Total time was registered using photocells (Brower Timing Systems). The test-retest CV of the EVAC test has been reported to be 4%.²²

2.5.3 | Medicine ball throw

The MBT test was administered on a custom-made measurement mat (Matteleverandøren AS) with a pre-printed scale to measure throw distance. The throw started in a standing position with feet in parallel, holding a 10 kg medicine ball at chest height. From this position, the medicine ball was thrust as far as possible. The feet had to be in touch with the test mat at all times. There were no other restrictions on technique, and conscripts were permitted to utilize their back and legs. Results were measured to the closest 0.1 meters. The conscripts were

given 3–4 attempts, and the best throw was used in the statistical analyses. The test-retest CV for MBT in our hands is 2%.²³

2.6 | Statistics

All statistical analysis was done in IBM SPSS (IBM SPSS Statistics, version 24, IBM Corp.). A mixed design ANOVA with sex as between-subject factor, and time as within-subject factor, was applied to investigate changes over time within sexes and possible interactions between time and sex. Where the sphericity assumption was violated, the Greenhouse-Geisser procedure was used to correct the degrees of freedom. A significant interaction between time and sex was followed up with pairwise comparisons with Bonferroni adjustments to compare each group's mean across different time points for each sex separately. Furthermore, sex differences in absolute changes and calculated percent change from pre-values at each time point were then evaluated with pairwise comparisons with Bonferroni adjustments for multiple comparisons. All reported p-values from these tests are Bonferroni adjusted. Because of large individual differences in changes in CK, these data were not normally distributed, and the mixed design ANOVA were therefore performed on log-transformed data. Mean differences between men and women in anthropometrics at pre-test were investigated using independent sample t tests. Correlations between changes in muscle mass and pre-selection exercise fat mass and muscle mass, between changes in performance and changes in muscle mass, and between changes in performance and changes in blood biomarkers were investigated with Pearson's *r*. To investigate if conscripts with lowest initial fat mass lost more muscle mass than conscripts with higher initial fat mass, we allocated the participants with pre-fat mass above the sexes average to "high fat mass" groups ($n = 12$ in male group and $n = 6$ in women group) and participants with fat mass below the sexes average to low fat mass groups ($n = 11$ in male group and $n = 6$ in women group). The changes in muscle mass in these two groups were investigated with an independent sample t test. Statistical significance was taken at an alpha-level of 0.05. Values are presented as mean \pm standard deviation (SD). Missing values were replaced (interpolated) for participants that did not attend one of the post-tests due to injury, sickness, or other logistical restrains. Values were calculated by adding the average percentage change for the whole group to the participants' values in the previous test. For the CMJ, 3 men and 2 women had missing values calculated. The corresponding numbers were 5 men and 3 women for the EVAC test and 4 men and 2 women for the MBT test. For body composition, 1 man and 1 woman had missing values calculated. No participants had more than 1 missing value for each test calculated.

3 | RESULTS

3.1 | Body composition

There was a significant main effect of time for body mass ($F_{3,1,100.8} = 251.5, P < .001$), muscle mass ($F_{3,5,116.3} = 58.8, P < .0001$), and fat mass ($F_{3,4,111.6} = 134.5, P < .001$), and a significant time \times sex interaction for body mass ($F_{3,1,100.8} = 53.1, P < .001$), muscle mass ($F_{3,5,116.3} = 32.7, P < 0.001$), but not for fat mass ($F_{3,4,111.6} = 2.6, P = .052$).

Men had a significantly higher body mass and muscle mass compared to women, whereas women had higher fat mass compared to men at all time points ($P < .001$, Table 1). Body mass decreased in both sexes from pre to post 0 hour (men: -6.5 ± 1.1 kg, $P < .001$, women: -2.7 ± 0.7 kg, $P < .001$, Figure 2A) with a significantly lower reduction in women than in men ($P < .001$).

The loss of body mass in the men resulted from both a loss of muscle mass (-2.7 ± 1.0 kg, $P < .001$, Figure 2C) and fat mass (-1.8 ± 1.1 kg, $P < .001$, Figure 2B). The remaining loss of body mass could be explained by loss of total body water (-3.3 ± 1.3 kg, $P < .001$, Figure 2D) from pre to post 0 hours. The loss of body mass in the women was entirely due to loss of fat mass (-2.8 ± 1.3 kg, $P < .001$, Figure 2B). The reduction in muscle mass was significantly larger in men than in women in both relative and absolute values ($P < .001$). There were no differences in percent change in fat mass between sexes, but the absolute reduction in fat mass was significantly higher in women than in men ($P < .001$).

The male "low fat mass group" lost significantly more ($P < .01$) muscle mass than the male "high fat mass group" during the field exercise (3.2 ± 0.8 kg vs. 2.2 ± 0.9 kg, respectively). There was no difference between the female "high fat" and "low fat" groups. Furthermore, there was a significant correlation between initial body fat percentage and loss of muscle mass in both sexes combined ($r = .83, P < .005$), and separately for men ($r = .75, P < .005$), but not for women ($r = .33, P = .315$, Figure 3). There were no other significant correlations between changes in muscle mass and pre-selection exercise body composition, or between changes in muscle mass and changes in anabolic and catabolic hormones.

Both sexes regained their initial body mass after 72 hours of recovery. One and two weeks after the exercise, the male conscripts had gained body mass compared to the pre-values (1.1 ± 1.3 kg, $P < .001$, and 1.8 ± 1.8 kg, $P < .001$, respectively), whereas the women did not display a similar increase and the changes from pre-values at these time points were lower in women than in men ($P < .05$).

Muscle mass was still significantly reduced 24 hours after the exercise in men (-2.0 ± 0.8 kg, $P < .001$), but had returned to pre-values after 72 hours (Figure 2C). After one week of recovery, muscle mass was slightly increased

TABLE 1 Body composition and physical performance in respond to the selection exercises and the following 2 weeks of recovery in both men and women

Variable		Pre	Post 0 h	Post 24 h	Post 72 h	Post 1 wk	Post 2 wk
BM (kg)	Men	79.5 ± 6.3	73.0 ± 5.7*	75.0 ± 5.9*	79.8 ± 6.2	80.6 ± 6.2*	81.2 ± 6.2*
	Women	67.7 ± 5.5	65.1 ± 5.4* [#]	65.8 ± 5.5* [#]	67.4 ± 6.3	68.0 ± 5.7 [#]	68.1 ± 5.7 [#]
MM (kg)	Men	43.1 ± 3.8	40.4 ± 3.3*	41.1 ± 3.3*	43.5 ± 3.7	43.8 ± 3.8*	43.1 ± 3.8
	Women	32.0 ± 1.9	31.9 ± 2.3 [#]	31.9 ± 2.3 [#]	32.6 ± 2.4	32.6 ± 2.1*	31.5 ± 2.0
FM (kg)	Men	4.2 ± 1.4	2.4 ± 0.5*	3.1 ± 0.9*	3.3 ± 1.0*	4.7 ± 1.3	6.4 ± 1.5*
	Women	10.8 ± 3.7	8.0 ± 3.3*	8.5 ± 3.1*	9.1 ± 3.1*	10.2 ± 3.2 [#]	12.0 ± 3.4* [#]
CMJ height (cm)	Men	38.7 ± 4.1	31.2 ± 4.1*	31.3 ± 3.9*	29.4 ± 3.9*	30.0 ± 4.0*	32.0 ± 4.0*
	Women	29.0 ± 3.6	23.5 ± 3.8*	24.2 ± 3.8*	24.8 ± 3.4* [#]	24.1 ± 3.7*	26.3 ± 3.1* [#]
CMJ MP (W)	Men	3813 ± 511	3144 ± 434*	3209 ± 441*	3080 ± 437*	3177 ± 457*	3409 ± 508*
	Women	2650 ± 384	2265 ± 280*	2387 ± 357*	2394 ± 309* [#]	2388 ± 333* [#]	2540 ± 310 [#]
EVAC time (s)	Men	43.0 ± 2.5	68.3 ± 10.0*	51.5 ± 5.6*	47.6 ± 3.2*	46.0 ± 3.0*	42.9 ± 2.4
	Women	45.6 ± 2.5	67.0 ± 15.0*	57.4 ± 4.9*	51.9 ± 4.9*	49.7 ± 3.6*	47.2 ± 2.4*
MBT length (m)	Men	4.8 ± 0.5	4.3 ± 0.6*	4.4 ± 0.6*	4.6 ± 0.5*	4.7 ± 0.5	4.8 ± 0.5
	Women	3.7 ± 0.3	3.2 ± 0.3*	3.4 ± 0.3	3.5 ± 0.3	3.5 ± 0.3	3.6 ± 0.3

Note: Values are mean ± standard deviation. * Significantly different from pre, [#] The percent change from pre are different from men.

Abbreviations: BM, body mass; CMJ, countermovement jump; FM, fat mass; MBT, medicine ball throw; MM, muscle mass; MP, maximal power.

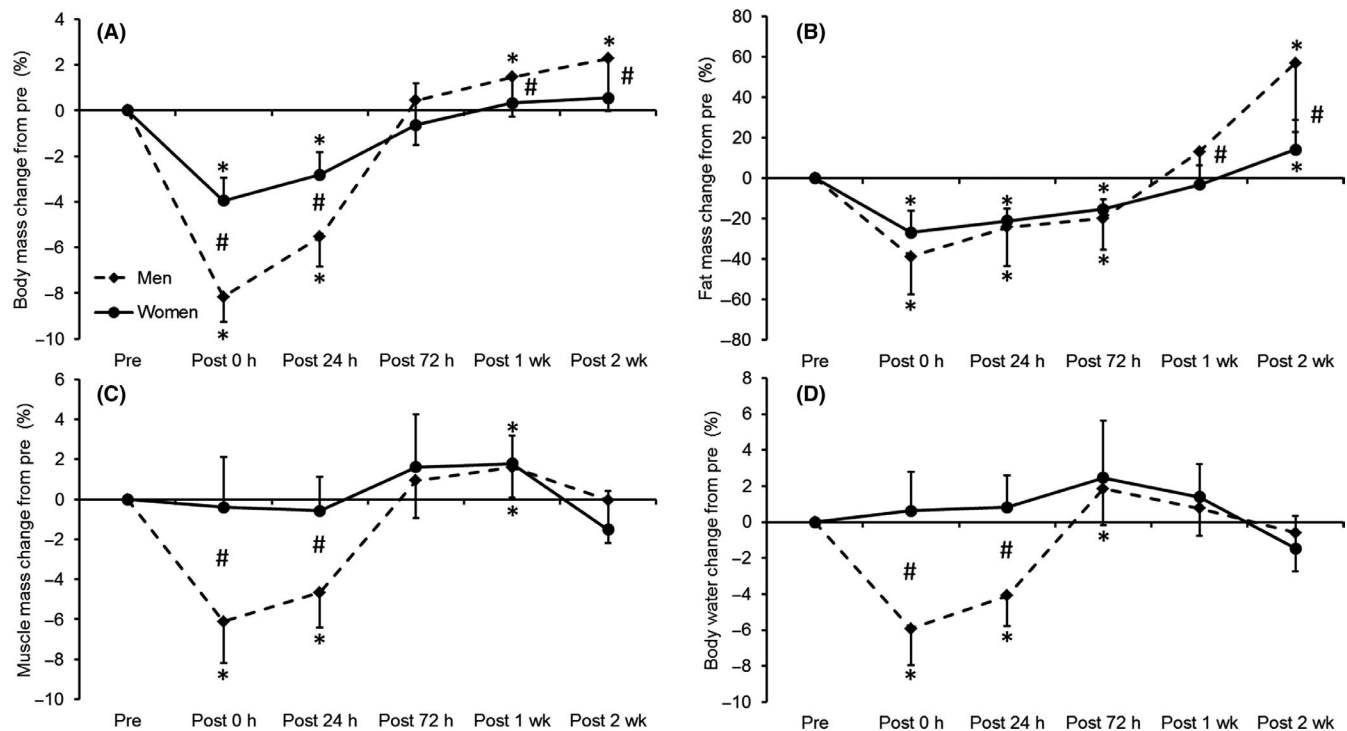


FIGURE 2 Percent changes in body composition from before (Pre) to directly after the selection exercise (post 0 h) and during the first two weeks of recovery (post 24 h to post 2 wk) for men (dotted lines) and women (solid lines). A, Body mass. B, Fat mass. C, Muscle mass. D, Total body water. Values are mean ± standard deviation. *Different than pre ($P < .05$), [#]the percent change from pre is different between men and women ($P < .05$)

compared to pre-values in both men (0.7 ± 0.6 kg, $P < .001$) and women (0.6 ± 0.5 kg, $P < .05$).

Both sexes had regained their initial fat mass one week after the exercise (Figure 2B). After two weeks, both men and

women had an increase compared to pre (men: 2.1 ± 1.0 kg, $P < .001$; women: 1.2 ± 1.1 kg, $P = .007$). The increase in fat mass was significantly larger in the men ($P < .001$), both in absolute and relative values.

3.2 | Physical performance tests

3.2.1 | Countermovement jump

For CMJ height, there was a significant effect of time ($F_{3,2,86.0} = 62.5, P < .001$) and a significant time \times sex interaction ($F_{3,2,86.0} = 7.72, P < .001$). Men jumped higher than women at all time points ($P < .001$, Table 1). Jump height decreased after the selection exercise (men: -7.5 ± 3.1 cm, $P < .001$, women: -5.5 ± 3.8 cm, $P < .001$), corresponding to 18%-19% reduction with no differences between

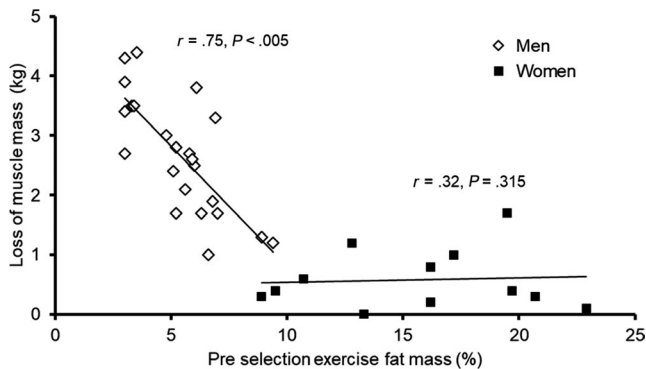


FIGURE 3 Correlation plots between pre-selection exercise fat mass and loss of muscle mass during the selection exercise in men (open symbols) and women (black squares)

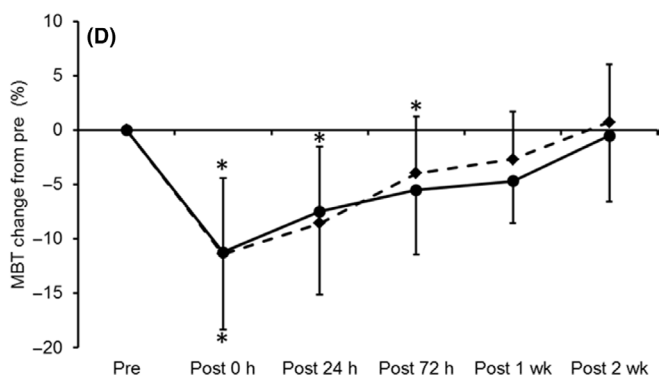
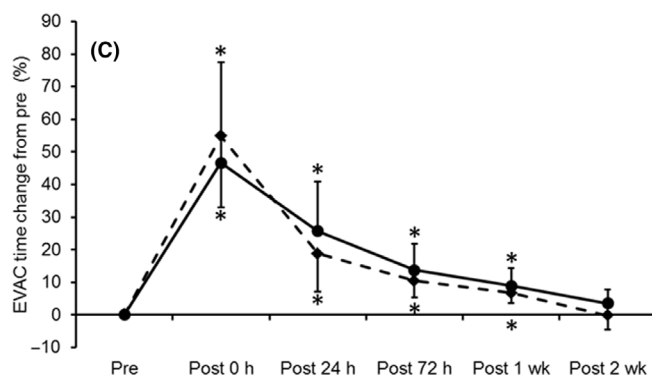
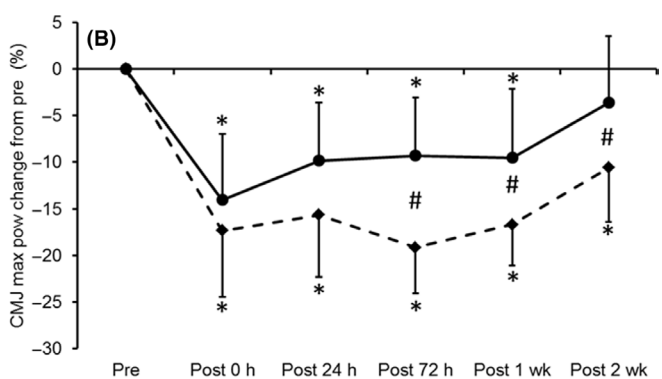
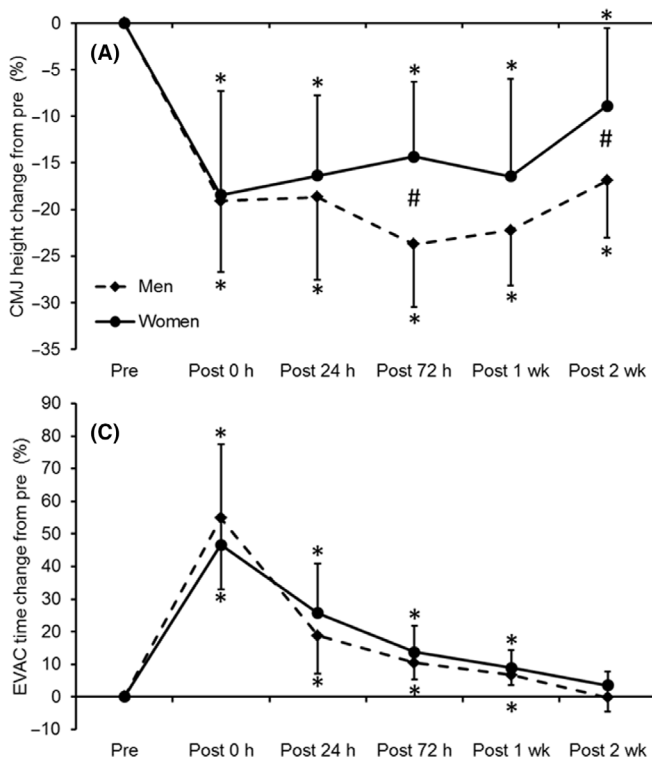


FIGURE 4 Percent changes in physical performance from before (Pre) to directly after the selection exercise (post 0 h) and during the first two weeks of recovery (post 24 h to post 2 wk) for men (dotted lines) and women (solid lines). A, Countermovement jump (CMJ) height. B, Countermovement jump (CMJ) maximal power. C, EVAC completion time. D, Medicine ball throw (MBT). Values are mean \pm standard deviation. *Different than pre ($P < .05$), #the percent change from pre is different between men and women ($P < .05$)

sexes (Figure 4A). Recovery was slow, and jump height was still significantly reduced two weeks after the selection exercise in both male (-6.6 ± 2.8 cm) and female conscripts (-2.7 ± 2.5 cm). The percent reduction in jump height 72 hours (men: $-23.8 \pm 6.1\%$, women: $-14.3 \pm 8.0\%$) and two weeks after the exercise (men: $-16.9 \pm 6.0\%$, women: $-8.9 \pm 8.3\%$) was larger in the men compared to the women ($P < .01$). There was also a significant drop in performance between post 24 hours and post 72 hours in the men (-1.9 ± 2.0 cm, $P < .001$) that was not present in the women. For CMJ maximal power, there was a significant effect of time ($F_{3,1,82.6} = 61.2, P < .001$) and a significant time \times sex interaction ($F_{3,1,82.6} = 9.83, P < .001$). The men had higher maximal power during the CMJ at all time points (Table 1) and the changes in maximal power followed a similar pattern as jump height (Figure 4B). After 2 weeks, maximal power in men were still significantly lower than pre-values (-404 ± 266 watts, $P < .001$), whereas the women had recovered.

3.2.2 | EVAC test

For EVAC completion time, there was a significant effect of time ($F_{1,3,25.0} = 64.3, P < .001$) but no time \times sex interaction ($F_{1,3,25.0} = 1.3, P = .275$). Despite men and women dragging manikins of different weights during the EVAC test, men

were faster than women (Table 1). Both sexes were about 50% slower after the selection exercise (men: $+25.3 \pm 8.7$ s, $P < .001$, women: $+21.4 \pm 14.2$ s, $P < .001$). Neither men nor women regained their pre-test performance until two weeks after the selection exercise (Figure 4C). There were no differences in changes from pre-values between the sexes at any time point.

3.2.3 | MBT

For MBT, there was a significant effect of time ($F_{3,3,78.3} = 35.8$, $P < .001$), but no significant time \times sex interaction ($F_{3,3,78.3} = 1.3$, $P = .201$). The men threw longer than women at all time points ($P < .001$, Table 1). Both sexes decreased their throw length after the selection exercise with about 11% (men: -0.5 ± 0.3 meters, $P < .001$, women: -0.4 ± 0.3 meters, $P < .001$). Both sexes were back to pre-values after one week of recovery (Figure 4D). There were no significant correlations between changes in any performance measurements and changes in muscle mass or any of the blood biomarkers.

3.3 | Blood biomarkers

The changes in blood biomarkers are displayed in Table 2. There was a significant effect of time ($F_{2,7,88.2} = 66.1$, $P < .001$) and a significant time*sex interaction ($F_{2,7,88.2} = 68.5$, $P < .001$) for testosterone. Even though the testosterone levels in men were low at pre-test, possibly because of the initial recruit period (10.6 ± 5.0 nmol L⁻¹), it further decreased by $58 \pm 11\%$ ($P < .001$) 24 hours after the selection exercise. Moreover, it was still reduced by $20 \pm 30\%$ ($P < .01$) after

72 hours of recovery. Testosterone showed an increase compared to pre-values after one week ($87 \pm 75\%$, $P < .001$) and two weeks ($113 \pm 73\%$, $P < .001$) of recovery. Testosterone levels in women were low (as expected), and no changes occurred throughout the study period.

For cortisol, there was a significant effect of time ($F_{2,6,85.4} = 26.0$, $P < .001$) and a significant time \times sex interaction ($F_{2,6,85.4} = 21.3$, $P < .001$). The cortisol levels were higher in men than women before the selection exercise ($P < .01$). Cortisol levels increased during the exercise by $26 \pm 26\%$ ($P < .001$) in men, and by $166 \pm 93\%$ ($P < .001$) in women. In men, cortisol levels were back to pre-values after 72 hours of recovery. In women, the cortisol levels stayed elevated for the whole recovery period. After two weeks, it was still raised by $153 \pm 96\%$ ($P < .001$) compared to pre-levels. The percent change in cortisol levels was larger in women compared to men at all time points.

For IGF-1, there was a significant effect of time ($F_{2,0,64.6} = 221.9$, $P < .001$) and a significant time \times sex interaction ($F_{2,0,64.6} = 3.35$, $P = .042$). The woman had significantly higher ($P < .01$) IGF-1 levels compared to men before the field exercise. IGF-1 levels decreased during the exercise for both sexes and was $28 \pm 9\%$ ($P < .001$) and $41 \pm 8\%$ ($P < .001$) lower at post 24 h compared to pre-test, for men and women, respectively. Thereafter, IGF-1 increased gradually, and the levels were higher than pre after both one week (men: $46 \pm 19\%$, $P < .05$, women: $36 \pm 31\%$, $P < .001$) and two weeks of recovery (men: $69 \pm 29\%$, $P < .001$, women: $52 \pm 21\%$, $P < .001$).

For CK, there was a significant effect of time ($F_{2,0,65.2} = 135.0$, $P < .001$) but no sex*group interaction ($F_{2,0,65.2} = 3.3$, $P = .092$). The men had higher CK values than the women before the exercise ($P < .01$). Both sexes had a large increase in CK levels 24 hours after the exercise (men: $353 \pm 430\%$, $P < .01$, women: $999 \pm 1967\%$, $P < .01$). While

TABLE 2 Serum levels of blood biomarkers in response to the selection exercises and the following 2 weeks of recovery in both men and women

Variable		Pre	Post 24 h	Post 72 h	Post 1 wk	Post 2 wk
Testosterone (nmol L ⁻¹)	Men	10.6 \pm 5.0	4.2 \pm 1.5*	8.0 \pm 3.9*	17.1 \pm 4.7*	19.8 \pm 4.5*
	Women	1.0 \pm 0.5	1.2 \pm 0.4	1.1 \pm 0.4	1.1 \pm 0.3	1.0 \pm 0.3
Cortisol (nmol L ⁻¹)	Men	564 \pm 136 ^a	682 \pm 79*	514 \pm 66 ^a	549 \pm 143 ^a	474 \pm 118 ^a
	Women	343 \pm 219	771 \pm 155* [#]	677 \pm 196* [#]	666 \pm 101* [#]	711 \pm 82* [#]
Testosterone/Cortisol	Men	2.0 \pm 1.1 ^a	0.6 \pm 0.2 ^{a*}	1.6 \pm 0.8 ^a	3.7 \pm 3.0 ^a	4.5 \pm 1.7 ^{a*}
	Women	-	-	-	-	-
IGF-1 (nmol L ⁻¹)	Men	14.0 \pm 2.4 ^a	10.0 \pm 1.6*	12.4 \pm 2.2*	20.3 \pm 3.1*	23.5 \pm 4.7*
	Women	17.6 \pm 5.1	10.1 \pm 2.6* [#]	13.7 \pm 4.3* [#]	23.7 \pm 6.9*	26.8 \pm 7.9*
CK (U L ⁻¹)	Men	1480 \pm 912 ^a	5882 \pm 6964*	1592 \pm 1955	261 \pm 334*	174 \pm 126*
	Women	515 \pm 381	4091 \pm 5098* [#]	1076 \pm 1470	164 \pm 74*	122 \pm 82*

Note: Values are mean \pm standard deviation. *Significantly different from pre, ^asignificantly different from women at the same time point. [#]The percent change from pre are different from men.

Abbreviations: CK, creatine kinase; IGF-1, insulin-like growth factor 1.

no conscripts had CK values above 5000 U/L at pre, 7 of the 23 men and 3 of the 12 women were above 5000 U/L 24 hours after the selection exercise. In both sexes, the CK levels were back to pre-values 72 hours after the exercise and decreased to levels below pre-exercise values after one week and two weeks (men: $-85 \pm 13\%$, $P < .01$, women: $-67 \pm 19\%$, $P < .01$) of recovery with a larger reduction in men ($P < .01$).

4 | DISCUSSION

The main findings of the current study were that men lost more body mass than women after a demanding military field exercise and that body mass loss in men was caused by a loss of both muscle mass and fat mass, whereas the entire body mass loss in women could be attributed to a reduction in fat mass. The strenuous field exercise led to large reductions in physical performance that did not differ between men and women. However, the recovery of explosive strength in the lower body was faster in woman than in men. All changes in body composition were recovered within one week of recovery in both sexes, but recovery of physical performance was slow, especially for explosive strength in the lower body, that was not recovered in neither men nor woman two weeks after the exercise. After the field exercise, [testosterone] decreased in men, [IGF-1] decreased in both sexes, while [cortisol] increased in both sexes. All biomarkers, except for cortisol in women, had returned to baseline within one week after the exercise.

4.1 | Body composition

The finding of men losing more body mass during the selection exercise than women, and that this was due to a larger loss of muscle mass, is supported by similar findings after a seven-day strenuous military exercise.⁶ However, the reason for this is not clear, and the design and measurements in the current study are not suited to give a definitive answer. Nevertheless, a possible reason might be the small differences in content in the selection exercises between sexes. In fact, the estimates of energy expenditure from the accelerometers and the energy intakes indicate that the absolute negative energy balance was approximately 20% larger in men compared to women (6700 vs. 5500 kcal per day). Energy balance calculated from the energy density of body fat mass change, muscle mass change, and the equation described by Hall²⁴ resulted in an estimate of approximately 30% larger negative energy balance in men than women. Both these estimates for energy balance have some weaknesses and are not suited as accurate measures of the absolute energy balance for men and women. However, they both estimate that the negative energy balance was approximately 20%-30% larger in men than in women, and this probably explains most of

the differences in loss of body mass. However, even though a more negative energy balance might have led to a more negative protein balance, it does not fully explain the fact that women lost only fat mass and no muscle mass whereas the men lost both fat and muscle mass. One possible reason for this could be that women oxidize more fat and less carbohydrates and amino acids compared to men during submaximal work. This has been reported both in laboratory studies of short term exercise,^{13,25} and during a military field exercise.⁶ Another possible reason might be the very low initial fat mass in the men, supported by the high correlation between initial fat mass and loss of muscle mass in our male participants. The lack of correlation between initial fat mass and loss of muscle mass in the women might be because women in the study were at a higher and more normal body fat level. These data are highly interesting from a practical point of view, since it indicates that higher levels of fat mass, up to a certain level, will protect against loss of muscle mass during field exercises or deployments where large energy deficiencies can be expected. Extrapolating the data in our male conscripts indicate that this level for men is approximately 12% body fat as measured by BIA.

Notably, all changes in body composition had recovered within one week. This quite fast recovery is in line with results from a study using a similar field exercise as in the current study.⁴ It was somewhat surprising that the reduction in muscle mass in the male conscripts was completely recovered already after 72 hours. It is speculated that this might be related to recovery of depleted glycogen stores,⁴ but the lack of changes in muscle mass in the females argues against this. The fact that the male conscripts had eaten before the body composition measurement at post 72 hours might have affected the results, and this measurement should therefore be interpreted with caution.

4.2 | Physical performance

There were no sex differences in the changes of physical performance during the selection exercise. This is surprising, considering the large difference in loss of muscle mass between the sexes. This indicates, as discussed below, that changes in body composition are not the main reason for changes in performance after demanding field exercises of this duration.

The recovery of physical performance was slow, especially for explosive strength in the lower body. These findings are in line with a recent study that also reported reduced jump height in CMJ two weeks after a similar field exercise as in the current study.⁴ Reports that CMJ height was recovered five weeks after an eight-week field exercise¹ indicate that two to five weeks are needed for a complete recovery of explosive strength in the legs after very strenuous field exercises.

Recovery of performance in MBT and the EVAC test did not differ between the sexes, whereas men had larger reductions in CMJ height than women after two weeks of recovery. This indicates that recovery of explosive strength in the legs was faster in women compared to men. The reason for this is unclear and possible sex differences in physiological mechanisms causing long-lasting alterations in leg muscle force-generating capacity should be further investigated. Some previous studies have speculated that the changes in body composition and the endocrine changes could explain changes in physical performance.^{1,5,8,26} However, in our data, there were no significant correlations between the changes in muscle mass, endocrine changes, and changes in performance during the exercise. Furthermore, changes in body composition and hormones were recovered after one week of recovery, and despite large sex differences in body composition changes during the exercise, no sex differences in physical performance changes were observed. Hamarsland and colleagues⁴ suggested that damage to the contractile apparatus is the main mechanism for the prolonged reduction in physical performance. The increase in CK levels after the selection exercise in the current study certainly indicates that some muscle damage was present. In addition, the slower recovery of CMJ performance in men can be due to the biphasic reduction of CMJ jump height between post 24 hours and post 72 hours in men. This is believed to be a delayed response to muscle damage and corresponding inflammatory processes.²⁷ However, without direct measures at the muscle fiber level it is difficult to speculate how this might differ between the sexes, and there were no sex differences in the CK response in this period.

An intriguing finding in the current study, as well as the study from Hamarsland and colleagues,⁴ is that explosive strength measured by CMJ recovered slower than other aspects of physical performance. This finding indicates that the ability to develop force at high contraction velocities recovers slower than the ability to develop force during contractions at low velocities or during isometric contractions. One possible explanation for this finding could be that the negative effects of military field exercises such as muscle fiber atrophy and muscle damage are more pronounced in type II muscle fibers (compared to type I), or that these field exercises induce a fiber type shift from type II toward type I fibers. Unfortunately, no studies have directly investigated how military field exercises affect the different muscle fiber types. Interestingly, type II fibers have been reported to be more prone to muscle damage after eccentric work than type I fibers.²⁸ Furthermore, studies investigating the effects of short-term hypocaloric diets have reported a larger muscle fiber atrophy in type II fibers than type I fibers in both rodents^{29,30} and human subjects,³¹ and an overall fiber type shift from fast fibers toward slow fibers in rats.³² We are not aware of any studies reporting a similar fiber type shift in humans, but hypocaloric diets have been reported to reduce maximal rate of force development, slowing

of maximal relaxation rate and larger losses of force at high than at low stimulation frequencies, indicating a leftward shift in the force-frequency curve in both rodents^{32,33} and humans.³⁴ Consequently, because of differences in the selection exercise between sexes, men had a larger energy deficit that may have caused more negative effects on type II fibers, or other cellular disturbances, and contributed to the slower recovery in explosive strength. However, it is unclear which changes occur in human muscles after demanding military field exercises, and future studies should include biopsies to investigate the amount of muscle damage, fiber type-specific changes, and changes in calcium handling in response to military field exercises.

4.3 | Hormones

The changes in anabolic and catabolic hormones followed a similar pattern in both sexes with low levels (anabolic) or high levels (catabolic) before the selection exercise, a further reduction (anabolic) or increase (catabolic) during the exercise, and a recovery above baseline two weeks after the exercise. The three weeks recruit period before the selection exercise was quite strenuous and the pre-values were probably not true normal values. Consequently, the increased values two weeks after the selection exercise probably represent a return toward normal values.

There was a large reduction in [testosterone] in the male conscripts. Together with the increased [cortisol] and reduced [IGF-1] in both sexes, this clearly shows the catabolic state of the participants during the selection exercise. Similar changes in testosterone, IGF-1, and cortisol are well documented in male soldiers after strenuous military field exercises.^{4,26} Such changes are believed to be related to the negative energy balance and to a lesser degree to the lack of sleep.²⁶

The increase in cortisol levels was larger in women compared to men, and while the cortisol levels progressively declined in men during the recovery period, they remained elevated for the women. The larger increases in women were probably related to the fact that they had significantly lower cortisol values before the exercise. The reason for this is unclear but may be because the women's blood samples at pre were drawn a little later in the morning, compared to men. Another possible reason is that the recruit period was more strenuous for our male participants. The reason for the prolonged elevated cortisol in women is interesting, but the reason and consequences for this are unclear and should be further explored in future studies.

4.4 | Limitations

The fact that the selection exercise and recruit period were performed separately for the male and female conscripts, and

may have some differences in content, is a challenge when analyzing sex differences. As discussed, the total energy expenditure and negative energy balance were larger for men than for women. However, as the relative energy requirement, time spent at different intensities and the relative reductions in performance were not different between sexes, we argue that the selection exercise was equally strenuous for men and women in relative terms.

Body composition was measured with BIA which has some weaknesses compared to for example DXA that might have affected the results. It is for example affected by the body fluids. Furthermore, at post 0h it was not possible to standardize the measurement and this measurement should be interpreted with caution. BIA has also been reported to underestimate percent body fat but has shown good validity in military personnel.²¹ Measuring energy expenditure with accelerometers also has some weaknesses, for example, how to account for extra load carriage. Therefore, these measurements should not be used as a measure for actual energy expenditure during the exercise, but only to compare sexes.

It was not possible to standardize the testing and project to a certain part of the women's menstrual cycle. However, the female participants filled out a questionnaire regarding the menstrual cycle and use of contraceptives. Three of the women used oral contraceptives, five had an etonogestrel contraceptive implant while five did not use any form of contraceptives. Five had regular menstruation. If anything, this should only increase the noise in our measurements and therefore not confound the observed differences between men and women. However, it might have increased the likelihood for missing other important differences.

The quite large amount of missing data is a challenge. Even though we calculated missing values on participants missing only one test, the study sample was reduced. The quite low sample size and missing data may result in our study being underpowered.

5 | CONCLUSION

This is the first study investigating sex differences in the effects of and recovery from a demanding military field exercise consisting of high levels of physical activity combined with food and sleep restrictions on physical performance, body composition, and blood biomarkers. The demanding field exercise led to large changes in body composition, explosive strength and anaerobic performance, and hormones in both sexes. In accordance with our hypothesis, the reductions in muscle mass during the field exercise were larger in men than women. Contrary to our hypotheses, this did not lead to any sex difference in the reduction in physical performance during the field exercise. Interestingly, the recovery of CMJ performance was faster in women compared to men.

All changes in body compositions, hormonal disturbances, and upper body performance were recovered after one week of recovery in both sexes. However, changes in lower-body physical performance outlasted changes in hormones and body composition, with anaerobic performance needing two weeks to recover, while CMJ performance was still depressed two weeks after the exercise.

5.1 | Perspectives

The substantial drop in physical performance during a demanding field exercise emphasizes that the physical performance of soldiers at baseline needs to be high in order to be military effective during strenuous missions and exercises.

The prolonged recovery period is important to consider when planning the long-term training of military units. The recovery time between such exercises should be more than two weeks to avoid decreased physical performance and increased injury risk.

Even though female conscripts performed at lower absolute performance levels than males, there was no evidence that field exercises have a more negative impact on women compared to men. However, the fact that the negative energy balance was larger in men must be taken into consideration.

Our results show that body composition and hormones are insensitive markers of changes in physical performance in the recovery period after a demanding field exercise. Therefore, evaluation of the physical state of soldiers during training and after exercise should include tests of physical performance. One such test could be the CMJ test, as it is easy to perform in the field, and it is sensitive to the changes that occur. This test has also been recommended by others.^{4,8}

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CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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