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Depressed Physical Performance Outlasts Hormonal Disturbances after Military Training

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ABSTRACT

HAMARSLAND, H., G. PAULSEN, P. A. SOLBERG, O. G. SLAATHAUG, and T. RAASTAD. Depressed Physical Performance Outlasts Hormonal Disturbances after Military Training. *Med. Sci. Sports Exerc.*, Vol. 50, No. 10, pp. 2076–2084, 2018. **Introduction**: The aim of this study was to investigate the effect of an arduous 1-wk military course on measures of physical performance, body composition, and blood biomarkers. **Methods**: Participants were apprentices in an annual selection course for the Norwegian Special Forces. Fifteen soldiers (23 ± 4 yr, 1.81 ± 0.06 m, 78 ± 7 kg) completed a hell week consisting of rigorous activity only interspersed by 2 to 3 h of sleep per day. Testing was conducted before and 0, 1, 3, 7, and 14 d after the hell week. Physical performance was measured as muscle strength and jump performance. Body composition was measured by bioelectrical impedance and blood samples were collected and analyzed for hormones, creatine kinase, and C-reactive protein. **Results**: Body mass was reduced by 5.3 ± 1.9 kg during the hell week and returned to baseline within 1 wk. Fat mass was reduced by 2.1 ± 1.7 kg and muscle mass by 1.9 ± 0.9 kg. Muscle strength in leg press and bench press was reduced by 20% ± 9% and 9% ± 7%, respectively, and both were approximately 10% lower than baseline after 1 wk of recovery. Jump-height was reduced by 28% ± 13% and was still 14% ± 5% below baseline after 2 wk of recovery. Testosterone was reduced by 70% ± 12% and recovered gradually within a week. Cortisol was increased by 154% ± 74% and did not fully recover during the next week. Insulin-like growth factor 1 was reduced by 51% ± 10% and triiodothyronine and thyroxine by 12% to 30%, all recovered within a week. **Conclusions**: One-week arduous military exercise resulted in reductions in body mass and performance, as well as considerable hormonal disturbances. Our most important observation was that whereas the hormonal systems was normalized within 1 wk of rest and proper nutrition, lower body strength and jump performance were still depressed after 2 wk. **Key Words:** STRENGTH, MUSCLE DAMAGE, RECOVERY, IGF-1, TESTOSTERONE, CORTISOL

High levels of physical activity combined with calorie and sleep restriction, cause severe physiological impairments or complete exhaustion, which in turn affects military performance. Five to 8 d of military training combined with caloric restriction has been reported to decrease body mass by 3% to 10% (1–6), indicating a substantial energy deficiency. Body mass reductions in this range are often accompanied by disturbances in the hormonal milieu. For example, military training has been demonstrated to increase circulating levels of cortisol and aldosterone and to decrease circulating levels of prolactin, testosterone, and insulin-like growth factor 1 (IGF-1) (4,7–12). One major concern with energy deficiency and the following changes in hormone levels is catabolism of muscle tissue. Indeed, fat and muscle mass have previously been reported to decrease by 7% to 28% and 2% to 6%, respectively (1–5,13). The interactions between changes in hormone levels and effects on muscle tissue are complex, but some of these changes appear to correlate with loss of body mass (cortisol and IGF-1 (14)) and muscle mass (IGF-1 and cortisol (8)).

Physical performance is not always observed to decrease in response to military training in studies measuring handgrip strength (15–17). Lower-body strength tests consistently show declines in physical performance after military training and are evidently more appropriate than hand grip strength tests (3,8,9,12,18), because military exercise typically involves strenuous marching with heavy loads, affecting the legs far more than the upper body extremities. Although declines in performance during arduous military training is reported, studies conducted so far have been unable to link

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the hormonal responses to the reduction in physical performance (8,9,12).

Studies including tests during the recovery period after arduous military training have found serum hormone levels (testosterone, IGF-1, and triiodothyronine [T3] to recover within 5 wk of refeeding (14), and lean body mass to recover within 4 (5) wk and 5 (14) wk of refeeding. An exception may be T3, which have been reported to stay elevated for several weeks in some studies (12), but not all (14). Physical performance (vertical jump height and power output) appears to have recuperated within 5 wk after an 8-wk US ranger course (9,12). A limitation in these previous studies is inclusion of only pretests and posttests, which makes the time course of performance changes elusive.

Although some previous scientific work has explored the physiological processes during arduous military activities, many unanswered questions remains. Especially, the time course of the recovery processes after military training has been largely ignored in the scientific literature. This is surprising, because such knowledge may be imperative for the health and current performance of the soldiers. Consequently, the present study had two aims: 1) to investigate the effect of an extremely demanding 1-wk military training course on physical performance, body composition and blood biomarkers among apprentices to the Norwegian Naval Special Operations Command and 2) to examine the recovery of these variables up to 2 wk after the course.

METHODS

Participants. Subjects were recruited from a group of apprentices participating in an annual selection course to join the Norwegian Naval Special Forces. The recruits were monitored during the first 6 wk of the selection course, which consisted of 3 wk basic military training in camp and a so-called hell week followed by 2 wk of recovery (Fig. 1).

From the group of recruits who volunteered for this study, 15 (23 ± 4 yr, 1.81 ± 0.06 m, 78 ± 7 kg) were able to complete the hell week. All subjects were adults (>18 yr), healthy and underwent a complete physical and medical examination before entering the course.

The physical fitness standards required to qualify for the selection course were 45 push-ups, 45 sit-ups in 2 min, 8 hang-ups, 400 m swimming in 10 min, 25 m swimming under water and completing a 5000-m with uniform, boots, weapon (4.2 kg) and water bottles (2 kg) in less than 27 min.

Participation in both the selection course and the present study was voluntary, and all recruits were free to withdraw at any time. A written informed consent was obtained from each subject before the start of the study. The project was evaluated by the Regional Committee for Medical and Health Research Ethics (southeast). The selection course for the Naval Special Forces is conducted annually and is very prestigious to complete. Less than 10% are able to complete this course, and it benefits career-potential greatly. Hence, it was not realistic to include a control group of recruits that was not exposed to the course.

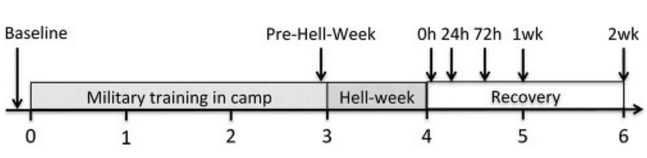

FIGURE 1—Timeline.

Course description. A crude selection occurred during the first week, based on physical and psychological tests. The recruits passing the first week were thereafter moved to a military camp for heavy physical activity and sleep restriction in a stressful environment for 3 wk. Thereafter a hell week, which consisted of sleep and caloric restriction and extreme amounts of physical activity for 20 $h{\cdot}d^{-1}$ in a very stressful environment, was performed (see Fig. 1). The main activity during the hell week was walking with a backpack (about 35 kg) in forestial and alpine terrains with a high pace. After the hell week, recruits were given a 2-wk recovery period. During the first 3 wk in camp, the recruits ate *ad libitum*. At the start of the hell week they received combat rations (10,000 kcal), which should last the entire week. The recruits were only given 2 to 3 h of sleep per day during the hell week.

Testing procedures. Testing was performed at seven different time points. Premeasurements (baseline) were completed at day 2 of the first selection week, and after 3 wk in camp on a resting day before the hell week (pre–hell week). Blood sample and measurement of body composition were performed immediately after termination of the hell week (at 12:00 noon), whereas physical performance was tested 8 h later (8:00 PM). Thereafter testing was conducted at day 1 (24 h), day 3 (72 h), and 1 and 2 wk after termination of the hell week. Blood samples were collected and body composition measures were made between 9:00 AM and 10:00 PM all testing days except at 0 and 24 h, at which they were performed between 12:00 noon and 1:00 PM.

Body composition. Body mass, fat mass, and muscle mass were measured with a four-electrode bioelectrical impedance scale (Inbody 720; Biospace, Beverly Hills, CA). When tested in the fasted state in the morning (overnight fasting) test–retest coefficient of variation (CV) in our laboratory is <2% for muscle mass and 6% for fat mass (n = 10). Compared with DXA measurements (Lunar iDXA), the estimated fat mass is systematically 3.6 ± 1.3 kg lower in the InBody 720 measurement when the same subjects are measured at the same time in our laboratory.

Physical performance. Counter movement jump (CMJ) was tested on a force plate (HUR Labs Oy, Tampere, Finland). The participants were instructed to drop down to about 90° in the knee joint and immediately jump as high as possible. Hands were kept on the hips during the jump. Three attempts were given with 30-s rest between jumps. If the third jump was highest, participants were given a fourth attempt. The test–retest CV for jump height in this test is 4% in our laboratory (n = 29).

Maximal isometric strength was measured in leg press and chest press, in a custom made machine built for the Norwegian military. During both tests the participants were seated upright and instructed to press against a bar connected to a force plate. For the leg press the knee angle was 110°. In the chest press the forearm was placed 90° to the bar and the elbow joint was 110°. A warm-up consisting of squats and push-ups and a contraction at 50% of maximal effort was conducted before the tests. Each participant was given two maximal attempts in both exercises, separated by 30 s. The test–retest CV for this test is less than 4% in our laboratory (n = 14).

Blood samples. Morning blood samples (9:00 AM to 10:00 AM) were collected 2 to 3 h after breakfast. Blood clotted in room temperature for 30 min before centrifuged at 1300g for 10 min. Serum was transferred into tubes and stored at −80°C until analyses. Serum was analyzed for testosterone (analytic CV, 9.2%), cortisol (5.4%), sex hormone-binding globulin (4.5%), creatine kinase (CK) (1.9%), C-reactive protein (CRP) (3.1%), TSH (4.6%), T3 (4.7%), thyroxine (T4) (6.6%) at Fürst (Oslo, Norway), and IGF-1 (7.5%) and insulin-like growth factor binding protein 3 (IGFBP-3) (6%) at The Hormone Laboratory (Oslo, Norway). Free testosterone was estimated based on testosterone and SHBG levels (free testosterone = 10 × testosterone/SHBG).

Statistics. Normally distributed data were analyzed for difference between time points using repeated measures ANOVA. A Dunnett *post hoc* tested for differences between means of pre–hell week and the other time points, except for testing between baseline and pre–hell week where a paired t-test was used. Nonparametric data were analyzed using the Friedmann's test. A Dunn's multiple comparisons test *post hoc* tested for differences between means of baseline and the other time points. Pearson's correlation coefficients (r) were calculated for changes in body composition, performance and hormone levels during the recovery period. An alpha level of 0.05 was used for all statistics. Statistical analyses were performed using GraphPad Prism (version 6.00 for Windows; GraphPad Software, La Jolla, CA). All values are reported as mean ± SD in tables, and changes are reported in percent ± SD. Because of illness and injuries (especially loss of skin from the foot sole), some data were not collected. Missing values were replaced (interpolated) by a value calculated from the participants initial value and the mean relative change at the given time point for the whole group. Because of the 25% missing data at 0 h for CMJ, this analysis was not interpolated and analyzed by an ordinary ANOVA.

RESULTS

The main aims of this study were related to the effects of the hell week and the following recovery. However, the changes between baseline and pre–hell week are important to have in mind. Therefore, the results are presented in two parts: first the changes occurring during the 3 wk in camp (from baseline to pre–hell week), and second the changes from pre–hell week to time points during the 2 wk after the hell week.

During the 3-wk training period before the hell week, body mass remained stable, but body composition changed with a small increase in estimated muscle mass (2.2% ± 2.4%). In addition, there was a small decrease in chest press strength (−5.2% ± 4.0%). In this period, reduced blood levels were observed for T3 (−8.3% ± 6.7%), T4 (−8.8% ± 5.3%), free testosterone (−24.6% ± 43.4%), and IGF-1 (−18.3% ± 19.1%). Four of the 15 soldiers increased CRP levels above reference values reaching 7 to 25 mg·L^{-1} in this period (Table 1).

Body composition. Body mass decreased by 5.3 ± 1.9 kg (6.6% ± 1.9%) during the hell week and returned gradually to pre–hell week levels 1 wk after hell week (Fig. 2A). The decrease in body mass was due to a reduction in fat mass by 2.1 ± 1.7 kg (37% ± 23%) and muscle mass by 1.9 ± 0.9 kg (4.5% ± 2.1%; Fig. 2B and C, respectively). The remaining loss of body mass was attributed to dehydration (total water content was reduced from 54.0 ± 4.5 kg to 52.2 ± 4.3 kg). Estimated muscle mass recovered through the next week, whereas fat mass was still reduced by 16% ± 19% 1 wk after the hell week. Dividing the participants into two groups based on pre–hell week fat mass revealed a greater loss of muscle mass in the "low fat mass" group (low fat mass, 2.5 kg and high fat mass, 1.3 kg, unpaired t-test) and a greater loss of fat mass during the hell week in the "high fat mass" group (low fat mass, 0.8 kg and high fat mass, 3.2 kg, unpaired t-test).

Blood biomarkers. Testosterone levels decreased by 70% ± 12% during hell week, and 72 h later, the testosterone levels were still below the lower range of reference value of 8.0 nmol·L^{-1} (7.1 ± 2.8 nmol·L^{-1}, 36% ± 23% lower than baseline). After 1 wk of recovery, testosterone had returned

TABLE 1. Body composition and performance tests in response to 1 wk of arduous military training and the following 1 wk of recovery.

Variable	Baseline	Pre–Hell Week	0 h	24 h	72 h	1 wk	2 wk
Body mass (kg)	77.9 ± 7.0	78.6 ± 6.7	73.4 ± 6.1^{a,b}	76.2 ± 6.4^{a,b}	76.1 ± 7.1^{a,b}	78.4 ± 6.7	
Body fat (%)	7.3 ± 4.1	6.0 ± 2.6	3.6 ± 0.9^{a,b}	3.5 ± 0.9^{a,b}	3.3 ± 1.8^{a,b}	4.5 ± 2.4^{a,b}	
Muscle mass (kg)	41.6 ± 3.3^{a}	42.5 ± 3.6^{b}	40.6 ± 3.7^{a,b}	41.7 ± 3.5^{a}	41.9 ± 3.8^{a}	42.9 ± 3.6^{b}	
Total body water (kg)	52.8 ± 4.1^{a}	54.0 ± 4.5^{b}	52.2 ± 4.3^{a}	54.2 ± 4.3	53.4 ± 4.9	54.7 ± 4.5^{b}	
Intracellular water (kg)	33.5 ± 2.6^{a}	34.2 ± 2.8^{b}	32.7 ± 2.8^{a,b}	33.5 ± 2.7^{a}	33.7 ± 2.9^{a}	33.8 ± 4.2	
Extracellular water (kg)	19.5 ± 1.7^{a}	20.0 ± 1.7^{b}	19.5 ± 1.7^{a}	20.7 ± 1.7^{a,b}	20.1 ± 1.9	20.2 ± 1.8^{b}	
Leg press (kg)	333 ± 51	322 ± 54	258 ± 54^{a,b}	274 ± 53^{a,b}	262 ± 52^{a,b}	282 ± 50^{a,b}	316 ± 57^{b}
Chest press (kg)	145 ± 23^{a}	137 ± 21^{b}	124 ± 21^{a,b}	127 ± 21^{a,b}	127 ± 17^{a,b}	122 ± 20^{a,b}	136 ± 19
CMJ (cm)	38.8 ± 4.2	37.7 ± 4.4	27.8 ± 7.3^{a,b}	29.1 ± 6.2^{a,b}	29.0 ± 5.6^{a,b}	29.4 ± 4.3^{a,b}	32.9 ± 4.1^{a,b}

[a]Significantly different from pre–hell week.
[b]Significantly different from baseline.

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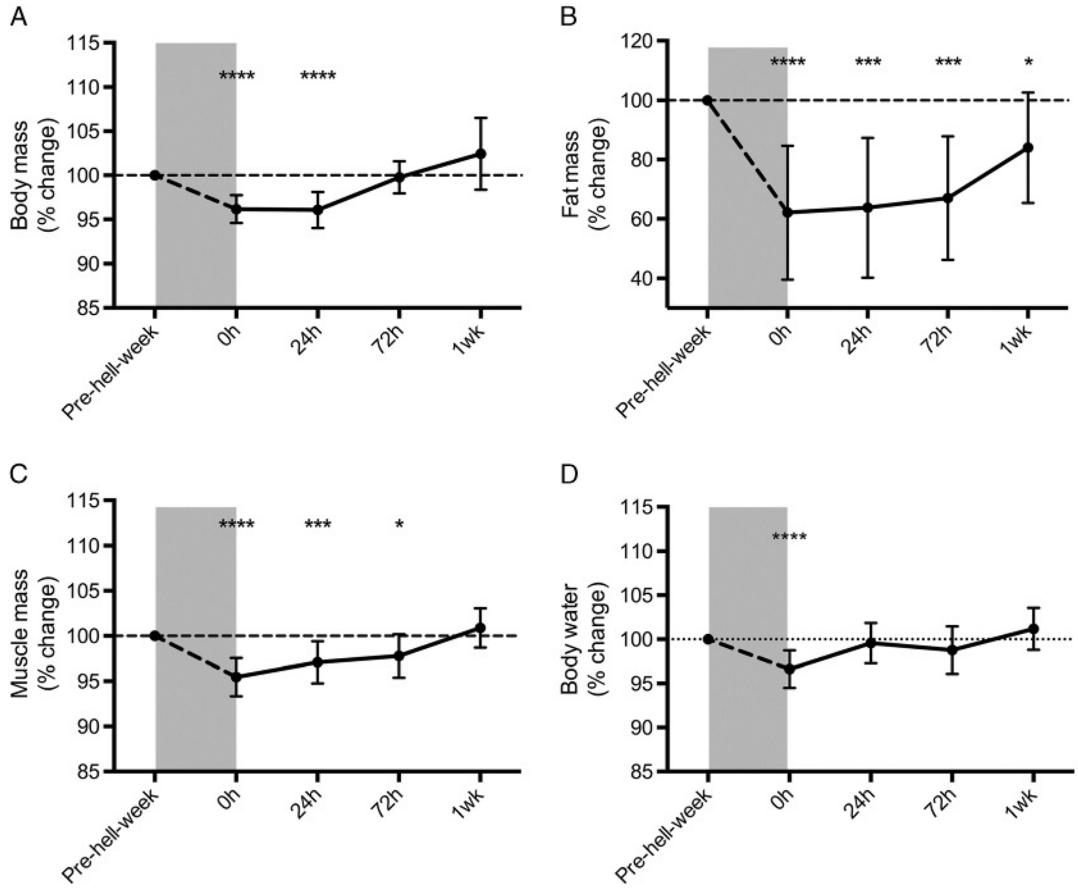

FIGURE 2—Changes in body mass (A), fat mass (B), muscle mass (C), and total body water (D) during 1 wk of arduous military training and 2 wk of recovery. Values are presented as means ± SD, *n* = 15, amount of missing data was 7% at 0, 24, and 72 h. *Significantly different from baseline, *P* < 0.05.

to normal values (15.3 ± 6.0 nmol·L^{-1}), but two soldiers were still below the reference range (7 nmol·L^{-1}). Sex hormone-binding globulin levels increased by 24% ± 21% during the hell week, stayed elevated for the next 72 h (25% ± 23% at 24 h and 33% ± 26% at 72 h), and were normalized after 1 wk of recovery. Free testosterone followed the same time course as testosterone and was reduced by 39% ± 79% at 0 h, 60% ± 47% at 24 h, and 50% ± 13% at 72 h after the hell week, and returned to normal values after 1 wk. Cortisol increased by 154% ± 75% during the hell week (0 h) and stayed elevated at 72 h (63% ± 36%) and 1 wk (43% ± 35%) after the hell week. The testosterone/cortisol ratio decreased by 87% ± 6% during hell week, by 63% ± 13% at 24 h, and 58% ± 13% at 72 h. The testosterone/cortisol ratio returned to baseline values after 1 wk.

IGF-1 and IGFBP3 were both reduced by 40% to 50% at 0 h before gradually returning toward pre–hell week values at 24 h (IGF-1, 45% ± 12%; IGFBP3, 37% ± 9%) and 72 h (IGF-1, 28% ± 13%; IGFBP3, 20% ± 10%), and normalizing after 1 wk of rest. T3 and T4 were significantly decreased at 0 h (−32% ± 10% and −12% ± 12%, respectively), with the lowest level for T4 at 24 h (−13% ± 12%). Both hormones gradually returned toward pre–hell week values, with T4 demonstrating a moderate increase from pre–hell week (but not baseline) after 1 wk of recovery (+8% ± 10%). The T3:T4 ratio decreased during the hell week (−77% ± 8%) and gradually returned toward pre–hell week values within 1 wk of recovery. TSH showed no immediate response to the hell week (2% ± 41%), but displayed a gradual nonsignificant increase of 24% ± 46% at 24 h and 25% ± 32% at 72 h and a significant increase of 58% ± 55% at 1 wk after the hell week. The CK levels were highly elevated at 0 h (700% ± 200%) and decreased to levels well below pre–hell week values after 1 wk of recovery. C-reactive protein was increased by 1300% to 1500% at 0 and 24 h, but was normalized below pre–hell week values within 1 wk (Table 2 and Fig. 4).

Performance. All measures of performance dropped substantially during the hell week. There were large reductions in both CMJ (−28% ± 13%) and leg press (−20% ± 9%), whereas the decrease in chest press (−10% ± 6%) was somewhat smaller (Fig. 3). None of the tests showed any clear signs of recovery during the first 72 h of rest. One week after the hell week, chest press performance returned to pre–hell week levels. Leg press performance recovered after 2 wk, whereas CMJ was still largely depressed after 2 wk of recovery (−14% ± 5%, Table 1).

Relations between changes in body composition, performance, and hormonal status. Because of many possible correlations, only the changes occurring during the

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TABLE 2. Levels of blood biomarkers in response to 1 wk of arduous military training and the after 1 wk of recovery.

Variables	Baseline	Pre–Hell Week	0 h	24 h	72 h	1 wk
Testosterone (nmol·L^{-1})	13.4 ± 5.1	10.6 ± 3.5	3.1 ± 1.2[a,b]	4.1 ± 2.0[a,b]	7.3 ± 2.8[a,b]	15.3 ± 6.0[a]
Free testosterone	5.1 ± 2.0[a]	3.3 ± 0.9[b]	1.5 ± 1.6[a,b]	1.2 ± 1.1[a,b]	1.6 ± 0.5[a,b]	4.7 ± 1.9[a]
Sex hormone-binding globulin (nmol·L^{-1})	27.3 ± 8.0	32.7 ± 9.5	40.1 ± 12.3[a,b]	40.1 ± 12.4[a,b]	43.4 ± 12.2[a,b]	33.3 ± 8.7[b]
Cortisol (nmol·L^{-1})	493 ± 116	458 ± 87	1122 ± 260[a,b]		714 ± 100[a,b]	633 ± 89[a,b]
Testosterone/cortisol (×100)	3.0 ± 1.6	2.4 ± 0.9	0.3 ± 0.1[a,b]		1.0 ± 0.4[a,b]	2.5 ± 1.1
IGF-1 (nmol·L^{-1})	39.0 ± 8.7[a]	30.7 ± 8.1[b]	14.6 ± 3.6[a,b]		21.5 ± 3.5[a,b]	32.6 ± 6.1
IGFBP3 (nmol·L^{-1})	115 ± 22[a]	102 ± 13[b]	63 ± 14[a,b]	64 ± 14[a,b]	82 ± 13[a,b]	107 ± 17
T4 (pmol·L^{-1})	18.1 ± 2.4[a]	16.4 ± 1.6[b]	14.5 ± 2.4[a,b]		16.8 ± 2.3[b]	17.7 ± 2.2[a]
T3 (pmol·L^{-1})	6.5 ± 0.3[a]	6.0 ± 0.4[b]	4.1 ± 0.7[a,b]		5.5 ± 0.3[a,b]	6.1 ± 0.6[b]
TSH (mU·L^{-1})	1.5 ± 0.8	2.0 ± 1.1	1.9 ± 1.0		2.4 ± 1.4[b]	3.0 ± 2.0[a,b]
CK, (U·L^{-1})	633 ± 437	324 ± 161	2210 ± 1359[a,b]	1732 ± 954[a]	414 ± 228	138 ± 71[b]
CRP (mg·L^{-})	1.6 ± 1.8	5.2 ± 7.8	23.1 ± 14.8[a,b]	20.1 ± 13.3[a,b]	7.7 ± 6.7	1.4 ± 0.6

Values are mean and standard deviation. Values that were likely to be affected by sampling at a later time of day at the 24 h time point have been removed.
[a]Significantly different from baseline.
[b]Significantly different from pre–hell week.

hell week are included here (Fig. 4). Change in muscle mass during the hell week correlated negatively with the absolute fat mass at pre–hell week (R = 0.78), and positively with absolute levels of testosterone at 0 h (R = 0.75) and absolute values and relative changes of T3 and T4 (R = 0.65–0.79). Changes in fat mass during hell week displayed a negative correlation with absolute levels of T4 at 0 h (R = −0.55). Absolute levels of CRP correlated with absolute levels of cortisol at 0 h (R = 0.67). Absolute levels and relative changes in IGF-1 tended toward and correlated with the change in CMJ performance during hell week, respectively (absolute: R = 0.48, change P = 0.54). Similarly, absolute levels and relative changes during hell week for IGFBP3 had a positive correlation with changes in CMJ performance during hell week (absolute: R = 0.56, change R = 0.69).

DISCUSSION

The aim of this study was to investigate the physiological impact of, and the following recovery from, a hell week of arduous physical activity combined with sleep and caloric restriction in the Norwegian Navy Special Operations Command. The main findings were: 1) body mass was reduced by 5.3 kg (1.9 and 2.1 kg reduction in muscle and fat mass, respectively) during the hell week. 2) CMJ performance and maximal isometric leg press performance dropped by approximately 30% and 20%, respectively, and CMJ did not recover within 2 wk of rest. 3) Free testosterone, IGF-1, IGFBP3, T3, and T4 decreased and stayed depressed for 72 h to 1 wk after hell week. Concomitantly, cortisol, CK, and CRP were elevated. 4) Initial muscle mass correlated negatively with loss of muscle mass during hell week. Absolute levels of testosterone at 0 h correlated with the loss of muscle mass during hell week, whereas changes in IGF-1 and IGFBP3 were moderately related to changes in performance in response to the hell week. Notably, in contrast to the prolonged reductions in CMJ performance and leg strength, the blood markers and upper body strength generally returned to pre–hell week levels within 1 wk after the hell week.

Changes in body composition. Total body mass, skeletal muscle mass, and fat mass was reduced by 5.3 kg (6%), 1.9 kg (2.4%), and 2.1 kg (38%), respectively, during the hell week. The absolute reductions in body mass, skeletal muscle mass, and fat mass are comparable to previous studies of comparable length (1–5,19). The greater percentage loss of fat mass compared with previous studies is likely due to the use of DXA to measure body composition in previous studies and the use of InBody 720 (underestimates fat mass) in the current study. The clear negative association between initial fat mass and loss of muscle mass during the hell week suggests that higher levels of fat mass protect against muscle loss under demanding military training. By extrapolating our data, it seems that an initial total fat mass of about 10 kg (as measured with InBody 720) would protect against muscle loss during the hell week, at least when the total reduction in body mass is around 4 to 6 kg. This may be of great interest for operative soldiers and should be investigated further in future studies. The 1.9-kg loss of muscle mass may be an overestimation caused in part by dehydration due to depleted glycogen stores, affecting the distribution of water between the intracellular and extracellular compartments (20). Still, this result falls within what should be expected based on previous studies (1–6). The role of glycogen stores depletion can also explain the rapid recovery of estimated muscle mass after hell week (21). The reduction in body mass is equivalent to a total calorie deficit of about 120 MJ (22). Based on the combat rations given to the recruits at the start of the hell week, energy intake was about 8 MJ·d^{-1}, which indicate a daily energy expenditure of about 32 MJ. Earlier comparable studies have reported an energy expenditure of between 25 and 50 MJ·d^{-1} (2,5,10,11,14).

Hormones. The hormonal changes reflect the very stressful conditions the recruits were exposed to during the hell week. Testosterone (total and free), IGF-1, T3, and T4 were markedly reduced, whereas SHBG, TSH and cortisol were increased. These findings are well supported by those of others (6,10,11,14).

In the current experiment, the soldiers were exposed to four major stressors: Psychological stress, calorie restriction, sleep deprivation, and demanding physical activity. Because of our descriptive study design, we cannot differentiate between these stressors. However, as suggested by Friedl and colleagues (14), the reductions in testosterone (total and free),

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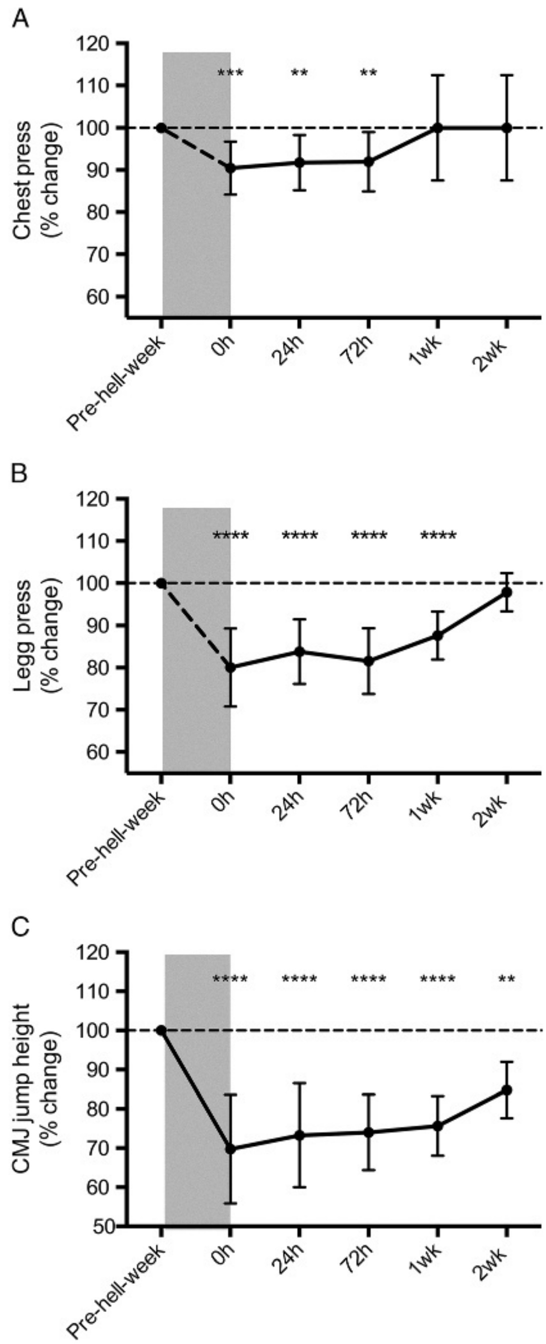

FIGURE 3—Changes in chest press performance (A), leg press performance (B) and CMJ performance (C) during 1 wk of arduous military training and 2 wk of recovery. Values are presented as means ± SD, n = 15, amount of missing data for the strength tests was 7% at 0 and 24 h, and 13% at 72 h. For CMJ, the amount of missing data was 26% at 0 h, 20% at 24 h, and 7% at 72 h. *Significantly different from baseline, P < 0.05.

T3, IGF-1 (23–25) and IGFBP3 (4) are probably caused primarily by the negative energy balance. The cortisol levels were strongly elevated at the end of hell week and probably reflect lipolytic and proteolytic effects to provide substrates for hepatic gluconeogenesis (14,26). The elevated cortisol levels after 1 wk of recovery and the suppressed testosterone:cortisol ratio at 72 h indicates a prolonged catabolic state, which corresponds with the halted recovery of performance. Cortisol was not fully recovered within 1 wk of rest, but did not correlate with the recovery of performance or body composition during the recovery period.

The reduced levels of IGF-1 may indicate an adaptation to maintain normoglycemia by inhibiting the insulin-like actions of IGF-1 on target tissues (27). The observed reduction in IGFBP3 is greater than previously observed (4,28) and suggests a shift in the association between IGF-1 and its binding proteins. The potential effect of this shift is difficult to interpret without measuring free IGF-1 and the other IGFBP. Blood IGF-1 levels seem associated with nitrogen balance and muscle mass (29). Indeed, Nindl and colleagues (30) found a modest correlation between reductions in fat free mass and free IGF-1 during military exercise. We were not able to replicate this correlation, but found IGF-1 and IGFBP3 to moderately correlate with leg press performance change during hell week. Our results thus, lend some support to previous investigations suggesting IGF-1 to be a marker for changes in nutritional and fitness status (30).

The T3:T4 ratio was decreased and implies reduced conversion of T3 from T4, possibly by reduced iodothyronine deiodinase activity in the liver and other tissues (31). The delayed increase in TSH probably reflects a compensation for the reduced T3 levels (reduced negative feedback). Collectively, these changes are as expected from calorie restriction, while the strenuous physical activity and sleep deprivation probably played minor roles (14).

The levels of the systemic inflammation marker CRP were elevated significantly above reference values. We suspect this to result from *Staphylococcus aureus* infections on the soldier hands, caused by untreated skin wounds. Medical personnel frequently observe this condition after military exercises such as this hell week in this region of Norway. However, similar CRP levels have been reported after a marathon (32) and a longer lasting military course (28), suggesting that the physiological stress of the hell week in itself could be sufficient to increase CRP to these levels. Unfortunately, we did not measure cytokines, but it is plausible that the increased CRP was the result of a systemic inflammation with elevated levels of IL-1β and IL-6 (28,33).

Somewhat surprisingly, there were no correlations between performance reductions and changes in body composition. Thus, the reduction in muscle mass appears not solely to be responsible for the reduced performance. In support of this assumption, performance followed a slower recovery pattern than that of muscle mass; as also reported by Nindl and colleagues (9). A lack of numeric association between reductions in muscle mass and reduced performance could partly be due to methodological challenges concerning impedance measurements. Changes in hydration status and muscle swelling are common after strenuous physical activity (34,35) and such physiological changes could affect the results from the bioimpedance measurements (20). In support of a true reduction of muscle mass, the muscle mass was found reduced by 2% after 24 h of rest, and

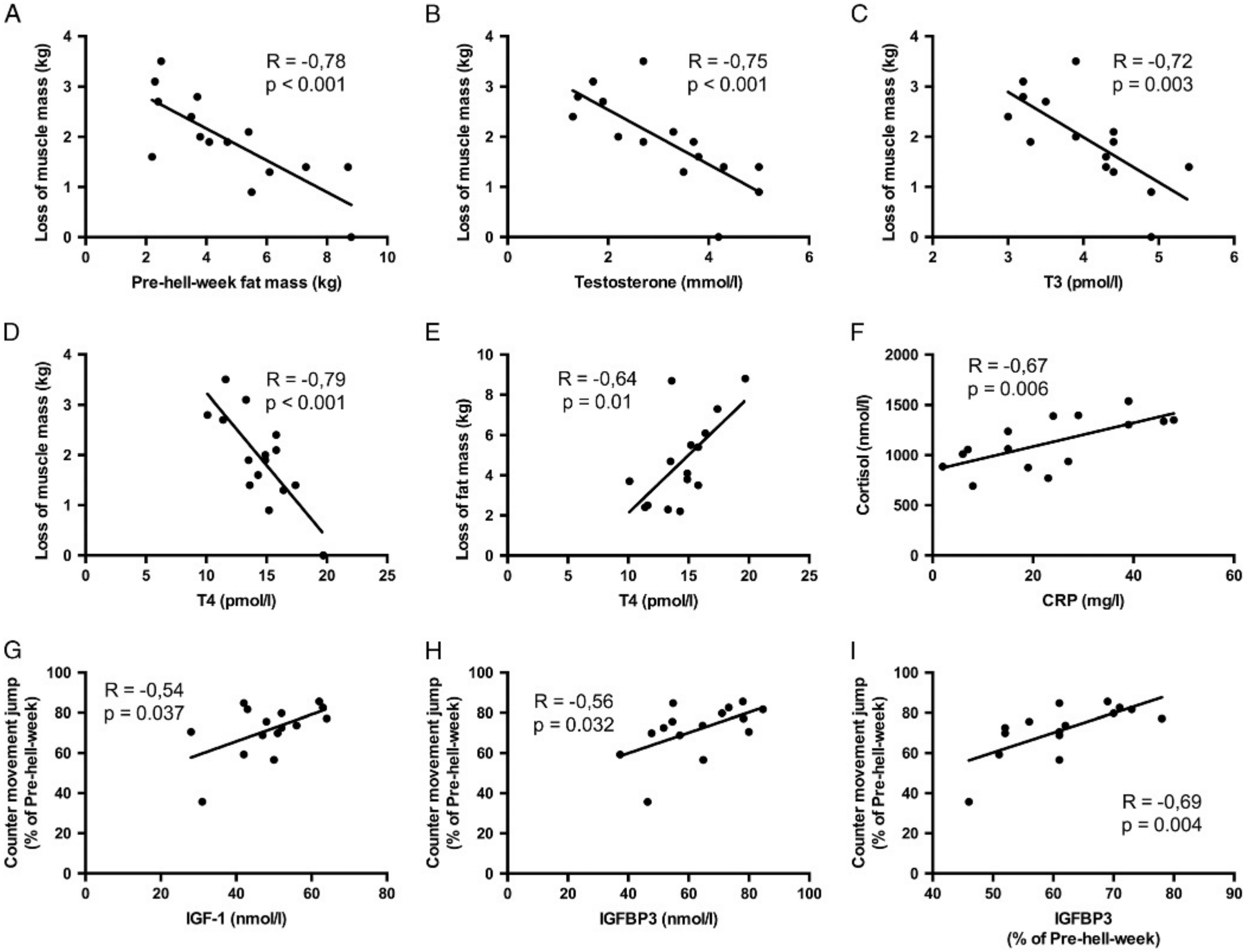

FIGURE 4—Correlation of (A): Pre–hell week fat mass and loss of muscle mass during hell week, (B) Testosterone and loss of muscle mass during hell week, (C): T3 and loss of muscle mass during hell week, (D): T4 and loss of muscle mass during hell week, (E) T4 and loss of fat mass during hell week, (F) CRP and Cortisol, (G): IGF-1 and CMJ, (H) and (I): IGFBP3 and CMJ.

it stayed at this level also at 72 h. Moreover, the reduction in muscle mass is comparable to similar studies (1,3,4).

Changes in performance. As anticipated, strength and CMJ performance were reduced after the hell week. Chest press, leg press and CMJ performance were all suppressed, with CMJ most severely affected (~30%). These performance deficits are larger than reported in earlier studies of similar duration (−5% to 9% for jumping performance; (1,3,18), and also larger than those observed after studies lasting 8 wk (16%–19%; (8,9,12). Results from different studies are not easily comparable, due to intervention differences, that is, duration, intensity, type of work, degree of caloric and sleep restriction, the time elapsing between the training and tests, as well as the tests chosen. The greater reductions in physical performance in the current study could be a result of a greater caloric restriction (24 MJ vs 12 MJ) compared to similar studies (1,3,18). In addition the near continuous marching in a hilly area with a 35-kg backpack is likely to have been more demanding on the lower body musculature than a 54-km ski march (18) and studies including more technical and instructional courses (1) of shorter duration (3). With regard to longer lasting studies, these studies include periods of recovery and caloric surplus, likely contributing to a reduced loss of physical performance (8,9,12).

Previous studies have focused on hormones, and that endocrine changes could explain or predict changes in physical performance and recovery (14,28,30,36). However, muscle mass and hormonal levels were generally normalized after 1 wk, which was considerably faster than recovery of performance. Considering the focus on hormones and muscle mass in relevant literature, this is an intriguing observation, because it implies that the main mechanism of reduced performance lay elsewhere. In research of laboratory-controlled experiments on eccentric exercise, we have previously reported that the reduced muscle performance and long-lasting recovery is caused by damage to contractile apparatus within the muscle fibers (37). Therefore, we suggest that muscle damage rather than atrophy was the main mechanism behind the reductions in performance. Indeed, the increased

CK levels support this claim; the levels (~2200 IU) were similar to what have been reported after isolated eccentric exercise (38) and marathon running (32), and higher than induced by a regular strength training session (39). Assuming that muscle damage explains most of the reduced muscle performance, the degree of muscle performance loss (>20%) and the prolonged recovery period (>2 wk) suggest moderate to severe muscle damage, at least in the lower body (37). Severe exercise-induced muscle damage may involve inflammation and muscle fiber necrosis (37). However, we cannot exclude that a form of central fatigue or pain and an increased activation-deficit could be a contributing factor to reduced muscle performance, as observed after other long-lasting exercise forms, such as a marathon (40). The restoration of the upper body (chest press) is faster than the lower body (leg press), and no significant pain or muscular discomfort after 1 wk of recovery, suggesting that central fatigue was not an important mechanism at the 2-wk timepoint.

Limitations. Our interpretations of changes in body composition are somewhat challenged by the underestimation of fat mass of our participants and the sensitivity to hydration status of the bioimpedance measures. The distribution of calories during the hell week was not standardized, but could potentially affect the hormonal and performance responses. Further, we do not know whether the recruits were able to find additional sources of calories during the hell week. Although we were able to show a substantial drop in physical performance during the hell week, lasting for more than 2 wk, we were unfortunately not able extend our testing period to observe when the return to baseline occurred. The missing data at certain time points remains a challenge, especially for the CMJ measures. However, the observed changes are still evident when excluding participants with missing data.

Perspectives. To further investigate the mechanisms behind the observed dissonance between body composition, hormonal changes, and physical performance, future studies should include biopsies to evaluate the amount of muscle damage in response to arduous military training. There is also a need for an assessment of different strategies to enhance the recovery after military training or missions, including nutrition, exercise, and medical interventions.

Practical implications. After 1 wk with arduous military exercise, we report a substantial drop in muscular performance, which lasts for more than 2 wk. To be able to tolerate such levels of stress, and still perform at the required level in military missions of similar character, the baseline physical performance levels of the soldiers need to be very high. If missions or exercises are repeated, sufficient recovery (>2 wk) should be allowed for, so that the physical performance does not decrease to critically low levels over time.

Our results clearly show that body mass, body composition and hormones (e.g., testosterone and cortisol) per se are insensitive measures for the recovery of physical performance in soldiers. Consequently, these measures should not be used solely to make decisions on readiness. We recommend dynamic exercises involving large muscles in the lower body, especially CMJ, for monitoring changes in physical performance in soldiers, and individuals in similar work occupations.

CONCLUSIONS

The novel aspect of this study was that recovery of both upper- and lower-body physical performances were monitored for 2 wk after 1-wk arduous military exercise, including calorie and sleep restrictions, psychological stress, and high levels of physical activity. The stressors resulted in reductions in body mass and performance, as well as considerable hormonal disturbances. Our most important observation was that although the hormonal systems and body composition normalized within 1 wk of rest and positive energy balance, CMJ performance was depressed even after 2 wk. This indicates that the lower body muscles suffer from significant muscle damage, which apparently required weeks of regeneration. Observations of prolonged reductions on physical performance should have implications for the planning of such military activities and the following recovery strategies and treatments.

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The authors declare no conflict of interest.

APPLIED SCIENCES

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