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7 **Effects of male paratroopers' initial body composition on changes in physical performance and**
8 **recovery during a 20-day winter military field training**

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34 ABSTRACT

35 Changes in physiological markers and physical performance in relation to paratroopers' initial body
36 composition were investigated during a 20-day winter military field training (MFT) and the
37 subsequent 10-day recovery period. Body composition, serum hormone concentrations and enzymatic
38 biomarkers, and physical performance of 58 soldiers were measured before, during, and after MFT.
39 Comparisons were done according to soldiers' body fat percentage before MFT between low-fat
40 (<12% body fat) and high-fat (>12% body fat) groups. Correlations between body fat percentage
41 preceding MFT and changes in muscle mass, physical performance, and serum hormone
42 concentrations and enzymatic biomarkers were investigated. It was hypothesized that soldiers with a
43 higher fat percentage would have smaller decrements in muscle mass, physical performance, and
44 serum testosterone concentration. The change in muscle and fat mass was different between groups
45 ($p<0.001$) as the low-fat group lost 0.8 kg of muscle mass and 2.0 kg of fat mass, while there was no
46 change in muscle mass and a loss of 3.7 kg of fat mass in the high-fat group during MFT. Fat
47 percentage before MFE correlated with the changes in muscle mass ($R^2=0.26$, $p<0.001$), serum
48 testosterone concentration ($R^2=0.22$, $p<0.001$), and evacuation test time ($R^2=0.10$, $p<0.05$) during
49 MFT. The change in muscle mass was correlated with the changes in evacuation test time ($R^2=0.11$,
50 $p<0.05$) and countermovement jump test results ($R^2=0.13$, $p<0.01$) during MFT. Soldiers with a higher
51 initial fat percentage lost less muscle mass, had smaller decrements in some aspects of physical
52 performance, as well as in serum testosterone concentration during MFT.

53

54 Keywords: body composition, military field training, strength performance, anaerobic performance,
55 hormonal changes

56 INTRODUCTION

57

58 Environmental extremes are an important part of the operative stressors soldiers need to be prepared
59 for when optimizing performance for military operation (Nindl et al. 2013). High physical
60 performance is especially important for special operations force (SOF) soldiers who face demanding
61 tasks in these challenging conditions. The demands of cold environment in combination with the
62 physical demands of the mission often lead to negative energy balance (Castellani et al. 2015, Ahmed
63 et al. 2020). Consequently, previous research has shown that military field training (MFT) lasting
64 several days is characterized by the loss of body weight, including both fat and muscle mass (Gan et
65 al. 2021, Vikmoen et al. 2020, Hamarsland et al 2018, Nindl et al. 2007, Johnson et al. 1994), the
66 decrease in physical performance (Gan et al. 2021, Vikmoen et al. 2020, Hamarsland et al 2018, Nindl
67 et al. 2007, Johnson et al. 1994, Hoyt et al. 2006), and the changes in hormonal biomarkers such as
68 testosterone and cortisol (Øfstengin et al. 2020, Kyröläinen et al. 2007, Nindl et al. 2007). While lower
69 fat mass has been associated with better performance in several military tasks (Pihlainen et al. 2018,
70 Lyons et al. 2005), it has been shown that a higher fat percentage can attenuate the loss of muscle
71 mass during prolonged MFT (Gan et al. 2021, Vikmoen et al. 2020, Hamarsland et al. 2018). This
72 could be explained by the higher rate of fat oxidation per kilogram of fat free mass observed in
73 individuals with larger quantities of fat mass, as this fat-predominant energy metabolism would
74 decrease the need to oxidize body's protein reserves during energy deficit (Hoyt et al. 2006). As
75 individuals with a higher fat percentage at the beginning of MFT may be less prone to the loss of
76 muscle mass, it is possible that this could also lead to smaller decrements in physical performance.
77 However, the evidence for this is controversial as there are findings supporting both a relationship
78 between muscle mass loss and a decrease in physical performance (Nindl et al. 2007, Johnson et al.
79 1994) as well as support for the null hypothesis (Vikmoen et al. 2020, Hamarsland et al. 2018).
80 Furthermore, the direct relationship between soldiers' fat percentage preceding MFT and changes in
81 physical performance have not been previously studied.

82

83 In addition to the decrease in physical performance, the decrease in serum testosterone and the
84 increase in serum cortisol are common findings in soldiers participating in MFT ([Øfstengin et al.](#)
85 [2020](#), [Hamarsland et al. 2018](#), [Szivak et al. 2018](#), [Kyröläinen et al. 2007](#), [Nindl et al. 2007](#)).
86 Interestingly there also seems to be a strong relationship between soldiers' fat percentage or fat mass
87 preceding MFT and the change in serum testosterone as leaner soldiers seem to have a greater
88 reduction in serum testosterone concentrations ([Berryman et al. 2022](#)). It has also been suggested that
89 a relationship exists between the change in serum testosterone concentration and the change in muscle
90 mass during MFT ([Berryman et al. 2022](#), [Hamarsland et al. 2018](#)) and that interventions attenuating
91 decrements in serum testosterone concentrations could possibly be used to reduce adverse changes in
92 muscle mass and physical performance ([Berryman et al. 2022](#)).

93
94 As the energy deficit, sleep deprivation, physical strain, and mental stress experienced during MFT
95 can cause a wide range of negative changes in body composition, physical performance, and hormone
96 concentrations, the recovery from strenuous MFT has been a topic of interest in the literature. The
97 time span for the recovery of physical performance seems to be longer than that of hormone
98 concentrations or body composition. While hormone concentrations and body composition changes
99 are usually recovered during the first week of recovery, some aspects of physical performance can
100 take longer than two weeks to recover ([Vikmoen et al. 2020](#), [Øfstengin et al. 2020](#), [Hamarsland et al.](#)
101 [2018](#)). Although knowledge about soldiers' recovery after MFT has increased in the recent years, it is
102 uncertain if body composition plays a role in the time span of the recovery process.

103
104 While there seems to be a relationship between fat percentage and change in muscle mass and serum
105 testosterone concentrations during MFT, their subsequent relationship with soldiers' physical
106 performance is not as clear. Therefore, the primary purpose of this study was to investigate the
107 hypothesis that there is a relationship between soldiers' fat percentage preceding MFT and the change
108 in muscle mass, physical performance, and serum testosterone concentration during MFT, where a
109 higher fat percentage leads to a smaller decrease in muscle mass, physical performance and serum
110 testosterone concentration The secondary purpose was to investigate the hypothesis that a higher fat

111 percentage is associated with faster recovery of physical performance and serum testosterone
112 concentration after MFT.

113

114 MATERIALS AND METHODS

115

116 Experimental design and procedures

117

118 The present study consisted of 20 days of MFT followed by a 10-day recovery phase. The 20-day
119 MFT (Figure 1) consisted of a lighter phase (10 days) which included basic cold weather and winter
120 warfare training, followed by a demanding phase (10 days) when the soldiers applied their skills in the
121 arctic environment performing reconnaissance tasks while skiing long distances and carrying heavy
122 individual equipment weighing 30–40 kg. During the demanding part of MFT the soldiers were
123 subject to heavy physical strain, cold weather, and sleep and energy deprivation. The recovery period
124 consisted of light military service and unregulated military leave. Measurements were conducted on
125 four different time points. PRE measures were collected 3 days before the start of the exercise, MID
126 measures between the light and heavy segments of MFT and, POST measures immediately after MFT.
127 Finally, RECO measurements were performed 10 days after the end of MFT. During MFT, the
128 average ambient temperature was -10°C (range $-4 - -18^{\circ}\text{C}$) and snow depth of 85 cm, thus practically
129 forcing soldiers to use skis for moving.

130

131 Participants

132

133 Fifty-eight male SOF soldiers voluntarily took part in the study. There were no female SOF conscripts
134 in the target population. The participants were divided into two groups according to their initial fat
135 percentage (Table 1). The present study was conducted according to the provisions of the Declaration
136 on Helsinki and was granted an ethical approval from the Ethical Committee of the University
137 Hospital of Helsinki (HUS/1020/2019). The study was approved by the Finnish Defence Forces
138 (AP12498). All subjects were informed of the experimental design, and the benefits and possible risks

139 that could be associated with the study prior to signing an informed consent to voluntary participate in
140 the study.

141

142 Physical performance testing

143

144 Soldiers' physical performance was assessed at PRE, POST, and RECO time points using a test
145 battery consisting of six tests. The physical performance test began with a 10-minute warm-up
146 consisting of light jogging and body-weight exercises. The tests were done in the following order:
147 standing long jump, medicine ball throw (MBT), countermovement jump (CMJ), weighted chin-ups,
148 sit-ups, and evacuation test (EVAC).

149

150 The standing long jump was performed on a rubber mat with an integrated measuring scale. The
151 participants were instructed to jump as far as possible freely swinging their arms for best results. Three
152 attempts with a short (< 1min) in-between resting period were allowed and the best jump was recorded
153 as the final result. The standing long jump has been proven to be a valid test for explosive force
154 production of the lower extremities with high repeatability (ICC = 0.95). ([Markovic et al. 2004](#))

155

156 The medicine ball throw (MBT) was performed seated on the floor using a 2 kg medicine ball. The
157 back, shoulders, and the back of the head were kept in touch with the wall and legs were kept straight
158 on the ground during the throws. The ball was thrown off the chest using both hands. Each participant
159 had four consecutive throws of which the longest one was recorded as the final result. MBT using this
160 method has been proven to be a reliable method for testing upper limb explosive force production
161 (ICC = 0.95) ([Van den Tillaar & Marques 2013](#)).

162

163 The countermovement jump (CMJ) height was calculated from the flight time recorded with a portable
164 contact mat (Newtest, Oulu, Finland). Participants were instructed to keep their hands on their waist
165 during the jump and the knees and ankles were to be extended during the landing. Three jumps were
166 performed of which the best one was recorded for statistical analyses. There was a short resting period

167 of one to two minutes between each jump. The CMJ has been proven to be a valid test for explosive
168 force production of the leg extensor muscles with high repeatability (ICC = 0.98). (Markovic et al.
169 2004)

170
171 In the weighted chin-up the participants completed maximum repetitions of chin-ups with a 10 kg
172 weight on the waist until exhaustion. Each repetition was initiated from a dead hang with straightened
173 arms and a visible pause was implemented between each repetition to minimize kipping and swinging.
174 The tip of the chin had to exceed the bar level both horizontally and vertically.

175
176 In the sit-up test the participants completed as many sit-ups as possible in two minutes. The
177 participants were assisted by holding down at the ankles during the test. The upper part of the back
178 had to make contact with the ground in the bottom position and elbows had to touch the knees or the
179 upper parts of the thighs in the top position. Fingers were interlocked behind the head. If the
180 movement was stopped for more than three seconds, the test was ceased.

181
182 In the evacuation course (EVAC) two laps were run against time around a track that was 10 meters
183 wide and 20 meters long with four cones that the participant had to go around. First lap was run
184 without load but for the second lap the participants had to drag a dummy weighing 80 kg. A detailed
185 description of the track is provided by Angeltveit et al. (2016) who state that the EVAC course is a
186 valid test for anaerobic performance with good repeatability (ICC = 0.89 after familiarization) and
187 face validity for SOF soldiers.

188
189 Body composition and hormone serum concentrations

190
191 Body composition was measured, and blood samples were collected at PRE, MID, POST, and RECO
192 time points after an overnight fast, excluding the POST time point where measures and samples were
193 taken directly after soldiers finished MFT and a fasted state could not be ensured. Measures and
194 samples were collected during the morning between 05:30 and 07:00.

195
196 Body composition was analyzed using multifrequency bioimpedance analysis assessment (InBody
197 720/770, Biospace Co. Ltd., Seoul, South Korea) with the subjects in their underwear. While the
198 method has been found to be reliable, it systemically overestimates muscle mass when compared to
199 measures taken by DEXA (Dual-energy X-ray absorptiometry). Still, the correlation between DEXA
200 and InBody analyses is high ($r=0.90$, $p<0,001$). (McLester et al. 2018.)

201
202 Blood samples were drawn from the median cubital vein and were centrifuged (Megafire 1.0 R
203 Heraeus, DJB Labcare Ltd, Buckinghamshire, UK) at $2000\times g$ for 10 min and frozen for a later
204 analysis. Cortisol (COR) and testosterone (TES) concentrations were analyzed using an Immulite 2000
205 XPI immunoanalyzer (Healthcare Diagnostics Products Ltd.). Serum creatine kinase (CK) activity was
206 analyzed using Indiko Plus chemistry analyzer (Thermo Fisher Scientific Ltd.). The sensitivity and
207 interassay coefficients of variance for these assays were 5.5 nmol/L and 6.5% for COR, 0.5 nmol/L
208 and 7.8% for TES, 0.08 $\mu\text{mol/L}$, and 7 U/l and 7.1% for CK.

209
210 Statistical analysis

211
212 Statistical analysis was performed in R (v R4.2.1). Descriptive statistics are presented as means \pm SD.
213 Subjects were split into two groups using 12 % of fat percentage as cut-off value ($n = 29$ per group, n
214 = 58 total).

215
216 Linear mixed models for repeated measurements with restricted maximum likelihood estimation were
217 used to examine differences between groups for response variables (body weight, muscle mass, fat
218 mass, physical performance tests, and hormonal and enzymatic biomarkers). A random subject effect
219 was used to account for repeated measurements. Fixed effects of time (PRE, MID, POST, RECO) and
220 group (over 12 % body fat, under 12 % body fat), as well as their interaction term, were specified.
221 Bonferroni post hoc tests were used to examine interactions and main effects. A pairwise Student's t
222 test with Bonferroni correction was used to compare measurements in MID, POST and RECO

223 timepoints to measurements at PRE timepoint. A pairwise Student's t test with Bonferroni correction
224 was used to compare groups for age and anthropometrics at PRE. If normal distribution was not
225 observed a Wilcoxon signed rank test was performed with Bonferroni correction.

226
227 Linear model was performed to evaluate linear dependency between fat percentage at PRE and change
228 in muscle mass (PRE to POST), change in testosterone concentrations (PRE to POST), change in
229 physical performance (PRE to POST), as well as to evaluate dependency between change in muscle
230 mass (PRE to POST) and change in physical performance (PRE to POST).

231
232 Appropriate transformations of variables were performed when a normal distribution was not observed
233 for parametric statistical testing. Pearson correlation coefficients were used to determine correlation
234 between variables. A 2-tailed P value < 0.05 was considered significant.

235

236

237

238 RESULTS

239

240 Body weight, muscle mass, and fat mass at all time-points are presented in Table 2 for each group
241 separately. There was a significant main effect of time for body mass ($p < 0.001$), muscle mass
242 ($p < 0.001$) and fat mass ($p < 0.001$) and a significant main effect of group for muscle ($p < 0.05$) and fat
243 mass ($p < 0.001$). While there was no significant group \times time interaction for the change of body mass,
244 there was a significant group \times time interaction for muscle (0.001) and fat mass ($p < 0.001$) and post-
245 hoc analysis indicated that the low-fat group had greater changes in muscle mass ($p < 0.001$) and
246 smaller changes in fat mass ($p < 0.001$) than the high-fat group from PRE to POST. The low-fat group
247 lost 0.8 ± 0.9 kg of muscle mass ($p < 0.01$) and 2.0 ± 1.2 kg of fat mass ($p < 0.001$). For the high-fat
248 group, no significant change was detected for muscle mass, but a 3.7 ± 1.4 kg decrease of fat mass
249 ($p < 0.001$) was observed. After a 10-day recovery period, body mass and body composition had
250 returned to PRE-values apart from fat mass for the low-fat group as there was a statistically significant

251 increase of 0.8 ± 1.1 kg of fat mass ($p < 0.01$) from PRE to RECO. Figure 2 shows the changes in body
252 mass, muscle mass, and fat mass from PRE to POST (A) and their level of recovery (ratio of RECO
253 and PRE measures) at RECO (B).

254

255 Physical performance

256

257 There was a significant main effect of time for all physical performance tests. Performance decreased
258 from PRE to POST in all of the tests used (Figure 3). Greatest reduction in performance appeared in
259 the EVAC-course time where increases of 23.8% and 18.6% were observed in the total time for the
260 low-fat and the high-fat groups, respectively. Physical performance was still suppressed at RECO in
261 most of the tests used but a return to PRE measurement values was observed in sit-up test for the low-
262 fat group and in EVAC-course for the high-fat group. There was no significant group \times time
263 interaction in any of the physical performance tests.

264

265 Hormonal and enzymatic changes

266

267 There was a significant main effect of time ($p < 0.001$) for serum testosterone concentration and a
268 significant group \times time interaction ($p < 0.001$). Serum testosterone concentrations decreased by 78.8%
269 and 65.0% from PRE to POST in the low-fat and the high-fat groups, respectively. There was a
270 significant main effect of time ($p < 0.001$) for serum cortisol concentration ($p < 0.001$) and a decrease of
271 21.4% ($p < 0.01$) in serum cortisol concentrations from PRE to POST for the high-fat group was
272 detected. There was no significant group \times time interaction. There was a significant main effect of
273 time ($p < 0.001$) for CK activity ($p < 0.001$), and an increase in CK activity was observed from PRE to
274 POST. There was no significant group \times time interaction All biomarkers returned to PRE
275 measurement values during RECO. Table 3 shows the serum hormone concentrations and creatine-
276 kinase activity at different time points and the average relative change from PRE, if statistically
277 significant.

278

279 Correlations between fat percentage, muscle loss, changes in physical performance, and changes in
280 blood biomarkers

281

282 Fat percentage at PRE was positively correlated with the change in muscle mass from PRE to POST
283 ($R^2=0.26$, $p<0.001$) and the change in serum testosterone concentration from PRE to POST ($R^2=0.22$,
284 $p<0.001$). The change in soldiers' muscle mass from PRE to POST was correlated with the respective
285 changes in CMJ performance ($R^2=0.13$, $P<0.01$) and changes in EVAC time ($R^2=0.11$, $p<0.05$), while
286 fat percentage at PRE was only correlated with changes in EVAC time ($R^2=0.10$, $p<0.05$). Scatter
287 plots and correlations are presented in figure 4.

288

289

290

291 DISCUSSION

292

293 The purpose of this study was to investigate the relationship between soldiers' fat percentage and
294 changes in muscle mass, physical performance, and blood biomarkers during a 20-day MFT in the
295 arctic environment and the following 10-day recovery period. The main findings were that soldiers
296 with a higher initial body fat percentage lost less muscle mass than those with a lower body fat
297 percentage, and greater losses of muscle mass were correlated with greater decreases in performance
298 in the EVAC test and the CMJ. In addition, a relationship between soldiers' body fat percentage
299 before MFT and the change in physical performance was observed in the EVAC test, where soldiers
300 with a lower fat percentage had a greater reduction in performance after MFT. Soldiers' body fat
301 percentage was also positively correlated with changes in serum testosterone concentrations during
302 MFT.

303

304 On average the soldiers in the low-fat group lost 2.0 kg of their fat mass and 0.8 kg of their muscle
305 mass. In the high-fat group the loss of fat mass was 3.7 kg with no statistically significant change in
306 muscle mass, and a correlation between the fat percentage at PRE and change in muscle mass during

307 MFT was observed ($r=0.51$, $p<0.001$). Similar observations have been done by Vikmoen et al. (2020)
308 and Hamarsland et al. (2018), though the correlations in their studies were even stronger ($r=0.75$,
309 $p<0.05$ and $r=0.78$, $p<0.001$, respectively). In a study by Gan et al. (2022) an 18 % energy deficit was
310 observed by recording food intake objectively and measuring energy expenditure by the doubly-
311 labelled water method during a 62-day Singapore Ranger course in a hot humid environment. Soldiers
312 with higher fat percentage (fat% >15) at PRE lost more fat mass and gained rather than lost muscle
313 mass during the course as compared to leaner soldiers. Previous studies suggest that fat oxidation
314 could be more efficient in individuals with a higher fat mass when the subjects are of normal weight
315 and fit. (Hoyt et al. 2006.) This could lead to the effect observed in the present study, where
316 participants of the high-fat group seem to have used more of the body fat reserves for energy
317 production, leading to a greater decrease in fat mass and sparing of lean mass during energy deficit.
318 The importance of this is highlighted by the fact that soldiers tend not to consume all of the available
319 food during MFT (Margolis et al. 2014) and interventions with increased protein consumption have
320 not been able to spare body mass nor muscle mass during MFT (Øfsteng et al 2020), making the most
321 obvious and accessible means of sparing muscle mass during MFT ineffective. In addition to the
322 maintenance of muscle mass fat mass can also help the soldiers to maintain safe core temperatures
323 when operating in cold temperatures (Savastano et al. 2009).

324
325 Soldiers' body mass, fat mass and muscle mass were fully recovered at RECO but there was a
326 significant overshoot of fat mass in the low-fat group as the group's fat mass at RECO exceeded the
327 fat mass at PRE by 13%. Similar findings with soldiers participating in strenuous MFT with negative
328 energy balance have been reported by Nindl et al. (1997) and Friedl et al. (2000) on US Army
329 Rangers. This overshoot of fat mass has previously been found to be larger in individuals with lower
330 fat percentages (Dulloo et al. 2017). Data from the Minnesota semi-starvation experiment suggests
331 that the overshoot in fat mass during recovery from semi-starvation is at least partly a product of over-
332 eating until muscle mass has been fully recovered to levels preceding the energy restriction (Dulloo et
333 al. 1997), which could explain why no overshooting of fat mass was not observed in the high-fat group
334 as they did not lose muscle mass during MFT.

335
336 As the decrease in physical performance during sustained military occupational stress is at least partly
337 linked to the energy deficit (Guezennec et al. 1994), it could be argued that the cold environment
338 during winter MFT could result in greater changes in physical performance through increased energy
339 expenditure and thus a larger energy deficit. If the soldiers' core temperature decreases during MFT,
340 this could induce shivering thermogenesis increasing resting energy consumption up to five-fold
341 (Haman & Blondin 2017) and an increase in the activity of brown adipose tissue (Van der Lans et al.
342 2014), which could increase heat production by 17 % on average among lean individuals (Claessens-
343 Van Oojien et al. 2006). Even if core temperature can be maintained through physical activity and
344 clothing, energy expenditure can still be increased as every kilogram of clothing increases energy it by
345 approximately 3 % and every layer of clothing by 4 % during physical activity (Rintamäki 2007).
346 Hackney et al (1991) compared the effects of MFT in warm and cold environments and found that
347 soldiers' anaerobic performance had greater decrements after cold-weather MFT, though there were
348 no differences in weight loss between the two types of MFT, which suggests that there was no
349 difference in soldiers' energy balance. However, direct comparison between different environmental
350 conditions is problematic as the contents of military training could vary significantly between the field
351 exercises. In the present study, the changes in body weight and body composition were not as marked
352 as ones reported in most previous research on MFT of similar duration (Vikmoen et al. 2020, Øfsteng
353 et al 2020, Hamarsland et al. 2018) which could suggest that the cold exposure during MFT did not
354 dramatically increase energy expenditure. Yet as mentioned previously, comparison of military field
355 exercises is problematic as the operative stressors (e.g., workload, recovery, sleep, energy and fluid
356 balance, stress level, environmental factors) of MFT can vary widely. Furthermore, the comparison is
357 distorted by the fact that soldiers in the present study used skis during MFT, as the energy expenditure
358 of skiing and marching soldiers most likely differ (Ainsworth et al. 2011). Nevertheless, it can be
359 stated that even though taking winter conditions into consideration during the planning of MFT is
360 understandably important, specific measures to combat increased energy expenditure might not be
361 necessary.

362

363 There was a 10–20 % decrease from PRE to POST in physical performance in all used assessment
364 methods. Significant relationship was found between change in muscle mass and change in physical
365 performance in the EVAC task ($r=-0.33$, $p<0.05$) and in the CMJ ($r=0.36$, $p<0.01$). Previously Johnson
366 et al (1994) and Nindl et al. (2007) have observed a similar relationship between loss of muscle mass
367 and decrease in physical performance in US Army Rangers. While fat percentage at PRE was
368 correlated with changes in muscle mass during MFT, fat percentage at PRE was correlated with only
369 the change in performance time on the EVAC task ($r=-0.31$, $p<0.05$). Although this relationship was
370 only observed on the EVAC task, it can be stated that the EVAC task is the most task-specific out of
371 the tests used, hence the most relevant for special force soldiers. Overall, the results suggest that a
372 higher fat percentage could be beneficial for soldiers taking part in prolonged MFT as this could lead
373 to attenuated decrements in some aspects of physical performance, possibly through the preservation
374 of muscle mass. It should be noted that only about 10 % of the variation in the change in physical
375 performance in the EVAC-task was explained by the change in muscle mass. Therefore, it is important
376 to consider the possible methods to combat muscle loss during MFT and the possible benefits and
377 drawbacks of their use.

378
379 Interestingly, the significant group difference observed at PRE in lower body explosive force
380 production (standing long jump, counter movement jump) diminished by the end of MFT. Even
381 though significant decreases were observed in these variables in both groups, the performance gap
382 between the groups narrowed during the follow-up. Thus, higher body fat content may have protected
383 the loss of lower body power during MFT. On the other hand, it is also possible that group differences
384 in explosive force production dynamics are more related to differences in muscle mass changes which
385 is supported by the observed correlation between the changes in muscle mass and counter movement
386 jump ($r=0.36$). This would seem logical since maximal strength and explosive force production are
387 dependent on neural activation and cross-sectional area of muscle (Kraemer et al. 2015, Häkkinen et
388 al. 1985). It is important to note though, that the high-fat group did not surpass the performance of the
389 low-fat group in any physical performance test at any time point. In fact, the low-fat group out-
390 performed the high-fat group in four out of six physical performance tests at PRE. This in mind,

391 favoring soldiers with higher fat percentages does not seem advisable. Therefore, it should be
392 examined whether a period of high calorie intake before MFT could help maintain the optimal body
393 composition and physical performance during MFT. It should be noted that the soldiers in this study
394 were very lean even in the high-fat group and excess body fatness for soldiers is not recommendable.
395 The optimal quantity of fat mass remains to be defined in future studies.

396
397 Soldiers' physical performance was not fully recovered at RECO in most of the tests used. A return to
398 PRE-values was observed only in the sit-up test for the low-fat group and in the EVAC-course for the
399 high-fat group. Recovery was deficient especially for explosive force production of the lower and
400 upper extremities. Similar findings have been made previously on the recovery of lower extremities,
401 but the recovery of explosive force production of upper extremities has usually been faster (Vikmoen
402 et al 2020, Hamarsland et al. 2018). The slower recovery time could be caused by the use of poles
403 while skiing, increasing the demand of upper body musculature when compared to marching soldiers.
404 As full recovery was reached in all the body composition and hormonal and enzymatic markers, it
405 seems that their isolated use for the assessment of soldiers' recovery from MFT is questionable since
406 they do not represent the complete recovery of physical performance.

407
408 It has been well-established that serum testosterone concentrations decrease, and cortisol
409 concentrations increase during demanding MFT. (Vikmoen et al. 2020, Øfsteng et al. 2020,
410 Hamarsland et al. 2018, Szivak et al. 2018, Kyröläinen et al. 2007) In the present study, serum
411 testosterone decreased throughout MFT at MID and at POST. There was a positive correlation
412 between fat percentage at PRE and the change in serum testosterone concentrations ($r=0.47$, $p<0.001$).
413 Wong et al. (2019) have noted in their review that during prolonged energy restriction serum
414 testosterone concentrations decrease mainly due to central processes that decrease the amplitude and
415 frequency of the pulsating secretion of luteinizing hormone. They also suggest that leptin could be a
416 factor in suppressed testosterone levels, as leptin supplementation seems to reverse starvation-
417 associated gonadal axis suppression. As serum leptin levels are positively correlated with body fat
418 percentage (Smith et al. 2006), it seems plausible that in the current study individuals with higher

419 body fat percentages had an attenuated response to starvation-induced gonadal suppression i.e.,
420 decrease in serum testosterone concentration, partly because of their higher leptin levels. It is
421 important to note though that leptin concentrations were unfortunately not measured during the present
422 study.

423

424 There was also an expected rise in cortisol concentrations from PRE to MID but unexpectedly the
425 lowest cortisol concentrations were measured immediately after the most demanding part of MFT at
426 POST. This finding is contrary to most other findings on the subject. As negative changes in soldiers'
427 testosterone levels and physical performance were marked, it seems unlikely that this contradictory
428 finding is because of low levels of stress, both physical and mental, experienced during MFT. A
429 possible explanation for the low cortisol concentration may be the disturbances in soldiers' circadian
430 rhythm (Opstad et al. 1994). Severe physical stress combined with sleep and energy deprivation has
431 been shown to diminish the normal daily variation of cortisol and thus, it is possible that during the
432 blood sampling at POST the normal biological increase in cortisol was absent, leading to lower
433 concentration levels than expected. Although there lies uncertainty in what caused the low cortisol
434 levels measured at POST, the results still suggest that cortisol concentration is not always a reliable
435 biomarker for measuring stress load during MFT.

436

437 Serum CK levels were elevated at MID reaching peak levels at POST with no observed between-
438 group differences. From the elevated CK levels we can determine that MFT caused a noticeable
439 amount of muscle damage. Hamarsland et al. (2018) suggested that muscle damage could in part
440 explain the discrepancy between recovery of body composition and hormonal and enzymatic markers
441 compared to the recovery of physical performance. While muscle mass itself was fully recovered, it is
442 possible and even likely that exercise-induced muscle damage still persisted at RECO.

443

444 The results of the present study should be interpreted identifying the following limitations. Body
445 composition was determined by bioimpedance method, which may overestimate muscle mass and
446 underestimate fat mass and fat percentage when compared to dual-energy X-ray absorptiometry

447 measurement method (Antonio et al. 2019). However, no differences were observed in the changes in
448 these variables between the two-abovementioned methods. The bioelectrical impedance analysis is
449 based on different conductivity of electricity in extracellular and intracellular water (Ling et al. 2011).
450 Thus, acute changes in these water compartments, for example as a result of dehydration, may
451 confound the body composition results, especially for muscle mass and fat mass quantification.
452 However, bioimpedance method is currently the most practical objective body composition
453 assessment method for field studies such as the present one and, the same method has been used in
454 other similar studies (Vikmoen et al. 2020, Hamarsland et al. 2018). Another limitation to this study
455 was that energy balance was not quantified. Quantification of energy intake and expenditure would
456 have provided more information for the interpretation of body composition changes, but unfortunately
457 the nature of MFT did not enable these measurement methods. Lastly, the lack of reproducibility is a
458 limitation seen in many similar studies for the large amount of randomness inherent to military field
459 training. Weather conditions, and the lack of control of energy balance and the amount of sleep can
460 affect the demands of MFT and as consequently affect the response seen in partaking soldiers. While
461 energy balance and the amount of sleep could be controlled to a satisfying degree, weather conditions
462 could still affect the demands of MFT especially in snowy conditions when long distances are covered
463 on skis.

465 CONCLUSION

466
467 This study brought supporting evidence to the hypothesis that soldiers' fat mass helps preserve muscle
468 mass during prolonged MFT which in turn preserves soldiers' physical performance, and a correlation
469 between fat percentage at PRE and muscle mass change from PRE to POST was observed. To our
470 knowledge this study is the first one to observe a direct relationship between soldiers' fat percentage
471 and the change in physical performance, as fat percentage at PRE was correlated to the change in
472 performance in the EVAC task.

473

474 Recovery from MFT was not markedly different between the two groups as significant difference
475 between PRE and RECO measurements were detected in all physical performance test for both groups
476 except for the sit-up test for the low-fat group and the EVAC-test for the high-fat group. All hormonal
477 and enzymatic markers were recovered back to PRE-measurement levels at RECO in both groups.

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609

610 TABLES

611 Table 1. Age, anthropometrics, and body composition of study participants at PRE.

	Fat% < 12 (n=29)	Fat% > 12 (n=29)	All (n=58)
Age (years)	19.4 ± 0.8	19.5 ± 0.8	19.4 ± 0.8
Stature (cm)	183.4 ± 5.1	180.2 ± 6.0*	181.8 ± 5.7
Body mass (kg)	79.8 ± 8.3	77.3 ± 6.5	78.5 ± 7.5
Fat mass (kg)	7.3 ± 1.9	10.7 ± 1.5***	9.0 ± 2.4
Muscle mass (kg)	41.7 ± 4.4	38.1 ± 3.5**	39.9 ± 4.3
Fat%	9.2 ± 2.0	13.9 ± 1.5***	11.5 ± 3.0

*Significantly different from the low-fat group: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$*

612

613 Table 2. Body mass, muscle mass, and fat mass at all measuring points for both groups.

	Group	PRE	MID	POST	RECO
Body mass (kg)	Low-fat	79.8 ± 8.3	79.4 ± 8.2	76.7 ± 8.1***	80.0 ± 8.2
	High-fat	77.3 ± 6.5	77.0 ± 6.4	74.4 ± 5.8***	77.8 ± 6.4
Muscle mass (kg)	Low-fat	41.7 ± 4.4	41.9 ± 4.5	40.9 ± 4.5**	41.3 ± 4.5
	High-fat	38.1 ± 3.5 ^{††}	38.7 ± 3.3*** [†]	38.4 ± 3.3 [†]	38.5 ± 3.7 [†]
Fat mass (kg)	Low-fat	7.3 ± 1.9	6.6 ± 1.7**	5.3 ± 1.6***	8.2 ± 2.2**
	High-fat	10.7 ± 1.5 ^{†††}	9.5 ± 1.8*** ^{†††}	7.0 ± 1.9*** ^{††}	10.3 ± 1.8 ^{†††}

614 *Significantly different from PRE: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$* 615 *Significantly different from the low-fat group: †, $p < 0.05$; ††, $p < 0.01$; †††, $p < 0.001$*

616 Table 3. Serum testosterone and cortisol concentration, and creatine kinase activity at different time
 617 points and the statistically significant average relative change from PRE.

	Group	PRE	MID	POST	RECO
Testosterone (nmol/L)	Low-fat	17.73 ± 3.84	14.40 ± 2.90 (-17.0 %) ^{***}	3.56 ± 2.28 (-78.9 %) ^{***}	17.43 ± 3.56 (n/a)
	High-fat	15.94 ± 2.57	13.31 ± 3.46 (-16.7 %) ^{***}	5.60 ± 3.55 (-65.0 %) ^{***†}	15.16 ± 3.79 (n/a)
Cortisol (nmol/L)	Low-fat	431 ± 56	475 ± 49 (+11.7 %) [*]	371 ± 172 (-15.4)	417 ± 56 (n/a)
	High-fat	437 ± 49	479 ± 71 (+10.0 %) ^{**}	335 ± 98 (-21.4 %) ^{**}	410 ± 75 (n/a)
Creatine kinase (IU)	Low-fat	209 ± 77	469 ± 270 (+131 %) ^{***}	3562 ± 1603 (+1843 %) ^{***}	200 ± 109 (n/a)
	High-fat	174 ± 65	417 ± 170 (+149 %) ^{***}	4037 ± 2966 (+2247 %) ^{***}	157 ± 65 (n/a)

618
 619 *Significantly different from PRE: *, p < 0.05; **, p < 0.01; ***, p < 0.001. N/a = not applicable.*

620 *Significantly different from the low-fat group: †, p < 0.05*

621 FIGURE CAPTIONS

622

623 Figure 1: Study design and measurement points.

624

625 Figure 2. A: Change in body mass, muscle mass, and fat mass from PRE to POST. B: Recovery of
626 body mass, muscle mass, and fat mass as presented by the ratio of RECO/PRE with 1 being fully
627 recovered. Low-fat group = black bar, high-fat group = white bar.

628 *Significantly different from PRE: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$*

629 *Significant difference between groups: †, $p < 0.05$; ††, $p < 0.01$; †††, $p < 0.001$*

630

631 Figure 3. Results of the physical performance tests at PRE, POST, and RECO for the low-fat (dashed
632 blue line) and high-fat (solid red line) groups. Standing long jump, MBT, CMJ, Weighted chin-up,
633 Sit-ups, EVAC-course. There was a significant main effect of time for all physical performance tests
634 ($p < 0.001$) and performance was decreased from PRE to POST. Significant difference between PRE
635 and RECO were detected in all physical performance test for both groups except for the sit-up test for
636 the low-fat group and the EVAC-test for the high-fat group.

637

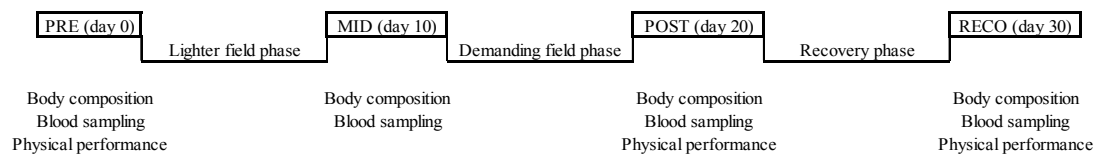
638 Figure 4. Correlations between A: change in muscle mass and fat % at PRE, B: change in testosterone
639 concentration and fat % at PRE, C: change in EVAC time and fat % at PRE, D: change in EVAC time
640 and change in muscle mass, E: change in CMJ and change in muscle mass.

641

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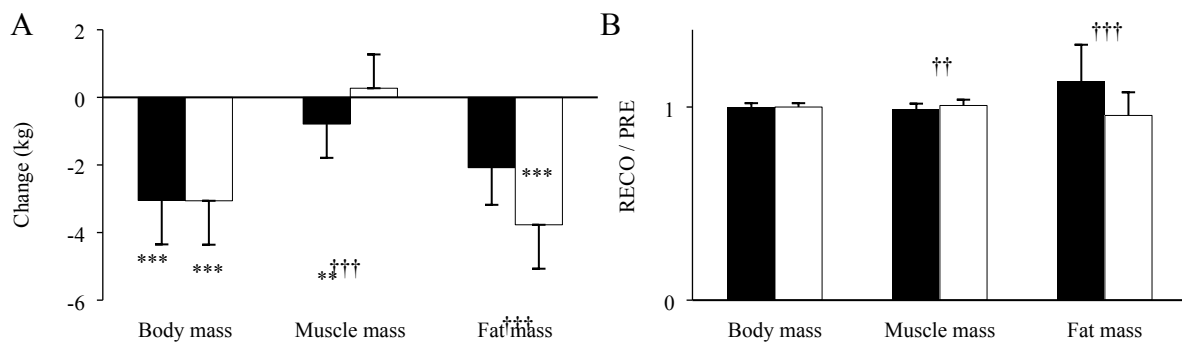
643 FIGURES

644 Figure 1



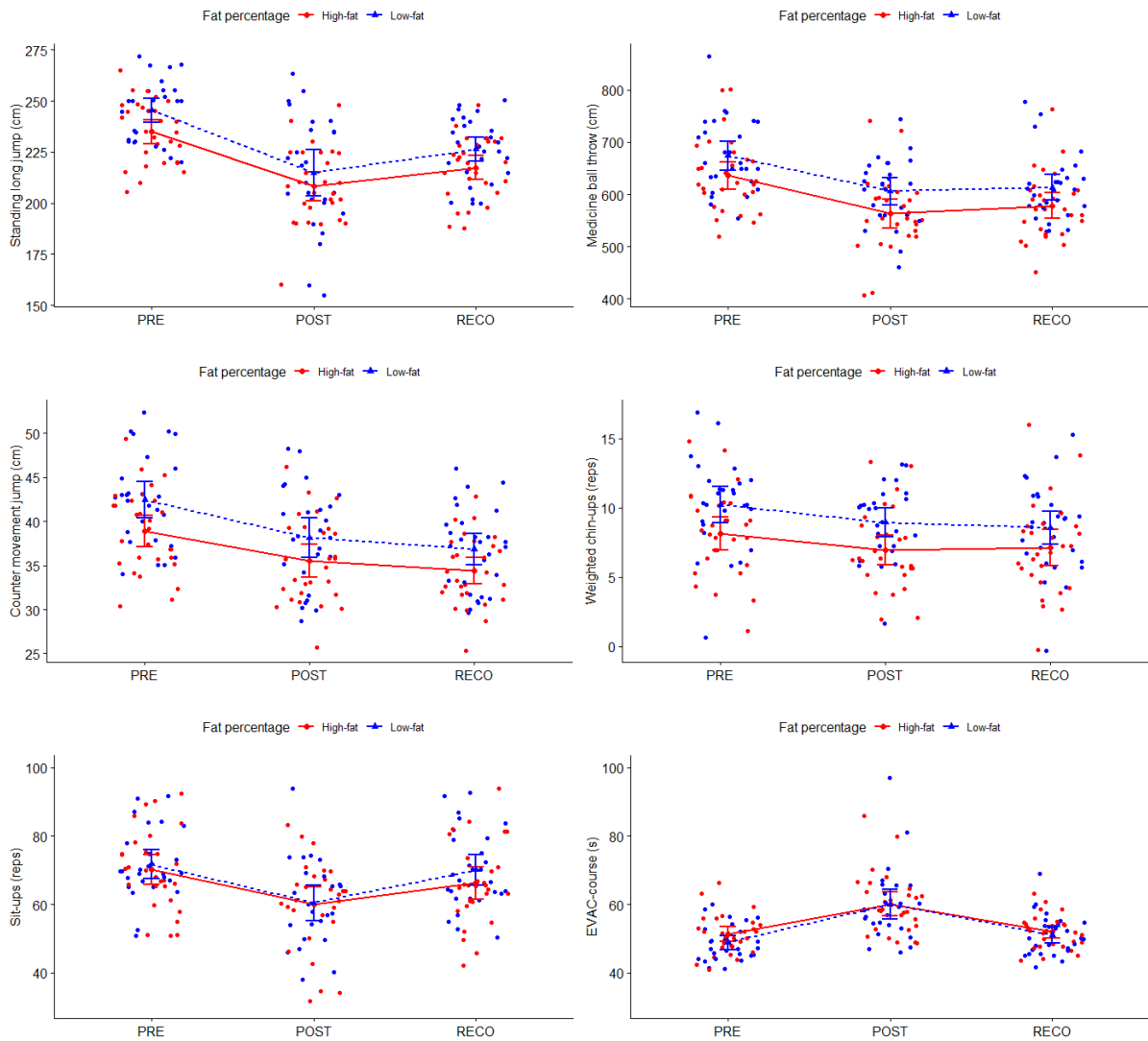
645

646 Figure 2



647

648 Figure 3



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653 Figure 4

