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Sex differences in effect and recovery of strenuous military field exercises

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Abstract

Purpose: Recovery and sex differences in response to strenuous military field exercises are largely unknown. The purpose of this study was to investigate the effect of strenuous military field exercises and the course of recovery on body composition and physical performance, and to examine potential sex differences in these responses.

Methods: 35 soldiers (23 men and 12 women) from the conscript division at the Norwegian Armed Forces Special Command volunteered to participate. Measurements were conducted before, 0 hours, 24 hours, 72 hours, 1 week and 2 weeks after a strenuous field exercise. Energy expenditure was measured during the exercise by accelerometers. Body composition was measured through bioelectrical impedance analysis (BIA) and physical performance was measured through a countermovement jump (CMJ), medicine ball thrust (MBT) and anaerobic performance through an evacuation test (EVAC-test).

Results: The men reduced their body mass and lean body mass (-8.16 ± 0.22 %, $p < 0.001$ and -6.13 ± 0.38 %, $p < 0.001$, respectively) more than the women (-3,96 ± 0.31 %, $p < 0.001$ and -0.36 ± 0.64 %, $p = 1.000$, respectively) after the field exercise with no different reductions in fat mass (men: 38.80 ± 3.47 %, $p < 0.001$, women: 27.02 ± 4.80 %, $p < 0.001$). All changes in body composition had recovered after 1 week. All performance variables were reduced to the same degree in men and women after the selection exercise. CMJ jump height was still reduced in both groups after 2 weeks, and the reduction after 72 hours (men -23.54 ± 6.79 %, $p < 0.001$, women: 14.33 ± 8.05 %, $p = 0.001$) and 2 weeks (men: -16.84 ± 6.10 %, $p < 0.001$, women: 8.88 ± 8.31 %, $p = 0.026$) was larger in the men compared to the women ($p < 0.001$). The same pattern of changes and sex differences was found for maximal power during the CMJ. MBT throw distance recovered after 1 week, and EVAC performance after 2 weeks with no differences between the groups.

Conclusion: The results show that the men lost more body mass and lean mass than women after a very strenuous military field exercise. Reduction in physical performance after the field exercise was similar between men and women. Both anaerobic capacity and upper body strength had recovered within two weeks. However, explosive strength in the legs was not recovered by two weeks in neither men nor women, and the recovery was slower in men compared to women.

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Acronyms

ATP – Adenosine triphosphate.

BIA – Bioelectrical impedance analysis

(Muscle) CSA – Muscle cross-sectional area

CMJ – Countermovement jump

EVAC-test – Evacuation test

FM - Fat mass

FOS – Forsvarets Opptak og Seleksjon (Armed Forces Admission and Selection)

FSK – Forsvarets Spesialkommando (Armed Forces Special Command)

LBM - Lean body mass

MAOD – Maximally accumulated oxygen deficit

MBT – Medicine Ball Throw

MTT – Military training tasks

MVC – Maximum voluntary contractions

NATO – North Atlantic Treaty Organization

NORNAVSOC – Norwegian Navy Special Operations Command

OC – Obstacle Course

RBL – Repetitive box lifting

REK – Regional Committees for Medical and Health Research Ethics

SOF – Special Operations Forces

VO_2 – Oxygen consumption

VO_{2max} – Maximal oxygen consumption

WMT – Winter military training

1 RM - One repetition maximum

1. Introduction

Members of the Armed Forces have a complex job that involves periods of both physical and mental strain, especially during combat training and operations. Military training is aimed at learning relevant skills and to improve physical, cognitive and mental capabilities in soldiers to ensure combat readiness (Vaara et al, 2015). Military service and operations involve strenuous and complex tasks that require peak physical and mental capabilities in soldiers. Soldiers are exposed to several dimensions of stress, which may influence performance in military tasks (Teien, 2013). Field exercises (FEX) are a common and important part military training. They attempt to simulate different challenges a soldier may face in real-world operations and have a high component of physical strain combined with low energy intake and sleep restrictions (Nindl et al, 1997; Teien, 2013; Margolis et al, 2014; Vaara et al, 2015). Several decremental effects related to body composition and physical performance have been reported after FEX (Consolazio et al, 1979; Johnson et al, 1994; Shippee et al, 1994; Nindl et al, 1997; Nindl et al, 2002; Nindl et al, 2007; Hamarsland et al, in press). An insight into the effect of the complex and strenuous environment that defines military tasks and FEX on a soldiers' physical traits are vital to the understanding of the total strain they are exposed to and may affect planning and executions of military operations. Knowledge of what type of task and operational demands that face soldiers in military service is also important when developing training programs in the Armed Forces. However, there is a lack of understanding of how the military and physical training effects the individual soldier (Cuddy et al, 2011). Studies on acute effects are somewhat prevalent, but literature about the course of recovery is lacking (Hamarsland et al, in press). Historically, the military service has been dominated by men and studies on the effects of military training mostly involve male subjects (Epstein et al, 2013). The Armed Forces have seen an increase in women enlisting, and Norway was the first North Atlantic Treaty Organization (NATO) member to introduce gender-neutral conscription in 2014 (Epstein et al, 2013; Regjeringen, 2014). How women are affected by military training is yet to be examined. Women are known to oxidize proportionally more fat at submaximal intensities and there have been observed sex differences in fatiguability, which means that it is likely that studies done on male are not necessarily transferable to female soldiers (Tarnopolsky, 2008; Hunter et al, 2016b). In one of the few studies done on sex differences after a military FEX, men and women were affected differently in body composition and substrate use (Hoyt et al, 2006b). It is however unknown if there are differences in effect on physical performance. Therefore, there is a need for further studies into sex differences in military service. Results could influence how the Armed Forces should conduct and execute their training, education and mission planning. The acute effects of military training on body composition and physical performance are somewhat explored, but recovery is yet to be examined to a large extent and there is little knowledge on the period needed for complete recovery after strenuous FEX in both men and women. An understanding of how soldiers recover after military training could dictate how military service is structured, and it is therefore worrying that there is a lack of insight into the course of recovery.

1.1 Aim

The aim of this study is two-fold. First, we aimed to examine if a strenuous military FEX affects men and women differently with regard to body composition and physical performance. Secondly, we wanted to study the course of recovery of physical performance and body composition in the first weeks after the FEX and examine if there are any sex differences in the recovery process. Results may give valuable insight into potential sex differences between soldiers and how they respond to military service as well as knowledge of recovery after strenuous activities that surpass the demands of everyday tasks and athletic training and performance.

2. Theory

2.1 Physical demands of military service

The physical demands of being a soldier are complex and rely on a variety of physical capabilities (Aandstad, 2011). The term “combat fitness” is used to describe a soldiers’ ability to effectively perform military tasks. It is achieved by acquiring military skills and meeting the physical fitness requirements specific to the soldiers’ service (Epstein et al, 2013). Combat fitness differs from athletic fitness by describing the ability to perform in all aspects of combat missions, or occupational demands, and not specific attributes in athletic exercises (Epstein et al, 2013). It is influenced by both mental and physical capabilities, like cardiopulmonary capacity, muscle strength and muscular endurance (Epstein et al, 2013). Several studies have tried to identify the most relevant occupational demands for military personnel, with a variety of results. NATO have identified three common work demands that are relevant to soldiers: digging, movement on foot and lifting/carrying (Aandstad, 2011). Digging is a traditional military activity, including for example filling sandbags or making trenches to construct firing positions. Studies have shown that digging requires around 50-60% of the soldiers' maximal oxygen consumption (VO_{2max}). Even though these levels of aerobic expenditure are fairly low, the duration of the task may be long and consequently the total work demand may be large (Aandstad, 2011). Movement on foot is considered one of the most physically demanding tasks, with additional loads often being carried over longer distances (Aandstad, 2011). Performance in heavy load carriage while moving on foot has been subject to several prediction efforts and studies have found correlations with both endurance and strength performance (Harman et al, 2008). Soldiers to ability march with additional loads may also be correlated with body mass and lean body mass (LBM) (Aandstad, 2011). Lifting and carrying is the most common physically demanding assignment that soldiers are exposed to (Aandstad, 2011). It is essential to many military services and may include carrying wounded soldiers away from the battlefield, moving objects and ammunition, loading heavy weapons or raising camps (Harman et al, 2008; Aandstad, 2011). Tasks involving lifting and carrying vary between single or repeated lifts. The U.S. Army Public Health Command (2014) has also identified several similar task demands for soldiers where cardiorespiratory fitness, muscular endurance and muscular strength are crucial (Hauschild et al, 2014). Well-developed strength and endurance is therefore considered to be vital for a soldier's success on the battlefield. Being able to predict a soldiers' physical capability to meet task demands within the service is of great importance, as a failure to meet the standards may result in loss of lives. Even though there have been established correlations with several physical attributes, a minimum requirement for physical fitness is yet to be established (Hauschild et al, 2014). Higher levels of physical performance may indicate better task performance, but a necessary lower threshold is not defined (Hauschild et al, 2014). Due to the decrements in physical performance caused by military training which will be discussed later, achieving high levels of strength, power and endurance is important to the soldier so that they may still complete the operational demands even in sub-optimal conditions (Nindl et al, 2007). However, before discussing how physical fitness influences military training, an understanding of the mechanisms behind strength and endurance is important.

2.2 Strength

Muscular strength in both upper and lower extremities are important in several task demands related to military service, such as lifts and stretcher carrying (Hauschild et al, 2016). Most of the previously mentioned work demands requires a level of strength and this attribute is important for soldiers' performance. Lifting and carrying is dependent on isometric and dynamic muscle strength and muscular endurance (Harman et al, 2008). Single lifts are a common military task and is correlated strongly with muscular strength in both upper and lower body (r = 0.75 and 0.60, respectively) (Hauschild et al, 2016). Isometric strength tests have been strongly correlated with lifting ammunition boxes (r = 0.806) (Rayson et al, 2000). Performance in causality evacuation and has been found to also be influenced by several measurements of strength (r = 0.65 – 0.73) (Bilzon et al, 2002; Hauschild et al, 2016). Several factors influence strength, both neural and muscular. There are several varieties of muscular strength, ranging from muscular endurance to maximal capacity for force development (maximal strength) (Hauschild et al, 2014). Muscular endurance is defined as muscles ability to sustain repeated contractions against submaximal resistance for an extended period of time and is often regarded as a separate trait (Raastad et al, 2010; Epstein et al, 2013). This physical trait is however considered to be an important to performance for many military tasks (Epstein et al, 2013). Tests for muscular endurance is commonly included in military physical fitness tests (Hauschild et al, 2016). Maximal strength is the highest amount of force the muscles are able to produce at slow velocities, both concentric and eccentric (Raastad et al, 2010). Explosive strength is the ability to produce large amounts of force at high velocities (Raastad et al, 2010). These two traits are influenced by different mechanisms in the muscle. The most important factor related to maximal strength is the cross-section of a muscle (CSA) (Raastad et al, 2010). This correlation between maximal strength and muscle CSA is at its peak at the largest muscle CSA. The ability to generate force is also affected by muscle architecture, which describes how the fibres are aligned, and fibre length. Fibre alignment is commonly divided into fusiform and pennate (further divided into unipennate, bipennate and multipennate) configurations. Muscles with a fusiform configuration have a rapid muscle shortening, while the pennate muscles tend to excel at generating high amounts of force (McArdle et al, 2014). Therefore, pennate muscles are more related to the exertion of maximal force and fusiform muscles are better suited for developing force at high velocity (Raastad et al, 2010). They are therefore a determent of explosive strength. In addition to these traits, the fibre type of the muscle also influences the force development at different velocities. There are two primary types of muscle fibre; slow-twitch fibres (type I) and fast-twitch fibres (type II). Fast twitch fibres are distributed in three subtypes: IIa, IIb and IIx. Type II fibres primarily contribute to fast, powerful muscle actions and has a high intrinsic speed of shortening and tension development, up to three to five times faster than slow twitch fibres (McArdle et al, 2014). These fibres are most relevant in explosive strength and forceful muscle actions that rely almost entirely on anaerobic energy metabolism (McArdle et al, 2014). Slow-twitch fibres are more fatigue resistant and are ideally suited for prolonged aerobic physical activity. They have a slower shortening speed, and the muscle fibre recruitment is more selective than in fast-twitch fibres (McArdle et al, 2014). Explosive force is also dependent on our ability to activate muscle fibres quickly and achieve a high neural firing rate (Raastad et al, 2010). Firing rate is the frequency of neural action potentials sent to the muscle. When this is increased, larger components of the muscle fibres potential to generate force is released (Raastad et al, 2010). Muscle fibres are recruited in a hierarchic system, whereas when the torque increases more fibres are activated (Raastad et al, 2010). The minor muscle units are recruited first, followed by larger units. As previously mentioned, slow-twitch fibres are generally recruited early on, whilst fast-twitch fibres are mostly involved when higher force is generated (Raastad et al, 2010).

2.2.1 Measurements of muscle strength

When measuring strength there is a variety of methods available. The one-repetition maximum (1RM) measurement is one of the most common methods for testing strength and is considered a gold standard (Peterson et al, 2006; Raastad et al, 2010). The test is a measurement of the maximum lifting capacity (the weight that can only be lifted for one repetition) in one specific lift or exercise through both eccentric or concentric range of motion (Peterson et al, 2006). Despite the relevance of maximal strength in military task success, these types of tests are rarely included in occupational test batteries (Hauschild et al, 2016) Measurements of maximal strength require long warm-up periods and involves equipment that need calibration and standardizations (Hauschild et al, 2016). It is therefore less used for military purposes (Kirknes et al, 2014). A commonly used scientific method of measuring strength and power in the lower extremities are jump tests (Raastad et al, 2010). These tests are often executed on force platforms, which measure the force exerted onto the surface. This form of testing relies on the correlation between explosive force and maximal strength (Raastad et al, 2010). There has been established a linear relationship between lower body muscular strength and explosive force performance tests (Peterson et al, 2006). Performance in vertical jump and broad jump tests have found strong correlations (*r* = 0.852 and *r* = 0.814, respectively) with 1RM back squat in athletes (Peterson et al, 2006). Performance in vertical jump tests predict lower body explosive power, a highly relevant attribute in high-intensity, short-duration activities occurring on the battlefield (Harman et al, 2008). Vertical jump tests such as the drop jump, countermovement jump (CMJ) and squat jump have also shown good reliability (coefficients of variation (CV): 4.8 ± 1.7, 3.0 ± 1.1 and 3.5 ± 1.6, respectively) (Gathercole et al, 2015). They are easy to conduct and require little equipment, making them suitable for field testing. Muscular endurance may be examined through the maximal number of repetitions completed with submaximal resistance. The push-up test is a common method of testing used in the Armed Forces, as it requires little equipment and is not time consuming and has been positively correlated with several military tasks (Hauschild et al, 2016). However, it is no longer included in the Norwegian Armed Forces physical fitness tests as it is a poor measurement of maximal strength (Kirknes et al, 2014).

2.3 Anaerobic performance

Several tasks in military service require maximal effort for short durations. Rapid movement and sprints across the battlefield and causality evacuation are likely scenarios that face soldiers during operations (Angeltveit et al, 2015). Harman and colleagues (2008) found that several simulated military task performance tests averaged between 43 and 84 seconds (Harman et al, 2008). These types of activities are largely related to the anaerobic system (McArdle et al, 2014). 30-meter sprints, a measure of anaerobic performance, has been significantly correlated with performance in both causality evacuation (*r* = 0.46) and obstacle courses (OC) (*r* = 0.64) (Harman et al, 2008). This system is divided into the alactic and lactic subgroups (Gastin, 2001). The alactic component of the anaerobic system releases the immediate energy required for intense physical activity of short duration, such as sprinting or swimming short distances or lifting weights. The energy comes from the intramuscular high-energy phosphate or phosphagen sources (adenosine triphosphate (ATP) and creatine phosphate) (McArdle et al, 2014). The lactic, or short term glycolytic energy system is most relevant in intense physical activity with durations between 20-30 to 180 seconds (Gastin, 2001). The energy released originates mainly from stored muscle glycogen breakdown by rapid anaerobic glycolysis (McArdle et al, 2014). This action leads to a fast and considerable accumulation of blood lactate, especially when large muscle groups are involved. Peak blood lactate concentration is often used to measure anaerobic energy release during exercise and may provide an indication of the extent of glycolysis (Gastin, 2001). The anaerobic pathways are capable of regenerating ATP at high rates but are limited by the amount of energy they may release during an intense exercise of short duration (Gastin, 2001). Anaerobic performance is often divided into two abilities, anaerobic power and anaerobic capacity. Anaerobic power a term for how fast muscles can reproduce ATP and is the sum of maximal metabolic rates from different energy transfer systems (Heck et al, 2003; Hallén & Rongland, 2017). Anaerobic capacity is how much ATP is produced by decomposition of creatine phosphate and production of lactate over a given time (Hallén & Rongland, 2017). The terms power and capacity are often misused in literature (McArdle et al, 2014).

2.3.1 Measurements of anaerobic fitness

Anaerobic fitness tests are used to estimate the power and/or capacity of skeletal muscle energy production through anaerobic pathways (Zagatto et al, 2011). Examples of tests are the maximally accumulated oxygen deficit (MAOD), Wingate tests, maximal anaerobic running tests and stair-sprinting power tests among others (Zagatto et al, 2011; McArdle et al, 2014). A military-specific work test for anaerobic performance was recently developed in the Norwegian Navy Special Operations Command (NORNAVSOC), called the evacuation test (EVAC-test) (Angeltveit et al, 2015). This test was designed to simulate the evacuation of a battlefield causality and has been significantly correlated with other measures of anaerobic performance, like the Wingate test ($r = 0.68$), 300-m sprint time ($r = 0.51$) and 300 m sprint mean power ($r = -0.67$). It displayed a moderate reliability between trial 1 and 2 ($r = 0.78$) and good reliability from trial 2 to 3 ($r = 0.89$) (Angeltveit et al, 2015). Determination of anaerobic energy release is unfortunately less precise compared to measurements of other physical attributes (Gastin, 2001). Anaerobic power measurements were not recommended in the new physical fitness tests for the Norwegian Armed Forces due to time and equipment constraints, even though studies have shown that anaerobic power is relevant in different tasks related to military operations (Legg & Patton, 1987; Harman et al, 2008; Kirknes et al, 2014)

2.4 Aerobic system

Aerobic fitness and endurance is relevant in a wide variety of military tasks and is often used as a predictor for performance in these (Aandstad, 2011). Studies have shown significant correlations between aerobic fitness and simulated military tasks such as causality evacuation ($r = 0.60 – 0.67$) and other relevant physical performance tests like 400-meter runs ($r = 0.68$), 30-meter sprint ($r = 0.53$), OC ($r = 0.57$) and repeated sprint-ability ($r = 0.66 – 0.90$) (Bilzon et al, 2002; Harman et al, 2008; Thébault et al, 2011). The aerobic system utilizes the combustion of carbohydrates and fats in the presence of oxygen to produce energy. It has a large capacity but is limited in its ability to deliver energy quickly (Gastin, 2001). When physical exercise continues beyond several minutes, it gradually it becomes the main contributor to performance (Gastin, 2001). The aerobic system is dependent on oxygen consumption (VO_2). VO_2 increases exponentially throughout the first minutes of submaximal exercise at a given intensity before reaching a plateau called *steady state*, which usually occurs between three or four minutes into the exercise (McArdle et al, 2014). This steady state reflects a balance between energy-requirements by working muscles and the ATP production through aerobic metabolism. The maximal oxygen consumption (VO_{2max}) is the maximum amount of oxygen a person utilizes over a given time period (McArdle et al, 2014). The VO_{2max} is a commonly used measurement for a person's aerobic fitness level, as there is a direct relationship between oxygen uptake measured at the mouth and the whole-body aerobic production of ATP (Gastin, 2001). VO2max is determined by cardiac output, pulmonary diffusing capacity, the O_2 carrying capacity of the blood and skeletal muscle factors related to the mitochondria and capillaries (Bassett & Howley, 2000) In addition to VO_{2max}, other determents for performance in aerobic activities are the lactate and ventilatory threshold and movement economy (Glace et al, 1998).

2.4.1 Measurements for aerobic fitness

Measurements of aerobic fitness and endurance are usually done by measuring $VO_{2max.}$ This can be tested through direct calorimetry, which is the gold standard for measuring cardiorespiratory fitness (Hauschild et al, 2016). This method is however equipment-demanding and impractical for mass routine screenings. Therefore, it is rarely used in testing of military personnel. A common method for measuring aerobic fitness in the Armed Forces is estimating VO_{2max} from more field expedient tests liked run-times from timed-distance runs (3000 meters, 1.5 mile run etc) or fixed time run tests (Cooper-test etc.) (Kirknes et al, 2014; Hauschild et al, 2016). These methods (1.5 – 26 mile runs or 12-minute runs) have been validated against VO_{2max} measurements and have a high reported test-retest reliability (Hauschild et al, 2016). Correlation coefficients for both timed distance runs and fixed time runs range from 0.70 to 0.90 (Kapnik et al, 2004). Reliability coefficients for timed distance range from 0.82 to 0.92, and coefficients for fixed time runs from 0.78 to 0.94 (Kapnik et al, 2004).

2.5 Military training and Special Operations Forces

Military operations are characterized by "multifactorial stress", a term that describes the different dimensions of strain a soldier may be exposed to (Teien, 2013). This includes physical activity, physiological challenges, sleep deprivation and reduced energy intake, amongst other. Outcomes of real-world military operations may be influenced by individuals physical and mental ability (Teien, 2013). Therefore, training and FEX attempt to simulate the multifactorial stress to best prepare soldiers for real world warfare (Teien, 2013). Military FEX generally involve a strenuous level of activity, with most of the components being of a physical nature (e.g. load carriage, walking/running, shooting, simulated warfare etc.) (Vaara et al, 2015). The activity varies from long periods of low-intensity to short periods of very high intensity and the energy expenditure can be compared to that of athletes participating in prolonged sporting events (Margolis et al, 2014b; Margolis et al, 2016). However, unlike athletes, soldiers during military training are not always able to consume high amounts of dietary energy leading to high caloric deficits. These deficits may be as high as 40% of total energy needs or more during a given time-period (Margolis et al, 2014a).

Most modern Armed Forces have developed units that are defined as Special Operations Forces (SOF). Special Forces operators are considered to be highly trained soldiers and are exposed to extremely strenuous operational demands that surpass those of conventional forces (Hammersmark, 2015). Selection into these types of military units attempt to identify individuals who display aptitude in situations that simulate the strain of a real-world military operation (Simpson et al, 2006). A challenge when selecting, educating and training Special Forces Operators is finding physically capable candidates (Cuddy et al, 2011). There are high attrition rates in most SOF training programs due the arduous and thorough selection and the demanding nature of the job (Simpson et al, 2006). Energy requirements for SOF soldiers during field exercises are higher than for conventional soldiers due to the physically demanding and unique nature of their training and operations (Margolis et al, 2014a). Studies conducted during Special Forces exercises and selection courses have observed daily energy expenditures of ~4200 kcal/day during a US Army Ranger course, ~5200 kcal/day in the US Army Special Forces Assessment and Selection, between 5000 and 8000 kcal/day in Norwegian and French Military training to as high as ~8000 kcal/day or more in French Army Commando training (Guezennec et al, 1994; Nindl et al, 1997; Margolis et al, 2014a). Sleep and rest is also often limited (Teien, 2013). Being exposed to these suboptimal conditions, soldiers and Special Forces operators experience several detrimental effects on both physical performance and body composition.

2.6 Effects of arduous military training

2.6.1 Physical performance

Decrements to physical performance in the aftermath of strenuous FEX is well documented. Studies on the US Army Ranger Course, a 62-day training program that is required for US Ranger soldiers, have found a comprehensive effect of muscular fatigue on performance (Johnson et al, 1994; Nindl et al, 2007). Measurements in strength, maximal lift capacity, vertical jump height and peak power output were all reduced significantly, as well as variables related to body composition (Nindl et al, 1997; Nindl et al, 2007). Margolis and colleagues (2014) observed a reduction in jump height and lower extremities peak power measured by a vertical jump test, similar to the beforementioned studies, after winter military training (Margolis et al, 2014b). A 72-hour military FEX lead to a reduction in squat jump power and work by ~9 and 15%, respectively and reductions in repetitive box lifting (RBL) and OC performance (Nindl et al, 2002). A recent study by Hamarsland and colleagues found a substantial drop in Countermovement Jump (CMJ, -28 ± 13 %), leg press (-20 ± 9 %), and in chest press performance (-10 ± 6 %) after selection week in the NORNAVSOC (Hamarsland et al, in press). Declines in performance has also been observed in other variables associated with physical fitness. There was a reduction in VO_{2max} in a group of underfed soldiers during a 10-day FEX in a jungle environment (Consolazio et al, 1979). A study by Guezennec and colleagues (1994) demonstrated a 15% decrease in cycling to exhaustion and a 7% decrease in VO_{2max} in a low-energy-intake group (~1800 kcal/day) during a 5-day military exercise (Guezennec et al, 1994).

Most of the observed reductions in physical performance have been found in the lower extremities, and in a lesser extent in the upper extremities. This may be attributed to the components of military training. Ruck marches, running, walking etc. are often more prevalent, and the upper extremities are exhausted to a lesser extent during FEX and military operations (Nindl et al, 2002; Simpson et al, 2006; Hamarsland et al, in press). However, studies have also reported decrements in upper body anaerobic power and strength in military training that have had a component of work involving the upper body (e.g. artillery shell loading) (Legg & Patton, 1987). As mentioned, the study on the NORNAVSOC selection week saw a reduced chest press performance after the demanding FEX (Hamarsland et al, in press). However, this was smaller than the reduced performance in the lower body.

Table 1. Overview of studies measuring effect of field exercises (FEX) on physical performance.

Authors	Type of military training	Conducted measurements	Change in performance
Consolazio et al, 1979	10-day manoeuvre in humid jungle environment. Subjects split in 4 groups with different energy intakes (600 kcal/day, 1000 kcal/day, 1500 kcal/day and 3500 kcal/day).	• Treadmill maximal work performance test • 15-mile march/run	- ↓ VO_{2max} in 600 kcal/day and 1500 kcal/day ↔ VO_{2max} in 1000 kcal/day and 3500 kcal/day - ↔ 15-mile march times in all groups
Legg & Patton, 1987	8 days of sustained manual work handling artillery shells and charges combined with partial sleep loss.	• Wingate test • Isometric right-hand grip strength	- ↓ Upper body mean power - ↑ Lower body peak and mean power - ↓ Isometric grip strength
Shippee et al, 1994	8-week US Army Ranger Course involving repeated periods of food restriction, sleep deprivation, environmental challenges and prolonged low intensity physical work.	• Lifting strength Maximal jump test	- ↓ Maximal lifting strength - ↓ Vertical jump height - ↓ Peak power
Johnson et al, 1994	8-week US Army Ranger Course involving repeated periods of food restriction, sleep deprivation, environmental challenges and prolonged low intensity physical work.	• Maximal handgrip test • Handgrip endurance • Lifting strength	- ↔ Maximal handgrip strength - ↔ Handgrip endurance - ↓ Maximal lifting strength
Guezennec et al, 1994	96 hours of patrolling carrying additional loads and simulated combat activities with sleep restrictions. Soldiers were divided into groups with different energy intake (1800 kcal/day, 3200 kcal/day and 4200 kcal/day).	• Maximal aerobic capacity • Anaerobic performance test	- ↓ Maximal aerobic capacity in 1800 kcal/day group - ↔ Maximal aerobic capacity in 3200 kcal/day and 4200 kcal/day group - ↔ Anaerobic performance in all groups
Nindl et al, 1997	8-week US Army Ranger Course involving repeated periods of food restriction, sleep deprivation, environmental challenges and prolonged low intensity physical work.	• Overall body strength • Vertical jump • Calculated peak power	- ↓ Maximal lifting strength - ↓ Vertical jump height - ↓ Peak power
Nindl et al, 2002	72 hours sustained military operation consisting of basic patrolling, combat drills, road marches, land navigation, litter obstacle course and a confidence course.	• Maximal strength (squat and bench press) • Ballistic power tests for upper and lower extremities. • Repetitive box lift (RBL) • Obstacle course (OC) • Grenade throw • Marksmanship • Wall building	- ↔ Maximal strength - ↓ Lower extremities ballistic power - ↔ Upper extremities ballistic power - ↓ RBL - ↓ OC - ↔ Grenade throw - ↔ Marksmanship - ↓ Wall building

Nindl et al, 2007	8-week US Army Ranger Course involving repeated periods of food restriction, sleep deprivation, environmental challenges and prolonged low intensity physical work.	• Maximal lifting strength • Vertical jump performance	- ↓ Maximal lifting strength - ↓ Vertical jump height - ↓ Peak power output
Margolis et al, 2014b	Soldiers conducting two subsequent training programs: First, 4-day military training tasks (MTT) in garrison consisting of weapon familiarization, mountainous terrain navigation and winter survival training followed by 3-day winter military training (WMT) consisting of ~20 km skiing per day while carrying ~45 kg loads	• Vertical jump test	- ↓ Vertical jump height - ↓ Lower body peak power
Welsh et al, 2008	8 days military operational field training consisting of carrying equipment (~20 kg), handling weapons, movement on foot with loaded backpacks, handling weapon and ammunition and patrols.	• Unloaded CMJ (1,5 and 30 repetitions)	- ↓ Mean power for 1,5 and 30 repetitions - ↓ Mean jump height for 1 and 5 repetitions - ↔ Mean jump height for 30 repetitions
Hamarsland et al, in press	NORNAVSOC selection program, consisting of ~1-week FEX with sleep and caloric restrictions and extreme amounts of physical activity for ~ 20 hours/day.	• CMJ • Maximal isometric strength	- ↓ CMJ - ↓ Strength in chest press and leg press

↑= *Increase in outcome variables,* ↓= *decrease in outcome variables,* ↔ = *no changes in outcome variables. MTT = Military training tasks. WMT = Winter Military Training. NORNAVSOC = Norwegian Navy Special Operations Command. FEX = Field Exercise. CMJ = Countermovement Jump. RBL = Repetitive box lift. OC = Obstacle course.* VO_{2max} = *maximal oxygen consumption.*

2.6.2 Body composition

Changes in body composition has been suggested to be one important explanation of the negative effect military training has on physical performance (Welsh et al, 2008.) As previously mentioned, soldiers may experience extended periods of strenuous physical activity that results in a high energy expenditure and a caloric deficit, which may lead to losses in body mass, fat mass (FM) and LBM (Nindl et al, 2007). This has been well documented in studies on the US Army Ranger Course. There has been observed reductions in body mass between 11 and 15%, reductions in FM between 5 and 42% and LBM reductions between 6 and 7% of initial values (Johnson et al, 1994; Shippee et al, 1994; Nindl et al, 1997; Nindl et al, 2007). Some soldiers have had their FM reduced to the lower limit of healthy levels (4-5%) (Friedl et al, 1994; Nindl et al, 2007). FEX of short durations have also displayed changes in body composition. Soldiers that underwent the 72 hours FEX suffered a ~3 % reduction of total body mass, with a ~2% drop in lean mass and a ~7% reduction in FM (Nindl et al, 2002). These levels of reductions are lower than what was observed during the Ranger Course. Whilst the shorter 72 hours FEX had a large energy deficit and involved physical strenuous activities, major changes in body composition may not occur during a 4-day period. The Ranger Course, which has mostly long periods of elevated activity levels and sleep and food restrictions results in larger changes in body composition. However, there have also been observed large changes in body composition during exercises of shorter durations. The study of NORNAVSOC's selection week yielded a total body mass reduction of 6,6%, with a 37% reduction in FM and a 4,5% reduction in LBM after a 7-day FEX (Hamarsland et al, in press). It is likely that the nature of the exercise (activities and tasks, duration, caloric intake, sleep restrictions etc.) influences the outcome related to body composition. Studies manipulating the energy intake of soldiers participating in a 10-day field manoeuvre illustrated the importance of energy balance. Soldiers given 600 kcal/day, 1000 kcal/day and 1500 kcal/day reduced their body weight after a FEX, while soldiers given 3500 kcal/day did not (Consolazio et al, 1979). Body composition changes are a result of a negative energy balance and likely influenced by the substrate use of the body during physical activity. Carbohydrate and fatty acids are the dominant fuels oxidized by muscle for energy production (Venables et al, 2005). Substrate utilization in humans is based on a "crossover concept" where fat (lipid) metabolism has a dominant role in sustaining efforts up to half or less of a person's aerobic capacity. When the intensity increases from moderate to hard, metabolism switches from lipid to carbohydrate dependence. At this point, blood and muscle glucose are increasingly utilized as substrates (Brooks, 1998). Exercise intensity is one of the most important regulators of substrate oxidation (Venables et al, 2005). The crossover point of muscle metabolic function is affected by fitness status. When measured at the same absolute intensity, individuals with a higher endurance fitness level display a decrease in carbohydrate utilization and an increase in lipid oxidation (Carter et al, 2001). The amount of glycogen contribution and glucose catabolic rates are an exponential function of intensity (Brooks, 1998). When there is a lack of energy availability the body has been found to utilize LBM to produce energy (Montain & Young, 2013). Several studies on acute and chronic undernutrition find that muscle mass is decreased when carbohydrate and fat oxidization is unable to meet energy requirements (Shetty, 1999).

2.6.3 Possible mechanisms behind reduced physical performance

The cause of the reduction in physical performance after military field exercises is possibly multifactorial. Prolonged physical activity and low energy intake during military and SOF training leads to a negative energy balance (energy expenditure exceeding energy intake) which is detrimental to body composition and may compromise physical performance (Nindl et al, 2002; Margolis et al, 2014b). However, the connections between body composition and reduced physical performance have been inconsistent (Johnson et al, 1994; Nindl et al, 1997; Nindl et al, 2002; Nindl et al, 2007; Hamarsland et al, in press). Body composition is not likely to be the sole reason for decrements in performance, as Knapik and colleagues (197) found no reduction in isometric strength, aerobic endurance and anaerobic performance after 3.5 days of fasting in a study by Knapik and colleagues (1987). This study did not involve any physical activity. However, isokinetic strength was reduced (Knapik et al, 1987). It has been suggested that a body mass loss of between 5 and 10% may lead to significant reductions in physical performance, which is often observed in military training that spans over several days (Nindl et al, 2002). There has been observed relationships between changes in body composition and maximal lifting capacity in a study by Johnson and colleagues (1994). A loss of LBM correlated significantly with a decline in performance and a reduction in explosive power (Johnson et al, 1994). On the other hand, Hamarsland and colleagues (in press) found a lack of associations between changes in body composition and depressed physical performance after the NORNAVSOC selection week (Hamarsland et al, in press). The reduced physical performance also outlasted the changes in body composition. Nindl and colleagues (1997) found that reductions in physical performance were greater compared to the loss of body mass and LBM (Nindl et al, 1997). There have also been observed a loss of lower-body anaerobic performance with the absence of reductions in leg LBM (Nindl et al, 2002). Reductions in physical performance have also been observed in conjunction with only modest reductions in body mass (Margolis et al, 2014b).

It is therefore likely that the decrements in physical performance after military training is caused by factors not only related to body composition. Several mechanisms have been suggested to be the cause of the reduction in physical performance, such as delayed muscular fatigue (Nindl et al, 2007). Human skeletal muscle fatigue is an acute reduction in maximal strength or reduced time to failure in submaximal work (Hunter, 2016a). It is defined by transient, exercise-induced reduction in maximal force or power of the muscle (Billaut & Bishop, 2009). Fatigue is also caused by decreased neural activation and a slower rate of relaxation (Raastad et al, 2000). The loss of strength is caused by peripheral factors such as damage in force-generating and/or transmitting structures within the muscle, and factors involving the central nervous system and neural pathways, amongst others (Warren et al, 2002; Ratel et al, 2015). Which part of the neuromuscular system that is influenced the most is determined by the task performed (Hunter, 2016a). The repeated microtrauma caused by exercise in muscles may, without adequate time for recovery, lead to compromised neuromuscular performance (Fry et al, 1994). Studies have shown changes in muscle fibre composition after military training exercise that prolonged exercise alone cannot explain (Hoyt et al, 2006a). Other causes suggested may involve hormonal factors, altered quality of contractile protein, neural changes and soreness (Nindl et al, 2007; Welsh et al, 2007; Margolis et al, 2014b; Hamarsland et al, in press). Hormonal changes were however monitored in the NORNAVSOC study, and values had been normalized by the post one week measuring point yet physical performance still had not recovered (Hamarsland et al, in press). The mechanisms behind the depressed performance after military FEX are still uncertain. It is also likely that it is affected by the level of physical exertion, caloric restrictions, psychological stress and sleep deprivation (Van Helder & Radomski, 1989; Nindl et al, 2002).

Table 2 Overview of studies measuring effect of field exercises (FEX) on body composition.

Author	Type of military training	Conducted measurements	Change in body composition

Consolazio et al, 1979	10-day manoeuvre in humid jungle environment.
	Subjects split in 4 groups with different energy intakes (600 kcal/day, 1000 kcal/day, 1500 kcal/day and 3500 kcal/day).
		• Nude body weight and direct water displacement.
		• Circumference.
		• Skinfold thickness.
			- ↓ Body mass and LBM in all groups <1500 kcal/day.
			- ↔ Body mass and LBM in the 3500 kcal/day group.
			- ↓ FM in all groups.
			- Circumference.
			  • ↓ Trunk circumference
			  • = Other circumferences
			- ↔ Skinfold thickness

Legg & Patton, 1987	8 days of sustained manual work handling artillery shells and charges combined with partial sleep loss.	• Nude body weight • Calculations of FM and LBM • Skinfold thickness	- ↓ Body weight - ↓ FM
Shippee et al, 1994	8-week US Army Ranger Course involving repeated periods of food restriction, sleep deprivation, environmental challenges and prolonged low intensity physical work.	• Body weight • DEXA • Circumference • Skinfold thickness	- ↓ Body weight - ↓ FM - ↓ LBM - ↓ Body fat (%) - ↓ Skinfold thickness - ↓ Circumference
Johnson et al, 1994	8-week US Army Ranger Course involving repeated periods of food restriction, sleep deprivation, environmental challenges and prolonged low intensity physical work.	• DXA	- ↓ Body weight - ↓ LBM
Guezennec et al, 1994	96 hours of patrolling carrying additional loads and simulated combat activities with sleep restrictions. Soldiers were divided into groups with different energy intake (1800 kcal/day, 3200 kcal/day and 4200 kcal/day).	• Body mass	- ↓ Body mass in all groups
Nindl et al, 1997	8-week US Army Ranger Course involving repeated periods of food restriction, sleep deprivation, environmental challenges and prolonged low intensity physical work.	• Nude body weight • DXA • Calculated LBM and FM	- ↓ Body mass - ↓ LBM - ↓ FM
Nindl et al, 2002	72 hours sustained military operation consisting of basic patrolling, combat drills, road marches, land navigation, litter obstacle course and a confidence course.	• DXA • Skinfold measurements	- ↓ Body mass - ↓ LBM in arms and trunk - ↔ LBM in the legs - ↓ FM in arms and trunk - ↔ FM in the legs - ↓ % Body fat - ↓ Subcutaneous fat
Hoyt et al, 2006b	5-7-day field exercise involving periods of sustained physical activity, long-distance foot marches, simulated combat patrols,	• DXA	- ↓ Body mass - ↓ LBM - ↓ FM

	obstacle courses and marksmanship training with severe food and sleep deprivation		

Nindl et al, 2007	8-week US Army Ranger Course involving repeated periods of food restriction, sleep deprivation, environmental challenges and prolonged low intensity physical work.	• Nude body weight
		• Skinfold thickness
		• Circumference
		• DXA
			- ↓ Body mass
			- ↓ Muscle CSA
			- ↓ LBM
			- ↓ FM
			- Circumference
			  • ↓ arms and legs
			  • ↔ Trunk

Margolis et al, 2014b	Soldiers conducting two subsequent training programs: 4-day military training tasks (MTT) in garrison consisting of weapon familiarization, mountainous terrain navigation and winter survival training followed by 3-day winter field exercise (WMT) consisting of ~20 km skiing per day while carrying ~45 kg loads	• Body weight by scale	- ↓ after MTT - ↔ after WMT
Welsh et al, 2008	8 days military operational field training consisting of carrying equipment (~20 kg), handling weapons, movement on foot with loaded backpacks, handling weapon and ammunition and patrols.	• Body mass by scale • DXA • Calculations of LBM and FM	- ↓ Body mass - ↓ FM - ↓ LBM
Hamarsland et al, in press	NORNAVSOC selection program, consisting of ~1-week field exercise (FEX) with sleep and caloric restrictions and extreme amounts of physical activity for ~ 20 hours/day.	• Bioelectrical impedance scale (InBody 720)	- ↓ Body mass - ↓ FM - ↓ LBM -

↑= *Increase in outcome variables,* ↓= *decrease in outcome variables,* ↔ = *no changes in outcome variables. MTT = Military training tasks. WMT = Winter Military Training. NORNAVSOC = Norwegian Navy Special Operations Command. FEX = Field Exercise. DXA = Dual-energy X-ray absorptiometry.*

2.7 The introduction of women on a large scale to the Armed Forces

Modern Armed Forces have seen an increase in the number of women serving. Women were until recently prohibited from joining units that conducted combat operations in the US Army (Hoyt et al, 2006b). Norway was in 2014 the first country in NATO to enlist both men and women to mandatory conscription (Regjeringen, 2014). The integration of women into the Armed Forces, especially in combat-oriented units has been controversial. There has been raised questions of the physical and physiological capabilities of women in military service (Epstein et al, 2013). In daily tasks, sex-related differences are mostly insignificant. However, during military service, mission success might be reliant upon soldiers accomplishing physically demanding activities under harsh conditions (Epstein et al, 2013). Female soldiers have been seen to exert themselves considerably more than their male counterparts when completing military tasks (Epstein et al, 2013). As the dynamics of the Armed Forces are changing with new tasks and the introduction of women on a large scale there is an increased need to prioritize physical training doctrines. There have been discussions on whether women are able to adapt to military physical and combat demands given the implementation of proper military-relevant training programs (Epstein et al, 2013). Efforts on closing the sex differences in physical capacity by manipulating training methods and tailor them to specific occupational demands may have a large impact on preparing women for combat-centric occupations (Nindl et al, 2016). Knowledge of gender differences is also of importance to the Armed Forces, as literature is lacking. There have already been observed potential differences in responses to military training, and further investigations are needed (Hoyt et al, 2006b).

2.8 Sex differences

2.8.1 Physical performance and body composition

The subjects and soldiers in the previously mentioned literature are mostly male. Historically, females have been underrepresented in studies on soldiers due to the low participation by women in the Armed Forces (Montain & Young, 2003). Studies on sex differences in physical performance and fatigue have however been prevalent in other disciplines outside the military. Men are considered to have a greater potential for strength and speed due to physiologic and anatomic differences (Hunter, 2016b). Absolute strength in women has been observed to be 40-55% lower in upper body strength and 30-40% lower in lower body strength (Epstein et al, 2013; Nindl et al, 2016). In addition, women in their 20s have approximately 30% less LBM than men at the same age (Nindl et al, 2016). Due to the greater levels of LBM and strength in men, they have a higher level of muscular endurance when compared to women. Therefore, in military tasks where the endurance level is fixed (e.g. carrying absolute weights over a predefined distance at a set pace) men have an advantage (Epstein et al, 2013). Women are estimated to have 40% lower absolute anaerobic power than men (17% lower when adjusted for LBM), and military relevant performance in anaerobic activities are lower in females than in males (Murphy et al, 1986; Epstein et al, 2013). This is demonstrated through studies on additional load carriage during explosive, anaerobic military tasks where there was a significant higher performance in men compared to women (Epstein et al, 2013). Loads carried by soldiers can range from 30 to 60 kg, regardless of body mass, and women are more susceptible to muscular fatigue from load carrying with fixed load compared to men (Bhambhani & Maikala, 2000). This has been a major concern when introducing women to combat-centric military roles (Epstein et al, 2013). VO_{2max} in untrained and trained women is on average 15-30% lower than in men of similar age and fitness (Epstein et al, 2013; Anderson 2017). Women have thinner left ventricular walls, less myocardial mass and smaller cavity size, leading to a lower cardiac output (Epstein et al, 2013). Stroke volume at a given VO_2 is smaller in women compared to men, which is compensated for by a higher heart rate. Due to maximal heart rate being similar in both genders, the resulting maximal cardiac output is therefore lower in women (Epstein et al, 2013). However, VO_{2max} within the genders do vary. Differences between untrained females and males have been observed to be smaller than in trained, and 76% of the untrained females had similar VO_{2max} levels to 47% of the untrained males (Drinkwater, 1973). When adjusted for anthropometric measures, the sex differences are narrowed (Epstein et al, 2013). It does however not disappear, likely due to the significant impact a lower cardiopulmonary capacity has on cardiorespiratory fitness (Epstein et al, 2013). As VO_2 is correlated with workload, women will during a fixed submaximal activity use a higher percentage of their VO_{2max} leading to a higher relative intensity, resulting in lower tolerance times (Epstein et al, 2013). Women have however shown responsiveness to specific training programs aimed at improving skills related to military operational performance, where the levels of improvement have been equal or greater than their male counterparts (Drain et al, 2015; Nindl et al, 2016). The lower athletic performance in women compared to men has been considered to be less relevant, due to the unique requirements of military operations. With knowledge of mechanisms behind gender differences, planning and adaptation of proper training doctrines, differences can be reduced, and combat readiness maintained (Epstein et al, 2013).

2.8.2 Fatiguability

Interestingly, there have been observed sex differences in fatigability that favour women (Billaut & Bishop, 2009). Studies have found women to be less fatigable in isometric contractions performance at the same relative intensity in single-limb muscle groups than men (Hunter, 2016a). Differences in anaerobic and aerobic exercise has also been demonstrated, where women exhibit less muscle fatigue after both multiple sprint exercises and long-duration exercise (Billaut & Bishop 2009; Hunter, 2016a). Glace and colleagues (1998) found sex differences in response to a 2 hours endurance run, where the men had a more negative development in running economy and VO_2 compared to women (Glace et al, 1998). Women have been observed to have a smaller reduction in maximal strength in the lower limb muscle after strenuous endurance exercise compared to men (Temesi et al, 2015). Females also appear to maintain the initial absolute power output for longer durations during anaerobic tests (Billaut & Bishop, 2009). The sex differences in fatigability vary depending on the task that is being performed, muscle groups involved and intensity of the muscle contraction (Hunter 2016b). Factors explaining the differences have been suggested to be differences in body composition, muscle metabolism and muscular characteristics amongst others (Billaut & Bishop, 2009). Due to the lower muscle strength, women generate lower absolute muscle force than men when the same relative work. Lower absolute forces have a lower muscle oxygen demand and less mechanical compression of vasculature, which is believed to be the cause of delayed fatigue (Epstein et al, 2013). There are indications that muscle anatomy is not the only cause of sex differences as there has also been observed differences in muscle metabolism. Men have a larger metabolite build-up in the muscle, which interferes with contractile function (Hunter, 2016a). Differences occur when data is expressed relative to body mass and LBM as well, and when subjects are matched for strength (Billaut & Bishop, 2009). Therefore, it is evident that other physiological (i.e. hormonal and neural) factors also contribute to the discrepancy between genders (Billaut & Bishop, 2009).

2.8.3 Sex differences in metabolism and body composition

Women have a higher requirement for essential FM, with the lowest acceptable limit for men being 3% and 12% for women (Anderson et al, 2017). Because of this, as well as a higher rate of FM accumulation during puberty compared to men, women have an ~20-25% body fat reserve, while men have ~13-16% (Nindl et al, 2016). Women in their 20s also weigh on average 14-18 kg less than males at the same age (Epstein et al, 2013). In addition to differences in body composition, females maintain a more fat-predominant metabolism than males (Hoyt et al, 2006b). Women have shown to oxidize more FM and less carbohydrate and amino acids during endurance exercises on similar intensities (Hunter, 2016b). Venables and colleagues (2005) observed that women had a greater contribution from lipids in substrate oxidation during exercise, as well as a higher absolute rate and a higher relative contribution to total energy expenditure from lipids than men across a wide range of exercise intensities (Venables et al, 2005). Lesser use of glycogen in the metabolism would decrease the protein used for gluconeogenesis during periods of reduced caloric intake and may reduce the loss of LBM (Hoyt et al, 2006b). The difference is suggested to be connected to difference in muscle fibre-types, which in turn is linked to a more fatigue resistant muscle in women, as well as differences in glycolytic capacity and oxidative capacity (Hunter, 2016b). It has also been connected to hormonal differences, specifically estrogen (Tarnopolsky, 2000). The glycogen-dependant metabolism in men may also have an effect on endurance performance which is supported by studies showing that sex differences in running performance are reduced as race distances increase (Bam et al, 1997; Hoyt et al, 2006b). This may be of consequence to performance in military specific tasks of longer duration. One of the only studies on sex differences in responses to military training supported the evidence that females have a higher fat oxidation per kg LBM and had a greater fractional contribution of FM to the total energy expenditure (Hoyt et al, 2006b). Females also had a smaller loss in LBM from initial values compared to men. This is likely to impact how female soldiers are affected by FEX and may influence the course of recovery (Hoyt et al, 2006b). A reduced drop in LBM could lead to different effects on physical performance, as LBM and muscle CSA are correlated with strength and anaerobic performance as well as military task performance (Raastad et al, 2010; Angeltveit et al, 2015). Reducing unfavourable changes may have large consequences for a soldier’s ability to meet operational demands and may affect performance during combat operations (Nindl et al, 2016; Hamarsland et al, in press). It has been suggested that a higher initial FM amongst soldiers would be protective against the muscle loss following demanding military training (Hamarsland et al, in press). Ranger students with higher levels of FM derived the majority of their energy from fat stores, whilst the contributions from FM in leaner soldiers were as low as 20% (Hoyt et al, 2006b). The perseveration of LBM is more effective if the soldiers have greater initial body fat availability (Hoyt et al, 2006b). In theory, this could indicate that women are more resistant to changes in body composition and decrements to performance following military training.

2.9 Recovery after of military field exercises.

An understanding of how soldiers are affected by intensified FEX is crucial to both planning and execution of military training and real-world operations. Recovery time of soldiers may affect operational readiness and performance during training and combat missions (Teien, 2013). However, studies on the course of recovery of strenuous FEX are lacking (Hamarsland et al, in press). Post-fatigue recovery is believed to follow an exponential pattern, since other relevant physiological processes such as heart rate, blood lactate elimination and oxygen uptake also occur exponentially (Rashedi et al, 2017). The recovery period of skeletal muscle and oxygen uptake is also largely influenced by the details of the task (Raastad et al, 2010; Teien, 2013). Following a bout of heavy resistance training, performance have been observed to require over 30 hours before returning to baseline values (Raastad et al, 2000). Eccentric muscle work may lead to even longer recovery periods before initial performance is regained (Raastad et al, 2010). Energy intake, hydration and rest are determents of the duration of recovery and may affect the time it takes before physical function is restored (Teien, 2013). If a muscle is not allowed optimal conditions or is exposed to repeated physical work, the duration of recovery is increased. When measuring sprint performance after a period of repeated physical strain, Mohr and colleagues (2015) found that the football-players still had reduced performance after three days of recovery (Mohr et al, 2015). This is particularly relevant to soldier's performance due to military operations rarely involving a single bout of heavy physical activity, but rather several bouts over a given period of time. The few studies investigating recovery after FEX have found that performance need long periods of time to recover. Hamarsland and colleagues' (in press) study of the NORNAVSOC' selection exercise observed that even though LBM had recovered to pre-values after one week, depression in leg press performance was not recovered until 2 weeks later. CMJ performance was still significantly lower than pre-values at 2 weeks (Hamarsland et al, in press). Nindl and colleagues (1997) observed that all measured values for strength, power and vertical jump height had returned to pre-levels at the five weeks after the ranger course (Nindl et al, 1997). At the same time, LBM had returned to pre-test values whilst total body mass had increased by 7,1%. This was due to primarily gains in FM (62% greater than pre-values). It is therefore evident that even though FM and LBM has been restored initial values, soldiers may still not have fully recovered (Nindl et al, 1997). As with most literature on effects of military training, women subjects are lacking. There is therefore an uncertainty of whether the course of recovery differs between the sexes.

3. Method and materials

3.1 Participants

The participants (n=35) were recruited from individuals participating in the basic training and selection process at the Armed Forces Special Command (Forsvarets Spesialkommando, FSK). The FSK conscript division consists of two troops, the Parachute Ranger Platoon and the all-female Special Reconnaissance Platoon. Applicants are initially invited to crude selection at the Armed Forces Admission and Selection (Forsvarets Opptak og Seleksjon, FOS), where they must pass physical- and medical tests and interviews. If found eligible, the candidates attend three weeks of basic training where they are educated in basic military skills, manoeuvres and weapons training. They are continuously evaluated and can at any time during the process be excluded if they are not found eligible or choose to choose to voluntarily withdraw. The service during basic training is both physically and mentally demanding. Following basic training, the conscripts must complete a selection exercise. This is a challenging FEX where most of the conscripts are excluded or choose to voluntarily withdraw from the selection process. Recruitment was administered in two parts. The candidates were informed at the start of basic training that there would be a study conducted before, during and after the selection exercise. The day before the pre-testing, candidates had a second presentation with information about the study. Participation in the study was voluntary and candidates could withdraw at any time. Candidates who volunteered to participate provided a written informed consent before testing commenced. A total of 114 men and 26 women volunteered to participate in the study. After the selection exercise, a total of 23 men and

12 women of the volunteers remained. Medical personnel declared the candidates healthy before the selection-process. The study was performed in compliance with the Declaration of Helsinki.

Participant characteristics of the candidates who completed selection are presented in table 3. The men had significantly higher height, weight and LBM, and the women had a significant higher FM at pre-test measurements.

Table 3. Participant anthropometry prior to the selection exercise.

	Men (n=23)	**Women (n=12)**	**P-value**
Age (years)	19.3 ± 1.9	19.75 ± 1.7	p = 0.488
Height (cm)*	183.0 ± 5.6	171.8 ± 1.8	p < .001
Weight*	79.5 ± 6.4	67.7 ± 5.5	p < .001
LBM (kg)*	43.1 ± 3.8	32.0 ± 1.9	p < .001
FM (kg)*	4.2 ± 1.4	10.8 ± 3.7	p < .001
BMI (kg/m^2)	23.7 ± 2.6	23.0 ± 1.9	p = 0.232

All characteristic values are mean ± standard deviation (SD).

3.2 Ethical considerations and approvals

Prior to the study, applications were sent to the Regional Committees for Medical and Health Research Ethics (REK). The study was found to be outside the mandate of REK, and could be conducted without their approval (REK, 2016). Soldiers, and especially conscripts, are considered a vulnerable group (De Nasjonale Forskningsetiske Komiteene, 2014). They are classified as subordinate members of a hieratic system and may feel subject to pressure from their superiors to partake in the study. The group that the participants in this study were recruited from were also participating in a selection-course and may feel that refusal to partake would affect their chances of being admitted. Therefore, we stressed on several occasions that participation in our study would in no way affect their evaluation during the course. Results would not be made available to the FSK before after selection was completed and only as anonymous data. The importance of written consent was specified to the candidates, and we also stressed the commanders not to put any pressure on the conscripts to participate in the study.

3.3 Experimental design

A test-battery consisting of measurements of body composition, countermovement jump (CMJ), medicine ball throw (MBT) and a test of anaerobic work capacity: the evacuation test (EVAC-test) was applied to measure the course of recovery after the selection exercise. The test-battery was applied at six time points during a 4-week period. Due to the high number of participant, the pre-tests were carried out over two test-days 2-3 days before the selection exercise started. Thereafter, testing was performed the day the participants returned from the FEX and after 24 hours, 72 hours, 1 week and 2 weeks. Figure 1 presents a complete timeline of the study. The test-battery was executed in the same order at all time points. Body composition was measured in the morning (between 06:00 and 08:00) prior to breakfast, while the physical test was performed 2-3 hours after breakfast. The only exception was the day they return from the field exercise when body composition was measured immediately after termination of the selection exercise and the physical test was performed 3-5 hours later.

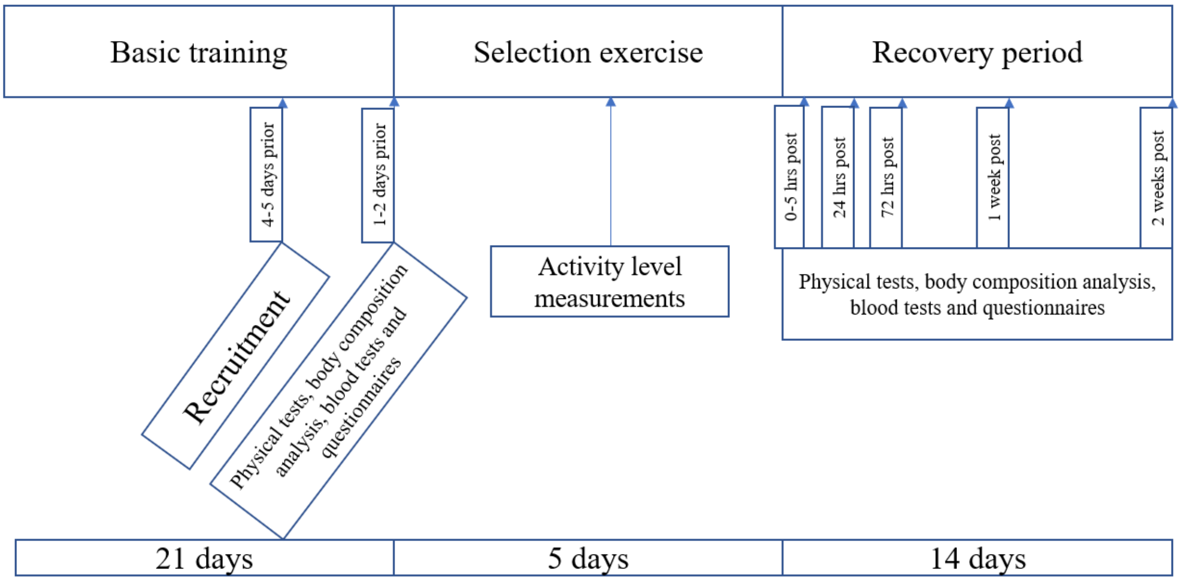

Figure 1. Timeline of the study.

3.4 Selection exercise

The selection exercise was conducted at the end of basic training and lasts for a total of five and a half days. It is designed to test the candidates' physical and mental resilience in extreme situations in sub-optimal conditions. The selection exercise is performed at the same time, but separately for the male and female conscripts. However, the content of the exercises is similar. Both the men and women consumed approximately 700 calories (kcal)/day during the field exercise.

3.5 Energy expenditure

Energy expenditure was measured by accelerometers (ActiGraph wGT3X-BT, ActiGraph, Florida, USA) in 8 male and 5 female participants during the selection exercise. Due to a misunderstanding, the women were not given accelerometers before day 2 and measurements were not done for this group during day 1. The exercise was finished early on the sixth day, and average energy expenditure was therefore estimated from measurements from day 2 to day 5.

3.6 Body Composition

Body composition was measured by bioelectrical impedance analysis (BIA) on an InBody 720 machine (Biospace Co., Seoul, Korea) according to the manufacturer's instructions. The BIA was administered in the morning (06:00 – 08:00) before breakfast and the participants were instructed to avoid eating, drinking and showering until the test was completed, and told to go to the toilet prior to the measurements. These rigid standardizations were not possible at the post 0 hours' time point when the BIA was administered immediately after the candidates returned to base from the selection exercise. Participants performed all measurements in their underwear.

3.7 Physical performance tests

The soldiers completed the physical tests after a general warm-up and in the following sequence: CMJ, MBT and EVAC. During the pre-testing, there was a technical malfunction with the platform used during the CMJ. Therefore, some of the participants completed the EVAC test first, followed by the CMJ and MBT while the platform was fixed. These participants conducted the test-battery in this order at all the following time points.

3.7.1 General warm-up

The physical tests started with a 10-minute long general warm-up that consisted of running at low to moderate intensity and exercises that targeted at muscles and joints involved in the different tests.

3.7.2 Countermovement Jump (CMJ)

The CMJ-test was performed on a force-platform (HUR Labs, Tampere, Finland). When conducting the jump, participants were instructed to stand on the platform with feet at shoulder-width. Following a countdown from the test-administrator, the soldiers then complete 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. There were no further restrictions on technique, but the soldiers were instructed to perform the test with the same technique each time. Each participant was given 3-4 trials, with a 30-second rest between each attempt. If the soldiers did not achieve peak jump height (a levelling or decrease of performance) after the 3-4 trials, the test was continued until they reached peak height.

3.7.3 Evacuation test (EVAC-test)

The EVAC-test was administered on a 10x20 meter course. Cones were placed on the left side at the 5- and 15 meters mark, and at the right side on the 10 meters mark (figure 2). The test started and ended at the same start line. A human shaped doll (70 kg for men and 50 kg for women (Ruth Lee, London, UK)) 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 doll at high intensity through the first two turns of the course. To compensate for not having the possibility to perform extensive familiarization the participants practiced pulling the doll during general warmup at pre-testing.

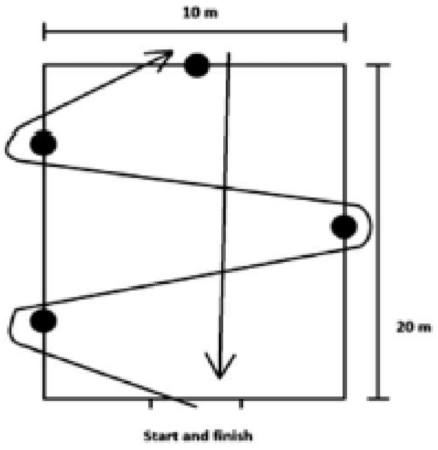

Figure 2. The EVAC test course. Both laps were completed in the same pattern (Angeltveit et al, 2015).

The test consisted of two laps through the course. The first lap was completed without the doll. When they passed the start/finish line after completing lap one, the doll was picked up by a handle on the side on the neck (figure 3) and pulled through the course on the second lap. The participants were instructed to complete both laps as quickly as possible and strong verbal encouragement was given throughout the test. Time was registered using photocells (Brower Timing Systems, Utah, USA). Total time were used for the analysis of performance.

Figure 3. Pulling technique during the EVAC-test.

3.7.3.1 Lactate measurements

After the EVAC-test was finished, the participants were instructed to perform an individual cool-down with light running for three minutes. They were then placed in a chair and a capillary blood sample was drawn from a fingertip for lactate-measurements (Lactate Scout+, EKF Creative Services, Texas, USA). The lactate analyser was calibrated at the beginning of each test-day.

3.7.4 Medicine Ball Throw (MBT)

The MBT-test was administered on a standardized test-mat used in physical performance testing in the Norwegian Armed Forces. The throw started with the candidates in a standing position, holding a 10 kg medicine ball at chest height. From this position with feet kept in parallel they thrust the medicine ball as far as possible. The feet had to be in touch with the test-mat at all times. There were no other restrictions regarding technique, and participants were permitted to utilize their back and legs as they saw fit. Results were measured to the closest 0,1 meters. The soldiers were allowed one test-throw, followed by three registered throws. The best of the three throws were used in the statistical analyses.

3.8 Statistics

All statistical analysis was completed in IBM SPSS (IBM SPSS Statistics, version 24, IBM Corp., Armonk, NY, USA). A Mixed Model ANOVA with sex as between subject factor, and time point during the study as within subject factor, was applied to investigate changes over time within sexes and possible interaction between time and gender. Where the sphericity assumption was violated, the Greenhouse-Geisser procedure was used to correct the degrees of freedom. A significant interaction between time and gender was followed up with pairwise comparisons with Bonferroni adjustment to compare each groups' mean across different time points. Furthermore, group differences in percent change from pre-values at different time points was evaluated with pairwise comparisons with Bonferroni adjustments for multiple comparisons. Differences in anthropometrics before the study were investigated using independent sample t-tests. Correlations were investigated through Pearsons *r*. An alpha-level of 0.05 was used for all statistics. Values are mean ± standard deviation.

Missing values were estimated for participants that did not attend one of the post-tests due to injury or sickness or other logistical restrains. Values were calculated by applying the average of percentage change for the group to the subjects' values from the previous test. For the CMJ, 3 men and 2 women had missing values calculated. The corresponding numbers were five men and three 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 at each test calculated.

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5. Article

Title: *Sex differences in effect and recovery after a strenuous military field exercise*

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Abstract:

Purpose: Recovery and sex differences in response to strenuous military field exercises are largely unknown. The purpose of this study was to investigate the effect of strenuous military field exercises and the course of recovery on body composition and physical performance, and to examine potential sex differences in these responses.

Methods: 35 soldiers (23 men and 12 women) from the conscript division at the Norwegian Armed Forces Special Command volunteered to participate. Measurements were conducted before, 0 hours, 24 hours, 72 hours, 1 week and 2 weeks after a strenuous field exercise. Energy expenditure was measured during the exercise by accelerometers. Body composition was measured through bioelectrical impedance analysis (BIA) and physical performance was measured through a countermovement jump (CMJ), medicine ball thrust (MBT) and anaerobic performance through an evacuation test (EVAC-test).

Results: The men reduced their body mass and lean body mass (-8.16 ± 0.22 %, $p < 0.001$ and -6.13 ± 0.38 %, $p < 0.001$, respectively) more than the women (-3,96 ± 0.31 %, $p < 0.001$ and -0.36 ± 0.64 %, $p = 1.000$, respectively) after the field exercise with no different reductions in fat mass (men: 38.80 ± 3.47 %, $p < 0.001$, women: 27.02 ± 4.80 %, $p < 0.001$). All changes in body composition had recovered after 1 week. All performance variables were reduced to the same degree in men and women after the selection exercise. CMJ jump height was still reduced in both groups after 2 weeks, and the reduction after 72 hours (men -23.54 ± 6.79 %, $p < 0.001$, women: 14.33 ± 8.05 %, $p = 0.001$) and 2 weeks (men: -16.84 ± 6.10 %, $p < 0.001$, women: 8.88 ± 8.31 %, $p = 0.026$) was larger in the men compared to the women ($p < 0.001$). The same pattern of changes and sex differences was found for maximal power during the CMJ. MBT throw distance recovered after 1 week, and EVAC performance after 2 weeks with no differences between the groups.

Conclusion: The results show that the men lost more body mass and lean mass than women after a very strenuous military field exercise. Reduction in physical performance after the field exercise was similar between men and women. Both anaerobic capacity and upper body strength had recovered within two weeks. However, explosive strength in the legs was not recovered by two weeks in neither men nor women, and the recovery was slower in men compared to women.

Key words: military, soldier, physical performance, recovery, body composition, field exercise, sex differences.

Introduction

Soldiers in the Armed Forces have a complex job with components of high physical and mental strain, especially during combat training and operations. Military training is aimed at acquiring the physical, cognitive and mental capabilities and skills relevant to succeed in military operations. An important part of training is to perform simulated combat training and demanding field exercises (FEX). Studies have shown that this type of training involves components of extreme physical strain, large energy requirements combined with low energy intake and sleep restrictions (1, 2, 3, 4). FEX of varying durations and intensities have previously been reported to lead to a reduced body mass due to reductions in both lean body mass and fat mass (5, 6, 7, 1, 8, 9, 10). Decremental effects have also been found in numerous aspects of physical performance, including aerobic performance (6, 11), anaerobic performance (12) maximal muscle strength (6, 7, 9, 10), explosive muscle strength (7, 1, 8, 9, 13, 14, 10) and performance in simulated military tasks (8). However, the relationship between changes in body composition and physical performance after FEX is still unclear (15, 10).

Because military service has historically been dominated by men, all the mentioned studies have been performed with only male participants. However, in recent years, most Armed Forces have seen an increase in women serving and enlisting. In fact, Norway introduced gender-neutral conscription in 2014 and the proportion of women in its Armed Forces is increasing (16). Due to physiological differences between the sexes, results obtained in male soldiers are not necessarily transferable to female soldiers. For example, women have been reported to oxidize proportionally more fat at submaximal intensities compared to men (17, 18). To our knowledge there is only one study on the physiological effects of FEX that include female participants (15). This study reported that men lost more body mass compared to women, and that a larger proportion of the body mass loss in men was lean body mass (LBM) after a demanding FEX (15). This indicates that women might have a better ability to conserve muscle mass under these conditions. Since muscle mass is related to both maximal strength (19) and anaerobic capacity (20, 21), this might lead to women having smaller decrements in performance. However, no study has investigated changes in physical performance in women following demanding FEX. Consequently, with an increasing number of women in the Armed Forces, there is a need for a better understanding of how women are affected and perform during and after strenuous military training.

Studies on the acute effect of military training on body composition and physical performance is as mentioned somewhat prevalent in men. However, literature on the course of recovery in the aftermath is sparse in both men and women. A study by Nindl and colleagues (1997) found that the decremental effects of the US Ranger Course had recovered after 5 weeks. However, this study did not include any measurements of recovery in the period shortly after the Ranger Course (1). In a recent study, Hamarsland and colleagues (in press) found that some aspects of physical performance were still depressed in male soldiers 2 weeks after a demanding FEX (10). The participants in both these studies were exclusively male, and any sex differences are still unknown. Knowledge about the course of recovery after military training has potentially great impact on how Armed Forces should plan and execute their training and operations, physical performance is critical to mission success.

Therefore, the purpose of this study was two-fold. Firstly, we wanted to examine if a strenuous military FEX affects men and women differently in regard to body composition and physical performance. Secondly, we wanted to examine the course of recovery in physical performance and body composition in the aftermath of the FEX in both men and women and investigate if there were any sex differences in the recovery process.

Method and materials

Participants

The participants (n = 35) were recruited from conscripts participating in the basic training and selection process at the Armed Forces Special Command (Forsvarets Spesialkommando, FSK). The FSK conscript division consists of two troops, the Parachute Ranger Platoon and the all-female Special Reconnaissance Platoon. Applicants are initially invited to crude selection, and if found eligible they attend three weeks of basic training where they are educated in basic military skills, manoeuvres and weapons training. Following basic training the conscripts must complete a selection exercise. This is a challenging FEX where most of the conscripts are excluded or choose to voluntarily withdraw from the selection process. Candidates who volunteered to participate provided a written informed consent before testing commenced. A total of 114 men and 26 women volunteered to participate in the study. After the selection exercise, a total of 23 men and 12 women of the volunteers remained (table 1). The project was evaluated by the Regional

Committees for Medical and Health Research Ethics (REK). It was found to be outside their mandate and could be completed without their approval (22). Since the participants in this study are also participating in a selection-course and may feel that refusal to participate would affect their chances of being admitted, we stressed that participation in the study would not affect their evaluation during the course. The study was performed in compliance with the Declaration of Helsinki.

Table 1. Participant anthropometry prior to the selection exercise.

	Men (n=23)	**Women (n=12)**	**P-value**
Age (yrs)	19.3 ± 1.9	19.75 ± 1.7	p = 0.488
Height (cm)*	183.0 ± 5.6	171.8 ± 1.8	p < .001
Body mass (kg)*	79.5 ± 6.4	67.7 ± 5.5	p < .001
Fat free mass (FFM) (kg)*	43.1 ± 3.8	32.0 ± 1.9	p < .001
Fat mass (kg)*	4.2 ± 1.4	10.8 ± 3.7	p < .001
BMI (kg/m^2)	23.7 ± 2.6	23.0 ± 1.9	p = 0.232

All characteristic values are mean ± standard deviation (SD).

Experimental design

A test-battery consisting of measurements of body composition, countermovement jump (CMJ), medicine ball throw (MBT) and a test of anaerobic work capacity: the evacuation test (EVAC-test) was applied to measure the course of recovery after the selection exercise. The test-battery was applied at six time points during a 4-week period. Pre-tests were carried out two to three days before the selection exercise started. Due to the high number of participants, the pre-test was conducted over two days. Post-tests were performed the day the participants returned from the exercise and 24 hours, 72 hours, 1 week and 2 weeks later. The test-battery was executed in the same order at all time points. Body composition was measured in the morning (between 06:00 and 08:00) prior to breakfast, while the physical test was performed 2-3 hours after breakfast. The only exception was the day they returned from the selection exercise when body composition was measured immediately after termination of the exercise and the physical test was performed 3-5 hours later.

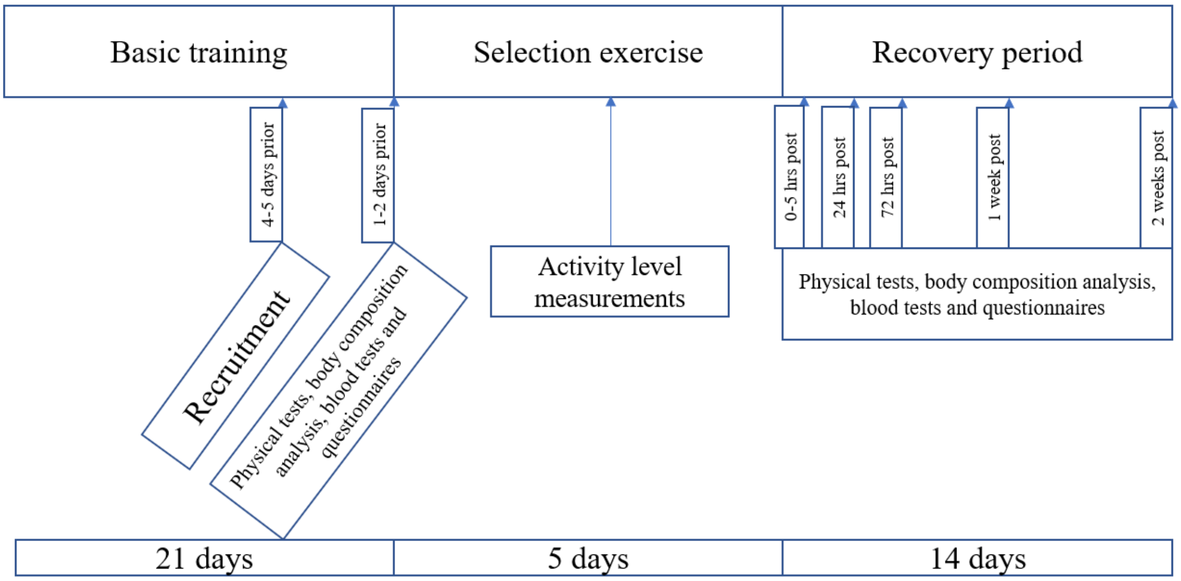

Figure 1. Timeline of the study.

Selection exercise

The selection exercise is conducted at the end of basic training and is a field-exercise that lasts for a total of five and a half days. It is designed to test the candidates' physical and mental resilience in extreme situations in sub-optimal conditions. The selection exercise is performed at the same time, but separately for the male and female conscripts. However, the content of the exercise is similar. Both the men and women consumed approximately 700 calories (kcal)/day during the field exercise.

Energy expenditure

Energy expenditure was measured by accelerometers (ActiGraph wGT3X-BT, ActiGraph, Florida, USA) in 8 male and 5 female participants during the selection exercise. Due to a misunderstanding, the women were not given accelerometers before day 2 and measurements were not done for this group during day 1. The exercise was finished early on the sixth day, and average energy expenditure was therefore estimated from measurements from day 2 to day 5

Body Composition

Body composition was measured with bioelectrical impedance analysis (BIA) on an InBody 720 machine (Biospace Co., Seoul, Korea) according to the manufacturer's instructions. The BIA was administered in the morning and the participants were instructed to avoid eating, drinking and showering until the test was completed, and told to go to the toilet prior to the measurements. The rigid standardizations were not possible on the post 0 hours' time point when the candidates returned from the selection exercise. Participants performed all measurements in their underwear.

Physical performance tests

Performance tests

The soldiers completed the physical tests after a general warm-up and in the following sequence: CMJ, MBT and EVAC. During the pre-testing, there was a technical malfunction with the platform used during the CMJ. Therefore, some of the participants completed the EVAC test first, followed by the CMJ and MBT while the platform was fixed. These participants conducted the test-battery in this order at all the following time points.

General warm-up

The physical tests started with a 10-minute long general warm-up that consisted of running at low to moderate intensity and exercises that targeted at muscles and joints involved in the different tests.

Countermovement Jump (CMJ)

The CMJ-test was performed on a force-platform (HUR Labs, Tampere, Finland). When conducting the jump, participants were instructed to stand on the platform with feet at shoulder-width. Following a countdown from the test-administrator, the soldiers then complete 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. There were no further restrictions on technique, but the soldiers were instructed to perform the test with the same technique each time. Each participant was given 3-4 trials, with a 30-second rest between each attempt. If the soldiers did not achieve peak jump height (a levelling or decrease of performance) after the 3-4 trials, the test was continued until they reached peak height.

Evacuation test (EVAC-test)

The EVAC-test was administered on a 10x20 meter course. Cones were placed on the left side at the 5- and 15 meters mark, and at the right side on the 10 meters mark (figure 3). The test started and ended at the same start line. A human shaped doll (70 kg for men and

50 kg for women, (Ruth Lee, London, UK)) 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 doll at high intensity through the first two turns of the course. To compensate being able to perform extensive familiarization the participants practiced pulling the doll during the general warmup at pre-testing.

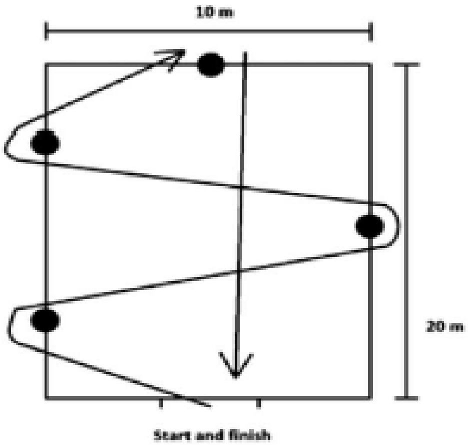

Figure 2. The EVAC test course. Both laps were completed in the same pattern (Angeltveit et al, 2015).

The test consisted of two laps through the course. The first lap was completed without the doll. When they passed the start/finish line after completing lap one, the doll was picked up by a handle on the side on the neck (figure 3) and pulled through the course on the second lap. The participants were instructed to perform both laps as quickly as possible and strong verbal encouragement was given throughout the test. Time was registered using photocells (Brower Timing Systems, Utah, USA). Total time were used for the analysis of performance.

Figure 3. Pulling technique during the EVAC-test.

Lactate measurements

After the EVAC-test was finished, the participants were instructed to perform an individual cool-down with light running for three minutes. They were then placed in a chair and a capillary blood sample was drawn from a fingertip for lactate-measurements (Lactate Scout+, EKF Creative Services, Texas, USA). The lactate analyser was calibrated at the beginning of each test-day.

Medicine Ball Throw (MBT)

The MBT-test was administered on a standardized test-mat used in physical performance testing in the Norwegian Armed Forces. The throw started with the candidates in a standing position, holding a 10 kg medicine ball at chest height. From this position with feet kept in parallel they thrusted the medicine ball as far as possible. The feet had to be in touch with the test-mat at all times. There were no other restrictions regarding technique, and participants were permitted to utilize their back and legs as they saw fit. Results were measured to the closest 0,1 meters. The soldiers were allowed one test-throw, followed by three registered throws. The best of the three throws were used in the statistical analyses.

Statistics

All statistical analysis was completed in IBM SPSS (IBM SPSS Statistics, version 24, IBM Corp., Armonk, NY, USA). A Mixed Model ANOVA with gender as between subject factor, and time point during the study as within subject factor, was applied to investigate changes over time within genders and possible interaction between time and gender. Where the sphericity assumption was violated, the Greenhouse-Geisser procedure was used to correct the degrees of freedom. A significant interaction between time and gender was followed up with pairwise comparisons with Bonferroni adjustment to compare each groups' mean across different time points. Furthermore, group differences in percent change from pre-values at different time points was evaluated with pairwise comparisons with Bonferroni adjustments for multiple comparisons. Differences in anthropometrics before the study were investigated using independent sample t-tests. Correlations were investigated through Pearsons *r*. An alpha-level of 0.05 was used for all statistics. Values are mean ± standard deviation. Missing values were estimated for participants that did not attend one of the post-tests due to injury, sickness or other logistical restrains. Values were calculated by applying the average of percentage change for the total group to the subjects' 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 at each test calculated.

Results

Energy expenditure

The men had a larger estimated average energy output than the women (7235 ± 408 kcal/day vs. 6041 ± 328 kcal/day, respectively, *p* < 0.001) (figure 4). When divided by body weight, there were no differences between the groups in average daily energy expenditure (men: 90.43 ± 4.82, women: 88.87 ± 3.91, *p* = 0.555).

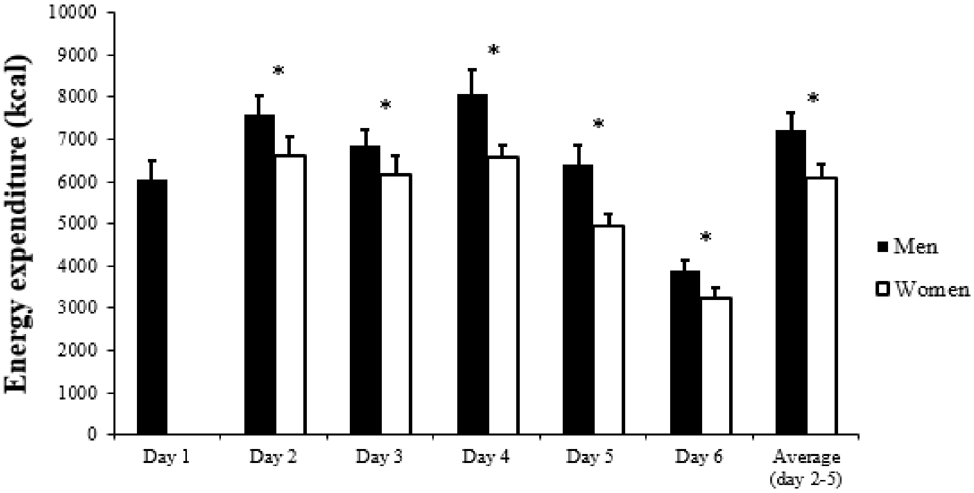

*Figure 4. Energy expenditure during the selection exercise for men and women. * = significant differences between groups. Average energy expenditure was calculated from day 2 till day 5, due to missing measurements from day 1 and the selection exercise finishing half way through day 6.*

Body mass

The men had a significantly higher body mass compared to the women at all time points (figure 5). Both men and women reduced their body mass from pre- to post 0 hours (men: - 6.50 ± 0.21 kg, *p* < 0.001 and women: -2.67 ± 0.29 kg, *p* < 0.001 respectively) and from pre- to post 24 hours (men: -4.42 ± 0.29 kg, *p* < 0.001, women: -1.90 ± 0.29 kg, *p* < 0.001 respectively). The reduction in body mass from pre to post 0 hours and pre to post 24 was significantly lower in the female group compared to the male group (*p* = 0.001). Both groups had regained their initial body mass by the post 72 hours' time point. At post 1 week and post 2 week the male group had increased their body mass compared to the pre-values (1.14 ± 0.25 kg, *p* = 0.001, and 1.77 ± 0.33 kg, *p* <

0.001 respectively). The women did not display a similar increase and the changes from pre-values at these time points were lower in the female group compared to the male group.

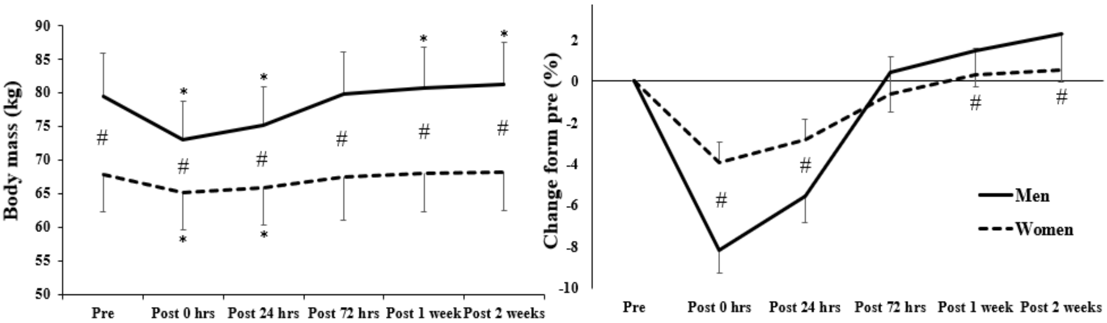

*Figure 5. Changes in body mass (left: total body mass, right: % change from pre) during the recovery period after the selection exercise. * = significant difference from pre-test values in the male group or female group. # = significant difference between groups.*

Lean body mass

The men had a higher total lean body mass compared to the women at all time points (figure 6). The men reduced their lean body mass from pre to post 0 hours (-2.67 ± 0.19 kg, $p < 0.001$) and pre to post 24 hours (-2.04 ± 0.16 kg, $p < 0.001$). It had returned to pre-values at post 72 hours and had at post 1 week increased slightly compared to pre-values (0.69 ± 0.12 kg, $p < 0.001$). The women did not display any major changes in their lean body mass throughout the follow-up period, except for a slight increase at the post 1-week time point (0.56 ± 0.16 kg, $p = 0.020$) There was a significant difference in the percent changes in lean body mass from pre-values between men and women at post 0 hours, post 24 hours and post 2 weeks.

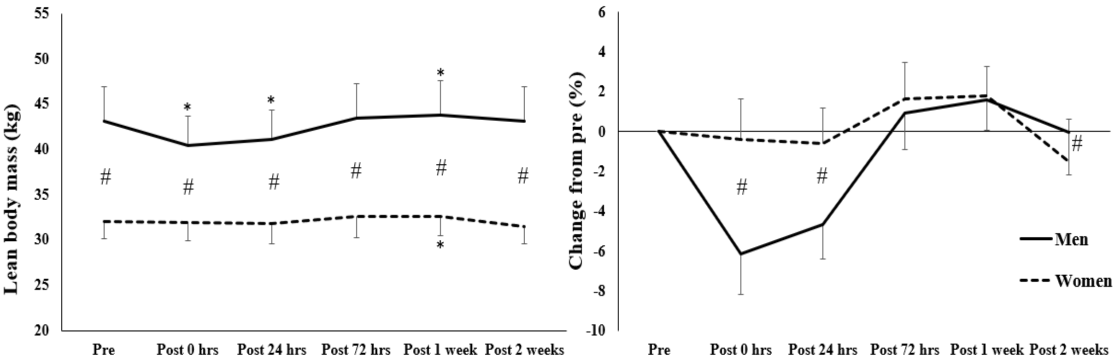

*Figure 6. Changes in lean body mass (left: total lean body mass; right: % change from pre-values) during the recovery period after the selection exercise. * = significant difference from pre-test values in the male group or female group. # = significant difference between groups*

Fat mass

The women had significantly higher fat mass at all measuring points (figure 7). Both the men and women had a significant reduction in absolute values after the selection exercise (men: -1.84 ± 0.25 kg, $p < 0.001$, women: -2.79 ± 0.34 kg, $p < 0.001$) with no differences in percent change between groups. The reduction in absolute fat mass was significantly higher in the women compared to the men ($p < 0.001$). Both groups had regained their initial fat mass 1 week after the exercise (men: $p = 0.161$, women: $p = 0.222$) and had an increase in total body fat 2 weeks after the exercise (men: 2.13 ± 0.22 kg, $p < 0.001$; women: 1.19 ± 0.31 kg, $p = 0.007$). The increase in both absolute values and percent after 2 weeks was significantly larger in the men ($p < 0.001$). There was a significant correlation in the men between initial fat mass and loss of lean body mass ($r = 0.706$, $p < 0.005$) which was not present in the women (figure 8).

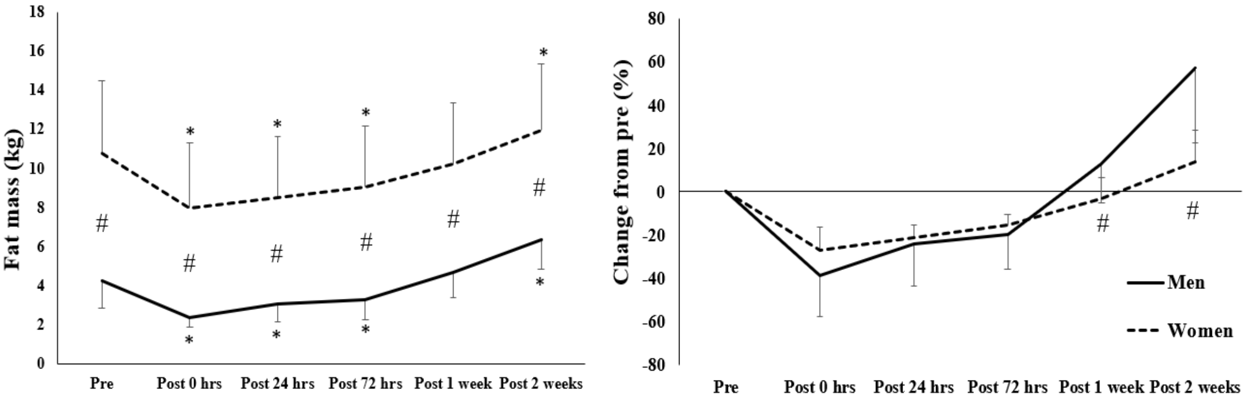

*Figure 7. Changes in body fat mass (left: total body fat, right: % change from pre-values) during the recovery period after the selection exercise. * = significant difference from pre-test values in the male group or female group. # = significant difference between group.*

Correlations between FM at pre-test and loss of LBM

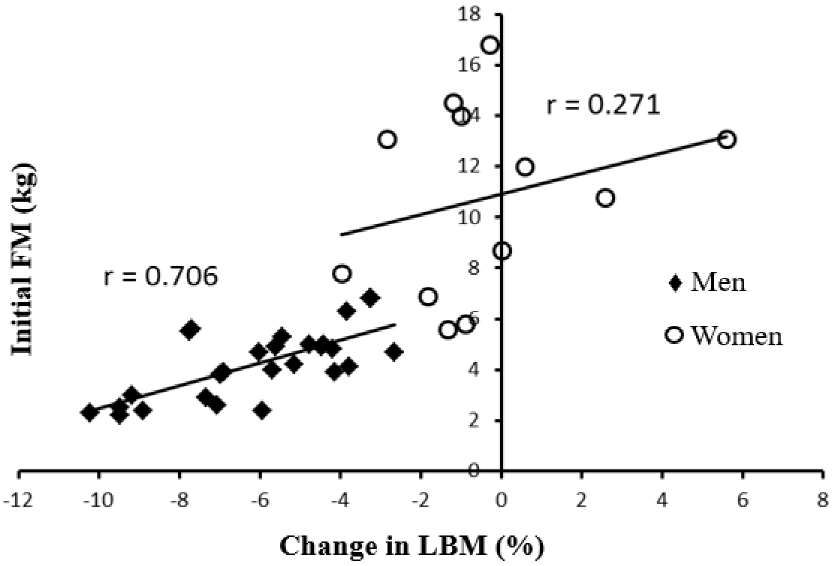

Figure 8. Correlations between initial fat mass (FM) at pre-testing and changes in lean body mass (LBM) after the selection exercise men and women.

Jump performance in counter-movement jump (CMJ).

Jump height

The men had a higher jump height than the women at all time points (figure 9). Both the men and women had a reduction in jump height after the selection exercise (men: -7.46 ± 0.82 cm, $p < 0.001$, women: -5.46 ± 0.98, $p < 0.001$) with no differences between the groups. Recovery was slow and jump height was still significant lowered for both men and women 2 weeks after the selection exercise by -6.63 ± 0.65 cm and -2.69 ± 0.78 cm respectively. The percent reduction in jump height at post 72 hours and post 2 weeks was larger in the men compared to the women ($p = 0.003$ and $p = 0.006$, respectively), indicating a slower recovery in the men. There was also a significant drop in performance between post 24 hours and post 72 hours in the male group (-1.87 ± 0.41 cm, $p < 0.001$) that was not present in the female group.

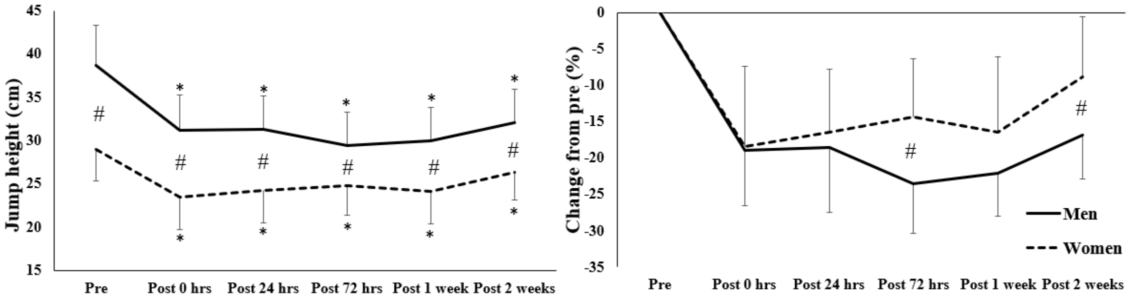

*Figure 9. Changes in jump height performance (left: cm, right: % changes from pre-values) during the recovery period after the selection exercise. * = significant difference from pre-test values in the male group or female group. # = significant difference between groups.*

Maximal power

The men had a significant higher maximal power at all time points (figure 10). The development in maximal power followed a similar pattern to jump height performance with men and women reducing maximal power to the same degree after the selection exercise, followed by a slower recovery in the men compared to the women. After two weeks, the men still had a significant reduction from pre-values (-404,09 ± 51.09 watt, *p* = 0.001) where the women did not (-110,39 ± 60,81 watt, *p* = 1.000).

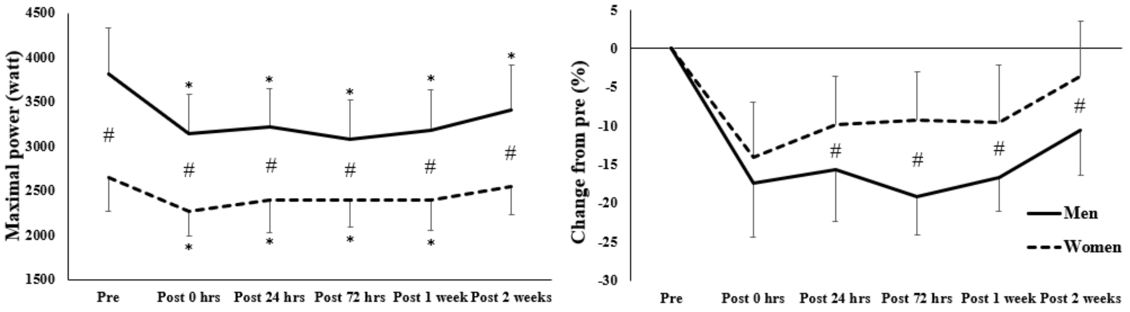

*Figure 10. Changes in maximal power measured by the CMJ test (left: watt, right: % change from pre-values) during the recovery period after the selection exercise. * = significant difference from pre-test values in the male group or female group. # = significant difference between groups.*

Anaerobic work capacity (EVAC test)

Despite men and women dragging dolls of different weight during the EVAC test, the men were significantly faster than the women at pre-testing, post 72 hours, post 1 week and post 2 weeks. Both groups had a significant reduction in performance after the selection exercise (men: -25.3 ± 3.77 seconds, *p* < 0.001, women: -21.4 ± 3.59 seconds, *p* < 0.001), and did not regain their pre-test performance until 2 weeks after the selection exercise (figure 11). There were no differences in changes from pre-values between the groups at any time point.

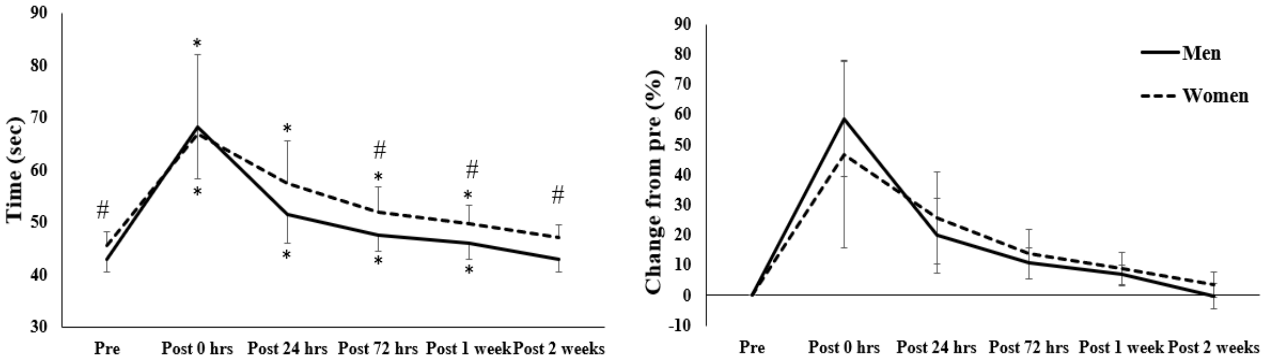

*Figure 11. Change in EVAC test performance (left: seconds, right: % change from pre-values) during the recovery period after the selection exercise. * = significant difference from pre-test values in the male group or female group. # = significant difference between groups.*

Lactate measured after EVAC

Pre-test measurements were equal between the men and women and both groups had a signficant drop in lactate levels after the selection exercise (men: -8.03 ± 0.75 mmol/L, $p < 0.001$; women: -7.60 ± 0.71 mmol/L, $p < 0.001$) (figure 12). Neither men nor women were back to initial levels after 2 weeks (men: -3.76 ± 0.68 mmol/L, $p < 0.001$, women: -4.55 ± 0.65 mmol/L, $p < 0.001$). There was a significantly larger percent reduction in lactate in the women compared to the men at post 72 hours (-14.5 ± 0.62 %, $p = 0.029$) and post 1 week (-11.2 ± 4.87 %, $p = 0.033$). Furthermore, the men had significantly higher lactate values at post 24 hours, post 72 hours, post 1 week and post 2 weeks.

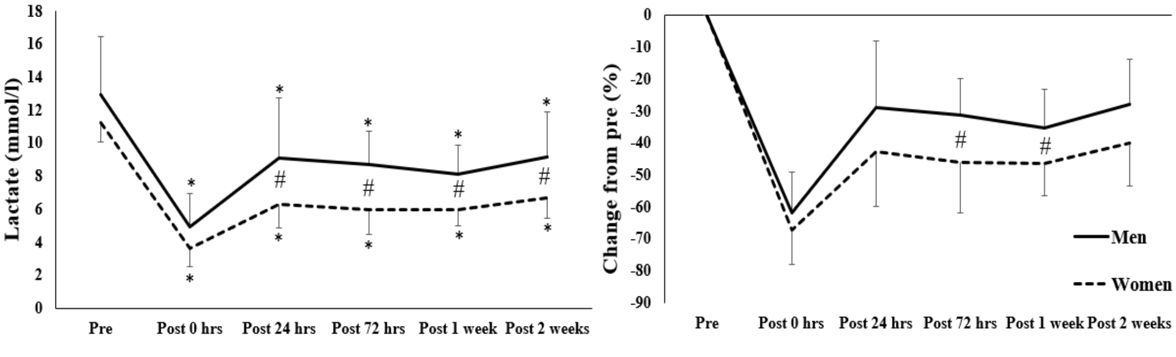

*Figure 12. Change in lactate measurements taken after EVAC (left: mmol/L, right: % change from pre-values) during the recovery period after the selection exercise. * = significant difference from pre-test values in the male group or female group. # = significant difference between groups.*

Medicine ball throw performance (MBT)

The men threw significantly longer compared to the women at all time points (figure 13). Both groups had reduced performance after the selection exercise to a similar degree (men: -0.54 ± 0.74 meters, *p* = 0.001, women = -0.42 ± 0.09 meters, *p* = 0.001). Both men and women were back to pre-values after 1 week of recovery. There were no differences in change from pre-values between the groups at any time point.

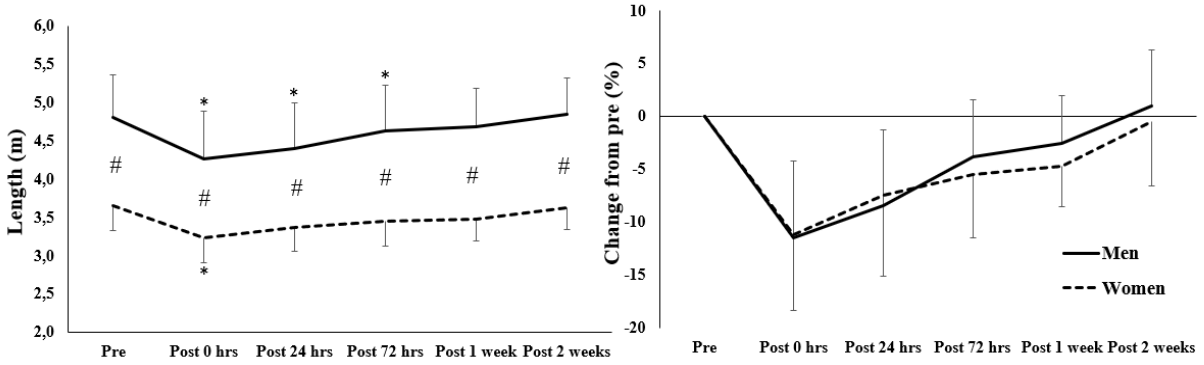

*Figure 13. Change in MBT performance (left: meters, right: % change from pre-values) during the recovery period after the selection exercise. * = significant difference from pre-test values in the male group or female group. # = significant difference between groups.*

Discussion

In the present study we investigated if there were any sex differences in the physiological response to a very demanding military field exercise. We found that men had a larger reduction in body mass and lean body mass after the field exercise compared to women. All changes in body composition returned to pre-values after 1 week, and both groups had increased their fat mass 2 weeks after the exercise. There was a similar drop in physical performance on all tests following the field exercise for men and women. The recovery of jump height and maximal power in the CMJ was slow for both sexes, but interestingly, the recovery was faster in the women compared to men. There were no sex differences in the recovery of anaerobic performance or muscle strength in the upper body.

Body composition

The changes in body composition after the selection exercise in our study are similar (10) or greater than other studies on FEX of similar length (11, 8, 13). The fact that our study yielded similar decrements in body composition as the NORNAVSOC study is likely due to the exercises being similar in content and duration (10). Why we found greater decrements in lean body mass and fat mass compared to other studies on military field exercises is also likely due to variations in content and duration (8, 13). FEX studied by Nindl and colleagues (2002) and Welsh and colleagues (2008) of 72 hours and 8 days duration, respectively, were less physical strenuous indicated by the measured total energy expenditure (8, 13). The 72 hours sustained operation estimated a total energy expenditure of ~4500 kcal/day, which is much lower than what was estimated during our selection exercise (8). Similarly, the 8-day field exercise studies by Welsh and colleagues (2008) had an energy deficit of ~2300 kcal/day, which is far less than in our study (men: -6535 kcal/day, women: -5341 kcal/day) (13). There were smaller decrements in body composition in our study compared to studies of longer durations (1, 6, 15, 9). During the US Army Ranger Course (62 days), soldiers experience long periods of caloric deficits and high activity. Similar levels of activity and caloric deficits to our study would, however, not be sustainable for the duration of the Ranger Course (6, 1, 9). Smaller caloric deficits per day were however still sufficient to yield changes in body composition, and as the Course was of longer duration than our study the decrements are likely to be greater.

One of the most intriguing findings in the current study was that men lost more body mass during the selection exercise compared to women, and that this mainly because of a larger loss of lean body mass. In fact, the women were able to preserve their lean mass during the selection exercise. That men lose more body mass and lean body mass than women after FEX are in line with what Hoyt and colleagues (2006) observed when comparing changes in body composition in male and female soldiers after a 7-day strenuous military exercise (15). They also found a smaller reduction in LBM in women compared to men (15). This suggests that the women maintain a fat-dominant fuel metabolism throughout the selection exercise, which has been observed in studies examining sex differences in substrate utilization (15, 23). The increased contribution of fat metabolism and reduced contribution from carbohydrate and protein is a likely explanation for the different changes in body composition between men and women (15). During periods of extreme underfeeding, like the current study, there have been observed an increased contribution from FFM in total body mass reductions. However, since substrate metabolism in women utilize less glycogen this may reduce protein use for gluconeogenesis, eventually reducing loss of lean body mass (15). The men did lose a higher amount of body mass after the selection exercise. As mentioned, the FEX for the men and women are held separately. It is likely that there are differences between activities conducted during the week and the measurements of energy expenditure did display a higher estimated activity level in the male group compared to the women. It was therefore expected that the men would reduce their body mass more. However, this alone is not likely enough to explain the major differences in body composition changes between the groups. For example, it does not explain the fact that women lost only FM, and no LBM whereas the men lost both. A higher FM before the FEX may perhaps be the cause of the lack of reduced LBM in women. Furthermore, previous studies have suggested that an additional FM may be protective against the decremental effect military training involving caloric deficits has on lean body mass (10). It is worth noting that this was measured in a male subject group, and it is unknown if that is the cause of the lack of decrements in LBM we have seen in the female group. Importantly, the initial FM at pre-testing displayed a positive correlation with reduction in LBM in the men ($r = 0.706$), suggesting that a higher FM led to a smaller decrement in LBM. The male participants who had an initial FM similar to the women lost the least amount of LBM after the FEX. This correlation was not apparent in the women. This may be explained by the fact that women did not lose any significant amount of LBM following the FEX. On the other hand, studies have shown that female fat metabolism is higher than male even when expressed relative to body composition (23), indicating that the different FM at pre-testing is not the only explanation.

The course of recovery of body mass, LBM and FM in the current study was comparable to results from the NORNAVSOC study. Whereas the NORNAVSOC subjects did not regain their body mass until one week after the exercise, and our subjects were back to pre-values after 72 hours. In LBM, the NORNAVSOC study saw an increase after 72 hours that continued at the post 1-week time point (10). Both groups in our study had an increase in LBM 1 week after the exercise. They did however have a higher rate of gain in FM when comparing to the NORNAVSOC study (10). Both the men and the women in our study had an increased LBM 1 week after the exercise and increased FM 2 weeks after the exercise compared to pre-values. The increases in both groups are likely due to an increased caloric intake in the recovery period. The study by Nindl and colleagues (1997) saw a similar increase in body mass and FM after the US Army Ranger Course. Post-exercise dietary recall data found that food consumption was greater after the exercise than before and that the diet had a higher concentration of "fatty foods" (1). The soldiers' service following the selection exercise is less strenuous and there were no restrictions on food consumption. To compensate for the loss of body mass, it is likely that the soldiers had a high energy intake and a low physical activity level, making gains in FM and body mass likely. Changes in muscle glycogen may also affect the changes in LBM. Furthermore, the soldiers are encouraged by their commanders to consume more food than normal during this period. Prior to the selection exercise, the soldiers go through 3 weeks of basic training. This period involves a high amount of physical activity, and it is likely that the soldiers already had experienced changes in body composition at the pre-testing. The increase may therefore also reflect a return to initial levels of FM and LBM from before basic training.

Physical performance

The reduction in CMJ jump height performance was similar in both groups and is comparable to those found in the NORNAVSOC study (10). The reduction was however greater than the previously mentioned 8-day sustained operations exercise where jump height was reduced by only 5,2% (13). Again, the larger reduction in our study is likely due to a higher level of activity and a larger caloric deficit. Both groups still had significant reductions in explosive power measured through jump height at the two-week time point, in addition to maximal power in the male group. These results are similar to results from the NORNAVSOC selection week study, where CMJ jump performance had not recovered after two weeks (10). The reduced jump performance outlasts the changes in body composition, making it clear that LBM and FM are not the sole cause of reduced performance in this test. Furthermore, had body composition been the main determent of physical performance, there should have been a lower reduction in performance in the female group compared to the men. Muscle function is assumed to be more sensitive to catabolism than body composition, and it has been suggested that it is muscle damage rather than solely atrophy which causes the reduction (1, 10). Due to CMJ performance being determined by rate of force development, Hamarsland and colleagues suggest that this is an indication of preferential damage to type II fibres (10). Hormonal changes, structural changes in muscle and joint tissue or neural fatigue are also suggested to contribute to the changes and long-lasting recovery process (10). Nindl and colleagues reported that jump performance in Ranger soldiers were recovered after five weeks (1). This may indicate that certain physical attributes require between two and five weeks to fully recover, because CMJ performance still was reduced 2 weeks after the selection exercise in both our study and the NORNAVSOC study, whereas the other performance tests in both studies had returned to pre-values. This suggests that the mechanisms that are yet to recover primarily are related to explosive strength. For example, it is possible that tendon stiffness and the elastic properties of the muscle are affected by the strenuous field exercise, and this may influence the depressed jump performance. However, this is only a speculation and must be examined further.

The women had smaller reductions than men in both jump height and maximal power when compared to pre-values after 2 weeks of recovery. This indicates that the women had faster recovery of explosive strength than the men after the selection exercise. The difference in recovery between men and women may be attributed to several factors. Firstly, there were differences in changes in body composition as a result of the selection exercise where the women did not lose any FFM. Even though changes in body composition may not be the sole reason for performance reductions, it may still be relevant because leg muscle mass is a determinant of performance in vertical jump tests (24, 17). The men needed to regain muscle mass in addition to other factors linked to performance that may have affected the duration of recovery. As discussed, it is likely other mechanisms that are not reflected in lean body mass that cause some of the prolonged reduced jump performance, and these were discussed above. However, as we can only speculate in these mechanisms it is difficult to determine which of them may differ between the sexes. A possible reason for the sex differences may that the selection exercise may be slightly different between the men and women, as discussed earlier. Differences in strain or activities during the selection exercise may be a cause of differences in recovery. However, the two selection exercises were designed to be similar in content and aims. The fact that differences in energy expenditure disappeared when they were normalized for body mass indicated that the exercises were equally strenuous in relative terms. This is further supported by the fact that there were no sex differences in the reductions of performance from pre to post 0 hours. One interesting difference in recovery in CMJ performance were that men exhibited a secondary reduction of CMJ jump height and maximal power between the post 24 hours and post 72 hours' time point that was not apparent in the women. A secondary reduction of performance has previously been observed in studies on neuromuscular fatigue and recovery. Raastad and Hallén (2000) saw a significant reduction in force 22 hours after an exhausting strength training protocol (25). Gathercole and colleagues observed a reduction in CMJ and drop-jump performance 72 hours after an exhausting running protocol (26). The reduction is believed to be caused by a delayed exercise-induced mechanism (17). This mechanism is likely a neural and mechanical response to muscle damage and corresponding inflammatory and structural remodelling processes (26). Further investigations involving muscle biopsies are needed to confirm this.

EVAC test performance was reduced in both groups after the selection exercise, but there were no differences in the reduction or rate of recovery between the men and women. Other studies on the effect of military FEX on anaerobic performance have yielded conflicting evidence. Guezennec and colleagues (1994) have previously found no effect whereas Legg & Patton (1987) observed a decrease in lower body peak and mean power in the Wingate test, (12, 11). Nindl and colleagues also observed decrements in ballistic power tests of the lower extremities (8). This supports the notion that military field training may influence anaerobic performance, depending on the content. The difference in findings may yet again be attributed to difference in content of the field exercises. The selection exercise in our study is likely a more strenuous, and with a higher caloric deficit than the field exercise studied by Guezennec and colleagues (1994) (11). Maximal lactate levels were also reduced after the selection exercise and did not return to pre-values after two weeks of recovery. The difference between recovery of EVAC test performance and lactate blood values is interesting. However, there has previously been observed a significant correlation between type II muscle fibre and peak post exercise blood lactate (27). This might support the notion that the reduction in rate of force development measured through the CMJ is to some extent caused by changes in muscle fibre composition suggested by Hamarsland and colleagues (in press) (10). The EVAC test has been validated against several anaerobic performance tests with significant correlations (19). However, it did not correlate with the MAOD test, suggested to be the only "real" anaerobic capacity test. There is a possibility that the test is not sufficiently sensitive to uncover minor changes in anaerobic performance. It is also possible that the lack of correlation with the MAOD test is because the duration of the EVAC test is insufficient to measure the entirety of anaerobic capacity and is rather a measure of anaerobic power.

The MBT performance had returned to pre-values after one week of recovery with no differences between the sexes. The reduced performance observed in upper body strength is similar to the NORNAVSOC study (10) and greater than other studies on FEX (Nindl et al, 2002). This is also likely attributed to differences in content of the field exercise, and our study being more strenuous on the upper extremities. The course of recovery was faster than what was observed in the NORNAVSOC study, where chest press performance was not regained until two weeks after the field exercise (10). The MBT test has shown good correlations with the 1RM bench press and should therefore be a valid measure of upper body strength (28). This may indicate that the strain on the upper body was lesser in the current study compared to the NORNAVSOC study. Supporting this, the reduction in MBT is also smaller than what was seen in CMJ and EVAC performance, indicating a larger strain on the lower body during the selection exercise. The difference in effect on extremities is observed in several other studies, where a higher component of strain on the lower body is prevalent (8, 29, 10). This is a likely explanation for why depression of lower body performance measured through the CMJ outlasts upper body performance measured through MBT.

Limitations of the study

Measurements of aerobic capacity and how the selection exercise affected this capacity as well as the course of recovery was not included in this study. Initially, there was an aerobic test included in the test-battery, but due to time constraints during the post-tests the measurement was cut. Later studies should include aerobic measurements, as it is central to task demands of military service and literature has previously seen reductions in cardiorespiratory fitness following FEX in men. However, possible sex differences have not been investigated.

Another limitation is that the selection exercise is carried out separately for men and women. This increases the chances of differences in physical strain or other components and may influence the results. However, as the content and aim of the exercises and relative energy requirement are similar this is not likely to have had a large impact on the results.

After the selection exercise, several of the soldiers had injuries of a varying degree which limited participation on different time points. The study sample was therefore reduced. To counteract this missing data and increase the study sample, missing values were calculated for persons who missed one of the subsequent post-tests. This increased the number of subjects to an acceptable amount.

Practical implications

As physical performance was still depressed two weeks after the termination of the selection exercise, it is evident that the soldiers still had not recovered at this time. This should be considered when planning military training regimens. Solberg and colleagues (2015) suggested that frequent maximum intensity training combined with a strenuous job caused a high rate of training-related injuries in Special Forces Operators (30). High frequencies of demanding FEX without adequate periods of rest may further increase the risk of injuries. There was no evidence in our results that indicated FEX having a larger impact on woman compared to men, supporting the notion that women are physically capable of military service. If anything, the female soldiers coped with the FEX better than men expressed through the faster recovery of CMJ performance and lack of LBM reductions. However, it is worth noting that absolute physical performance values were lower in women compared to men. This is important to bear in mind when planning and executing military operations with both male and female soldiers. As our study has shown significant decrements in physical performance after FEX, it is evident that a high level of physical fitness is needed for successful performance in military service. Having fitness levels above the requirements would allow the soldiers to still perform at high levels even in the presence of a performance drop caused by operational stress (9).

Conclusion

There were significant decrements in body composition and physical performance in both men and women after the selection exercise. Changes in body composition were recovered one week after the exercise, while physical performance in CMJ was still reduced after two weeks of recovery. Depression in performance outlasted changes in body composition, indicating that these changes are not the sole reason for reduced physical function after the military exercises. There were differences between men and women in body composition changes, where the men lost more lean body mass than the women. It is likely that the differences are caused by the better ability in women to utilize fat at submaximal intensities and a higher initial fat mass, and a possible difference in caloric restriction. There were also differences in recovery of the CMJ, where women had a faster recovery in both jump height and maximal power. The cause of this is harder to determine but may be linked to the changes in body composition as well as mechanisms not uncovered through our test battery.

This study is a unique insight into the Special Forces environment and provides particularly interesting results from a selection exercise that is unlike most others. An opportunity to study a physically fit male and female group of Special Forces candidates that undergo a similar extremely strenuous military field exercise is rare. The results are unique and is an excellent basis to construct further studies on. As previously mentioned, studies on the mechanisms behind the delayed reduction in performance and sex differences would be of importance.

Conflicts of interest

The author declares no conflicts of interest

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