JYU DISSERTATIONS 431

Kai Pihlainen

Effects of Combined Strength and Endurance Training on Body Composition and Physical Fitness in Soldiers During a 6-Month Crisis Management Operation

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF SPORT AND HEALTH SCIENCES

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Esitetään Jyväskylän yliopiston liikuntatieteellisen tiedekunnan suostumuksella
julkisesti tarkastettavaksi yliopiston vanhassa juhlasalissa S212
lokakuun 30. päivänä 2021 kello 12.

Academic dissertation to be publicly discussed, by permission of
the Faculty of Sport and Health Sciences of the University of Jyväskylä,
in building Seminarium, old festival hall S212 on October 30, 2021 at 12 o'clock.

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2021

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Cover picture by Kai Pihlainen

ISBN 978-951-39-8845-6 (PDF)
URN:ISBN:978-951-39-8845-6
ISSN 2489-9003

Permanent link to this publication: http://urn.fi/URN:ISBN:978-951-39-8845-6

“Sweat more during peace; bleed less during war”

Sun Tzu (544-496 BC)

ABSTRACT

Pihlainen, Kai
Effects of combined strength and endurance training on body composition and physical fitness in soldiers during a 6-month crisis management operation
Jyväskylä: University of Jyväskylä, 2021, 113 p.
(JYU Dissertations
ISSN 2489-9003; 431)
ISBN 978-951-39-8845-6

The aim of this thesis was to study a) physical activity, workload and stress in soldiers, b) effects of combined strength and endurance training on body composition and physical performance, and c) training-induced changes in endurance performance during a 6-month crisis management operation in Lebanon. In addition, d) a novel military simulation test (MST) was used to study associations between physical fitness, body composition and occupational performance variables in soldiers. Ninety-one male soldiers voluntarily took part in the baseline measurements. Blood and saliva samples, multifrequency bioimpedance analyses, neuromuscular, endurance and military-specific performance tests, and physical activity recordings were performed on three occasions during the operation in Lebanon. After the baseline measurements, the soldiers were randomly allocated to either the control group or one of the three combined strength and endurance training groups, which included different ratios of strength and endurance training. The main results indicated that a) soldier physical workload and stress level were low during the operation and their hormonal profiles indicated a sufficient recovery state; b) soldiers provided with a training program were able to maintain or improve their fitness level in all measured physical performance variables during deployment, whereas muscular power of the lower extremities decreased in the control group; c) soldiers whose endurance performance decreased during the intervention were initially physically fitter, had more muscle mass and less fat mass than their counterparts who were able to maintain or improve their endurance performance. Furthermore, d) muscular power of the lower extremities, aerobic fitness and muscle mass were positively associated with a higher MST performance. To conclude, physical attributes affecting soldier readiness during high-intensity work include aerobic fitness, muscular power of the lower body and muscle mass. Several of these variables were susceptible to decline in soldiers who were initially fitter. Thus, individually designed combined strength and endurance training with proper periodization should be implemented for soldiers during deployment. Moreover, the volume of endurance training should be at least as high as each individual's existing level prior to the operation to attenuate decrements in aerobic fitness and operational readiness.

Keywords: Military, Deployment, Physical activity, Concurrent training.

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TIIVISTELMÄ (FINNISH ABSTRACT)

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Yhdistetyn voima- ja kestävyysharjoittelun vaikutukset kehon koostumukseen ja fyysiseen toimintakykyyn kuuden kuukauden kriisinhallintaoperaation aikana.
Jyväskylä: University of Jyväskylä, 2021, 113 s.
(JYU Dissertations
ISSN 2489-9003; 431)
ISBN 978-951-39-8845-6

Väitöskirjan tarkoituksena oli tutkia a) fyysistä aktiivisuutta ja kuormittavuutta, b) yhdistetyn voima- ja kestävyysharjoittelun vaikutuksia kehonkoostumukseen ja fyysiseen toimintakykyyn, c) kestävyyskunnon muutoksia selittäviä tekijöitä kuuden kuukauden kriisinhallintaoperaation aikana Libanonissa. Tutkimuksessa selvitettiin lisäksi d) sotilastyötehtäviä ja taistelukentällä vaadittavia liikesuorituksia simuloivan tehtäväradan suoritusaikaan yhteydessä olevia muuttujia. Yhdeksänkymmentäyksi vapaaehtoista miessotilasta otti osaa alkumittauksiin. Veri- ja sylkinäytteenotto, monitaajuuksinen bioimpedanssi-analyysi, lihasvoima- ja kestävyyskunto- sekä tehtäväratamittaukset ja fyysisen aktiivisuuden rekisteröinti toistettiin kolme kertaa operaation aikana. Alkumittausten jälkeen sotilaat arvottiin satunnaisesti joko verrokkiryhmään tai yhteen kolmesta yhdistetyn voima- ja kestävyysharjoittelun ryhmistä, joissa voima- ja kestävyysharjoittelun määrän suhde vaihteli ohjelmien välillä. Tutkimustulokset osoittivat, että a) operaation aikainen fyysinen kuormitus oli varsin alhainen ja fysiologiset muutokset viittasivat parantuneeseen palautumistilaan, b) ohjelmoidun harjoittelun ryhmissä fyysinen kunto kehittyi tai säilyi lähtötilanteen tasolla kaikissa mitatuissa muuttujissa, mutta verrokkiryhmällä alaraajojen räjähtävä voimantuotto heikkeni, c) kestävyyskuntoaan operaation aikana heikentäneiden sotilaiden fyysinen kunto oli lähtötilanteessa korkeampi ja heillä oli lisäksi enemmän lihasmassaa ja vähemmän rasvamassaa kuin sotilailla, jotka kykenivät parantamaan kestävyyskuntoaan operaatioalueella. Lisäksi d) suurempi alaraajojen räjähtävä voima, parempi kestävyyskunto ja suurempi lihasmassan määrä olivat korrelatiivisessa yhteydessä sotilastyötehtäviä simuloivan testin suoritusaikaan. Tutkimustulokset korostavat sotilaan monipuolisten kunto-ominaisuuksien (kestävyyskunto, alaraajojen räjähtävä voimantuotto, lihasmassa) merkitystä operatiivisessa työssä. Kyseiset ominaisuudet ovat alttiita heikkenemään pitkien sotilasoperaatioiden aikana erityisesti hyväkuntoisilla sotilailla. Tutkimustulokset puoltavat yksilöllisen yhdistetyn voima- ja kestävyysharjoitteluohjelman käyttöönottoa, ja erityisesti kestävyysharjoittelua tulisi jatkaa operaatiota edeltäneellä tasolla, jotta kestävyyskunto ja sotilaallinen valmius pystyttäisiin ylläpitämään nopeasti vaihtuvissa operatiivisissa olosuhteissa.

Avainsanat: Sotilas, sotilasoperaatio, fyysinen aktiivisuus, yhdistetty harjoittelu.

ACKNOWLEDGEMENTS

There might have been easier ways to get the PhD done than performing the data collection in the middle of a war zone in the Middle East. However, following the example and work ethics of my supervisor and prior boss Matti Santtila it felt worth the effort. Matti, your passion for work and example of building up your PhD thesis while working as a Chief of the Physical Education in the Training Division of the Finnish Defence Command has inspired me since the beginning. Thank you for your example of the right attitude and encouragement through this long journey! I am also deeply grateful for the support and experience Professors Heikki Kyröläinen and Keijo Häkkinen have provided me as my supervisors. Thank you for seeing enough potential in me and in the thesis topic to accept "us" under your wings. Heikki, you have always, weekdays or weekends, mornings or evenings, given time and commitment to support me in the challenging phases. Keijo, you have mastered the scientific field of developing and testing physical performance for several decades and it can be perceived in everything you do. You have been leading and guiding me to stay on the right path along the whole process.

I also wish to express my gratitude to the reviewers of my thesis, Glyn Howatson and Dan Billing, who took the time needed to gain familiarity with my work and contributed valuable comments. I am extremely proud and grateful for Professor Bradley Nindl for kindly accepting the invitation to serve as my opponent in the public defense of this dissertation.

So many individuals from the Finnish Defence Forces made important decisions to make the study arrangements possible before and during the deployment, and it is not justifiable to the others to name one or some. Based on fairness, it may be more suitable to express my special gratitude to the organization, my employer, the Finnish Defence Forces, for offering the opportunity to perform this PhD study in Lebanon. However, without study participants there would be no results. I am grateful for all those soldiers who shared their time and voluntarily took part in numerous measurements of the study during the deployment.

At this point, I want to acknowledge biomedical laboratory technician Pasi Ollila, with whom I had the chance to spend six months in the military base while performing the data collection for the thesis. Pasi participated to every possible measurement of the study. Only his blood sampling duties kept him away from supporting me with the other phases (measurements, data transfer etc.) of the study. We became good friends during our stay in Lebanon and we share many good memories that will last a lifetime. During the three measurement phases of the study, I also received personnel support from Finland to conduct the tests. These personnel of the Finnish Defence Forces were carefully selected, representing the best knowledge of the methods being used. In alphabetical surname order, my warm thanks go to Henry Forss, Joonas Helén, Manne Isoranta, Petri Mynttinen, Tarja Nykänen, Tommi Ojanen and Matti Santtila. In addition, I want to thank Harri Rintala for supporting the tests at the final measurement phase while, at the same time, collecting data by interview method for other study purposes. In addition, special thanks to Tommi Vasankari and Henri Vähä-Ypyä, UKK-institute for health promotion research, for methodological support in assessment of physical activity and Tommi, also for being a co-writer in the first article of my thesis.

I am grateful for MATINE, the Scientific Advisory Board for Defence (Finland) and the Defence Support Foundation for the financial support, and Johanna Stenholm, Mia Laakso and Moona Myllyaho for their assistance in the data analyses, and Risto Puurtinen and Aila Ollikainen for their blood analyses in Jyväskylä. Especially, I want to thank Elina Vaara and Jani Raitanen for the assistance in the statistical analyses. Also, many thanks for my current boss Lasse Torpo for providing me support in the writing phase of the thesis and for Jouni Ilomäki for being a great co-worker.

It would be unfair not to acknowledge my friends for maintaining social balance throughout these years of studies. Especially, I want to thank my volleyball friends, Antti, Peetu, Rami, Povis, Henkka, Tuomas, Teemu, Tero, Hessu, Ville, Miksu, Kim, Jussi, Kopse, Harri and Panut, for your friendship. Equally, I want to express my gratitude to some of my work-related friends, Jani Vaara, Tommi Ojanen and Tuomas Honkanen, for the inspiring conversations and good time we have had, with exercise science binding us together along the way.

Finally, and most deeply, I want to thank my family, Aulikki, Velmu and Asier for your patience and understanding to give me the time for studies which occasionally may have felt never-ending. Well, now it is done. Love you all!

Helsinki 2.9.2021
Kai Pihlainen

LIST OF ORIGINAL PUBLICATIONS

The present thesis is based on the following original research articles, which are referred to in the text by their Roman numerals:

I **Pihlainen K.**, Santtila M., Vasankari T., Häkkinen K., Kyröläinen H. 2018. Evaluation of occupational physical load during 6-month international crisis management operation. International Journal Occupational Medicine and Environmental Health 31(2), 185-197.

II **Pihlainen K.**, Santtila M., Häkkinen K., Kyröläinen H. 2018. Associations of Physical Fitness and Body Composition Characteristics With Simulated Military Task Performance. Journal of Strength and Conditioning Research 32(4), 1089-1098.

III **Pihlainen K.**, Kyröläinen H., Santtila M., Ojanen T., Raitanen J., Häkkinen K. 2020. Effects of combined strength and endurance training on body composition, physical fitness, and serum hormones during a 6-month crisis management operation. Journal of Strength and Conditioning Research. Publish ahead of print Dec 17, 2020.

IV **Pihlainen K.**, Häkkinen K., Santtila M., Raitanen J., Kyröläinen H. 2020. Differences in Training Adaptations of Endurance Performance during Combined Strength and Endurance Training in a 6-Month Crisis Management Operation. International Journal of Environmental Research and Public Health 17(5), 1688.

The author of this thesis, who is the first author of the abovementioned publications, was mainly responsible for designing the studies, leading and participating in the collection of data during the crisis management operation. He was also responsible for leading data analyses, interpreting results, preparing the manuscripts, and managing the review process during publication procedures.

ABBREVIATIONS

1RM	One repetition maximum
3000-m	Three kilometer running test
ACSM	American College of Sports Medicine
ADP	Adenosine diphosphate
AMP	Adenosine monophosphate
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
BIA	Bioelectrical impedance analysis
BLa	Blood lactate
BM	Body mass
BMI	Body mass index
CMJ	Countermovement jump
COR	Cortisol
DXA	Dual-energy X-ray absorptiometry
DMR	Dead mass ratio
ECW	Extracellular water
EMG	Electromyography
FATM	Fat mass
HiR	High responder
HIT	High-intensity endurance training
HR	Heart rate
HR_{peak}	Peak (i.e. highest measured) heart rate
ICW	Intracellular water
IDF	Israeli Defence Forces
IED	Improvised explosive device
IGF-1	Insulin-like growth factor-1
ICC	Intraclass correlation coefficient
LAF	Lebanese Armed Forces
LB	Lower body
LIT	Low-intensity endurance training
LoR	Low responder
MET	Metabolic equivalent
MID	Middle measurement phase
MIT	Moderate-intensity endurance training
MOS	Military occupational specialty
MST	Military simulation test
MVC_{lower}	Maximal isometric force of the lower extremity extensor muscles
MVC_{upper}	Maximal isometric force of the upper extremity extensor muscles
NATO	North-Atlantic Treaty Organization
PA	Physical activity
PCr	Phosphocreatine
POST	Final measurement phase
PRE	Baseline measurement phase

RM	Repetition maximum
RPE	Rating of perceived exertion
saAA	Salivary alpha-amylase
saCOR	Salivary cortisol
SEM	Standard error of measurement
SHBG	Sex hormone binding globulin
SJL	Standing long jump
SMM	Skeletal muscle mass
TBW	Total body water
TES	Testosterone
UB	Upper body
UN	United Nations
UNIFIL	United Nations Interim Forces in Lebanon
UNP	United Nations Post
U.S.	United States
VO_2max	Maximal oxygen consumption
VO_2peak	Peak oxygen consumption

CONTENTS

1 INTRODUCTION

Some ten years after World War II, the Training Division of the Finnish Defence Command published a « Warfighter Manual », which dramatically described the physical demands of combat for human performance as follows:

> "Locomotion in the battle field, patrolling, guerilla warfare, marching and the use of tools require grit and physical fitness. Changes in temperature and weather, temporary lack of food and other abnormal circumstances require hardiness and resilience"… "Sometimes, the circumstances may feel overwhelming. The nerves of some of your friends may break, someone may even collapse due to the shock of combat. You may even start to dream of easier environments. Endurance and stamina are required at these moments. Do not let down your superiors and comerades, have trust in them, as they have trust in you too."[1]

Despite technological development and efforts to lighten the occupational physical workload of soldiers, numerous studies have confirmed that even in the 21st century, the military working environment is still physically and psychologically demanding compared to many civilian occupations, even during peace time (Tharion et al. 2005). A soldier's daily energy expenditure typically varies between 4000 and 5000 $kcal \cdot d^{-1}$ during military field training and deployment (Barringer et al. 2018; Kyröläinen et al. 2008; Tharion et al. 2005). Common military field tasks including marching, manoeuvring in varying terrain, and manual materials handling such as lifting or carrying loads and shovelling, are often performed in protective clothing and in a prolonged manner (Henning et al. 2011; Sharp et al. 1998). According to Boye et al. (2017), U.S. Army soldiers spend more time performing physically demanding tasks (but not physical training) during deployment than when not on deployment. In such circumstances, tasks are often performed without the possibility to control the workload via pacing or recovery periods, which may induce central and/or peripheral fatigue.

In combination with fatiguing work itself, soldiers may encounter physiological challenges such as negative energy balance, sleep deprivation and hot or cold ambient temperatures during their operative duties (Henning et al.

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1 Warfighter Manual, Defence Command Finland, 1956 (personal translation)

2011; Nindl et al. 2013). Environmental hazards, including air pollutants, mines, improvised explosive devices and the threat of direct enemy fire may significantly increase the cognitive load and mental stress of soldiers during military operations. These life-threatening risk factors emphasize the need for maintenance of continuous vigilance and readiness during operative duties.

The ability to perform a wide variety of military occupational duties demands a high level of muscular and aerobic fitness in soldiers. However, the most optimal methods of developing or maintaining physical and occupational performance during a prolonged military deployment are still under debate. Furthermore, adaptation of muscular strength and particularly power appears to be compromised by concurrent strength and endurance training compared to training the same volume of either mode separately (Fyfe et al. 2014; Häkkinen et al. 2003; Wilson et al. 2012). This is a particular concern in basic military training, which typically includes a high volume of prolonged low-intensity physical activity, which may interfere with neuromuscular performance adaptations (Kyröläinen et al. 2018; Santtila et al. 2009a).

General physical fitness measures are often set as requirements for military occupations, and variables such as cardiorespiratory fitness, lower body strength and upper body muscular endurance have been shown to be relevant for several military occupational tasks (Hauschild et al. 2017). In addition to traditional fitness tests, the occupational physical performance of soldiers is assessed using military specific simulations in many countries. According to the development process of physical employment standards presented by the North Atlantic Treaty Organization (NATO 2019), task-specific tests are typically used to study associations between occupational performance and physical fitness variables, and for setting the minimum criteria for military training or employment to physically demanding military positions.

While many studies have evaluated the physiological stressors experienced by soldiers during military field training, as well as strength and/or endurance training adaptations to physical performance in non-deployed soldiers, limited information is available concerning the abovementioned variables collected during prolonged international deployments (Dyrstad et al. 2007; Warr et al. 2013). The present study was designed to investigate physical workload during a 6-month crisis management operation (study 1) in Lebanon. The second aim was to study associations between a novel, occupationally relevant military simulation test and physical fitness variables (study II). Finally, changes in body composition and physical fitness of soldiers due to combined strength and endurance training during a military operation (study III) with an additional focus on endurance training adaptations (study IV) were investigated.

2 REVIEW OF THE LITERATURE

2.1 Terminology

The present section describes the key terminology of the thesis. Here, the term "soldier" and the scope of this thesis are limited to current military occupational subgroups (i.e. specialties) who typically perform their duties on foot, are subjected to load carriage, and face the possibility of direct enemy contact. Such occupational specialties mainly operate within the Army, but similar duties also exist within the Air Force and the Navy. Further, the literature review of the present thesis focuses only on males, as the participants in the four studies that make up this thesis did not include females.

A commonly used term within the military context, "readiness", is defined as the capability of a soldier to meet or overcome the physical demands of any duty to accomplish the mission successfully. Thus, it is a combination of physical and mental (including cognitive) capabilities.

"Physical activity" refers to body movement that results in an increase in energy expenditure. Accordingly, physical activity can be viewed as a continuum where one end refers to inactivity (e.g. resting metabolism) and at the other end is the highest possible physical exercise intensity an individual can perform (Kyröläinen et al. 2003b, 15).

"Physical fitness" refers to a measure of the functional ability of the body to manage in activities involving physical exertion (Kyröläinen et al. 2003b, 12). The main components of physical fitness include aerobic fitness, muscular fitness and mobility and agility. The focus of the present study was on aerobic fitness and muscular fitness (TABLE 1).

Aerobic fitness (i.e. cardiorespiratory fitness, cardiovascular fitness), consisting of aerobic and anaerobic capacity, may be defined as the ability to maintain performance at a specific power output or velocity for a longer duration of time (Kyröläinen et al. 2003b, 12). The most common measure of aerobic fitness is maximal oxygen uptake (VO_2max), which can be measured directly during a laboratory test. However, aerobic fitness is commonly assessed using indirect field-based methods such as the 12-min (Cooper 1968) or 3000-m running test.

Muscular fitness can be defined as the ability of the neuromuscular system to produce force against external resistance. Muscular fitness can be divided into three subcategories, which are muscular (maximal) strength, power (explosive strength) and muscular endurance (Kyröläinen et al. 2003b, 12) (TABLE 1). Based on training adaptation research (e.g. Häkkinen et al. 1981), muscular strength can be further divided into neural and hypertrophic components.

Definitions of physical fitness component subcategories are presented in TABLE 1. Note that the energy sources presented in the table overlap with various physical activity intensities, and they should therefore be regarded as the main but not the only energy sources within each category.

TABLE 1 Definitions of physical fitness component subcategories (modified from Kyröläinen et al. 2003b and, NATO 2019). Abbreviations: ATP, adenosine triphosphate, PCr, phosphocreatine.

Fitness component	Fitness sub-category	Definition	Main energy sources	Activity examples
Aerobic fitness	Aerobic capacity	Ability to sustain physical activity for a longer period of time (>2min - hours), typically involving dynamic activities	Oxidatively metabolized glycogen, fatty acids, muscle protein	Sustained patrolling, marching
	Anaerobic capacity	Ability to sustain intermittent or continuous near maximal intensity physical activity for a short period of time (seconds [a] to minutes [b]), typically involving dynamic activities	Muscular stores of ATP and PCr [a], Blood glucose, liver and muscle glycogen [b]	Combative actions, e.g. repetitive rushes in combat load
Muscular fitness	Muscular strength	Ability of a muscle group to exert maximal force in a single voluntary contraction (< 5 sec)	Muscular stores of ATP and PCr	Lifting a heavy supply box or a casualty
	Muscular power	Ability to exert maximal external force in the shortest possible time	Muscular stores of ATP and PCr	Jumping over an obstacle
	Muscular endurance	Ability of a muscle group to repeatedly generate moderate-to-high absolute force for a prolonged period of time (seconds to minutes)	Blood glucose, liver and muscle glycogen	Repetitive lifting and carrying

2.2 Physical fitness and body composition requirements in military occupations

Many of the common physically demanding military tasks involve carrying, lifting and/or moving external loads (Sharp et al. 1998). Thus, it is obvious that such activities load the neuromuscular system and require muscular strength, power and endurance. As the work duration of military tasks increases, the role of oxygen transport from the lungs to the active muscles grows. Operational duties are often performed in a prolonged manner at low intensity, resulting in increased energy expenditure mainly from aerobic metabolism (TABLE 1). However, duties may also include critical phases (e.g. combat or casualty evacuation) which raise the physical activity unexpectedly to very high levels (Henning et al. 2011; Sharp et al. 1998), requiring anaerobic energy production (TABLE 1). Under such conditions, a soldier may not have sufficient recovery time and could thus experience symptoms of fatigue. Acute physical fatigue has a negative impact on cognitive function and critical combat skills such as shooting accuracy (Knapik et al. 1991; Martin et al. 2020; O´Leary et al. 2020), and thus also readiness and ultimately mission success. From another perspective, a higher aerobic fitness level has been associated with better stress tolerance and improved ability to maintain cognitive performance (Drain et al. 2016; Martin et al. 2020).

During deployment, soldiers often wear combat gear including body armor and carry military equipment, which have negative effects on occupational performance in terms of weaker mobility and power production, as well as slower walking, running, and box-lifting performance times (Drain et al. 2016; Joseph et al. 2018). It has also been stated that body mass and body mass index (BMI) are not as important determinants of occupational performance as lower fat content and higher muscle mass, which have been found to be associated with improved physical performance in military environments (Bishop et al. 2008; Crawford et al. 2011; Lyons et al. 2005; Pierce et al. 2017; Vanderburgh & Crowder 2006; Vanderburgh et al. 2008). This is logical since a larger cross-sectional area of muscle is related to greater force production (Häkkinen et al. 1981; Jones et al. 2008) and thus lower relative workload (% 1RM) during submaximal lifting tasks (Sharkey & Davis 2008, 4-7).

To ensure that personnel are physically capable of carrying out their duties, several armed forces have implemented minimum physical requirements or physical employment standards for the selection of individuals to military occupations (NATO 2019). Briefly, the development of physical employment standards for a given military occupational specialty (MOS), e.g. infantry man, starts with the identification of the most demanding tasks of a given MOS by using an expert panel. Thereafter, physiological demands (e.g. heart rate, oxygen consumption, muscle activity, fatigue) are objectively monitored by using measurement devices such as heart rate monitors, portable gas analyzers, electromyography (EMG) electrodes, and blood lactate analyzers. After recognizing the most important physiological components of the task, tests assessing these components may be developed. After analysis of the demands, test methods are developed. Typically, general fitness tests are feasible (i.e. easy to administer) but their fidelity (i.e. similarity between the test and the task) is insufficient. Sometimes, general fitness tests do not adequately assess all essential components of occupational performance, and simulations of actual military tasks are added to the test battery. After the test battery is established, minimum requirements are defined, either based on normative values (e.g. previously published, population-based test results) or based on the criteria defined by a subject matter expert group and/or statistical analyses (NATO 2019). In addition to occupational selection, physical requirements may also be applied to the entry or graduation conditions of military training or courses, annual testing and pre-deployment (Drain & Reilly 2019).

As in many other countries, physical fitness requirements for a professional soldier in Finland are based on the law:

> "Professional soldiers are required to maintain the basic military skills and physical condition commensurate with their duties. Provisions on the basic skills required for specific posts, and physical condition and fitness tests, may be issued by decree of the Ministry of Defence."[2]

Thus, a Finnish soldier is required to have adequate aerobic and muscular fitness levels for his/her occupational duties during peace and war time, and during his/her homeland and international deployment. In the Finnish Defence Forces, assessments of aerobic and muscular fitness are performed annually, and both components of fitness must satisfy the task-specific minimum standards (Defence Command, 2019).

2.3 Physical workload and occupational demands of soldiers

General physical work-related stressors include demanding activity phases, such as excessive handling and carrying of heavy loads, ergonomically poor working postures, a high volume of squatting, kneeling, lying, repetitive tasks with high handling frequencies, and work involving high-intensity physical exertion and exposure to force (Grimm et al. 2019; Hauret et al. 2010). Since the criteria described above are representative of many common military tasks, a soldier cannot avoid facing these occupational stressors, especially during deployment. If a heavy workload is sustained for longer periods, fatigue will accumulate and result in the need for a prolonged period of recovery. If recovery is not allowed, the risk of musculoskeletal injuries or disorders increases (Halvarsson et al. 2018; Sell et al. 2019).

It has been estimated that in order to avoid accumulation of metabolic stress and fatigue, prolonged continuous work should not exceed 40-50% of a person's

2 Act on the Defence Forces (551/2007, 43 §)

maximal aerobic capacity (Boffey et al. 2019; Drain et al. 2016). Thus, accumulation of stress from physical workload is dependent on an individual's capabilities. A lower physical fitness level has been associated with weaker military performance in several studies (Burley et al. 2020; Hauschild et al. 2017). In addition, a low level of aerobic or muscular fitness, high BMI, and prior injuries are known risk factors for musculoskeletal injuries among military (Sell et al. 2019) and athletic populations (Jones et al. 2017; Wardle & Greeves 2017).

Therefore, it could be argued that a high level of physical fitness, in combination with the necessary occupational skills, are significant factors for success in an operative military environment. While modifications of external (i.e. task-related) demands during operative military duties may not be possible, strategies for decreasing physical workload include improvement of physical fitness along with other actions, such as improved nutrition, to avoid a detrimental increase in body fat mass (Jones et al. 2017; Sell et al. 2019).

2.3.1 Load carriage

Load carriage is perhaps the most common military task for soldiers within all military branches (Knapik et al. 2004). Load carriage has been reported to be the second most frequent military activity type that causes injuries during deployment, and higher relative and absolute loads are associated with a higher risk of injury (Roy et al. 2012). In the present thesis, load carriage refers to duties that are performed on foot in a prolonged manner, such as patrolling or marching while carrying external load (combat gear). In addition, load carriage duties may include shorter intervals of high-intensity movements, such as running during combat situations.

Laboratory and field studies assessing the physical demands of prolonged load carriage have documented average oxygen consumption values of 17-23 $mL \cdot kg^{-1} \cdot min^{-1}$ during walking at a pace of 5-6 $km \cdot h^{-1}$ with combat gear weighing 24-27 kg (Crowder et al. 2007; Pihlainen et al. 2014). Several studies have reported relationships between load carriage performance and physical fitness, as well as body composition (Hauschild et al. 2017; Lyons et al. 2005; Rayson et al. 2000; Ricciardi et al. 2008). As an example of shorter duration load carriage, Harman et al. (2008) observed significant inverse relationships between vertical jump height and both 30-m sprint time and 400-m run time in combat load. More recently, a review consisting of 14 studies indicated a negative impact of tactical load on measures of power (sprint times and vertical jump performance) and agility, assessed by performance times on obstacle courses (Joseph et al. 2018). The importance of aerobic fitness increases as the duration and distance of the load carriage performance increase (Harman et al. 2008; Lyons et al. 2005; Santtila et al. 2010), and the relative work intensity also needs to decrease accordingly (Drain et al. 2016).

It has been suggested that the additional weight of the external load should not exceed one third of the body mass of the carrier in order to avoid accumulation of fatigue during sustained load carriage (Haisman 1988). However, despite technological advances in the development of military materials, the weight of the load carried by soldiers has linearly increased for decades, currently varying between 20 and 60 kg during demanding military operations (Knapik et al. 2004; Nindl et al. 2013). Furthermore, studies have observed increases in energy expenditure (Lyons et al. 2005) and cardiovascular strain (Fallowfield et al. 2012) in relation to the weight of the carried load, and also in relation to the carried load including the fat mass of the soldier (Lyons et al. 2005). Thus, larger body size and greater muscle mass, combined with lower fat mass, may have positive effects on sustained load carriage performance.

2.3.2 Manual materials handling

Manual materials handling refers to tasks including digging, lifting, carrying, pushing and/or pulling objects (Carstairs et al. 2018). According to the literature, an average energy expenditure of 14 mL · kg^{-1} · min^{-1} has been reported during lift and carry tasks with an average load of 28 kg (Patton et al. 1995). Due to a wide variety of activity types and intensities of manual materials handling tasks, the relative oxygen consumption has been reported to vary between 7 and 41 mL · kg^{-1} · min^{-1} (Ainsworth et al. 2011; Patton et al. 1995; Pihlainen et al. 2014).

According to Carstairs et al. (2018), a large proportion (~ 80%) of physically demanding tasks consist of manual materials handling. Unfortunately, manual materials handling (e.g. lifting, carrying) also represents the most common reason for musculoskeletal injuries during deployment. Roy et al. (2012) reported that 45% of the soldiers surveyed in their study sustained a musculoskeletal injury during a 12-month deployment in Afghanistan. The most common reasons for injuries were lifting and carrying external loads. The injury risk increased with higher lifting frequencies and when higher relative (percentage of body mass) loads were handled (Roy et al. 2012).

A subjective acceptable level for the maximal load that can be lifted by an individual has been reported to vary around 85% of one repetition maximum (1RM) (Savage et al. 2014). Therefore, it is obvious that for lifting tasks, higher absolute strength is associated with the ability to lift heavier loads. A meta-analysis by Hydren et al. (2017) reported that lean mass was the strongest predictor of lifting capacity, explaining 69% of the variance in this manual handling task. However, manual materials handling may also be performed in a prolonged, repeated manner. In this case, the task should be performed at a submaximal level to reduce the accumulation of fatigue and the risk of injury (Roy et al. 2012; Savage et al. 2014). It has been recommended that in order to reduce the risk of work-related musculoskeletal injuries, the average load in repetitive lifting tasks should not exceed 20% of the individual's maximal lifting strength (Sharkey & Davis 2008, 161). Since the weight of military supplies (e.g. ammunition box) is typically standard, an individual with higher absolute muscular strength can lift an object of the same absolute weight at a lower relative intensity, and thus with a lower injury risk, than a weaker individual.

A review by Hauschild et al. (2017) reported stronger relationships between single, high load lifting tasks and muscular strength (upper body, r = 0.75; lower body r = 0.60) compared to aerobic fitness (r = 0.30), whereas aerobic fitness was more strongly associated (r = 0.60) with lower intensity repeated tasks.

2.3.3 Combat tasks

Army combat tasks including crawling, rushes, climbing, sprints starting from and ending in a prone position, and casualty evacuation are typically performed at high intensities during very demanding situations, often under enemy fire. Faster crawling performance has been found to be associated with higher aerobic fitness (r = 0.80), muscular endurance of the upper body (r = 0.66), and lower body strength (r = 0.65) (Hauschild et al. 2017). Rushing speed was found to be positively associated with survivability in military combat simulations (Billing et al. 2015; Blount et al. 2013). Mala et al. (2015) observed an inverse relationship between the power of the lower extremities and 5-m sprint performance time with combat load (r = −0.66). Both vertical and horizontal jump performance have also been shown to be strongly associated with sprinting speed in elite athletes (Loturco et al. 2015). As for load carriage tasks, combat gear has a negative impact on combat movement performance (Billing et al. 2015; Joseph et al. 2018; Martin & Nelson 1985). Billing et al. (2015) reported that the susceptibility to enemy fire, assessed as the duration of exposure, increases linearly with increasing external load.

Casualty evacuation is not necessarily common, but it is a critical military task for soldiers, and one of the most physically demanding (Larsson et al. 2020). Every soldier should be mentally and physically prepared for casualty evacuation, either individually or as a member of a group. Angeltveit et al. (2016) reported that the time taken to individually drag an 80-kg mannequin around a course correlated inversely with absolute maximal oxygen uptake (r = −0.72), maximal countermovement jump power (r = −0.58), mean power measured via the anaerobic Wingate test (r = −0.68) or 300-m run (r = −0.67), and 1RM leg press (r = −0.42). The respective correlations for body composition variables were: Body mass (r = −0.82), lean body mass (r = −0.72) and stature (r = −0.66). Linear regression analysis also demonstrated that 72% of the variance in casualty drag performance was explained by body mass and maximal oxygen uptake (Angeltveit et al. 2016). Poser et al. (2019) reported that peak isometric deadlift force and lean mass were the strongest predictors of the time taken to complete a 50-m fireman carry with an 84-kg mannequin. A review by Hauschild et al. (2017) indicated correlations between higher stretcher carry performance and greater lower body strength (r = 0.73), aerobic fitness (r = 0.66), upper body strength (r = 0.65) and upper body muscular endurance (r = 0.58). These and other studies (Chasse et al. 2019; Knapik et al. 2012) have shown that a combination of high anaerobic and aerobic capacities, high levels of lower body muscular strength and power combined with high body mass - especially muscle mass - are, from an occupational standpoint, beneficial physical fitness and body composition variables for a soldier during combat situations.

2.4 The effects of military operations on body composition and physical fitness

As mentioned earlier, the occupational physical workload of a deployed soldier includes physically lighter duties, such as supervision, observation and guarding, and also more demanding tasks like patrolling on foot, fortification or combat duties. However, performing the same tasks during international military operations may be mentally and physically more demanding due to additional stress factors encountered in hostile environments (Nindl et al. 2013). Deployed soldiers are expected to maintain readiness and occupational performance in extreme air temperatures, during irregular work shifts and sustained physical activity, and also, in the possible presence of dehydration and malnutrition. These factors may lead to fatigue and tax their cognitive performance while increasing their stress levels (Martin et al. 2019; Martin et al. 2020; Nindl et al. 2013). For example, total energy expenditure can easily exceed 4000 kcal $\cdot$ d^{-1} during military field exercises while energy intake rarely equals this amount (O´Leary et al. 2020). Consequently, these operative stressors may lead to negative changes in muscle mass (Church et al. 2019; Friedl et al. 2000; Nindl et al. 2007a), compromised performance, and increased risk of injury, illness and even task or mission failure (Friedl et al. 2000; Henning et al. 2011).

After sustained military field exercises, several studies have reported 15% to 20% decreases in lower body muscle strength, 10% decreases in upper body muscle strength and decreases of 10% to 30% in lower body muscle power of the lower extremities, as well as decreases in aerobic fitness (Henning et al. 2011; Nindl et al. 2007a; Ojanen et al. 2018; O´Leary et al. 2020; Vaara et al. 2015). For example, Nindl et al. (2007a) reported decreases of 16% and 20% in vertical jump height and maximal lifting strength, respectively, during an 8-week intensive military training course consisting of prolonged physical activity and severe (1000 kcal $\cdot$ d^{-1}) negative energy balance. Similar findings have been reported by Vaara et al. (2015) who found a reduction in maximal strength of the lower but not the upper extremities following a five-day paratrooper field exercise. Negative changes in physical fitness are often accompanied by decreases in body mass, fat mass and muscle mass (Henning et al. 2011; Nindl et al. 2007a; Ojanen et al. 2018; Vaara et al. 2015), as well as decrements in occupational performance (e.g. obstacle course, repetitive box-lift). These changes all reflect symptoms of cumulative fatigue and homeostatic disturbances induced by the high workload of field exercise activity (O´Leary et al. 2020).

While an extensive number of studies have been published regarding the effects of military field exercises on body composition and physical fitness, far fewer papers are available from actual military operations (TABLE 2). By 2019 (excluding the publications of the present thesis), ten peer-reviewed journal articles were available documenting body composition and/or physical fitness changes during a military operation (Dyrstad et al. 2007; Fallowfield et al. 2014; Farina et al. 2017; Lester et al. 2010; Nagai et al. 2016; Rintamäki et al. 2012;

Sedliak et al. 2019; Sharp et al. 2008; Warr et al. 2012; Warr et al. 2013). A decrease in aerobic fitness has been the most consistent finding in these studies (Dyrstad et al. 2007; Lester et al. 2010; Sharp et al. 2008; Warr et al. 2012). Only one study (Sedliak et al. 2019) reported an increase of 6% in aerobic fitness during a six-month deployment in Afghanistan. In addition, an increase or maintenance of muscle endurance (e.g. number of repetitions in pull-ups, sit-ups and push-ups) has been reported in four out of eight studies. Strength and power of the upper and lower extremities were maintained or increased in all but one study, where a 5% decrease in upper body power was observed, as assessed by a medicine ball throw (Sharp et al. 2008).

Regarding changes in body composition, increases in body mass were observed in two (Dyrstad et al. 2007; Lester et al. 2010), decreases in four (Rintamäki et al. 2012; Sharp et al. 2008; Warr et al. 2012; Warr et al. 2013) and no changes in four (Fallowfield et al. 2014; Farina et al. 2017; Nagai et al. 2016; Sedliak et al. 2019) of the available ten studies. Fat mass increased in two of these studies (Lester et al. 2010; Sharp et al. 2008), whereas decreases were observed in three studies (Fallowfield et al. 2014; Warr et al. 2012; Warr et al. 2013), no changes in two studies (Farina et al. 2017; Rintamäki et al. 2012), and three studies (Dyrstad et al. 2007; Nagai et al. 2016; Sedliak et al. 2019) did not report fat mass results. Fat free mass increased in three studies (Farina et al. 2017; Lester et al. 2010; Warr et al. 2012), decreased in two studies (Sedliak et al. 2019; Sharp et al. 2008) and remained unchanged in one study (Fallowfield et al. 2014). Three studies did not report changes in fat free mass (Nagai et al. 2016; Rintamäki et al. 2012; Warr et al. 2012).

Variation between the studies in terms of changes in body composition and physical fitness are likely explained by differences in security situation, resources, possibilities and motivation for physical training, duration of the follow-up and methodological issues. For example, Sharp et al. (2008) reported decreases in aerobic training frequencies during deployment when compared to the time preceding the deployment. A similar trend was observed for strength training, as the distribution of soldiers who performed strength training less than once a week increased from 2% before the operation to 20% during the operation. PRE-POST change in strength training frequency also correlated with change in fat-free mass (r = 0.37). Dyrstad et al. (2007) observed an increasing trend in self-reported strength and endurance training frequency during the first 6 months of a 9-month follow-up in Kosovo, followed by a decreasing trend in the frequencies of both training modalities. A positive association (r = 0.46) was also found between average training volume (minutes per week) and change in VO_2max. Furthermore, intrinsic motivation towards physical training predicted the physical training volume during deployment, and a significant (70%) difference in average weekly training volume was found between the high and low intrinsic motivation groups (Dyrstad et al. 2007). Warr et al. (2013) compared soldiers who performed strength and endurance training more or less than three times per week and provided supporting findings regarding training frequency and changes in body composition as well as physical performance. A significant group difference was observed in relative upper body muscular strength favoring the group who strength trained >3 times per week. A similar group difference was also observed in VO_2max favoring the group with higher aerobic training frequency (Warr et al. 2013).

TABLE 2 Studies investigating changes in body composition and physical fitness during international military operations.

Study	**N**	**Deployment country, duration**	**Summary of results**
Dyrstad et al. 2007	71	Kosovo, 12 months	Body mass ↑ 3%, aerobic fitness ↓ 3%, pull-up ↑ 38%, sit-up ↔, push-up ↔
Sharp et al. 2008	110	Afghanistan, 9 months	Body mass ↓ 2%, fat free mass↓ 4%, fat mass ↑ 8%, aerobic fitness ↓ 5%, lifting strength ↔, lower body power ↔, upper body power ↓ 5%
Lester et al. 2010	73	Iraq/Afghanistan, 13 months	Body mass ↑ 3%, fat free mass ↑ 3%, fat mass ↑ 9%, aerobic fitness ↓ 13%, lower body strength ↑ 8%, upper body strength ↑ 7%, lower body power ↔, upper body power ↑ 9%
Warr et al. 2012	60	Iraq/Afghanistan, 10-15 months	Body mass ↓ 2%, fat mass ↓ 11%, aerobic fitness ↓ 11%, lower body strength ↑ 14%, upper body strength ↑ 10%, sit-up ↑ 11%, push-up ↑ 16%
Rintamäki et al. 2012	20	Chad, 4 months	Body mass ↓ 4%, fat mass ↔, lower body strength ↔, lower body power ↑ 27%, grip strength ↔, sit-up ↑ 11%, push-up ↔, repeated squats ↔
Warr et al. 2013	88	Iraq/Afghanistan, 10-15 months	Body mass ↓ 2%, fat free mass ↑ 2%, fat mass ↓ 18%, aerobic fitness ↔, lower body strength ↑ 14%, upper body strength ↑ 9%
Fallowfield et al. 2014	105	Afghanistan, 6 months	Body mass ↔, fat free mass ↔, fat mass ↓ 17%, aerobic fitness ↔, Lifting strength ↔, sit-up ↔, push-up ↔
Nagai et al. 2016	35	Afghanistan, 11-12 months	Body mass ↔, fat percentage ↔, aerobic fitness ↔, anaerobic power ↑ 7 %
Farina et al. 2017	49	Afghanistan / Other, 3-6 months	Body mass ↔, fat free mass ↑ 1%, fat mass ↔, grip strength ↑ 6 %
Sedliak et al. 2019	25	Afghanistan, 6 months	Body mass ↔, fat free mass ↓ 2%, aerobic fitness ↑ 6%, pull-up ↑ 60%, 4x10m run ↓ 3%, 10x10 m run ↔

2.5 Biomarkers of acute and chronic stress in military environments

The effects of military operations on body composition and physical fitness are mediated by several biomarkers (e.g. hormones, signaling proteins and enzymes), which modulate energy metabolism and tissue level adaptations, including muscle protein breakdown and synthesis. In addition to the physical strain associated with demanding military tasks, operational stressors such as negative energy balance, sustained readiness and sleep deprivation, high ambient temperature, altitude and environmental toxins may separately or collectively disturb homeostasis of the body and thus increase the stress level of soldiers during operations (Church et al. 2019; Henning et al. 2011; Nindl et al. 2013). Collectively, these stress factors affect metabolic and endocrine function, as evidenced by increases in catabolic and decreases in anabolic biomarkers during physically demanding military training (Nindl et al. 2013; O´Leary et al. 2020; Pasiakos et al. 2019). Catabolism promotes signaling of muscle protein breakdown for gluconeogenesis and maintenance of safe blood glucose levels during sustained physical activity, which may have deleterious effects on immune function and physical performance in the long run (Church et al. 2019; O´Leary et al. 2020). The present thesis focuses on four serum anabolic and catabolic biomarkers commonly used in military field studies: testosterone, sex-hormone binding globulin, insulin-like growth factor-1 and cortisol. In addition, the role of salivary alpha-amylase is briefly discussed.

2.5.1 Testosterone and sex-hormone binding globulin

Testosterone (TES), produced in the Leydig cells of the testes, is regarded as the most potent anabolic hormone in men. This androgen hormone influences the development of male characteristics, including muscle mass, bone mass and muscular fitness. Absence of bioavailable testosterone leads to a reduced ability to develop strength and muscle mass (Kraemer et al. 2015, 227-228). TES can only exert its signaling function through the cellular receptors when it is not bound to other molecules. Sex-hormone binding globulin (SHBG) is a glycoprotein that binds testosterone and therefore mediates the amount of bioavailable free TES in the bloodstream (Wheeler 1995). In males, the reference values for serum total TES and SHBG are 10-38 $nmol \cdot L^{-1}$ and 11-78 $nmol \cdot L^{-1}$, respectively. TES has been used extensively as an overall marker of anabolic status during military training. TES levels below the reference values have often been reported after sustained field exercises with caloric restrictions (Henning et al. 2011). Increased levels of SHBG and decreases in TES have been reported to indicate insufficient recovery (Häkkinen et al. 1985b). Thus, the TES/SHBG ratio may be a potential marker of overtraining. Typically, normal serum basal TES levels are restored after a recovery period of two to four days including adequate rest and nutrition following arduous military field training (Salonen et al. 2019). TES exhibits circadian variation, whereby levels are highest during night-time sleep or early morning and decrease throughout the day (Dabbs 1990; Wheeler 1995). Thus, a longitudinal follow-up of TES levels requires a precise determination of sampling time in accordance with the wake-sleep cycle.

2.5.2 Insulin-like growth factor-1

Unlike most hormones, insulin-like growth factor-1 (IGF-1) is not produced in a single endocrine gland, but rather in the liver and many other types of cells, including muscle cells. It is also a multifactorial hormone that can act in the same cell where it is released from, the adjacent cell, or it can circulate in the bloodstream bound to one of many binding proteins. As is the case for free TES, only 1-2% of IGF-1 circulates in a free, unbound form (Kraemer et al. 2015, 230-231). Circulating levels of IGF-1 are mediated by a promoted role of growth hormone, and both of these hormones are involved in the regulation of muscle mass (Lee et al. 2017). In addition to protein synthesis, IGF-1 is associated with many other anabolic outcomes including cellular growth, proliferation, repair and regeneration. Higher circulating IGF-1 values have also been associated with improved cardiovascular health and muscular endurance (Nindl et al. 2011). As is the case for TES, significant decreases in IGF-1 levels have been reported during an 8-week US Army Ranger course (Friedl et al. 2000; Nindl et al. 2007a), highlighting its utility for monitoring metabolic stress during military occupational tasks.

2.5.3 Cortisol

Cortisol (COR) is known as the primary catabolic hormone, which is stimulated in response to mental and physical stress. COR is secreted from the adrenal cortex by activation of the hypothalamic-pituitary axis (Adam & Kumari 2009). During sustained physical stress, the main function of COR is to maintain blood glucose levels by stimulating gluconeogenesis, i.e. enhancing the enzyme activity involved in the synthesis of glucose from amino acids and lipids. In turn, COR also blocks protein synthesis signaling (Kraemer et al. 2015, 234-237). Chronic stress has a negative impact on cognitive function, and elevated COR levels may suppress immune function, increasing the risk of illness and infection (Szivak & Kraemer 2015). COR has been identified as a potential biomarker of overtraining in military training environments (Tanskanen et al. 2011). However, conflicting findings have also been reported regarding the use of COR as a marker of chronic overtraining, especially among athletes whose ability to recover and adapt to stress is highly developed through training (Cadegiani & Kater 2019). Even though COR levels rise above basal levels during acute stress, chronic stress may also result in lowered resting levels and attenuated responses to acute stress (Chandola et al. 2010; Henning et al. 2011). However, sustained sleep deprivation (3-7 days) during military exercises has been reported to increase average COR values and blunt its circadian rhythm (Wolkow et al. 2015). In addition, a low TES/COR ratio has been shown to be associated with blunted training adaptations and strength performance (Häkkinen et al. 1985b; Lee et al. 2017). COR exhibits a circadian rhythm in healthy recovered humans, with values at their lowest during sleep and highest in the morning after waking (Adam & Kumari 2009). In Finland, the reference serum values for COR are 150-650 nmol · L^{-1}. COR samples can also be obtained from saliva, but salivary COR (saCOR) concentration is typically 1:50 compared to blood serum concentration.

2.5.4 Salivary alpha-amylase

Salivary alpha-amylase (saAA) is produced locally in salivary glands by activation of the sympathetic nervous system, and its main function involves the initiation of carbohydrate digestion (Nater & Rohleder 2009). As with COR, this enzyme exhibits circadian rhythm but as COR levels decrease during daytime, saAA levels rise. In addition, the acute wake-up response for saAA is a decrease within the first 30 minutes, whereas COR levels simultaneously increase (Nater et al. 2007, Rohleder & Nater 2009). The interest in physical workload studies has arisen from findings documenting significant correlations between saAA and norepinephrine during an acute bout of exercise. Since then, saAA has been proposed to reflect the acute activation of the sympathetic nervous system due to mental and/or physical stress in an intensity-dependent manner. While elevated levels can be observed during and up to 1-2 hours post-exercise, chronic training adaptations to basal saAA levels have not been established (Guilhem et al. 2015; Rohleder & Nater 2009). However, it is possible that higher aerobic fitness attenuates acute stress responses (e.g. lower saAA levels) to a psychosocial stress test (Wyss et al. 2016).

2.5.5 Experiences from military studies

The effects of acute and chronic physiological stress on soldiers have mainly been examined during military basic training (Santtila et al. 2009b) and military field exercises (Friedl et al. 2000; Kyröläinen et al. 2008; Nindl et al. 2007a). While increases in serum TES and maintenance of baseline COR have been reported-during an 8-week follow-up during military basic training performed mainly in the garrison (Santtila et al. 2009b), many studies have collectively demonstrated significant decreases in TES and IGF-1 concentrations after military field exercise lasting longer than one week (Friedl et al. 2000; Kyröläinen et al. 2008; Nindl et al. 2007a). For example, Friedl et al. (2000) observed significant decreases in TES and IGF-1 concentrations, accompanied by increases in SHBG and COR, after an 8-week military field exercise. These changes were associated with marked reductions in body mass, and the adaptations were soon compensated when energy balance returned to normal (Friedl et al. 2000).

Most of the abovementioned studies assessing hormonal changes during military training have been shorter than eight weeks in duration, and the disturbances in hormonal balance have returned to baseline levels soon after recovery with adequate energy intake. In most studies, the subjects were more or less novice soldiers, either conscripts or recruits. Jensen et al. (2019) studied the hormonal balance of 65 elite soldiers with more than seven years of military experience. In this cross-sectional study, the aim was to determine possible hormonal signals of overtraining among special operators engaging in daily rigorous physical training and experiencing a negative energy balance. A high prevalence (43%) of soldiers with symptoms of overtraining (i.e. TES levels < 10.4 $nmol \cdot L^{-1}$) was observed. These soldiers also displayed high SHBG and COR levels, indicating accumulated stress load. There is very limited documentation available of changes in anabolic and catabolic blood biomarkers during a military operation. In a study of 49 Special Operations Forces soldiers, Farina et al. (2017) reported a 14% decrease in serum COR and a 10% increase in SHBG while total TES remained unchanged during a three-to-six-month combat operation in Afghanistan and other respective operations.

To conclude, successful performance of military occupational tasks requires a considerable amount of aerobic and anaerobic capacity, muscle strength, power and endurance. Operational stressors may force soldiers to perform their duties whilst sleep deprived and under negative energy and fluid balance, which further increase the physical demands of the tasks. Cumulatively, the sustained high internal workload caused by these stressors may lead to disruptions in homeostatic regulation. Without sufficient recovery, decreases in anabolic and increases in catabolic hormones may lead to increased muscle protein breakdown signaling and thus decreases in muscle mass and physical performance, all of which are typical symptoms of overtraining. Collectively, these adaptations likely lead to diminished work capacity (Welsh et al. 2008). Thus, highly stressed soldiers may not be able to maintain optimal occupational performance and readiness in the operative environment and could expose themselves (and possibly others) to risk of injury or even mission failure (FIGURE 1).

It has been suggested that in addition to having higher occupational performance capacity, physically fit soldiers may be more resilient to operational stressors in demanding military environments (Szivak & Kraemer 2015). This is partly explained by improved sensitivity of the neuroendocrine system and thus the ability to recover faster from high operative stress (Szivak et al. 2018). Therefore, the role of adequate functional capacity and the assessment of its components are important for maintaining readiness before and during deployment.

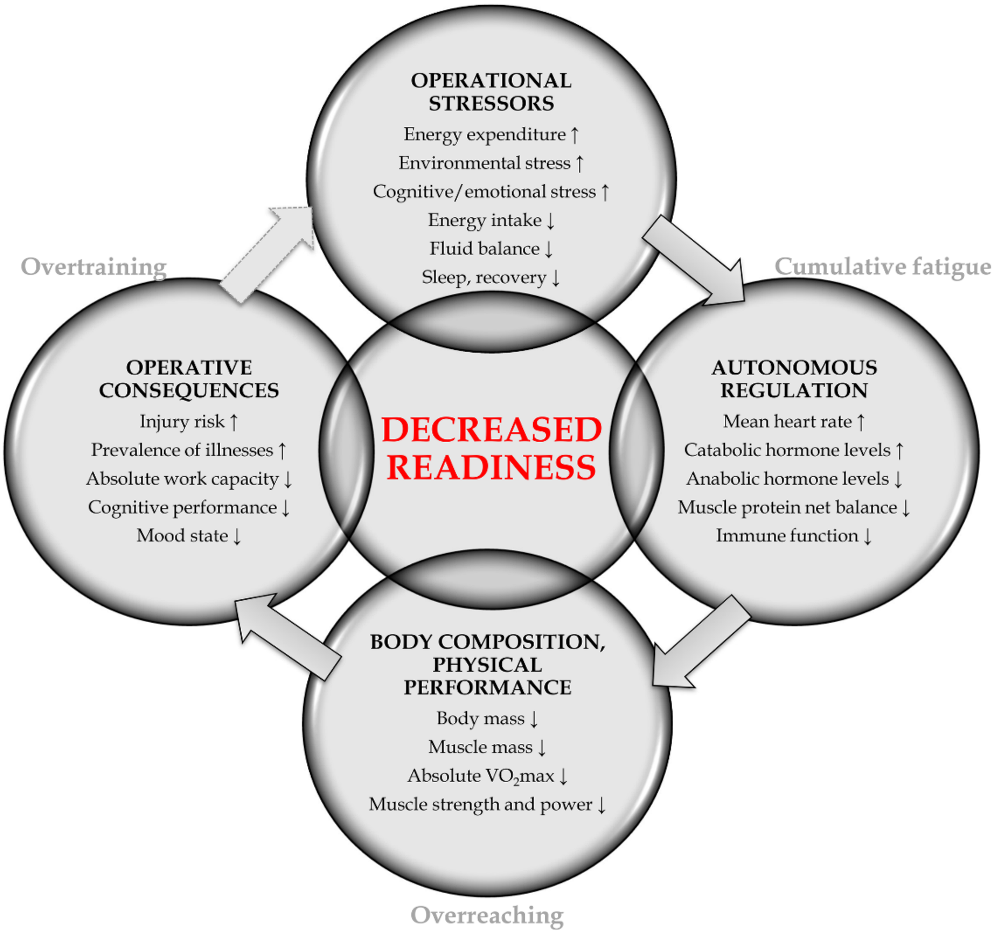

FIGURE 1 Theoretical model of operational stressors and their negative effects in physically demanding military environments (Modified from Church et al. 2019; Henning et al. 2011; Nindl et al. 2013).

2.6 Methods for assessing the physical capabilities of soldiers

Methods for assessing the physical capabilities of soldiers can be divided into two main categories, namely general fitness tests and occupational performance tests (Hauschild et al. 2017). Traditionally, the physical performance of soldiers has been tested using population-based aerobic and muscular fitness tests such as a 12-minute running test and the maximum number of push-ups in one or two minutes (Knapik et al. 2006; Santtila et al. 2006). According to a systematic review by Herrador-Colmenero et al. (2014), the most common fitness component assessed in the military and security forces was aerobic fitness (81% prevalence among studies included in the review), with the 2.4 km run being the most commonly used test. Muscular fitness (e.g. sit-up and push-up tests) and body composition (e.g. BMI, percent body fat) were the second and third most commonly assessed components of fitness, with prevalence of 69% and 64%, respectively (Herrador-Colmenero et al. 2014).

2.6.1 General physical fitness tests

Regarding general physical fitness components, Hauschild et al. (2017) reported that the highest correlations with performance on twelve common physical military tasks, including load carriage, numerous manual materials handling tasks, combative movements and their combinations, were found in tests assessing aerobic fitness, lower body strength and upper body muscular endurance. The most valid and reliable field assessments of aerobic fitness included timed 2.4–4.8 km running tests, vertical and horizontal jump tests to assess lower body strength and power, and push-up tests to evaluate upper body muscular endurance (Hauschild et al. 2017).

As already noted, assessment of aerobic fitness in soldiers is important due to its associations with performance in several military tasks (Hauschild et al. 2017; Nindl et al. 2015). Based on the guidelines of the American College of Sports Medicine (ACSM), direct assessment of aerobic capacity (VO_2max, commonly expressed relative to body mass) requires measurement of oxygen and carbon dioxide from the expired air during a graded endurance test until exhaustion (ACSM 2014, 73-75). This method requires a well standardized environment (e.g. laboratory), and is therefore often not feasible for large study samples, such as in the military. Several indirect methods have been developed for military purposes. In the Finnish Defence Forces, the most commonly used method of assessing aerobic fitness in conscripts and professional soldiers is the 12-min running test, and performance on this test is strongly correlated ($r = 0.90$) with relative VO_2max (Cooper 1968). Similar relationships have been found between distance-based running tests (e.g. 3.2 km running test) and relative VO_2max among soldiers (Mello et al. 1988; U.S. Army Public Health Command 2014, 35).

Muscular (maximal) strength has been acknowledged as the most relevant component of fitness from a military performance perspective (Nindl et al. 2015). However, while fitness test batteries used by the armed forces extensively focus on muscular endurance, methods of assessing muscular strength are very rarely included in their test batteries (Nikolaiditis et al. 2019). Traditional measures of dynamic muscular strength within civilian as well as military populations include 1-5RM squat, leg press, deadlift and 1RM bench press or shoulder press (ACSM 2014, 96; Foulis et al. 2017b). While less sophisticated equipment is needed for the dynamic tests, reliable 1RM performance requires a good, safe technique and practice (ACSM 2014, 96-98). Isometric devices have been developed to increase accuracy and standardization of muscular strength measurements. In general, methods of measuring isometric peak force production of the lower extremity extensor muscles have shown good reliability and construct validity among trained and untrained males (Drake et al. 2017).

The current test battery for assessing muscular fitness in the Finnish Defence Forces consists of standing long jump, 1-min sit-ups and 1-min push-ups (Defence Command, 2019). Standing long jump has been shown to assess explosive strength (power) of the lower extremities with a similar reliability as vertical jump tests (Markovic et al. 2004). Since standing long jump performance has also been shown to strongly correlate with performance on military tasks such as single lift and stretcher carry (U.S. Army Public Health Command 2014, 30), it has been recommended as a field-expedient option for assessing muscular power in soldiers (Nindl et al. 2015). Regarding muscular endurance of the upper body and trunk, repeated push-ups and sit-ups (or curl-ups) have been identified as simple field tests by the ACSM (2014, 99-101). Vaara et al. (2012) found a moderate correlation (r = 0.61) between 1-min push-up and maximal isometric bench-press performance. Moderate relationships have also been reported between upper body muscular endurance test results and military tasks such as crawl (pooled r = 0.66), repeated lift and carry (pooled r = 0.62) and stretcher carry (pooled r = 0.58), while correlations between core/trunk muscular endurance and military tasks seem to be weaker (Hauschild et al. 2017).

Body composition is included as a component of health-related physical fitness in some definitions (ACSM 2014, 3; Nindl et al. 2015). Anthropometric measures such as body mass and stature can be used to calculate BMI. In addition, the amounts and distributions of muscle or fat can be assessed indirectly by measuring body part circumferences or skinfolds (ACSM 2014, 63-69), or more accurately by using more advanced technology. While the most precise criterion methods such as computed tomography and dual-energy X-ray absorptiometry (DXA) are very expensive and require laboratory conditions with highly trained personnel, there are indirect but more feasible options for military use. Multi-frequency bioelectrical impedance analysis (BIA) is based on differences in electric conductivity of tissues. The electrical current is conducted differently through the extracellular (ECW) and intracellular (ICW) water as a function of the current frequency. According to Ling et al. (2011), six different electrical frequencies are used to predict the ICW and ECW components of total body water (TBW). While the low-level frequencies (≤ 50 kHz) rely on the conductive properties of extracellular fluid, high-level frequencies (≥ 250 kHz) are conducted through both ICW and ECW. Thus, muscle mass can be estimated as TBW (ICW + ECW)/0.73. Fat mass is calculated as the difference between total body mass and muscle mass. A general overestimation of muscle mass and underestimation of fat mass, as well as fat percentage, has been reported in studies comparing BIA and DXA methods (Aandstad et al. 2014; Antonio et al. 2019; Sillanpää et al. 2014). However, good reliability values have been reported for multi-frequency BIA against DXA for the assessment of muscle mass, fat mass and fat% in adult males within the normal BMI range, especially when the measurement standardization (e.g. timing of measurement, clothing, fasting) has been performed properly (Aandstad et al. 2014; Antonio et al. 2019; Ling et al. 2011; McLester et al. 2020).

2.6.2 Occupational physical performance tests

While the most commonly used physical fitness tests among the armed forces assess aerobic capacity and muscular endurance, army soldiers engaged in combat situations require an adequate level of anaerobic capacity to perform high-intensity assignments in rapidly changing, life-threatening situations (Kraemer & Szivak 2012). Such high-intensity tasks typically include sprinting, rushes, climbing, quick changes in direction, jumping, crawling, lifting and carrying loads, and casualty evacuation (O´Neal et al. 2014).

The relevance of general fitness tests for assessing combat readiness has been questioned in a number of studies, and it has been argued that such health-related fitness tests performed in light sports clothing and using the person´s own body mass as resistance favour soldiers with low body mass and high relative endurance capacity (Vanderburgh & Crowder 2006; Vanderburgh 2008). Yet, operative military duties are often performed whilst wearing combat gear and body armor, which increase the amount of load being carried (Knapik et al. 2004; O´Neal et al. 2014; Taylor & Groeller 2003). The increase in the weight of the carried load negatively influences the physical performance of soldiers during tasks of longer (Crawford et al. 2011) and shorter (Billing et al. 2015; Jaworski et al. 2015; Laing-Treloar & Billing 2011; Larsen et al. 2012) duration (Charlton & Orr 2014). Previous studies have collectively demonstrated that less body fat (Crawford et al. 2011; Kusano et al. 1997; Lyons et al. 2005) and more fat free mass (Kusano et al. 1997; Lyons et al. 2005) are beneficial body composition factors in such tasks.

These findings have led to the development of more occupationally relevant tests that evaluate military task-specific physical performance (Hauschild et al. 2017; Richmond et al. 2008; Payne & Harvey 2010; Vanderburgh & Crowder 2006). Typical occupational physical performance tests include walking or running various distances with combat load (Billing et al. 2015; Nindl et al. 2015; Santtila et al. 2010; Taylor & Groeller 2003), manual materials handling (Richmond et al. 2008), lifting and carrying loads (Carstairs et al. 2016), and obstacle courses (Jaworski et al. 2015; Larsen et al. 2012) that include mimicking of tactical movements used in combat situations. Foulis et al. (2017a) reported relatively high reliability measures, including intra-class correlations (ICCs) of 0.76-0.96 and standard errors of measurement (SEM) of 3-16% among several occupational tests including sandbag carry, casualty evacuation, move under fire, carrying and manual handling of tank ammunition, and a 6.4-km march. The highest reliability values were observed in the casualty drag test and the 6.4-km march, while longer lasting learning effects were observed especially in tests requiring manual materials handling (Foulis et al. 2017a). Collectively, these simulations consist of various military-specific test protocols for assessing anaerobic capacity and maneuver abilities of soldiers. Furthermore, such tests can be used to develop optimized physical training programs for soldiers preparing for a specific aim such as a military occupational specialty or an international military operation (Carlson & Jaenen 2012; Frield et al. 2015; Mala et al. 2015).

2.7 Physical training to maintain or improve military performance

Despite the overall physical demands of military occupational duties, performing military tasks alone is unlikely to provide an adequate stimulus for the cardiorespiratory and neuromuscular systems to maintain or improve physical fitness, and thus additional training stimuli are needed. Studies have also confirmed that appropriate physical training can enhance occupational performance capacity, reduce on-duty musculoskeletal injury risk and thus increase workforce availability (Drain & Reilly 2019).

Physical fitness can be developed by modifying physical activity behavior or through physical training. In the present thesis, the focus is on combined strength and endurance training, while physical training may also include elements such as speed, coordination, flexibility and agility training (Bompa & Buzzichelli 2019, 4-5; Garber et al. 2011). Depending on training variables, e.g. volume (duration, distance, repetitions), intensity (load, velocity, power), work-rest-ratio, and mode (type of exercise), a single exercise session induces several acute responses during (increased heart rate and oxygen consumption, muscular fatigue, increase in stress hormones) and immediately after the training session (decreased performance capacity, depleted muscle glycogen stores, increase in anabolic hormones). Depending on the magnitude of the training stimulus, supercompensation may be observed within 24-72 hours post-exercise, whereby physical performance rebounds to a higher level than before the exercise. When several such training sessions are performed in conjunction with optimal recovery periods (and proper nutrition), adaptive effects can be observed in the form of increases in physical performance and overall health (Bompa & Buzzichelli 2019, 12-19; Garber et al. 2011; Hawley 2002).

Long-term adaptations are highly specific to the training variables used, and in some cases, such as when combining strength and endurance training, acute and chronic adaptations may even be opposed to each other and thus compromise training outcomes in muscular strength (Hickson 1980) or power (Häkkinen et al. 2003). On the other hand, if the overall training stimulus is inadequate (e.g. too low training load, too long recovery periods between training sessions) in relation to an individual´s training status, a gradual loss of training adaptations leads to decreases in physical performance. For example, decreases of up to 15-20% in aerobic fitness (VO_2max) (Swank & Sharp 2016, 131) and about 10% in muscular strength (Häkkinen et al. 1985a) can already be observed four weeks after the cessation of training. Detraining is an important consideration for physically demanding occupations, since a decline in an individual's physical fitness increases the relative physiological demands of performing a task, reduces overall working capacity during prolonged assignments, and thereby increases the risk of injury (Roy et al. 2012).

In order to maximize training adaptations with an optimal combination of the training variables presented above, training sessions must be well planned and be part of a progressive periodized training program. Periodization of training refers to sequencing of training sessions and periods with specific goals for each training phase (Haff 2017, 182). General long-term periodization models have been adopted from competitive sports for the development and maintenance of physical fitness in soldiers (Billing & Drain 2017; Haff 2017, 199-205). Among professional armed forces, the main goal for training is to meet the physical requirements of deployment. During basic training and initial employment training, the goal is to ensure that physical fitness at least meets the baseline fitness standards. Thereafter, preparation for deployment aims to increase fitness further to meet the demands of the operation (Billing & Drain 2017; Haff 2017, 201). Deployment-based training can be periodized by dividing the training into three phases (i.e. mesocycles). The goal of the pre-deployment training phase is to increase strength, aerobic and anaerobic fitness, as well as to increase lean muscle mass reserves. During deployment, the aim is to at least maintain these qualities. The post-deployment mesocycle may be considered as a transition period, where the aims are recovery, possible injury rehabilitation, re-evaluation and return to the pre-deployment training regime (Billing & Drain 2017; Haff 2017, 201).

While the abovementioned external training load variables can theoretically be adjusted to optimize performance, several internal factors including age, body composition, baseline physical fitness, training history, recovery status and genetics contribute to the ultimate training outcomes (Bouchard & Rankinen 2001; Impellizzeri et al. 2019; Kyröläinen et al. 2018; Tanskanen et al. 2009). Individual training adaptations vary for aerobic fitness (Ross et al. 2019) as well as for muscle strength and hypertrophy (Ahtiainen et al. 2016) in response to identical training, most likely due to these internal training load factors (Impellizzeri et al. 2019). When compared to training responses of subjects with a higher fitness level, acute training load is higher among untrained subjects during identical military basic training (Jurvelin et al. 2020; Santtila et al. 2008), which may lead to increased risk of overtraining and injury in unfit subjects (Jones & Hauschild 2015).

As described in previous chapters, several operative stressors within the military context may alter acute training responses and chronic adaptations to physical training (Henning et al. 2011; Kyröläinen et al. 2018; Nindl et al. 2013). Military training and field work represent high-volume, low-intensity endurance-type physical activities which, when combined with excessive physical training and inadequate recovery, may lead to non-functional overreaching and ultimately overtraining syndrome (Kyröläinen et al. 2018; Tanskanen et al. 2011; Vrijkotte et al. 2019). Non-functional overreaching and overtraining syndrome refer to exercise-induced impairments of physical performance as a result of inadequate recovery and cumulative chronic fatigue (Vrijkotte et al. 2019). These pathophysiological states suppress immunology and increase the risk of injury and illness, while recovery of baseline performance level may take several months (Vrijkotte et al. 2019). In addition to high training load, monotonous training with inadequate periodization may lead to overtraining symptoms (Grandou et al. 2020) such as decreased physical performance, particularly an inability to maintain intensity during long training sessions and reduced time-to-fatigue (Cadegiani & Kater 2019; Grandou et al. 2020), lowered TES/COR and TES/SHBG ratios (Tanskanen et al. 2011) and depressed mood state (Vrijkotte et al. 2019). Importantly, negative energy balance (including insufficient intake of carbohydrates and protein), sleep disturbances and excessive simultaneous physical and cognitive load - typical operative stressors in a military environment - have been identified as predictors of overtraining syndrome in athletes (Cadegiani & Kater 2019). Thus, optimal periodization of physical training in the military should take into consideration not only external training load factors, but also the nature of military training, job demands and individual characteristics of the trainees (Jones & Hauschild 2015; Jones et al. 2017).

2.7.1 Acute loading responses and chronic adaptations to strength training

Strength training refers to progressive overload of muscles and the entire neuromuscular system by high muscle contraction force and anaerobic ATP resynthesis (Ahtiainen 2017, 51). Appropriate application of strength training alters neuromuscular function, improving an individual´s capacity to produce force in a training-specific manner (Häkkinen et al. 1981; Häkkinen et al. 1985a; Kraemer & Szivak 2012).

During the first weeks of strength training, neuromuscular performance is improved mostly via neural adaptations, i.e. enhancing the firing patterns of the motor units of the trained muscles (Häkkinen & Komi 1983; Häkkinen et al. 1998). Increased muscle activity and force production enable higher workloads (i.e. higher intensity and volume) during strength training, which further enhances acute hormonal responses associated with protein synthesis (Ahtiainen et al. 2003; Häkkinen et al. 1981; Häkkinen 1989). Thus, positive adaptations to systematic strength training also include increased size of the muscle glycogen stores and improved rate of protein synthesis, which lead to increased cross-sectional area of the trained muscles, typically appearing after 4-8 weeks of strength training (Ahtiainen 2017, 51-64; Häkkinen et al. 1981; Häkkinen et al. 1985b; Häkkinen 1989; MacDougall et al. 1980; Yarasheski et al. 1993). In addition to increases in muscle mass, connective tissues also adapt to strength training, as evidenced by increases in cross-sectional area of tendons and ligaments, as well as increases in bone mineral density (Ahtiainen 2017, 55; Hughes et al. 2018).

Acute responses and chronic adaptations to strength training are highly specific in relation to training variables, especially volume, intensity and recovery between sets. As the need for force production (i.e. training intensity) increases during a single set, more motor units are activated to match the work demand. With lower force production requirements (low or submaximal exercise intensity), mainly smaller, aerobic (type I) muscle fibers are activated, while with higher force production requirements (high intensity), activation of bigger, anaerobic (type II) muscle fibers increases (Kraemer & Szivak 2012). Thus, strength training that includes a high volume with a relatively high number (15-30) of repetitions per set performed at low intensity (e.g. <60% of 1RM) primarily improves muscular endurance, whereas lower volume training consisting of fewer (1-10) repetitions and higher intensity (>80% of 1RM) develops muscular strength. In order to increase muscular power, high velocity and explosive muscle activations are required. Optimal rest periods between sets can be shorter (≤1.5 min) at lower intensities (muscular endurance, hypertrophic strength training), while longer recovery periods (2-5 min between sets) are required for higher intensity (muscular strength and power) training (Kraemer & Szivak 2012).

Acute responses to a single hypertrophic (Häkkinen 1994) and maximal (Howatson et al. 2016; Häkkinen 1993) strength training session observed during or immediately after training include decreases in force production ability and voluntary muscle activation levels (i.e. neuromuscular fatigue). A hypertrophic training session with high training volume and short recovery periods between sets increases serum COR, growth hormone, TES and local IGF-1 concentrations within a few minutes to a few hours after the session. These changes during recovery are associated with signaling processes within the activated muscle cells and an increased rate of protein synthesis (Ahtiainen et al. 2003; Kraemer et al. 1999; Kraemer et al. 2016, 73-84). Larger acute hormonal responses have been observed in athletes with a longer training history vs. novice individuals (Ahtiainen et al. 2003; Häkkinen 1989), which is likely a chronic training adaptation.

Findings regarding chronic changes in basal circulating hormone levels such as growth hormone, TES or IGF-1, are somewhat controversial. It appears that acute increases in anabolic hormone concentrations after strength training are not maintained for longer than a few hours, and adaptations in the endocrine system are more related to increases in hormone receptors within the muscle tissue, allowing more possibilities for hormonal interactions and protein synthesis signaling (Ahtiainen 2017, 60-61). It has been suggested that resting concentrations are more likely to reflect the current homeostatic status of the muscle tissue (French 2016, 102), but studies have also reported increases in basal anabolic hormone levels during 6–10-week strength training periods (Häkkinen et al. 1987; Kraemer et al. 1999). Nevertheless, changes in acute serum anabolic hormones such as TES, as well as their basal concentrations, have been shown to be associated with changes in muscle mass and strength (Ahtiainen et al. 2003; Häkkinen et al. 1985b; Häkkinen et al. 1987).

Collectively, these training-specific adaptations enhance the ability to produce higher absolute force and power output (Häkkinen & Komi 1983; Häkkinen et al. 1998; Suchomel & Stone 2017). Average improvements of 5% and 21% in muscle size and strength, respectively, have been reported in previously untrained individuals after a 20–24-week strength training intervention (Ahtiainen et al. 2016). However, individual differences in strength training adaptations may vary considerably (Ahtiainen et al. 2016). In addition to its positive effects on activities requiring muscular fitness, carefully planned and implemented strength training may positively influence endurance performance. For example, maximal, explosive-type strength training has been shown to improve endurance performance by improving running economy in athletes (Balsalobre-Fernández et al. 2016; Hughes et al. 2018; Paavolainen et al. 1999a).

In the military context, Vantarakis et al. (2017) compared changes in physical fitness and occupational performance after an 8-week strength training intervention vs. regular Naval Cadet freshman year training. The intervention group performed additional linearly periodized daily strength training sessions, while the regular cadet training included daily jogging, calisthenics and team sports or swimming. Significant intervention-induced improvements were observed in upper and lower body strength (1RM squat, 1RM bench press), muscular endurance (repeated push-ups and abdominal crunches), anaerobic fitness (30-m sprint time) and occupational performance, assessed using a Navy-specific obstacle course (Vantarakis et al. 2017). In addition, interventions aiming to improve muscular fitness have reported positive outcomes in several military tasks, including load carriage (Heilbronn et al. 2020; Wills et al. 2019), lifting tasks (Hendrickson et al. 2010; Kraemer et al. 2001) and casualty drag (Hendrickson et al. 2010). However, some studies have shown that despite overall strength training-induced improvements in neuromuscular performance, arduous military training may hinder some strength training adaptations, especially muscular power development. This may be due to high overall training load and negative energy balance, leading to metabolic disturbances of muscle hypertrophy (Santtila et al. 2009a).

2.7.2 Acute responses and chronic adaptations to endurance training

Endurance training has traditionally referred to exercise modes performed at lower relative intensities (50-70% of VO_2max) and over a longer duration. More recently, a rather common and time-sparing application of endurance training includes high-intensity (>70% of VO_2max) interval–type endurance training (Helgerud et al. 2007, Hughes et al. 2018). Regular chronic endurance training improves aerobic fitness via central (e.g. increased oxygen uptake capacity) and peripheral (e.g. increased capillary and mitochondrial density) adaptations, which together improve oxygen transport and utilization, further delaying muscle fatigue during prolonged submaximal activity (Bassett & Howley 2000; Fitts & Widrick 1996; Hawley 2002; Helgerud et al. 2007; Holloszy & Coyle 1984; Hughes et al. 2018).

Acute responses to endurance training are specific to the volume and intensity of exercise. Within minutes of performing a moderate-intensity endurance training session, several responses are observed, including increases in heart rate, cardiac output, oxygen uptake, systolic blood pressure and blood flow in the working muscles. During aerobic exercise, these responses enable energy (ATP) to be regenerated at a sufficient rate to balance the increased oxygen cost of the exercise (Swank & Sharp 2016, 116-120). When exercise intensity is increased, oxygen debt begins to accumulate, and an increasing portion of the energy is produced anaerobically by the anaerobic lactic (i.e. glycolytic) system. After reaching the lactate threshold, an increase in lactate production occurs relative to exercise intensity, which also promotes cortisol and growth hormone release (French 2016, 102; Herda & Cramer 2016, 50-58). In such cases, aerobic metabolism is increased for minutes to hours after the cessation of exercise (Børsheim & Bahr 2003).

As with strength training, activation of muscle fibers follows the size principle during endurance exercise. Low exercise intensity mainly activates type I muscle fibers with a lower ability to produce force but more fatigue resistance, while activation of type II fibers requires higher exercise intensities (Bompa & Buzzichelli 2019, 276; Costill et al. 1976; Hawley 2002). Neuromuscular fatigue and thus a decreased ability to produce force, has been observed immediately after both moderate- and high-intensity endurance training (Jones & Howatson 2019, 140-146; Paavolainen et al. 1999b).

Chronic adaptations are highly specific to training volume and intensity. Low-to-moderate intensity endurance training induces primarily peripheral adaptations, such as increased capillary and mitochondrial density, and increased cellular level enzyme activity in the trained muscles, leading to improved fat oxidation and decreased accumulation of lactate during submaximal effort (Ahlborg et al. 1974; Bassett & Howley 2000; Fitts & Widrick 1996; Holloszy & Coyle 1984). High-intensity endurance training (HIT) additionally leads to central adaptations such as strengthening of the left ventricle wall, and thus increases in stroke volume and cardiac output (Helgerud et al. 2007; Knuttgen et al. 1973). Fatigue resistance improves via increases in muscle glycogen stores and an elevated lactate threshold (Herda & Cramer 2016, 50-51). At the neuromuscular level, the cross-sectional area of predominantly small, type I muscle fibers increases, and conversion of anaerobic fiber types (IIx) towards more aerobic (IIa) fibers may occur, especially when low-to-moderate intensity aerobic training is emphasized (Bompa & Buzzichelli 2019, 276; French 2016, 88-96; Hawley 2002; Hughes et al. 2018). In addition, increases in tendon and extracellular matrix of muscles contribute to the use of elastic energy during endurance exercise (Hughes et al. 2018). Together, these adaptations lead to improved endurance performance via increased aerobic capacity (VO_2max) and improved exercise economy (Glowacki et al. 2004; Hughes et al. 2018). While an average increase of 15% in VO_2max has been reported as a typical adaptation to endurance training, inter-individual variation may be huge, varying from no change up to a 100% increase in aerobic capacity (Bouchard & Rankinen 2001; Hawley et al. 2018). Aerobic metabolism promotes the production of energy from fats, so a common adaptation to chronic aerobic endurance training is a reduction in body fat content (Bassett & Howley 2000). A high volume of aerobic endurance training may also lead to a catabolism-induced negative net-protein balance, decreases in serum testosterone levels, and thus decreases in muscle mass and muscle power (Fitts & Widrick 1996; Hackney 2019, 30; Swank & Sharp 2016, 120-124).

The overall volume of low-to-moderate intensity physical activity is typically high during military training (Jurvelin et al. 2020; Ojanen et al. 2018; Wyss et al. 2012), which may explain why added aerobic endurance training does not always induce positive training adaptations during military service (Santtila et al. 2009a). On the other hand, a reduced volume and an increased intensity of endurance training has been reported to elicit larger training-induced improvements in aerobic fitness compared to more traditional low-to-moderate intensity endurance training during military service (Burley et al. 2020; Knuttgen et al.

1973). While these periodized training programs reflect the adaptations of young recruits in their early military career, very few endurance training studies have examined experienced professional soldiers. Regarding self-regulated aerobic endurance training during a military operation, an increase in training volume has been shown to be associated with an increase in aerobic fitness (Dyrstad et al. 2007). Moreover, an endurance training frequency of at least three times a week has been shown to be adequate to maintain or improve VO_2max during deployment (Warr et al. 2013).

2.7.3 Compatibility of strength and endurance training

Combined (or concurrent) training is defined as simultaneously incorporating both strength and endurance exercise within a periodized training regime (Fyfe et al. 2014; Hickson 1980; Häkkinen et al. 2003; Paavolainen et al. 1999a). In this thesis, combined training refers to training both strength and endurance during the same microcycle (e.g. the same week) but not in the same session, whereas in concurrent training the same training session includes both training regimes. Many typical military tasks such as load carriage, moving under fire, casualty evacuation and manual materials handling require both qualities of physical fitness, so the development of optimal occupational performance capacity of a soldier most likely requires a combination of strength and endurance training.

The effects of combined and concurrent training have been studied extensively since the early 1980´s, when Hickson (1980) presented the theory of interference effect. The original interference effect refers to attenuated adaptation of muscular (i.e. maximal) strength following 6-10 weeks of high frequency (5 times strength + 6 times endurance training per week) and high volume (each mode for 30-40 min per session) concurrent training. Later, it was shown that intensive concurrent or combined strength and endurance training interferes especially with the development of muscular power (i.e. explosive strength) during a prolonged (>12 weeks) training period (Häkkinen et al. 2003). In fact, Häkkinen et al. (2003) reported no interference of muscular strength or hypertrophy during a 21-week (gradually increasing intensity) strength training intervention performed only twice a week versus the same training program combined with additional endurance training, also performed twice a week. However, no development in explosive force production (i.e. muscular power) was observed in the combined training group, with a significant difference compared to strength training only. Several studies supporting the findings of Häkkinen et al. (2003) have been presented thereafter (Eklund et al. 2015; Schumann et al. 2015), also within the military context (Santtila et al. 2009a).

In a 6-week follow-up (Jones et al. 2013), training adaptations were examined in twenty-four strength trained men in response to concurrent strength and endurance training three times per week, but with varying training ratios (e.g. 1:1 = endurance training session followed each strength training session; 3:1 = endurance training session was performed after every third strength training session). The training groups were also compared to a control group that performed no training and a group that only performed strength training. Both strength (5 x 6 repetitions at 80% 1RM) and endurance (30 min of continuous repetitions at 30% 1RM) training included the performance of unilateral leg extensions. The main findings in the concurrent training groups were that one weekly endurance training session (group 3:1) did not interfere with muscular strength development, whereas three weekly endurance training sessions led to an interference effect. In addition, compared to the control group, muscle mass (thigh girth) only increased in the group that performed one weekly endurance training session. Thus, Jones et al. (2013) concluded that the magnitude of the interference effect was related to endurance training frequency (and/or overall volume of endurance training), with higher endurance training frequency resulting in larger interference.

Fyfe et al. (2014) suggested that a combination of a high endurance training load and inadequate recovery induces residual fatigue, which may attenuate strength development due to poorer training quality and thus a compromised adaptation stimulus. The suggested major modulators of interference include exercise order (endurance first), proximity (inadequate recovery time between the training modes), and high endurance training load (Fyfe et al. 2014). Häkkinen et al. (2003) demonstrated that attenuated neural drive, caused by fatigue from preceding endurance exercise, may ultimately lead to interference in explosive strength development. Jones et al. (2017) reported that endurance exercise performed prior to strength training induced greater blood cortisol and lactate concentrations compared to the opposite exercise order and thus, impaired the subsequent strength training performance. Other suggested mechanisms that impair the development of muscular strength and power include endurance training-induced muscle damage, depletion of muscle glycogen stores, skeletal muscle fiber-type transformations towards slower types, and decreased muscle mass (García-Pallarés & Izquierdo 2011; Leveritt et al. 1999). Various differences in the setting of combined or concurrent training studies have made the investigation of interference challenging. These differences include the training history of the study population, training mode, volume and frequency, as well as sequencing and length of recovery between the training modes. Moreover, different studies have employed different methods of measuring strength and endurance performance.

Regarding the military context, Burley et al. (2020) hypothesized that by reducing the overall training load of endurance-type military training, lower volume and higher intensity combined strength and endurance training may induce more positive adaptations in physical performance of recruits during basic military training. During the 12-week study, military recruits in the experimental group performed 40 individualized high-intensity strength (6-8RM free weight deadlifts, squats etc.) and endurance (3-min interval runs above 80% of heart rate reserve) training sessions, whereas the control group performed a similar volume of standard military physical training (i.e. moderate-to-high intensity running, circuit training, load carriage). The main outcomes of this study included improvements in muscular strength, power and endurance in response to individualized, high-intensity, low-volume training, which also required a smaller time commitment during military basic training. In addition, the experimental group improved aerobic fitness and load carriage performance more than the control group, despite performing 50% fewer endurance training sessions, with a corresponding reduction in objectively measured physical activity. Together, these findings suggest that more individualized progressive training periodization with lower total training load may improve overall training quality, and result in more effective training adaptations during military training.

Taking into consideration the methodological challenges, combined strength and endurance training has proven to be an effective and time-efficient method of improving physical fitness and occupational performance within the military context (Kyröläinen et al. 2018). It has been suggested that at least eight hours should separate the two training modes to ensure proper recovery, and if possible, strength and endurance training should target different muscle groups to maximize recovery and adaptations (Jones & Howatson 2019, 150-151). More recently, Doma et al. (2019) suggested that due to similar mechanisms including residual neuromuscular fatigue, also endurance training outcomes may be impaired following a strength training session. However, longitudinal negative effects have not been consistently observed, especially among recreationally active individuals (Rønnestad & Mujika 2014; Schumann et al. 2014; Taipale et al. 2010). In order to optimize endurance training adaptations, acute fatigue resulting from high volume, high intensity strength training (up to 24 hours) should be avoided (Eklund et al. 2016), especially when preparing for a high intensity endurance training session (Doma et al. 2019).

3 PURPOSE OF THE THESIS

The present thesis investigated physical workload and associations between occupational performance and body composition, as well as physical fitness variables during a 6-month crisis management operation in the Middle East. An additional purpose of the thesis was to determine the optimal distribution of strength and endurance training to maintain or improve the physical fitness of crisis management soldiers during deployment. The specific aims and hypotheses of each study in this thesis were:

1) To investigate changes in body composition, serum and saliva stress biomarkers, objectively measured volume and intensity of physical activity, and heart rate responses in soldiers during a 6-month international crisis management operation. Based on previous studies (Henning et al. 2011; Nindl et al. 2013), it was hypothesized that the occupational workload would result in symptoms of accumulative stress but to a lesser extent than observed previously during combat operations (Original paper I).

2) To evaluate cross-sectional associations between physical fitness and body composition characteristics and simulated high-intensity military task performance whilst wearing combat load. The primary hypothesis was that muscular power of the lower extremities, together with greater muscle mass and less body fat (Lyons et al. 2005; Mala et al. 2015), would be associated with better performance whilst wearing combat load (Original paper II).

3) To examine the effects of different combinations of strength and endurance training on body composition, physical performance and serum anabolic and catabolic biomarkers during a six-month crisis management operation in the Middle East. Based on previous literature (Dyrstad et al. 2007; Haff 2017, 181-205; Warr et al. 2013), it was hypothesized that aerobic fitness in particular would decrease during the operation, but with a periodized strength and endurance training program performed 2-3 times per week, endurance performance would be preserved during deployment (Original paper III).

4) To investigate individual training responses and adaptations of endurance performance to combined strength and endurance training during a 6-month crisis management operation in the Middle East. It was hypothesized that individual-specific training factors such as fitness status, training history and body composition (Burley et al. 2018; Impellizzeri et al. 2019; Kyröläinen et al. 2018; Pihlainen et al. 2020) would influence training adaptations during the operation (Original paper IV).

4 MATERIALS AND METHODS

4.1 Description of the UNIFIL mission

The present research project was conducted in 2014 during the 6-month international United Nations Interim Forces in Lebanon (UNIFIL) crisis management operation in the Middle East (FIGURE 2). The responsibilities of the UNIFIL troops included monitoring the cessation of hostilities between Israel (Israeli Defense Forces, IDF) and Lebanon (Hezbollah) after the July war in 2006. In addition, the mission of UNIFIL was to support the government of Lebanon to extend its authority to South Lebanon through the Lebanese armed forces (LAF) and to assist the local population.

One of the most typical operative duties for the UNIFIL soldiers was patrolling for four to six hours in vehicles around the area of the operative responsibility. Other common operative tasks included guarding of the military base for one to eight hours. Soldiers at headquarters and in logistic units worked mainly inside the military base. The operative units worked in three shifts around the clock, while the headquarters and logistic tasks were performed mainly during the daytime. However, separate individual duties that required 24-hour readiness were assigned to all personnel groups.

The UNIFIL operational environment remained relatively calm throughout the study period. Nonetheless, the security situation was susceptible to sudden changes, requiring soldiers to conduct their daily duties in a peaceful environment while simultaneously remaining vigilant of different types of threats.

The average ambient temperature, recorded in one-hour intervals throughout the 6-month study period (Thermochron iButton, Maxim Integrated, San Jose, California, USA) inside the military camp was 22.3 ± 4.3°C (range: 11–36°C). The soldiers had air-conditioning in their accommodation, and no heat-related illnesses were reported during the study period.

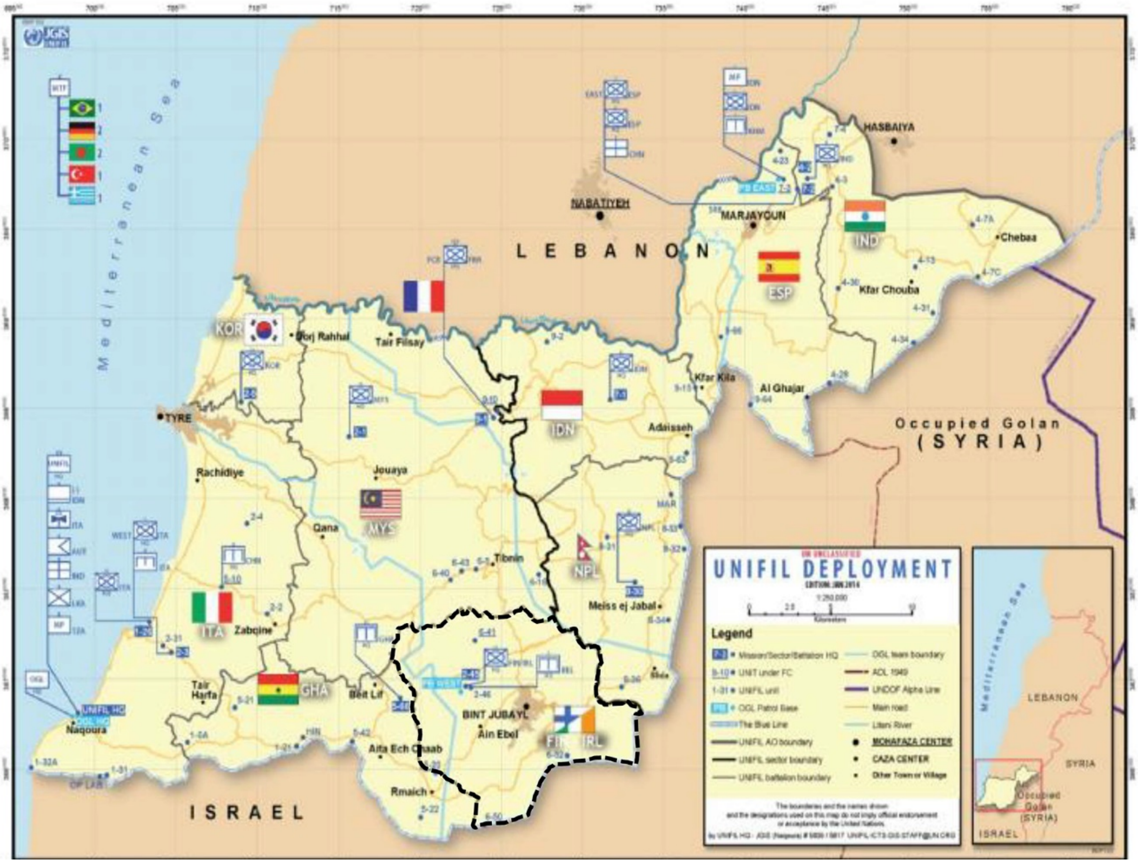

FIGURE 2 The area of responsibility of the Finn-Irish battalion is depicted with a dashed and bolded line.

4.2 Participants

In total, 93 of the 250 available healthy male soldiers who were recruited to serve from 6 to 12 months in the crisis management operation in South Lebanon voluntarily applied to participate in the study. The follow-up consisted of assessments of health and occupational performance variables in the deployment area performed at three time-points. The present thesis focused on changes in body composition and physical fitness, while additional parallel studies with the same subjects focused on other aspects of human performance, such as mental and social wellbeing, nutrition etc.

Prior to deployment, soldiers were clinically examined by a physician. The exclusion criteria for the deployment included health limitations requiring permanent medication, and a distance less than 2300 meters covered in the 12-min running test. All soldiers from the rotation unit were informed of the study design, and thereafter participating soldiers gave written informed consent to voluntarily participate. The soldiers were not paid or rewarded for their participation in the study. The study was approved by the Chief of Personnel of the Finnish Defence Forces (AJ7326/30.4.2013), and it was conducted in accordance with the guidelines of the Ethical Committee of the Hospital District of Central Finland (KSSHP E1/5.4.2013).

For the present thesis, 91 male soldiers took part in the baseline measurements, thus leaving two dropouts at that point. Thereafter, the number of subjects varied within the measurements since the soldiers were not able to participate in all measurements due to their duties. Two soldiers were withdrawn from the operation for medical reasons that were not related to the study. In addition, another two subjects voluntarily withdrew from the study due to lack of motivation. Thus, in the first study, 79 soldiers (30 ± 8 years, 179 ± 7 cm, 79 ± 8 kg) with body composition assessments from all three measurement phases were included in the statistical analyses. They were further divided into two subgroups based on their operative duties (operative infantry units, n = 41 and headquarters + logistic units, n = 38). In the second study, 81 male soldiers (30 ± 8 years, 180 ± 6 cm, 79 ± 9 kg) took part in cross-sectional assessments of physical fitness, body composition and occupational performance. For the third study, which focused on training adaptations to combined strength and endurance training, 78 male soldiers (29 ± 8 years, 180 ± 7 cm, 79 ± 8 kg) were included in the statistical analyses. They were further randomly divided into four groups: a control group or one of the three training groups that included varying distributions of strength and endurance training. Finally, in the fourth study, the total sample included 66 male soldiers (30 ± 9 years, 180 ± 7 cm, 79 ± 8 kg) from the training intervention groups. In this study, endurance tests were performed at baseline and at the end of the operation.

4.3 Experimental design

The present thesis consisted of three main parts. The first part focused on describing the physical workload experienced by the UNIFIL soldiers during a 6-month operation. Additionally, changes in serum and saliva biomarkers and body composition were measured to investigate possible long-term adaptations to occupational stressors (original paper I). The aim of the second study was to determine the associations between physical fitness components and a military task simulation, representing an acute occupational stress scenario induced by a combat situation (original paper II). Studies III and IV examined adaptations in body composition and physical performance in response to combined strength and endurance training (original paper III), as well as inter-individual differences in endurance-related training adaptations (original paper IV) during the operation.

4.3.1 Study I

Volume and intensity of physical activity, heart rate responses and saliva stress biomarkers were measured during duties on three occasions in order to evaluate the acute physical workload of soldiers during the operation. Furthermore, physiological adaptations to occupational physical stress were assessed via changes in body composition, as well as morning samples of serum anabolic and catabolic biomarkers. To determine possible differences in physical workload between soldiers performing operative duties outside the military base versus those mainly operating inside the base, soldiers were divided into two groups according to their tasks, and the groups were compared. The soldiers in the operative infantry units formed group A while those at headquarters and logistic units formed group B. The results were also collated for the total subject group (i.e. group A+B).

4.3.2 Study II

A novel military simulation test (MST) was added to the test battery of the present research project to study the anaerobic performance of soldiers and the interrelationships between MST (dependent variable), physical fitness and body composition variables. The focus of the present study was on the results of the baseline measurements in soldiers who did not have prior experience of MST. It was designed in collaboration with physical training experts and professional soldiers, consisting of maneuvers and tasks that might occur in a combat situation during a patrol or transport in the deployment area. In addition, prior studies focusing on military tasks and simulations were taken into account in the development of MST.

4.3.3 Study III-IV

To determine whether the periodized strength and endurance training program performed at least twice per week could preserve physical fitness, body composition and occupational performance during deployment, the soldiers were randomly assigned to the control group or one of the three combined strength and endurance training groups. The proportion of strength training relative to endurance training varied between the intervention groups. All training groups were provided with a nonlinear progressive training program consisting of two weekly training sessions. In group **Es**, 75% of training sessions consisted of endurance training and 25% of strength training. On the contrary, 75% of sessions included strength training in the **Se** training group. Finally, the strength-to-endurance training ratio was equally balanced (i.e. 50% strength training) in the **SE** group. In total, the training programs of all intervention groups consisted of 50 exercise sessions during the study period (FIGURE 3).

The training was self-reported using training diaries. The soldiers were encouraged to at least maintain their habitual training volume but to adjust the strength-to-endurance training ratio according to the prescribed program. The outcomes were determined based on aerobic fitness (3000-m running test performance) and muscular fitness (lower and upper body muscular strength, lower body muscular power, muscular endurance of lower and upper body and trunk) variables, body composition (skeletal muscle mass, fat mass) and serum hormone samples (TES, SHBG, COR, IGF-1).

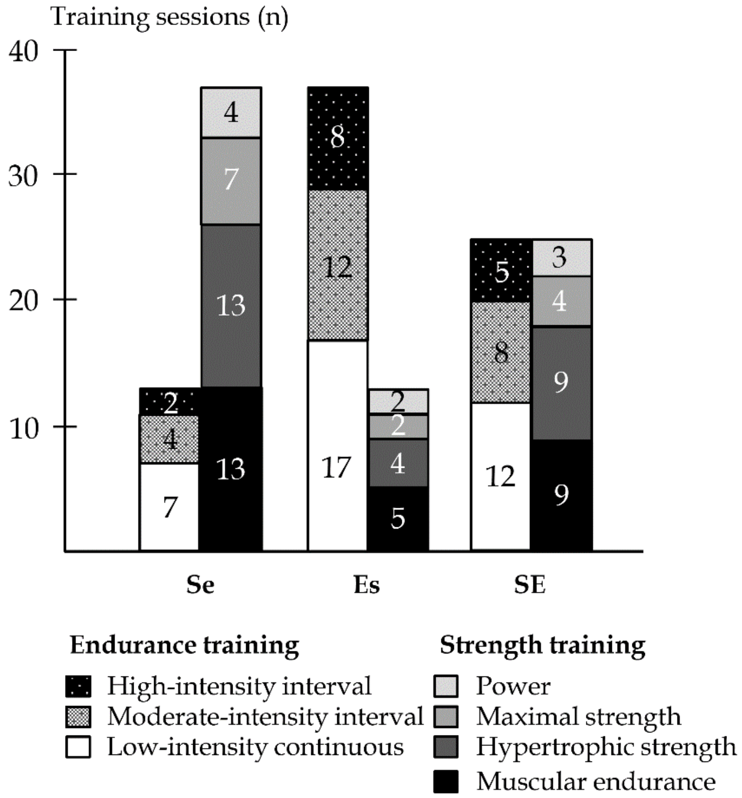

FIGURE 3 The number (n) of strength and endurance training sessions performed by each group during the operation. **Se** = strength emphasized training group; **Es** = endurance emphasized training group; **SE** = evenly balanced strength and endurance training group.

The composition of strength and endurance exercises (see below) was similar in all intervention groups, but the frequency of training varied between the groups. In general, the periodization model was non-linear, and the first half of the study focused on low-to-moderate-intensity exercises. Thereafter, the training intensity was increased, and volume decreased during the latter half of the study period.

Endurance training:

1. Low-intensity endurance exercise
- 30–60 min continuous
- Target HR 60–75% HR_{peak}, target RPE 13–15
- Modes: walking, running, bicycle or rowing ergometer

2. Moderate-intensity endurance exercise
- 3-4 x 8-10 min, active recovery 3–5 min between intervals
- Target HR 75–85% HR_{peak}, target RPE 15–17
- Modes: walking, running, bicycle or rowing ergometer

3. High-intensity endurance exercise

- 4 x 4 min, active recovery 3 min between intervals
- Target HR 90–95% HR_{peak}, target RPE 16–19
- Modes: running, bicycle or rowing ergometer

Strength training:

1. Muscular endurance exercise

- Kettlebell circuit, 2–3 rounds, set duration 30–50 sec, set recovery 30–10 sec. Recovery between rounds 2-3 min
- Kettle bell weight 8–20 kg (10–40% 1RM)
- Intensity: low to moderate

1. Two-handed swing
2. Lunge and twist
3. Plank
4. Right arm clean and jerk
5. Lateral lunges
6. Two-handed combined biceps curl, press and French press
7. Left arm clean and jerk
8. Deadlift
9. Around the head
10. Two-handed combined pull-over and sit-up

2. Hypertrophic strength exercise

- 3–5 x 8-10 repetitions (stationary), 60–120 sec recovery between sets
- Load 60–80% 1RM
- Before exercises 1 to 4, a warmup set with 6-8 reps, 30–50% 1RM are performed
- Intensity: low

1. Barbell deep squat
2. Barbell bench press
3. Barbell dead lift
4. Barbell military press
5. Barbell row
6. Barbell biceps curl
7. Barbell lying triceps extension
8. Barbell calf raise (15–20 reps/set, load 30–50% 1RM)

3. Maximal strength exercise

- Exercises 1 to 3: 4 x 2-4 repetitions (stationary), 3-5 min recovery between sets
- Load >80% 1RM
- A warmup set with 6-8 reps, 30–50% 1RM are performed
- Intensity: moderate

1. Barbell squat
2. Barbell bench press

3. Barbell dead lift
- Exercises 4 to 6: 2-4 rounds (circuit), 2-3 min recovery between rounds
- Intensity: moderate
4. Barbell military press (8-10 x 60-80% 1RM)
5. Pull-up (80-90% 1RM)
6. Plank with knee twist (80-90% 1RM)

4. Power exercise
- Exercises 1 to 3: 4 x 4-6 repetitions (stationary), 2-5 min recovery between sets
- Load 40-60 % 1RM (sets of 40%/50%/60%/40% 1RM)
- A warmup set with 6-8 reps, 30–50% 1RM are performed
- Intensity: high
1. Clean and jerk
2. Half squat
3. Barbell bench press
- Exercises 4 to 7: 2-4 rounds (circuit), 2-3 min recovery between rounds
- Intensity: low to moderate
4. Pull-up (80-90% 1RM)
5. Crunch (80-90% 1RM)
6. Dip (80-90% 1RM)
7. Back extension "superman" (80-90% 1RM)

4.4 Measurements

The baseline measurements (PRE) were carried out after two weeks of non-standardized acclimatization inside military base UNP 2-45 in South Lebanon. The baseline measurements were repeated 9 (MID) and 19 (POST) weeks after the PRE measurements. Physical fitness components (muscular fitness, aerobic fitness) and occupational performance (military simulation test) were assessed on separate days with a minimum of 24 hours between the tests. Soldiers were advised to avoid any physical training the day before each test session.

4.4.1 Anthropometrics and body composition

Body composition measurements were conducted in the morning after a minimum 10-hour overnight fast at the hospital of the military base. Soldiers were barefoot and wearing light underwear, and they were advised to empty their bladder within 30 minutes of the measurement.

Height was measured to the nearest 0.1 cm using a wall-mounted height board (Seca Bodymeter 206, Seca, Hamburg, Germany). Body mass (BM), skeletal muscle mass (SMM) and fat mass (FATM) were determined to the nearest 0.1 kg using segmental multi-frequency bioimpedance analysis (InBody 720, Biospace, Seoul, South Korea) in accordance with the manufacturer's guidelines. Soldiers were advised to stand in an upright position with their feet on the electrodes (two for each foot) of the device platform. Arms were abducted with a palm-grip on the handle electrodes (two for each palm).

The reliability of the method used in the present study has been reported to be good for FATM (ICC 0.98, SEM 0.87), FAT% (ICC 0.98, SEM 0.99) and SMM (ICC 0.99, SEM 0.84) in males (McLester et al. 2020). While a general overestimation of SMM and an underestimation of FATM and FAT% has been reported relative to the DXA method, no differences were observed in the changes in these variables between the abovementioned methods (Antonio et al. 2019). However, variation between individuals may be higher with the BIA method than with DXA (Antonio et al. 2019).

4.4.2 Blood biomarkers

Blood sampling was conducted in the morning after an overnight fast and the body composition measurements. Due to the circadian rhythm of COR, awakening response rather than basal level may be a more appropriate term for our samples, since they were obtained approximately 30 minutes after waking. An increase in the awakening response of cortisol has been identified as a potential neuroendocrine biomarker for work-related stress (Chandola et al. 2010).

Blood samples were drawn from the antecubital vein. Serum was separated from blood using a centrifuge (1000 rpm, 8 min) and frozen below –20°C for further transportation and analysis. Assays for serum TES, SHBG, COR and IGF-1 were performed by Immulite 2000 XPi (Siemens Healthcare, Llanberies, UK) using commercial chemiluminescent enzyme immunoassay kits according to the manufacturer's guidelines. The inter-assay coefficients of variance (CV) for assays of TES, SHBG, COR and IGF-I were 7.0–7.2, 4.5–6.2, 4.6–5.8 and 3.7–7.4%, and corresponding sensitivity values were 0.5, 0.02, 5.5 nmol $\cdot$ L^{-1} and 2.6 pmol $\cdot$ L^{-1}, respectively.

4.4.3 Aerobic fitness (endurance performance)

Aerobic fitness was evaluated using the 3000-meter running test (3000-m). The test was performed on a standardized 1.13-km track covered with asphalt. The total ascent and descent of the track was 32 meters. The soldiers were instructed to complete the test with maximal effort and in the shortest possible time. The outcome measure, duration of test performance, was recorded with a stopwatch (Select Sport, Glostrup, Denmark), while heart rate (HR) was recorded using chest-strapped monitors (Memory belt, Suunto, Vantaa, Finland). Peak heart rate (HR_{peak}) was determined for workload assessments and endurance training prescription using computer analysis software (Firsbeat PRO, Firstbeat Technologies, Jyväskylä, Finland), and defined as the highest recorded HR during the 3000-m test.

4.4.4 Muscular strength, power and endurance

Maximal isometric force of the lower (MVC_{lower}) and upper (MVC_{upper}) extremity extensor muscles was measured bilaterally in a sitting position using an electromechanical dynamometer (University of Jyväskylä, Jyväskylä, Finland). The MVC_{lower} measurement (Häkkinen et al. 1998) was performed in a horizontal leg press position with knee and hip angles fixed at 107° and 110°, respectively. For the MVC_{upper} measurement, the handlebar was adjusted to the height of the shoulders so that elbow angle was maintained at 90°. In both measurements, joint angles were determined using a goniometer, and soldiers were instructed to perform three maximal efforts with a minimum of 30 seconds recovery between trials. For each test, the trial with the highest force output was selected for further analyses. Both of these tests have shown high reliability, with ICCs varying between 0.95-1.00 and CV<2.0% (McMaster et al. 2014).

Muscular power and muscular endurance tests were performed according to the instructions of the Finnish Defence Forces (Pihlainen et al. 2011). A standing long jump (SLJ) was used to assess power production of the lower extremities (Bosco et al. 1983; Markovic et al. 2004). Before performing a minimum of three test attempts, the soldiers were instructed about proper technique, and five to seven warm-up trials were performed. The jumps were performed on a 10-millimeter-thick rubber mattress designed for the purpose (Fysioline Co, Tampere, Finland). The jumps were performed from a standing position, feet at pelvis to shoulder width. Explosive bilateral take off was assisted by powerful extension of the hips and swinging of the arms. The landing was performed bilaterally and falling backwards led to disqualification of the attempt. The result of the best jump was expressed in centimeters as the shortest distance from the landing point to the starting line.

Dynamic muscle endurance of the trunk and upper extremities was assessed using sit-up, push-up and pull-up tests, respectively. A specialized test supervisor showed the correct technique before each test. The soldiers were also informed that incorrectly performed repetitions would not be included in the test result. Sit-ups were used to measure performance of abdominal and hip flexor muscles. In the starting position, the soldier laid on his back while legs were supported at the ankles by an assistant. The knees were flexed to an angle of 90°, with elbows pointing upwards and fingers crossed behind the back of the head. A successful repetition required that the soldier lifted his upper body from the starting position and brought the elbows to knee-level. The result of the test was expressed as the number of consecutive successful repetitions performed in 60 seconds (Viljanen et al. 1991).

The push-up test was used to measure performance of the arm and shoulder extensor muscles (ACSM 2014, 99-101). Before taking the starting position, the soldier laid face down on the floor, feet parallel at pelvis to shoulder width and hands positioned so that the thumbs could reach the shoulders while the other fingers pointed forward. Before the initiation of the test, the soldiers were instructed to extend their arms to the starting position and keep the feet, trunk and shoulders in line throughout the test. A successful repetition required that the soldier lowered his torso by flexing the arms to an elbow angle of 90° and returned to the starting position by extending his arms. The result of the push-up test was expressed as the number of consecutive successful repetitions performed in 60 seconds.

The pull-up test was used to measure the performance of the arm and shoulder flexor muscles. In the starting position, the soldiers hung by their hands from a horizontal bar, with arms and feet straight. The underhand grip was instructed to be at shoulder width, and the hip and legs were to be extended throughout the test. A successful repetition required that the body was raised by flexing the arms from the starting position until the chin was above the bar. The result of the test was expressed as the number of consecutive pull-ups until volitional exhaustion (Schmidt 1995). The reliability of repetitive muscular endurance tests has been reported to be high, with ICC´s >0.90 (Alaranta et al. 1994; Augustsson et al. 2009).

4.4.5 Military simulation test (MST)

MST consisted of typical army soldier maneuvers and tasks. The test was performed on an artificial grass court wearing a combat uniform, leather boots and combat gear including body armor, a helmet and an assault rifle replica (3 kg). From the starting position of lying supine, the soldiers performed four consecutive 6.2 m rushes, changing direction after each rush. After the last rush, they low crawled for 11.3 m, followed by a sprint of 21.8 m. After the sprint, the soldiers ran another 21.8 m jumping over three 40 cm obstacles (Movemakers Step, Movemakers, Tiistenjoki, Finland) separated by a distance of 5 m. Thereafter, the soldiers lifted, carried and lowered two 16 kg kettlebells (Eleiko Co, Halmstad, Sweden) four times over a distance of 5 meters. This was followed by a zig zag run of 42.4 m. Finally, before sprinting back to the starting line the soldiers dragged a 65 kg mannequin (Ultimate sandbag, Ultimate sandbag training, Scottsdale, AZ, USA; two sandbags, attached to each other with cable ties) around a 24-meter circle. The total length of the MST track was 242.5 m (FIGURE 4).

Prior to the MST, a saliva sample was obtained from all soldiers with a cotton swab according to the manufacturer´s guidelines (Salivette, Sarstedt, Nümbrecht, Germany), and blood lactate (BLa) was measured from the fingertip (Accutrend Plus, Roche Diagnostics GmbH, Mannheim, Germany) from 59 randomly selected soldiers. Thereafter, the soldiers rated their perceived exertion (RPE; Borg 1982) and performed three countermovement jumps (CMJ) on a force platform (FP8, HUR Labs, Oulu, Finland) both in their underwear (boxers, t-shirt and socks; CMJ1) and in the combat load excluding the rifle replica (uniform, boots, helmet, body armor, modular vest; CMJ2). The soldiers were allowed 30 s for recovery between the jumps in both clothing conditions. CMJ data were automatically transported to computer software (Force Platform Software Suite, HUR Labs, Oulu, Finland), and jump height was calculated from the take-off velocity.

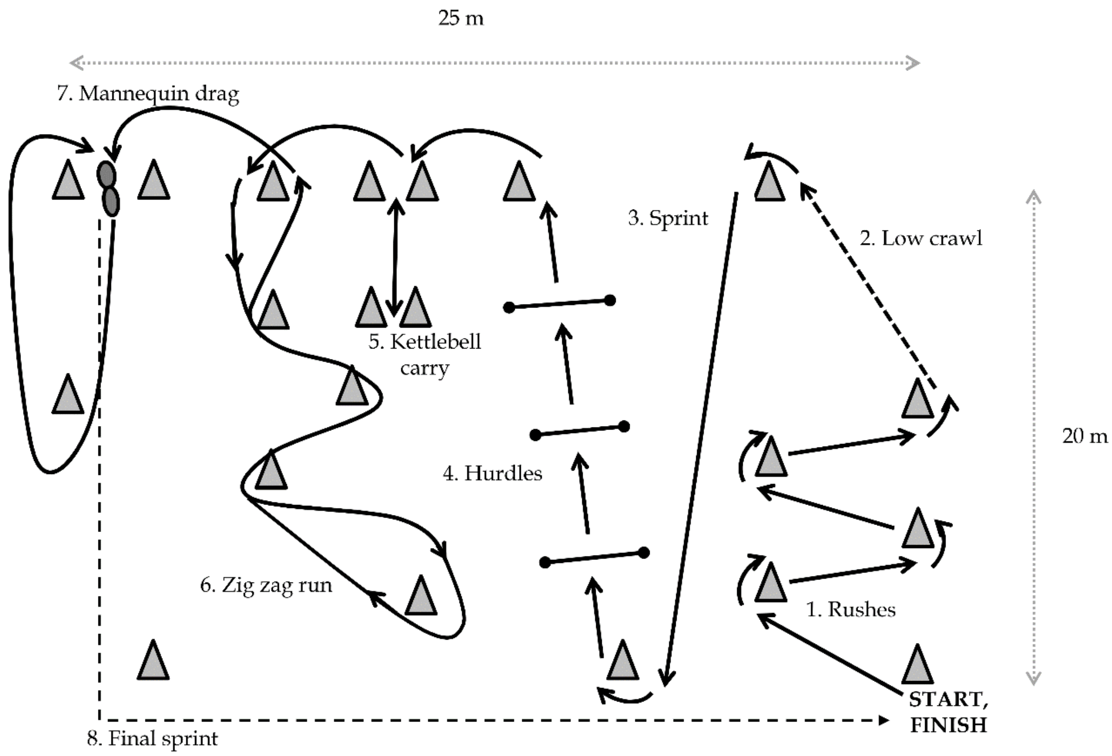

FIGURE 4 Illustration of the Military Simulation Test track.

Before performing the MST, each soldier was individually familiarized with the track by a supervisor who also gave verbal instructions during the test. The soldiers were instructed to complete the track in the shortest possible time. Performance time was recorded with a stopwatch, and HR was recorded with a memory belt (Memory belt, Suunto, Vantaa, Finland).

RPE and saliva sampling were repeated within one minute of completing the MST. Immediately after giving the saliva sample, the soldiers performed another three CMJs in the combat load excluding the assault rifle replica (CMJ3). Finally, BLa was obtained 5 min after the test.

4.4.6 Occupational physical workload

Occupational physical workload was evaluated using continuous HR recordings, saliva samples and RPE assessments, as well as accelerometer recordings for physical activity (PA) measurement. Soldiers were instructed about how to use the measurement methods in advance at the military base, and the measurements were self-initiated during their typical duties in the operational environment.

HR was continuously recorded for up to three days (depending on memory storage limits) with a recordable memory belt (Memory belt, Suunto, Vantaa, Finland). Individual absolute and relative (%HR_{peak}) mean HR were analyzed (Firstbeat PRO, Firstbeat Technologies, Jyväskylä, Finland) over 24-h periods to provide average values for each measurement phase.

Saliva samples, with simultaneous RPE (Borg 1982) assessments, were collected six times during one typical working day using cotton swabs according to the manufacturer's guidelines (Salivette, Sarstedt, Nümbrecht, Germany). Soldiers were instructed to take saliva samples and record RPE scores after a normal night's sleep immediately upon waking, and 30 min, 1 h, 4 h and 10 h after waking. The last sample was collected just before going to bed at night. With the exception of the first sample, the soldiers were instructed to rinse their mouth with water 10 min prior to sampling. The soldiers were also told to keep the sealed sample containers in a dry and, if possible, cool place during their duties. The samples were delivered to the military base hospital on the morning following sampling and stored at –20°C, and were later transported in a frozen state for further analysis. The samples were thawed and centrifuged at 3500 rpm for 10 min. SaCOR and saAA were analyzed as potential non-invasive biomarkers of physical and mental stress (Bocanegra et al. 2012; Clow et al. 2006; Nater & Rohleder 2009). SaCOR was analyzed by Immulite 2000 XPi (Siemens Healthcare, United Kingdom) using chemiluminescent enzyme immunoassay kits, while saAA assays were performed by Konelab 20XTi (Thermo Fisher Scientific, Vantaa, Finland) using the enzyme photometric measurement method (inter-assay CV 13.2% and 3.2%, respectively). Daily mean values from all ratings (RPE) and samples (saCOR, saAA) were used for further statistical analyses.

PA was recorded with a tri-axial accelerometer at a frequency of 100 Hz (Hookie AM20, Traxmeet, Espoo, Finland). The device was positioned to the left side of the trunk at the height of the hips with an elastic band. The soldiers were instructed to wear the accelerometer for 10 days at all times with the exception of sleeping and water activities (i.e. shower, swimming). The minimum requirement for the inclusion of accelerometer data for further analyses was four days with at least 10 h of wearing time each day. The accelerometer data were analyzed for running and total step counts, as well as metabolic equivalent (MET) intensity levels of sedentary (MET < 1.5), light (MET 1.5-3.0), moderate (MET 3.0-6.0) and vigorous (MET > 6.0) PA using mean amplitude deviation according to a previously published validation study by Vähä-Ypyä et al. (2015). This validation against objectively measured VO_2 showed high within-individual correlations with walking speeds ($r = 0.99$), but also with running ($r = 0.98$) and with their combination ($r = 0.98$). The sensitivity and specificity values for 3 METs (100% and 96%) and 6 METs (96% and 95%) were also high (Vähä-Ypyä et al. 2015).

4.4.7 Exercise behavior (interview)

To assess differences in habitual strength and endurance training before vs. during the operation, the soldiers were interviewed six weeks before the deployment, where they were asked about endurance and strength training frequency in the preceding two months. The soldiers were asked "*On average, how many times per week have you performed endurance-type of training, e.g. walking, running, swimming, cycling, during the preceding two months?*" Similarly, for strength training, the soldiers were asked "*On average, how many times per week have you performed strength-type of training, e.g. gym training, weight lifting, during the preceding two months?*"

The interview was repeated in the deployment area during the POST measurements.

4.5 Statistical analysis

In study I, data were analyzed using repeated measures analysis of variance (ANOVA) and t-tests when appropriate. If the model was statistically significant, pairwise group and time comparisons were performed. If normality assumptions were not met, logarithm transformations were applied or nonparametric tests were used. The relationships between relative changes in measured variables were tested for linearity with Spearman's product moment correlation coefficients. Statistical significance was defined as $p < 0.05$.

In study II, descriptive statistical methods were used to calculate means and standard deviations (SD). Relative differences between variables measured before and after MST were analyzed using One-Sample Wilcoxon Signed Rank Test, due to non-normality and outliers. Associations between MST and other measured variables were tested for linearity with Spearman´s product moment correlation coefficients. Stepwise multivariate regression analyses were used to model log-transformed MST. Statistical significance was defined as $p < 0.05$.

In study III, descriptive statistics such as mean, SD, 95% confidence intervals (CI) and percentages were calculated where appropriate. Differences in within- and between-group changes, including for all intervention groups combined (**SE+Se+Es**), were analyzed using linear regression models. Models were adjusted for the baseline value of a given outcome, and group **C** was the reference group. Outliers (z-score < -3.3 or > 3.3) were detected and removed separately from each model. Unstandardized regression coefficients were expressed with 95% CI. Moreover, relationships were examined between explanatory variables (body composition, physical performance, biomarkers) and the relative changes from PRE to POST in SMM, FATM, 3000-m, and MVC_{lower}. Analyses were performed using backward linear regression with stepping method criteria $p = 0.05$ for entering and $p = 0.10$ for removing. Explanatory variables with $p < 0.05$ in the univariate analysis were included for backward linear regression.

In study IV, the soldiers were re-classified as "High responders" (HiR) and "Low responders" (LoR), based on PRE-POST changes in endurance performance. The HiR group consisted of soldiers whose 3000-m test time improved (i.e. decreased), while soldiers whose 3000-m test time either stayed the same or got worse during the operation were assigned to the LoR group. Descriptive statistics (mean ± SD) were calculated when appropriate. Group differences were tested using the Mann-Whitney test. In addition, relationships between relative changes in measured variables were tested with Spearman's rank correlation coefficient. Statistical significance was defined as $p < 0.05$.

5 RESULTS

5.1 Occupational physical workload during a crisis management operation (Study I)

Serum TES concentration in group A increased by 12% ($p < 0.01$) from PRE to MID, while COR decreased by 14% ($p < 0.01$) from MID to POST. SHBG decreased in both groups from MID to POST (group A; –18%, $p < 0.01$, group B; –9%, $p < 0.05$) as well as from PRE to POST (group A; –19%, $p < 0.05$, group B; –14%, $p < 0.01$). These changes led to increases in the TES/SHBG ratio by the end of the study in all groups (TABLE 3). The TES/COR ratio increased accordingly, but only in the total subject group and in group A. Between-group differences were observed in the TES/SHBG ($p < 0.05$) and TES/COR ratios ($p < 0.01$) at POST. While no within-group changes were observed in IGF-1 during the study, higher IGF-1 concentrations were found in group A at all timepoints, as well as lower concentration of COR at POST ($p < 0.05$).

Regarding acute responses, daily average $\%HR_{peak}$ of all soldiers (group A+B) decreased by 2% ($38 \pm 4\%HR_{peak}$ vs. $37 \pm 4\%HR_{peak}$, $p < 0.05$) from PRE to MID. While no changes were observed in daily mean saCOR concentrations, saAA increased between PRE and POST in the combined group (A+B) by 108% ($37 \pm 34\ U \cdot mL^{-1}$ vs. $55 \pm 40\ U \cdot mL^{-1}$, $p < 0.05$), in group A by 116% ($35 \pm 24\ U \cdot mL^{-1}$ vs. $56 \pm 45\ U \cdot mL^{-1}$, $p < 0.05$) and in group B by 103% ($41 \pm 41\ U \cdot mL^{-1}$ vs. $55 \pm 37\ U \cdot mL^{-1}$, $p < 0.05$).

TABLE 3 Serum biomarkers (mean ± SD) at the beginning (PRE), middle (MID) and end (POST) of the 6-month international crisis management operation. TES, testosterone; SHBG, sex-hormone binding globulin; IGF-1, insulin-like growth factor; COR, cortisol. Group A (n = 29) – operative infantry units; group B (n = 30) – headquarter and logistic units. * Within-group comparison: significantly different from PRE ($p < 0.05$). ** Within-group comparison: significantly different from MID ($p < 0.05$). # Between-group comparison: significantly different from group A ($p < 0.05$).

Variable	PRE	MID	POST
TES ($nmol \cdot L^{-1}$)			
Total group (A+B)	15.9±4.6	17.2±4.0*	17.3±3.6
Group A	16.3±5.4	18.0±4.1*	17.9±3.5
Group B	15.5±3.8	16.5±3.9	16.8±3.8
SHBG ($nmol \cdot L^{-1}$)			
Total group (A+B)	32.3±12.0	31.8±12.1	26.6±13.2*,**
Group A	31.0±13.4	32.4±15.7	25.5±16.4*,**
Group B	33.6±10.5	31.2±7.5	27.7±9.3*,**
TES/SHBG			
Total group (A+B)	0.54±.020	0.60±0.21	0.80±0.43*,**
Group A	0.58±.021	0.64±0.25	0.95±0.55*,**
Group B	0.50±.019	0.55±0.16	0.65±0.18*,**,#
IGF-1 ($nmol \cdot L^{-1}$)			
Total group (A+B)	27.4±9.9	27.6±10.2	25.9±9.8
Group A	31.9±9.2	33.0±9.0	28.8±10.8
Group B	23.0±8.5#	22.3±8.6#	23.1±7.9#
COR ($nmol \cdot L^{-1}$)			
Total group (A+B)	425±101	445±116	400±123**
Group A	420±108	476±127	368±138**
Group B	429±96	414±98	430±99#
TES/COR			
Total group (A+B)	0.04±0.02	0.04±0.01	0.05±0.02*,**
Group A	0.04±0.02	0.04±0.01	0.05±0.02*,**
Group B	0.04±0.01	0.04±0.01	0.04±0.01#

No between-group differences were observed in saAA during the study, but saCOR concentration was higher in group B (20 ± 5 vs. 17 ± 7 $nmol \cdot L^{-1}$, $p < 0.05$) at POST. The daily mean RPE of all soldiers (group A+B) remained unchanged (9 ± 1) throughout the study with no between-group differences observed.

Objectively measured PA levels remained at rather low levels throughout the study. The total subject group (A+B) spent 76 ± 6% of wearing time at a level of sedentary behavior (MET < 1.5) at PRE (TABLE 4). Increases of 5% ($p < 0.05$) and 4% ($p < 0.05$) in absolute sedentary time (h:min) were observed between MID

and POST in the total subject group (A+B) and in group A, respectively. A reduction of 12% ($p < 0.05$) in absolute volume of light PA (MET = 1.5–3.0) was observed in group B (–12 ± 29%, $p < 0.05$) between PRE and MID. However, group B was more active than group A, regardless of the PA level.
The daily step count of all soldiers (groups A+B) decreased throughout the follow-up (PRE-MID, 9472 ± 2547 vs. 8321 ± 2720, $p < 0.05$; PRE-POST, 9472 ± 2547 vs. 8517 ± 2772, $p < 0.05$). Despite the reduction in step count between PRE and POST (10 594 ± 2122 vs. 9288 ± 3133, $p < 0.05$), group B was more physically active than group A at the PRE (10 594 ± 2122 vs. 8291 ± 2460, $p < 0.01$) and MID (9515 ± 2985 vs. 7065 ± 1720, $p < 0.01$) measurement points (FIGURE 5).

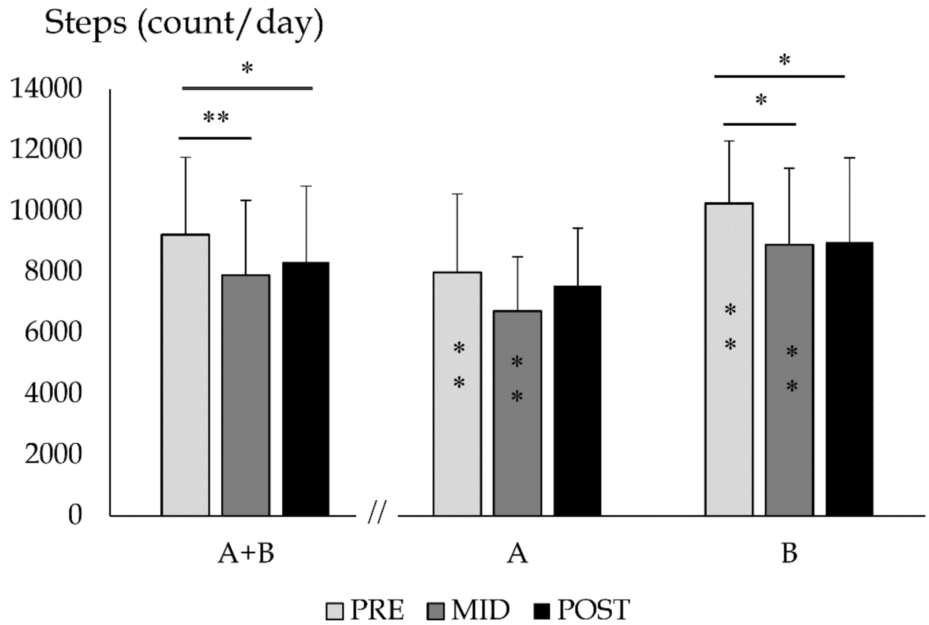

FIGURE 5 Daily step count at the beginning (PRE), middle (MID) and end (POST) of the 6-month international crisis management operation. Group A+B - total group (N = 39), group A – operative infantry units (N = 19), group B – headquarter and logistic units (N = 20). Within-group comparison: marked with horizontal line (* $p < 0.05$, ** $p < 0.01$). Between-group A and B comparison: marked inside the bars (* $p < 0.05$, ** $p < 0.01$).

TABLE 4 Absolute and relative (to total accelerometer wearing time) volume of physical activity at different metabolic equivalent (MET) intensities (mean ± SD) at the beginning (PRE), middle (MID) and end (POST) of the 6-month international crisis management operation. Group A (n = 19) – operative infantry units; group B (n=20) – headquarter and logistic units. * Within-group comparison: significantly different from PRE ($p < 0.05$). ** Within-group comparison: significantly different from MID ($p < 0.05$). # Between-group comparison: significantly different from group A ($p < 0.05$).

Variable	PRE		MID		POST	
	Absolute [h:min]	Relative [%]	Absolute [h:min]	Relative [%]	Absolute [h:min]	Relative* [%]
MET<1.5						
Total group (A+B)	11:04±1:44	76±6	10:41±1:41	78±5	11:08±1:42**	78±5*
Group A	10:58±1:32	78±5	10:46±1:29	79±5	11:13±1:44**	79±5
Group B	11:10±1:57	75±6	10:37±1:53	77±6	11:03±1:42	77±5*
MET 1.5–3.0						
Total group (A+B)	1:45±0:26	12±3	1:38±0:22	12±3	1:39±0:25	12±3
Group A	1:35±0:20	11±3	1:37±0:18	12±2	1:33±0:22	11±3
Group B	1:55±0:26#	13±3	1:38±0:26*	12±3	1:45±0:27	12±3
MET 3.0–6.0						
Total group (A+B)	1:27±0:23	10±3	1:17±0:21*	9±3*	1:16±0:22*	9±2*
Group A	1:17±0:19	9±2	1:10±0:15	9±2	1:11±0:16	9±2
Group B	1:36±0:24#	11±3	1:24±0:24*	10±3#	1:21±0:26*	9±3*'**
MET>6.0						
Total group (A+B)	0:10±0:09	1±1	0:09±0:08	1±1	0:10±0:09	1±1
Group A	0:09±0:09	1±1	0:07±0:05	1±1	0:08±0:08	1±1
Group B	0:12±0:09	1±1	0:11±0:09	1±1	0:12±0:09	1±1

5.2 Associations between physical performance/body composition variables and military task performance (Study II)

At PRE, mean (±SD) MST performance time was 148 ± 22 s (range 100-214 s). Average HR during the test was 169 ± 11 bpm (range of means 146-185 bpm) or 90 ± 4% HR_{peak} (range of means 80-96% HR_{peak}). MST induced three- and fourfold increases in saAA (1 min POST) and BLa (5 min POST), respectively. In addition, mean RPE (6-20) rating was 18 ± 1 immediately after the MST (TABLE 5).

TABLE 5 Mean (± SD) acute changes in saAA, saCOR, RPE, BLa and CMJ induced by MST. saAA, saliva alpha-amylase; saCOR, saliva cortisol; RPE, rating of perceived exertion; BLa, blood lactate; CMJ, countermovement jump; MST, military simulation test. [a], both RPE values estimated in combat load; [b], both jumps performed in combat load.

Variable	PRE	POST	% change	p	n
saAA ($U \cdot mL^{-1}$)	66±66	179±166	306±321	<0.001	68
saCOR ($nmol \cdot L^{-1}$)	13.9±6.2	14.9±6.8	12±49	0.332	65
RPE (6-20)[a]	12±2	18±1	81±42	<0.001	81
BLa ($mmol \cdot L^{-1}$)	2.6±1.5	10.8±3.7	414±294	<0.001	57
CMJ (cm)[b]	28.5±5.1	27.0±5.0	−5±9	<0.001	81

Self-rated RPE and CMJ were performed twice before MST; in light underwear and in combat load (19.5 ± 1.0 kg). The weight of the combat load increased RPE by 14% ($p < 0.001$) from 10 ± 2 to 12 ± 2 and reduced CMJ performance by 25% ($p < 0.001$) from 38 ± 6 to 29 ± 5 cm. The Spearman correlation analysis demonstrated that the strongest individual predictor of MST performance was explosive force production of the lower extremities, especially for CMJ2 ($r = -0.66$, $p < 0.001$) (FIGURE 6).

All four variables assessing muscular power of the lower extremities were among the top five most strongly correlated with MST. In addition, the correlation between CMJ2 and SLJ was high ($r = 0.81$, $p < 0.001$). Among individual body composition variables, MST was most strongly correlated with FAT% ($r = 0.53$, $p < 0.001$) and SMM ($r = -0.47$, $p < 0.001$). Neither body mass ($r = -0.18$, $p = 0.10$) nor BMI ($r = 0.07$, $p = 0.55$) were associated with MST time. The use of dead mass ratio (DMR), adopted from Lyons et al. (2005) increased body composition-based correlations significantly, and this variable was the best individual predictor of MST performance ($r = -0.67$, $p < 0.001$; FIGURE 7). DMR was calculated dividing BM by FATM accompanied with the weight of the carried combat load.

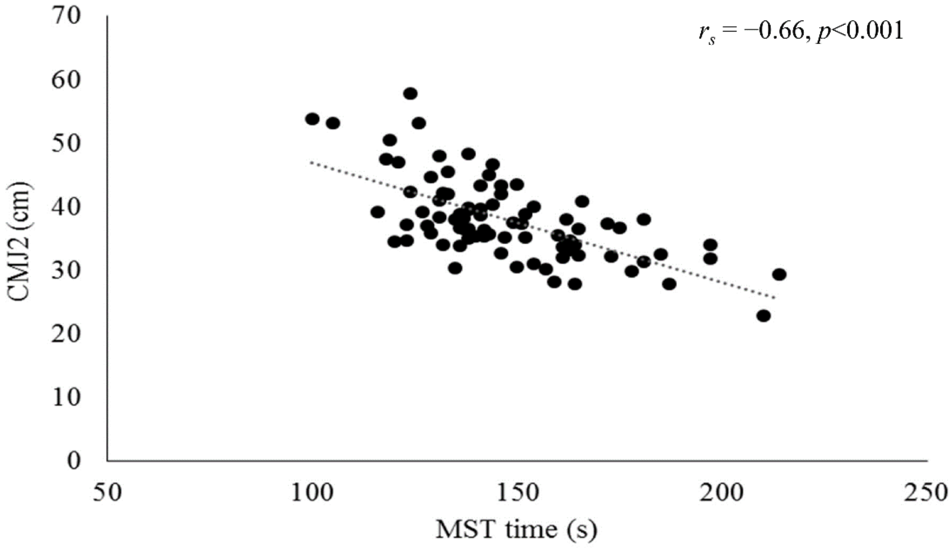

FIGURE 6 Height of the countermovement jump performed with combat load excluding the assault rifle replica (CMJ2) plotted against military simulation test (MST) time. r_s, Spearman correlation.

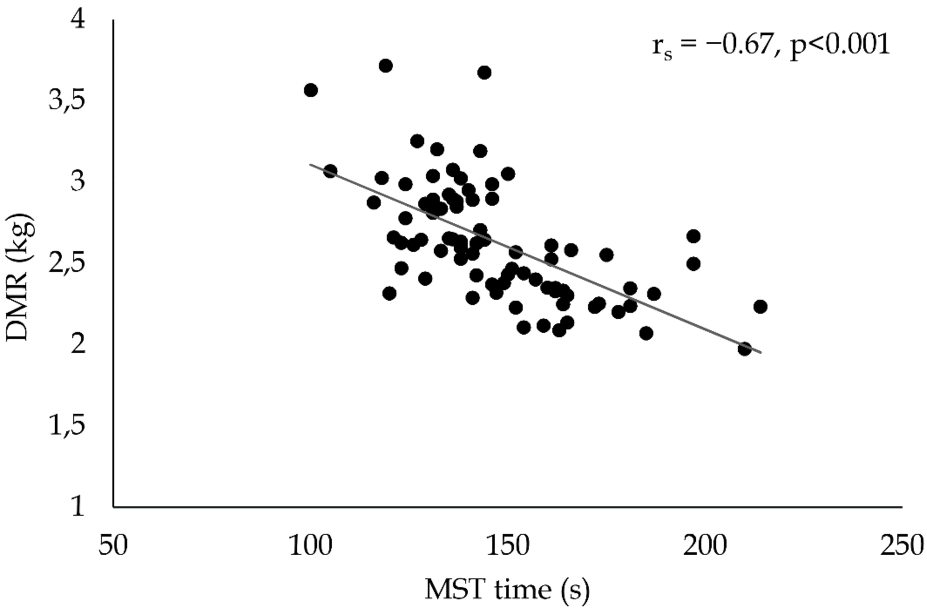

FIGURE 7 Dead mass ratio (DMR) plotted against military simulation test (MST) time. r_s, Spearman correlation.

The stepwise regression analysis showed that four variables (CMJ2, 3000-m, SMM and push-ups) were significantly associated with MST time. Together, these variables explained 66% ($R^2_{adj} = 0.658$) of the variance in MST time. CMJ2 independently explained 47% of the variance in MST time. The run time in 3000-

m improved the predictive power of the model by 13% (combined R^2_{adj} = 0.608). Significant but minimal improvements were achieved by adding SMM (combined R^2_{adj} = 0.633) and push-ups (combined R^2_{adj} = 0.658) to the prediction model.

5.3 Effects of combined strength and endurance training on body composition and physical performance during a military operation (Study III)

During the deployment, the average strength and endurance training frequency of the whole subject group was 3.2 ± 1.5 training sessions per week, of which 1.5 ± 0.9 sessions focused on strength and 1.7 ± 1.2 focused on endurance training (TABLE 6). The most active groups in terms of the average weekly training frequency were **SE** (3.3 ± 1.2) and **C** (4.0 ± 2.0).

TABLE 6 Group-wise weekly mean ± SD and range of the training frequency, volume of endurance training and volume load of strength training in the combined strength and endurance training groups and the control group during the operation. SE, 50% strength training group; Se, 75% strength training group; Es, 25% strength training group, C, control group, LIT, low-intensity endurance training; MIT, moderate-intensity endurance training; HIT, high-intensity endurance training; LB, lower body; UB, upper body.

	SE		Se		Es		C	
Training variables	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Endurance training frequency (times)	1.5±0.6	0.6-3.1	0.7±0.6	0.0-2.0	2.2±0.8	0.8-3.5	2.2±1.7	0.0-6.5
Strength training frequency (times)	1.6±0.8	0.4-2.8	1.7±0.5	1.1-2.4	0.8±0.4	0.0-1.4	1.8±1.4	0.0-4.7
Total training frequency (times)	3.1±1.2	1.2-5.0	2.4±0.7	1.4-3.7	3.0±1.1	0.8-4.4	4.0±2.0	1.6-8.6
LIT (<75% HR_{peak}) volume (min)	62±30	30-151	50±18	30-81	78±32	36-144	55±37	20-125
MIT (75-85% HR_{peak}) volume (min)	48±13	24-67	49±17	30-72	43±12	27-60	43±15	21-65
HIT (>85% HR_{peak}) volume (min)	38±22	16-77	30±11	22-38	33±12	23-53	17±5	13-20
LB strength training volume load (x1000 kg)	15.7±7.2	3.0-31.1	16.8±6.5	4.4-26.8	16.2±7.0	4.7-27.7	10.8±7.6	3.4-34.9
UB strength training volume load (x1000 kg)	11.2±4.5	4.2- 20.8	10.0±3.0	6.2-15.0	10.1±4.2	1.8-17.3	15.0±9.3	3.8-34.5

BM increased by 1% ($p < 0.05$) in the **SE** group during the whole study period. SMM increased by 1% ($p < 0.05$) in the combined group and by 2% ($p < 0.05$) in **SE** (FIGURE 8). Furthermore, FATM increased in the combined group by 3%. Within-group changes in body composition are presented in TABLE 7. Between-group comparisons demonstrated that the decrease in SMM between PRE and POST was higher in **Es** than in the control group **C** (coef. −0.7 kg, 95% CI −1.3 to −0.1 kg, $p < 0.05$).

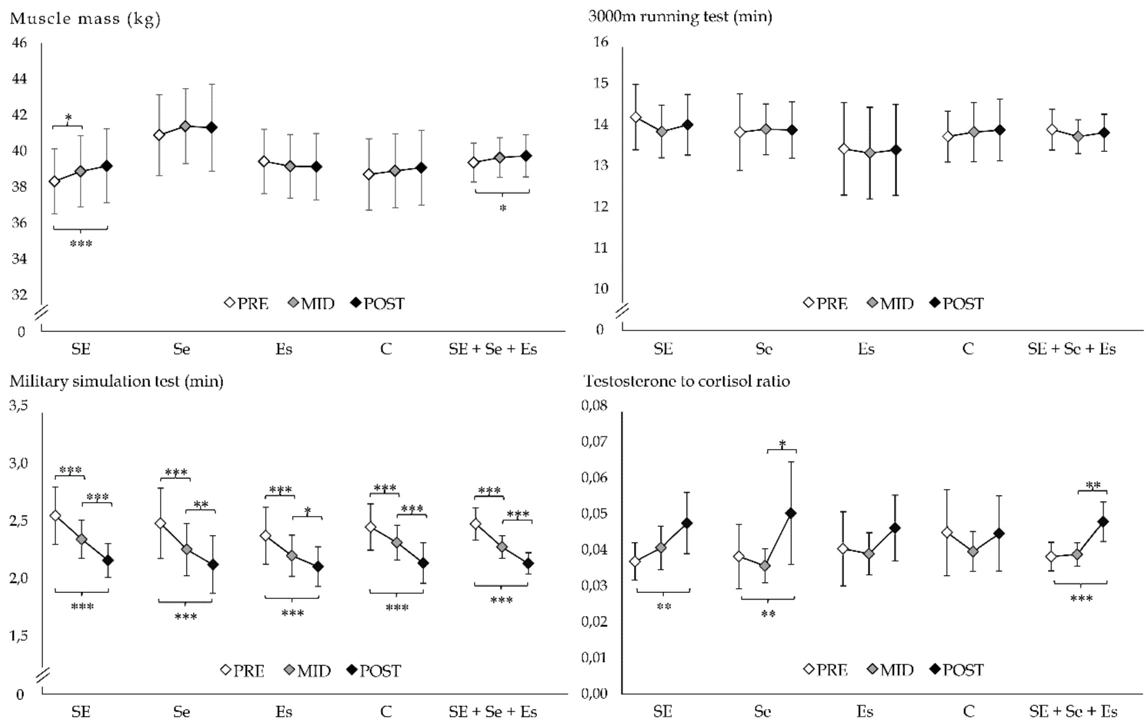

FIGURE 8 Within-group means and standard deviations for muscle mass, 3000-m running test, military simulation test and testosterone-to-cortisol ratio of the combined strength and endurance training groups and the control group during the operation. SE, 50% strength training group; Se, 75% strength training group; Es, 25% strength training group, C, control group. *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

TABLE 7 Body composition variables (mean ± SD) of the combined strength and endurance training groups and the control group at baseline (PRE), after 9 (MID) and 19 weeks (POST) and their changes within groups based on unstandardized coefficients (Coef.) and 95% confidence intervals (CI) from linear regression models. Bold values, $p < 0.05$. SE, 50% strength training group; Se, 75% strength training group; Es, 25% strength training group, C, control group.

	n	PRE	MID	POST	**Within groups** PRE-MID Coef. (95% CI)	PRE-POST Coef. (95% CI)	MID-POST Coef. (95% CI)
Body mass (kg)							
SE	23	77.8±8.0	78.2±8.4	78.8±8.9	0.4 (-0.4; 1.2)	**1.0 (0.01; 1.9)**	0.6 (-0.02; 1.2)
Se	15	80.3±6.6	80.7±6.9	81.3±7.3	0.5 (-0.5; 1.4)	1.0 (-0.2; 2.2)	0.6 (-0.2; 1.3)
Es	18	80.6±6.6	79.8±6.0	79.9±6.2	-0.8 (-1.7; 0.1)	-0.7 (-1.8; 0.4)	0.1 (-0.6; 0.8)
C	22	78.2±8.8	77.9±8.9	78.5±9.1	-0.3 (-1.1 0.5)	0.4 (-0.6; 1.4)	**0.7 (0.1; 1.3)**
SE, Se, Es	56	79.4±7.2	79.4±7.3	79.8±7.6	0.0 (-0.5; 0.5)	0.4 (-0.2; 1.1)	**0.4 (0.05; 0.8)**
Muscle mass (kg)							
SE	23	38.3±4.2	38.9±4.6	39.2±4.7	**0.6 (0.1; 1.0)**	**0.9 (0.5; 1.3)**	0.3 (-0.1; 0.7)
Se	15	40.9±4.1	41.4±3.8	41.3±4.4	0.5 (-0.1; 1.1)	0.3 (-0.2; 0.9)	-0.1 (-0.6; 0.4)
Es	18	39.4±3.6	39.2±3.5	39.1±3.7	-0.3 (-0.8; 0.2)	-0.3 (-0.8; 0.2)	-0.02 (-0.5; 0.4)
C	22	38.7±4.5	38.9±4.6	39.1±4.7	0.2 (-0.3; 0.7)	0.4 (-0.03; 0.8)	0.2 (-0.2; 0.6)
SE, Se, Es	56	39.4±4.0	39.6±4.1	39.7±4.4	0.2 (-0.03; 0.6)	**0.4 (0.1; 0.7)**	0.1 (-0.2; 0.4)
Fat mass (kg)							
SE	23	10.9±3.9	10.3±3.8	10.5±3.1	-0.6 (-1.2; 0.1)	-0.3 (-1.0; 0.3)	0.2 (-0.3; 0.8)
Se	15	9.2±3.1	8.8±3.1	9.6±3.0	-0.6 (-1.4; 0.3)	0.2 (-0.7; 1.0)	0.6 (-0.1; 1.3)
Es	18	11.9±4.0	11.6±3.9	11.8±3.5	-0.1 (-0.9; 0.7)	0.1 (-0.6; 0.9)	0.3 (-0.3; 1.0)
C	22	10.6±4.7	10.1±4.4	10.5±4.9	-0.5 (-1.2; 0.2)	-0.1 (-0.8; 0.6)	0.4 (-0.2; 1.0)
SE, Se, Es	56	10.7±3.8	10.3±3.7	10.7±3.3	-0.4 (-0.8; 0.02)	-0.05 (-0.5; 0.4)	**0.4 (0.02; 0.7)**

No within-group changes were observed in 3000-m time but all groups improved their MST time between every measurement point (FIGURE 8). No differences in the changes in 3000-m or MST times were observed between the intervention groups and **C**. SLJ decreased by 2% ($p < 0.05$) in **C** during the study.

Significant PRE-POST increases in MVC_{lower} occurred in all intervention groups (TABLE 8). Between-group analysis (reference group **C**) showed a higher PRE-POST increase in the combined intervention group (coef. 415 N, 95% CI 97 to 733 N, $p < 0.05$) and **Se** (coef. 611 N, 95% CI 181 to 1040 N, $p < 0.05$). Compared to **C**, the increase in MVC_{lower} was significantly higher between PRE and MID in **Se** (coef. 632 N, 95% CI 232 to 1031 N, $p < 0.05$), while in **Es** the respective change was higher between MID and POST (coef. 353 N, 95% CI 10 to 696 N, $p < 0.05$). MVC_{upper} increased from PRE to MID in the combined intervention group by 2% ($p < 0.05$), whereas between MID and POST, a decrease of 3% ($p < 0.05$) was observed in **C** (TABLE 8). All groups showed improvements in muscular endurance test results throughout the study (TABLE 9).

TES increased by 16% ($p < 0.05$) in **Es** and by 10% ($p < 0.05$) in the combined intervention group during the study. In the same time period, COR decreased by 9% ($p < 0.05$) in the combined intervention group. The TES/COR ratio increased during the different phases of the study in the combined intervention group, **Se** and **SE**, but not in **C** or **Es** (FIGURE 8). No differences were detected in the above-mentioned changes between the intervention groups and the **C** group. No within- or between-group changes were observed in IGF-1. The TES/SHBG ratio increased between PRE and POST in all groups, while between-group comparisons showed a PRE-MID decrease in **Se** compared to **C** (coef. −0.12 $nmol \cdot L^{-1}$, 95% CI −0.24 to −0.01 $nmol \cdot L^{-1}$, $p < 0.05$), but between MID and POST the respective change was positive (coef. 0.23 $nmol \cdot L^{-1}$, 95% CI 0.05 to 0.42 $nmol \cdot L^{-1}$, $p < 0.05$). Within-group changes in serum anabolic and catabolic biomarkers are presented in TABLE 10.

TABLE 8 Muscular strength and power variables (mean ± SD) of the combined strength and endurance training groups and the control group at baseline (PRE), after 9 (MID) and 19 weeks (POST) and their changes within groups based on unstandardized coefficients (Coef.) and 95% confidence intervals (CI) from linear regression models. Bold values, $p < 0.05$. SE, 50% strength training group; Se, 75% strength training group; Es, 25% strength training group, C, control group.

					Within groups		
	n	PRE	MID	POST	PRE-MID Coef. (95% CI)	PRE-POST Coef. (95% CI)	MID-POST Coef. (95% CI)
Maximal voluntary force of the lower extremities (N)							
SE	19	4216±797	4547±964	4651±1036	**331 (83; 580)**	**435 (168; 702)**	97 (-130; 324)
Se	12	4168±1110	4997±1598	4908±1448	**833 (520; 1146)**	**740 (404; 1077)**	-34 (-323; 255)
Es	15	4337±735	4609±828	4863±982	264 (-17; 544)	**526 (225; 827)**	256 (-0.1; 511)
C	19	4196±1081	4395±1191	4325±1013	201 (-47; 450)	129 (-138; 397)	-98 (-326; 131)
SE, Se, Es	46	4243±853	4684±1116	4787±1121	**440 (272; 608)**	**544 (372; 716)**	115 (-31; 262)
Maximal voluntary force of the upper extremities (N)							
SE	20	1150±261	1177±263	1167±263	27 (-9; 64)	18 (-23; 60)	-9 (-42; 25)
Se	11	1121±204	1142±213	1163±210	20 (-29 69)	40 (-16; 95)	18 (-27; 64)
Es	15	1199±185	1228±172	1204±172	33(-9; 74)	12 (-36; 59)	-19 (-58; 20)
C	19	1104±253	1137±250	1102±232	30 (-7; 68)	-6 (-48; 36)	**-37 (-72; -3)**
SE, Se, Es	46	1159±223	1185±223	1178±220	**27 (4; 51)**	21 (-6; 48)	-6 (-28; 16)
Standing long jump (cm)							
SE	18	234±26	237±27	231±28	2.8 (-0.9; 6.6)	-3.2 (-7.8; 1.4)	**-6.0 (-10.0; -2.1)**
Se	12	238±21	238±20	236±17	-0.1 (-4.7; 4.5)	2.1 (-7.8; 3.5)	-2.0 (-6.9; 2.8)
Es	15	238±20	241±22	238±22	3.1 (-1.0; 7.3)	0.9 (-4.1; 6.0)	-2.0 (-6.4; 2.3)
C	19	236±25	235±28	230±29	-1.3 (-4.9; 2.4)	**-5.6 (-10.0; -1.1)**	**-4.4 (-8.3; -0.6)**
SE, Se, Es	45	236±22	238±23	235±25	2.2 (-0.2; 4.5)	-1.5 (-4.4; 1.4)	**-3.6 (-6.1; -1.1)**

TABLE 9 Muscular endurance variables (mean ± SD) of the combined strength and endurance training groups and the control group at baseline (PRE), after 9 (MID) and 19 weeks (POST) and their changes within groups based on unstandardized coefficients (Coef.) and 95% confidence intervals (CI) from linear regression models. Bold values, $p < 0.05$. SE, 50% strength training group; Se, 75% strength training group; Es, 25% strength training group, C, control group.

					Within groups		
					PRE-MID	PRE-POST	MID-POST
	n	PRE	MID	POST	Coef. (95% CI)	Coef. (95% CI)	Coef. (95% CI)
Sit-ups (repetitions in one minute)							
SE	20	45±10	47±9	48±8	**1.8 (0.3 to 3.4)**	**2.8 (0.8 to 4.7)**	0.9 (-0.6 to 2.4)
Se	12	46±7	47±8	49±9	0.6 (-1.4 to 2.7)	**2.7 (0.2 to 5.3)**	**2.1 (0.1 to 4.0)**
Es	15	48±9	50±8	50±9	**2.6 (0.8 to 4.4)**	**2.5 (0.2 to 4.8)**	-0.0 (-1.8 to 1.8)
C	19	46±10	46±10	48±10	-0.1 (-1.7 to 1.5)	1.8 (-0.3 to 3.8)	**1.8 (0.3 to 3.4)**
SE, Se, Es	47	46±9	48±8	49±9	**1.8 (0.8 to 2.8)**	**2.7 (1.4 to 3.9)**	0.9 (-0.1 to 1.9)
Push-ups (repetitions in one minute)							
SE	20	40±12	41±10	44±13	0.7 (-2.0 to 3.5)	**4.3 (0.7 to 8.0)**	**3.6 (0.7 to 6.5)**
Se	11	37±11	41±11	46±11	2.7 (-1.0 to 6.4)	**8.7 (3.7 to 13.7)**	**5.9 (2.0 to 9.8)**
Es	15	44±14	46±15	50±13	2.1 (-1.1 to 5.3)	**6.7 (2.4 to 11.0)**	**4.8 (1.4 to 8.2)**
C	19	39±13	39±12	45±16	-0.2 (-3.0 to 2.6)	**5.7 (2.0 to 9.5)**	**5.9 (2.9 to 8.8)**
SE, Se, Es	46	41±13	42±12	47±13	1.6 (-0.2 to 3.4)	**6.2 (3.7 to 8.6)**	**4.5 (2.6 to 6.4)**
Pull-ups (repetition maximum)							
SE	20	9±6	11±5	12±6	**1.8 (0.7 to 2.8)**	**2.7 (1.4 to 4.0)**	0.9 (-0.0 to 1.9)
Se	12	9±4	10±6	12±6	0.8 (-0.5 to 2.2)	**2.9 (1.1 to 4.6)**	**2.0 (0.7 to 3.3)**
Es	15	12±5	13±6	15±6	**1.5 (0.3 to 2.7)**	**3.6 (2.0 to 5.1)**	**2.1 (0.9 to 3.2)**
C	19	9±5	11±6	12±6	**1.8 (0.8 to 2.9)**	**2.8 (1.4 to 4.2)**	0.9 (-0.1 to 2.0)
SE, Se, Es	47	10±5	11±6	13±6	**1.4 (0.8 to 2.1)**	**3.0 (2.2 to 3.9)**	**1.6 (0.9 to 2.2)**

TABLE 10 Serum anabolic and catabolic biomarkers (mean ± SD) of the combined strength and endurance training groups and the control group at baseline (PRE), after 9 (MID) and 19 weeks (POST) and their changes within groups based on unstandardized coefficients (Coef.) and 95% confidence intervals (CI) from linear regression models. Bold values, $p < 0.05$. SE, 50% strength training group; Se, 75% strength training group; Es, 25% strength training group, C, control group.

	n	PRE	MID	POST	**Within groups** PRE-MID Coef. (95% CI)	PRE-POST Coef. (95% CI)	MID-POST Coef. (95% CI)
Testosterone (nmol · L^{-1})							
SE	19	15.4±3.9	16.4±3.7	16.7±2.9	0.7 (-0.8 to 2.3)	0.9 (-0.5 to 2.3)	-0.3 (-1.8 to 1.2)
Se	11	15.4±2.5	15.9±2.4	17.4±2.7	0.2 (-1.8 to 2.2)	1.7 (-0.2 to 3.6)	0.7 (-1.3 to 2.7)
Es	12	16.9±7.1	18.0±4.9	19.0±5.1	1.5 (-0.4 to 3.5)	**2.7 (0.9 to 4.5)**	1.5 (-0.4 to 3.4)
C	16	16.3±4.5	18.6±4.6	17.2±3.4	**2.4 (0.8 to 4.1)**	1.1 (-0.5 to 2.7)	-0.5 (-2.2 to 1.1)
SE, Se, Es	42	15.9±4.7	16.7±3.8	17.6±3.6	0.8 (-0.2 to 1.8)	**1.6 (0.6 to 2.6)**	0.5 (-0.5 to 1.5)
Cortisol (nmol · L^{-1})							
SE	19	431±74	421±127	385±130	-7 (-61 to 47)	-44 (-98 to 9)	-55 (-113 to 2)
Se	11	430±97	459±95	402±156	31 (-40 to 102)	-27 (-98 to 43)	-48 (-123 to 27)
Es	12	455±114	453±132	409±118	20 (-49 to 88)	-33 (-101 to 35)	-39 (-111 to 33)
C	16	401±118	465±109	412±105	42 (-17 to 102)	-2 (-61 to 57)	-39 (-102 to 23)
SE, Se, Es	42	438±91	440±120	396±131	10 (-26 to 47)	**-37 (-72 to -1)**	**-49 (-87 to -11)**
Sex-hormone binding globulin (nmol · L^{-1})							
SE	19	31.0±10.2	25.7±8.3	23.6±10.4	**-6.0 (-9.3 to -2.6)**	**-7.9 (-11.7 to -4.0)**	-2.8 (-6.7 to 1.1)
Se	11	32.4±11.8	35.6±8.6	22.5±8.9	3.2 (-1.2 to 7.7)	**-9.9 (-14.9 to -4.8)**	**-12.5 (-17.5 to -7.5)**
Es	12	34.7±14.9	32.8±11.9	30.9±16.6	-0.8 (-5.0 to 3.5)	-3.0 (-7.8 to 1.9)	-1.6 (-6.3 to 3.1)
C	15	32.2±11.9	32.4±10.1	27.2±9.8	0.1 (-3.7 to 3.9)	**-5.0 (-9.3 to -0.7)**	**-5.0 (-9.2 to -0.8)**
SE, Se, Es	42	32.4±11.9	30.3±10.3	25.4±12.4	-2.1 (-4.5 to 0.4)	**-7.0 (-9.6 to -4.4)**	**-5.0 (-7.8 to -2.3)**

Multiple linear regression with backward elimination showed that relative changes in strength training frequency, MST time and the TES/SHBG ratio explained 32% of the variance in the change in SMM ($R^2_{adj} = 0.317$). Relative changes in LB strength training volume load and in 3000-m time were correlated with relative change in FATM ($R^2_{adj} = 0.514$). Finally, the relative change in 3000-m time was associated with respective changes in BMI, MST time, pull-up repetitions and PRE-3000-m time, which together explained 68% of the variance in 3000-m time ($R^2_{adj} = 0.675$).

5.4 Endurance-related training adaptations during a military operation (Study IV)

More than half (51%) of the soldiers improved their endurance performance and were thus classified as HiR in terms of combined strength and endurance training adaptations. Before the operation, no differences were observed in endurance training frequency between the HiR and LoR groups, while the LoR group performed strength training more frequently than HiR (Mean ± SD: 1.8 ± 1.4 vs. 2.9 ± 1.2 times · $week^{-1}$, $p = 0.008$). At baseline, the mean 3000-m test times of the HiR and LoR groups did not differ (866 ± 106 s vs. 822 ± 85 s, $p = 0.17$). Significant baseline differences between the HiR and LoR groups (FIGURE 9) were observed in SMM (38 ± 4 vs. 40 ± 4 kg, $p = 0.046$), FATM (13 ± 4 vs. 10 ± 6 kg, $p < 0.001$), maximal strength of the lower extremities (3959 ± 532 vs. 4564 ± 1116 N, $p = 0.049$), SLJ (227 ± 16 vs. 242 ± 27 cm, $p = 0.016$) and MST (156 ± 23 vs. 143 ± 24 s, $p = 0.028$). In addition, a trend towards a lower baseline 1-min push-up test result was found in the HiR group (37 ± 12 vs. 44 ± 13 reps/min, $p = 0.053$).

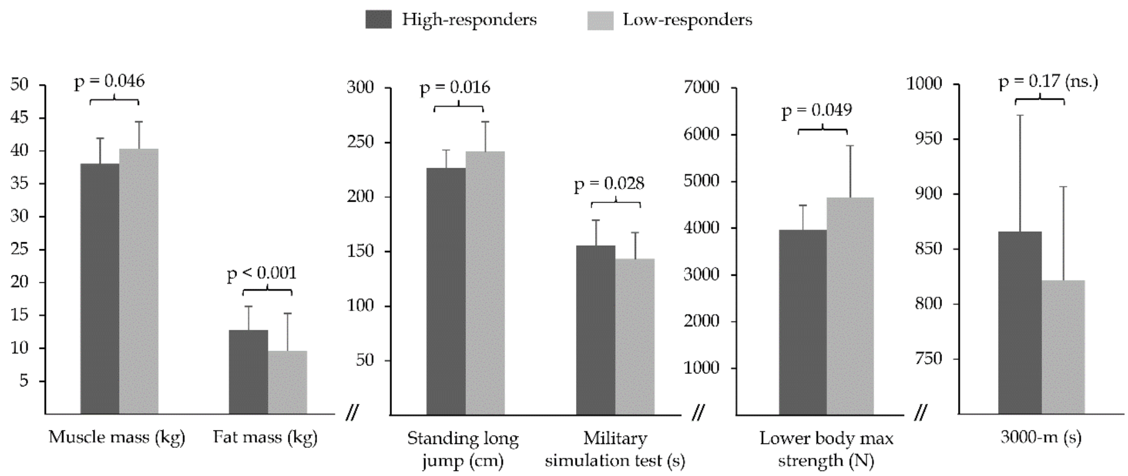

FIGURE 9 Comparison of body composition and physical performance between the high-responders and low-responders for endurance performance at baseline. ns. refers to non-significant.

The HiR group performed strength training of the lower body with a lower average volume (i.e. total amount of lifted weight $\cdot$ week^{-1}) than the LoR group (14354 ± 6076 vs. 19489 ± 6202 kg $\cdot$ week^{-1}, $p = 0.010$). A trend towards a lower average strength training frequency was observed in the HiR group (1.3 ± 0.7 vs. 2.1 ± 2.4 sessions $\cdot$ week^{-1}, $p = 0.052$).

Significant differences in the relative changes in body composition and physical fitness variables during the operation favoring the HiR group (FIGURE 10), included BM (−1 ± 3 vs. 2 ± 3%, $p < 0.001$), FATM (−8 ± 12 vs. 14 ± 20%, $p < 0.001$), 1-min push-up (28 ± 22 vs. 12 ± 26%, $p = 0.004$), and MST (−14 ± 7 vs. −8 ± 7%, $p = 0.006$). Training frequency determined from interviews revealed a relative decrease in endurance training (-40%) in the LoR group, while the HiR group increased their endurance training frequency by 28% (group comparison, $p < 0.001$).

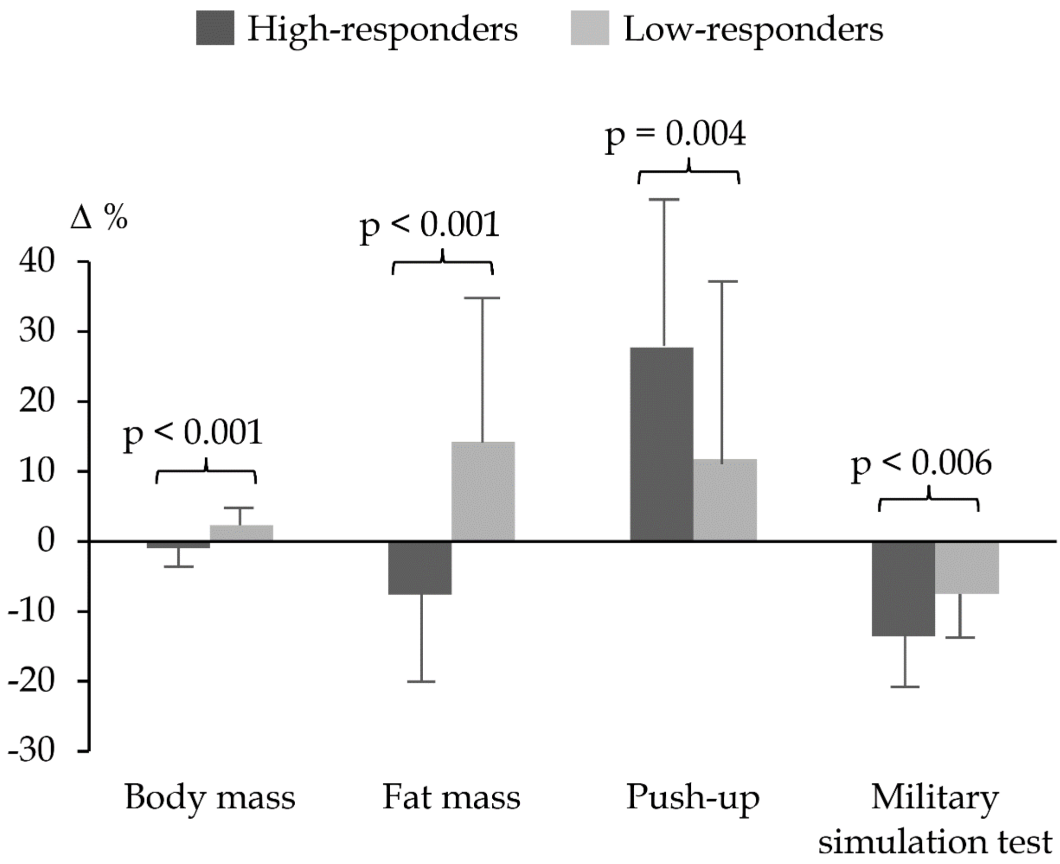

FIGURE 10 Comparison of differences in relative changes in endurance-related variables with statistically significant group differences between the high-responders and low-responders.

In the total group of participants, the increase in average strength training frequency correlated with the relative increase in BM ($r = 0.42$, $p = 0.004$), SMM ($r = 0.31$, $p = 0.036$) and FATM ($r = 0.35$, $p = 0.018$). The increase in the strength-to-endurance training ratio (%) correlated with the relative increase in BM ($r = 0.43$, $p = 0.034$), and there was a trend towards decreased endurance performance (strength-to-endurance training ratio vs. 3000-m, $r = 0.33$, $p = 0.065$).

The relative increase in weekly endurance training frequency during the deployment vs. pre-deployment correlated with the relative reduction in 3000-m time ($r = -0.57$, $p < 0.001$; FIGURE 11). The relative increase in 3000-m time correlated with the respective increase in BM ($r = 0.41$, $p = 0.004$) as well as FATM ($r = 0.53$, $p < 0.001$). The relative increases in MST time correlated with the respective increases in 3000-m time ($r = 0.48$, $p < 0.001$).

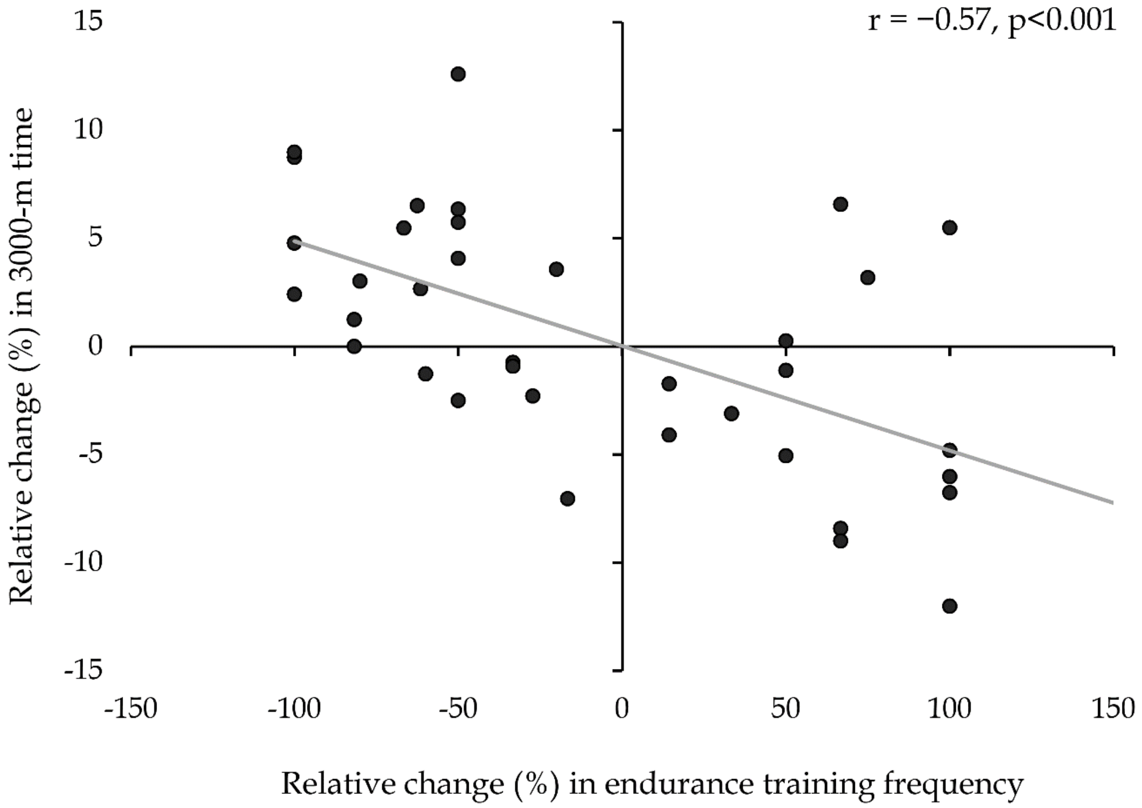

FIGURE 11 Relative increase in weekly endurance training frequency during the deployment (compared to pre-deployment) plotted against relative reduction in 3000-m time.

6 DISCUSSION

6.1 Occupational physical workload during a crisis management operation (Study I)

Based on previous studies (Henning et al. 2011; Nindl et al. 2013), it was hypothesized that the occupational workload may induce symptoms of accumulative stress but to a lesser extent than in combat operations. Study I demonstrated that soldiers did not exhibit symptoms of physical overload during operative (group A) or in headquarter and logistic staff (group B) duties. In fact, the occupational physical load of the soldiers was surprisingly low. The average daily PA remained below the traditional activity guidelines (Tudor-Locke et al. 2008). Relative heart rate ranged between 37% and 38% of HR_{peak}, and RPE remained at a level of 9 out of 20. These values are indicative of light physical workload (Howley 2001). In support of these findings, the hormonal changes observed during the operation indicated an improved anabolic state.

It has been proposed that a physically active lifestyle can be quantified as at least 10 000 steps taken per day (Tudor-Locke et al. 2008). This criterion was only satisfied in group B at the PRE timepoint. As was the case in the present study, low PA quantity was also recorded during a 4-month peacekeeping operation in Chad, where less than 6000 steps were recorded during the one-day measurement period (Rintamäki et al. 2012). Significantly higher volumes of PA have been reported during military field training (Ojanen et al. 2018; Wyss et al. 2012). For example, Wyss et al. (2012) reported that the average daily volumes of moderate (MET = 3.0–6.0) and light (MET = 1.5–3.0) PA were more than 3 and 4 times higher, respectively, for Swiss army recruits compared to the initial values of the present study. Furthermore, several physically demanding phases (e.g. marching, manual materials handling, sports activities) were not included in the Swiss data, further increasing the gap between the quantity of moderate and vigorous PA levels in the present study and the military basic training in the Swiss Armed

Forces. The quantities of low, moderate and vigorous PA during the crisis management operation in study I were very similar to the respective quantities of conscripts during garrison training reported by Ojanen et al. (2018). However, low and moderate PA, but not vigorous PA, seem to increase significantly during conscript field training compared to garrison training. For example, the average step count during garrison training was 9550 (9472 at PRE in study I), compared to a value of 13 940 (45% higher) during field training (Ojanen et al. 2018). Thus, the average volume of PA in the present study was comparable to conscript garrison training but significantly lower than PA experienced during military field training (Ojanen et al. 2018).

The low (<40% HR_{peak}) average HR values reflect the observed PA levels. HR responses were additionally recorded throughout the study period during three common military duties including patrolling (n = 13), guarding (n = 11) and logistics (n = 25). The HR values during these tasks were 43±5% HR_{peak}, 42±4% HR_{peak} and 40 ± 5% HR_{peak}, respectively. The observed relative values of <50% HR_{peak} and RPE <10 are classified as a very light level of physical load (Howley 2001). The results can be at least partly explained by the fact that both of the selected operative duties, patrolling and guarding, were performed mainly by sitting in a vehicle or standing at the gate of the military base, whereas logistic duties included various physical maintenance tasks such as material handling, plumbing, construction and electricity works around the larger area of the military base.

Decreases in anabolic biomarkers, increases in catabolic biomarkers and subsequent decreases in BM, FATM and SMM have been found as a response to prolonged physical exertion combined with energy and sleep deprivation in several military field training studies (Friedl et al. 2000; Henning et al. 2011; Nindl et al. 2007a; Nindl et al. 2007b), while results are more limited from actual military operations. In study I, there were no indications of catabolism and the average body mass of soldiers increased by 0.5 kg during the study. In addition, even though the soldiers operated in three shifts around the clock, the results did not indicate sleep (data not shown) or energy deprivation (Nykänen et al. 2019). The overall changes in BM of soldiers were modest, and at the end of the study they were largely explained by increases in SMM. Regarding changes in lean mass, TES and COR, similar findings have been presented by Farina et al. (2017) in U.S. Army soldiers during an international 3-6-month military deployment. As in the present study I, small but significant increases in lean mass and TES were observed by Farina et al. (2017), accompanied by a decrease in COR. The only difference between these studies was the increase in SHBG in the study of Farina et al. (2017), whereas in the present study I, SHBG decreased and thus increased the concentration of bioavailable TES.

COR and alpha-amylase have been suggested to reflect the sympathetic activation of the central nervous system as a consequence of physical or psychological strain (Clow et al. 2006; Nater & Rohleder 2009). Many studies have shown increases in basal levels of COR and alpha-amylase as a response to both acute and chronic stress (Edmonds et al. 2015; Friedl et al. 2000; Henning et al. 2011;

Nindl et al. 2007a; Tanskanen et al. 2011). With regard to physical strain, acute increases in COR have been observed at workloads exceeding 60% of VO_2max (Tremblay et al. 2005), although psychological stress may add to the overall stress response during lower intensity activities (Doan et al. 2007). In the present study, saCOR remained unaltered but saAA increased during the operation in both groups. Based on changes in other biomarkers, it is assumed that the increase in saAA was more affected by psychological distress than physical overload.

The overall security situation in South Lebanon remained mainly calm without hostilities during the follow-up period. The nature of military duties in the present study differed markedly from previous investigations of military deployments (Henning et al. 2011; Nindl et al. 2013), which may partly explain the conflicting results. On the other hand, soldiers were required to maintain a high level of readiness for quickly changing security situations. As such, the required level of physical performance (i.e. functional reserve) may not be maintained during operations lasting several months just by performing the given military duties. This highlights the need for individually prescribed and potentially obligatory training programs to maintain adequate physical fitness and occupational performance during deployment.

6.2 Associations between physical performance/body composition and military task performance (Study II)

Study II demonstrated that high lean mass in relation to FATM and weight of the combat gear (i.e. DMR) and a high level of muscular power of the lower extremities were individually associated with better MST performance. These results are well in line with previous studies that used task-specific anaerobic simulations (O´Neal et al. 2014; Mala et al. 2015; Angeltveit et al. 2016). The results of study II also showed that CMJ2 jump height and 3000-m time, together with SMM and 1-min push-up test result, were strong predictors of MST time. In support of findings from other military-specific test studies (Hauschild et al. 2017), MST was found to be a promising military-specific method of assessing muscular power of the lower extremities and endurance capacity, which are important performance components in anaerobic combat situations. The findings of study II supported the hypothesis that muscular power of the lower extremities, together with greater muscle mass and less body fat (Lyons et al. 2005; Mala et al. 2015), are associated with better performance in combat load.

Blood lactate has traditionally been used as a biomarker of exercise intensity, but non-invasive methods have also been introduced in a number of studies (Bocanegra et al. 2012; Chicarro et al. 1999; De Oliveira et al. 2010). For example, De Oliveira et al. (2010) found strong associations between BLa and saAA during an incremental exercise test. In the present study II, significant increases in RPE, BLa and saAA at the termination of the test indicated that MST performance was subjectively and physically very demanding for the soldiers. However, no associations were observed between acute biomarkers.

Rushing speed has been found to be positively associated with survivability in military simulations (Billing et al. 2015; Blount et al. 2013). Mala et al. (2015) observed a significant inverse relationship ($r = -0.66$) between vertical jump peak power and 5-m sprint time in combat load. Both vertical and horizontal jump performances have also been shown to be strongly associated with sprinting speed in elite athletes (Dobbs et al. 2015; Loturco et al. 2015). Harman et al. (2008) tested a number of anthropometric measures and fitness tests with the goal of building predictive models of physical performance in the battlefield. Vertical jump height was a key variable in all prediction equations for four combat-specific tests performed with fighting load (400-m run time, obstacle course time, five 30-m rushes and a simulated casualty rescue). Based on the findings of previous studies as well as the present study II, it can be concluded that explosive power of the lower extremities is essential in anaerobic combat situations. Dobbs et al. (2015) found that horizontal jump performance showed a stronger relationship with 30-m sprint speed in rugby players than did vertical jump performance. In the present study II, SLJ showed a stronger correlation than CMJ1 with MST. Furthermore, a strong correlation between SLJ and CMJ2 ($r = 0.81$) supports the use of SLJ as an easy-to-administer method of assessing the lower body power of soldiers in the field.

It has been established that both anaerobic and aerobic metabolic pathways contribute to continuous, near maximal intensity muscle work that exceeds two minutes in duration (Kraemer et al. 2015, 39). An association between aerobic capacity and load carriage performance has been found, particularly in studies using longer load carriage test protocols (Lyons et al. 2005; Santtila et al. 2010). However, despite the short durations (43-84 s) of battlefield-specific tests in the study of Harman et al. (2008), the second most common variable after the vertical jump that was predictive of battlefield-specific performance was the 3.2-km run, which featured in three out of the four models. In the present study II, 3000-m run time correlated moderately with MST time ($r = 0.48$) and improved the stepwise regression model predictive power by 13%.

Combat gear and body armor are typically carried by soldiers in operational environments. Their external load impairs combative movement ability (Billing et al. 2015; Martin & Nelson 1985), as well as repeated high-intensity military task performance in soldiers (Jaworski et al. 2015; O´Neal et al. 2014). The results of Jaworski et al. (2015) indicate that an increase in the relative weight of the carried load decreases combat performance capability. Billing et al. (2015) investigated the effects of increasing load on susceptibility to enemy fire during tactical combat movements. The duration of exposure to enemy fire during the experiment increased linearly with increasing external load, and the impact of weight was greater for slower performers than for their faster counterparts. Again, the only significant difference in the measured body composition (height, body weight, fat mass, muscle mass) or physical performance (maximal aerobic capacity, upper and lower-body power) variables between the fast and slow performers was greater lower-body power in the fast performers.

The present study II supported previous findings (Bishop et al. 2008) demonstrating that BM alone is not a good predictor of high-intensity military performance in combat load, as it was not associated with MST time. Bishop et al. (2008) reported that BM explained only a minor part (~6%) of indoor obstacle course completion time. Instead, improved obstacle course performance was more strongly explained by a lower amount of body fat and higher muscular strength, endurance and power relative to BM, as well as by technique and agility (Bishop et al. 2008). In the present study, moderate correlations between MST and SMM ($r = -0.47$), as well as between CMJ2 and DMR ($r = 0.73$) and SMM ($r = -0.56$), indicate that higher lean mass improves short duration (≤ 3 min) military-specific performance. The inclusion of SMM as a significant variable in the stepwise regression model supports this suggestion. The highest body composition-based correlation ($r = -0.67$) with MST was observed when using the DMR equation adopted from Lyons et al. (2005). They found strong correlations between metabolic demands (relative oxygen consumption, $\%VO_2max$) and DMR in a load carriage test with increasing external loads. From a physiological perspective, this seems logical. The energy expenditure of the working muscles increases in relation to force output, which in turn depends on the weight of the carried load in weight-bearing movements (Lyons et al. 2005). In the present study II, the "dead mass" was made up of the combination of fat mass and combat load. A smaller dead mass in relation to BM leads to a lower relative energy expenditure, and thus the ability to perform MST in a shorter time. However, DMR was not included in the regression analysis, probably due to multicollinearity with the other body composition variables.

In support of previously published studies, the present findings suggest that important characteristics for a soldier involved in combat situations are a high level of muscular power of the lower extremities, high aerobic fitness, and a large muscle mass in relation to fat mass and the external load carried during operations. Thus, workouts focusing on the development of lower body strength and power should be included in training programs designed for soldiers engaging in anaerobic combat situations.

6.3 Effects of combined strength and endurance training on body composition and physical performance during a military operation (Study III)

At the group level, the results of Study III supported the hypothesis that endurance performance may be preserved during deployment by performing a periodized strength and endurance training program 2-3 times per week. Study III showed that the intervention groups (**SE**, **Se**, **Es**) that performed program-based combined strength and endurance training were able to maintain or improve all of the examined physical fitness variables during the military operation. From the physical performance point of view, these soldiers were able to maintain their operative readiness during the study period. In addition, both TES/COR and TES/SHBG ratios increased during the operation in the combined intervention group, indicating a shift to a more anabolic status, and thus providing a favorable physiological milieu for positive training adaptations. MVC_{lower} improved more in the combined intervention group than in the **C** group. While non-significant changes within the training groups occurred according to the specificity principle of training, large inter-individual variations in training adaptations were observed. Possible explanatory factors for not finding statistically significant differences include a low number of subjects in each study group and individual differences in baseline fitness levels, which should be taken into consideration when implementing training programs for soldiers during deployment.

The **SE** group, who performed equal proportions of strength and endurance training (49% strength training), was the only group that showed an increase in SMM, while simultaneously maintaining aerobic fitness during the operation. Increases in muscle mass during military operations have been reported previously in two studies (Lester et al. 2010; Warr et al. 2013). **SE** also improved MST time, MVC_{lower}, 1-min sit-up and 1-min push-up performance, and pull-up performance during the deployment. These changes were accompanied by a decrease in SHBG and increases in the TES/COR and TES/SHBG ratios. When comparing the training and fitness outcomes between **SE** and **C**, it seems that **SE** achieved essentially the same training effects with a slightly lower training frequency but with a higher volume and higher relative share of high-intensity endurance training than **C**. Strength and endurance training were emphasized rather equally in both groups. However, the lower body strength training load was higher than the upper body strength training load in **SE,** while it was the opposite in **C**.

The **Se** group spent 77% of weekly training time performing strength training, and showed improvements in the same physical fitness test results as **SE**, while other variables remained unchanged. Compared to **C**, **Se** showed a larger improvement in lower body strength. In addition, although the TES/SHBG ratio decreased more in **Se** between PRE and MID, it also increased between MID and POST when compared to **C**. As was the case for **SE**, strength training volume load in **Se** was higher for the lower body than the upper body, suggesting that the soldiers in the intervention groups focused their training on more important muscle groups from a military occupational performance perspective (Billing et al. 2015, Hauschild et al. 2017).

The same positive training adaptations as those observed in **SE** and **Se** were also observed in **Es**, which included 75% endurance training. This group improved MST time, MVC_{lower} and all repetitive muscular endurance test results during the study period. Despite the different planned and reported endurance training volumes, all groups were able to maintain their endurance performance during the operation. This is particularly important from the perspective of the groups with lower endurance training volume, given that high mechanical load in running may increase musculoskeletal injury risk and thereby reduce the operative workforce during deployment (Roy et al. 2012). Overall, maintenance of endurance performance may be considered a positive adaptation during a military operation, as in many earlier studies aerobic fitness has been shown to decrease during longer deployments (Dyrstad et al. 2007; Lester et al. 2010; Sharp et al. 2008; Warr et al. 2012).

Currently, there are no military standards for physical training during deployment in the Finnish Defence Forces. Since the soldiers in the **C** group were not provided with a training program, their exercise behavior and changes in body composition and physical performance reflect individual preferences, and are comparable to previous samples of similar military operation studies. During the operation, **C** improved military-specific performance (MST) and muscular endurance of the trunk and arm flexors while maintaining aerobic fitness and body composition. Many previous studies of military operations have demonstrated positive changes in muscular endurance (Dyrstad et al. 2007; Rintamäki et al. 2012; Sedliak et al. 2019; Warr et al. 2012), while decrements in aerobic fitness have also been observed (Dyrstad et al. 2007; Lester et al. 2010; Sharp et al. 2008; Warr et al. 2012). In the present study, aerobic fitness was maintained at least at baseline levels. Similar results were reported after a 4-month military operation in Chad by Rintamäki et al. (2012) and after a 6-month operation in Afghanistan by Fallowfield et al. (2014).

Interestingly, the highest average training frequency (4 ± 2 times per week), with 46% of the training sessions focusing on strength training, was reported in the **C** group. On the other hand, the average lower body strength training volume load (kg $\cdot$ week^{-1}) in **C** was the lowest, and the respective upper body training volume load was the highest among all groups of this study. In accordance with previous studies (Solberg et al. 2015), this suggests that the training programs performed by the intervention groups may have emphasized lower body strength training more during the military operation. Despite the higher overall upper body strength training volume, no PRE-POST changes were observed in MVC_{upper} performance in the **C** group, but a decrease was observed between MID and POST. Furthermore, all other groups except **C** improved their lower body strength during the study, whereas power of the lower extremities, assessed by SLJ, only decreased in **C** between PRE and POST. This is important to note, given that lower body strength and power are very important physical attributes of combat-armed soldiers (Billing et al. 2015). It is possible that individual preferences do not necessarily reflect optimal training habits among tactical athletes, which may increase the risk of injuries while on-duty or during training (Pryor et al. 2012). These findings emphasize the role of strength and conditioning professionals in the prescription of periodized strength and endurance training programs during crisis management operations.

As mentioned previously, strength and endurance constitute the basis of soldier physical performance (Hauschild et al. 2017; Kyröläinen et al. 2018; Nindl et al. 2015). Optimally periodized combined strength and endurance training may improve muscle strength and endurance performance simultaneously without interference effects (Hickson 1980; Häkkinen et al. 2003). It must be taken into consideration that higher (> 3 times · week^{-1}) endurance training frequency and volume, especially with high overall training volume, may have a negative influence on muscular fitness, especially strength and power during concurrent training (Eklund et al. 2015; Häkkinen et al. 2003; Jones et al. 2016; Santtila et al. 2009a; Schumann et al. 2014; Wilson et al. 2012). In the present study, no interference effect on muscular strength development was observed. In fact, a relationship between higher strength training frequency and increased 3000-m time was found with linear regression analyses. Increased 3000-m time was also associated with increased FATM. Thus, decreases in aerobic fitness and increases in fat mass, which have been observed in several military operation studies (Fallowfield et al. 2014; Lester et al. 2010; Sharp et al. 2008), seem to be at least partly linked. Furthermore, a relationship was observed between increased FATM and slower MST time, which could be used from a physical performance perspective as an indirect measure of military readiness.

It has been proposed that in general adult populations neuromuscular performance and SMM can be maintained for up to 6-7 months with only one strength training session per week consisting of one set per muscle group, as long as exercise intensity (i.e. relative load) is maintained (Spiering et al. 2021). Maintenance of endurance performance for up to 15 weeks may require 2-3 weekly endurance training sessions, depending on initial fitness level. However, exercise volume may be reduced by 33-66%, or as low as 13-26 minutes, if training intensity (i.e. relative HR) is maintained (Spiering et al. 2021). Regarding the military context, Haff (2017, 181-205) suggested that the training objective during deployment should be maintenance of fitness levels, which could be achieved by performing strength training twice weekly, accompanied by anaerobic-aerobic endurance training one or two times per week. However, psychological stress induced by operative duties may contribute to internal training load, and should be taken into consideration in the daily training plan from the recovery perspective. In addition, other intrinsic factors such as individual physical fitness level and training status may affect internal training load, and thereby training adaptations (Impellizzeri et al. 2019). In the present study, baseline body composition (e.g. higher FATM) and physical performance (e.g. a poorer MVC_{lower} result) showed weak but statistically significant relationships with training outcomes, namely, larger improvements in 3000-m time. Another study in conscripts (Jurvelin et al. 2020) showed that despite the same standardized weekly program during basic military training, the highest internal training loads and the largest training adaptations were found in individuals with the lowest baseline fitness level and vice versa – the fittest individuals experienced the lowest internal training load (Jurvelin et al. 2020; Pihlainen et al. 2020). These results are in line with studies showing that untrained individuals seem to benefit from concurrent training to the same extent as when training each mode separately, while individuals with a longer training background seem to be more susceptible to interference effects (Coffey & Howley 2017). In the present study, large variability in training adaptations may have been at least partly explained by the inadequate individualization of the training, which was due to randomization of the training groups. The results of study IV showed that soldiers with higher baseline levels of FATM and lower levels of SMM and lower-body strength were more likely to improve their endurance performance during the military operation. Obviously, individualization of training is challenging in the military context, since the number of soldiers is typically high within the same training session. Moreover, training possibilities are limited in many hazardous deployment environments.

While acknowledging the abovementioned challenges, it would be of importance to provide support for physical training in the form of physical training facilities, equipment and prescription during deployment (Anderson et al. 2015). Furthermore, individualized training prescription should take into account factors such as baseline fitness level, and provision of a combined strength and endurance training programme should encourage soldiers to focus training more on qualities related to their task demands, such as strength and power of the lower extremities. Finally, compulsory physical training or other forms of supervised physical activities, along with the leading example of their superiors, might help less fit and less motivated soldiers to avoid declines in physical performance during longer operations.

6.4 Endurance-related training adaptations during a military operation (Study IV)

In support of the presented hypothesis, study IV showed that despite similar endurance performance at baseline, soldiers who were at a greater risk of decreased aerobic fitness, i.e. the LoR group, were initially leaner and had higher physical fitness in terms of lower body strength and power. In addition, endurance training frequency of soldiers in the LoR group was lower during the operation compared to before it. Increased FATM was also observed in the LoR group, whereas the HiR group showed a decrease in FATM during the operation. Relative increases in 3000-m time correlated with respective increases in BM ($r = 0.41$) and FATM ($r = 0.53$). Finally, the LoR group was not able to improve 1-min push-up and MST performance to the same extent as the HiR group. From a physical performance perspective, these changes in the LoR group may reflect a reduction in military readiness, which is not desirable during the operation and should be avoided by providing more individualized strength and endurance training programs during deployment. In addition to operative demands and task analysis, individualization of training should take into consideration factors like baseline physical fitness, training history and body composition.

Aerobic fitness is an important component of military occupational performance capacity during prolonged physical activities with extra loads, such as marching, as well as during intensive combat situations, e.g. rushes and casualty evacuation (Hauschild et al. 2017). Aerobic fitness can be developed through regular endurance training. Depending on the type of training, this can lead to central (e.g. increased stroke volume and cardiac output) and peripheral (e.g. increased mitochondrial density and cellular level enzyme activity) adaptations (Bassett & Howley 2000; Helgerud et al. 2007; Holloszy & Coyle 1984; Jones & Carter 2000). Together these adaptations manifest as improved endurance performance. The same adaptations are also associated with a decrease in FATM (Glowacki et al. 2004; Meredith et al. 1987), as observed in the present study IV.

Progressive strength training leading to neuromuscular adaptations, e.g. increased rate of force production, has also been reported to develop aerobic fitness through improved exercise economy and sprinting ability (Beattie et al. 2014; Denadai et al. 2017; Kyröläinen et al. 2003a; Paavolainen et al. 1999a; Paavolainen et al. 1999b). Concerns related to interference effects of combined strength and endurance training have been mainly addressed regarding the effect on muscular strength and power development (Eklund et al. 2015; Hickson 1980; Häkkinen et al. 2003; Schumann et al. 2014; Wilson et al. 2012). Studies documenting interference effects of combined training on aerobic fitness are scarce (Dolezal & Potteiger 1998). Recent original publications and reviews have concluded that combined strength and endurance training improves aerobic capacity to the same extent and decreases FATM even more than either training mode performed independently (Eklund et al 2015; Wilson et al. 2012). In the present study IV, the same absolute number of soldiers in the strength emphasized training group (group **Se**) and evenly balanced strength and endurance training group (group **SE**) improved their endurance performance during the study. Combined training may therefore be a superior training model for soldiers compared to strength or endurance training only (Kyröläinen et al. 2018).

Previous studies have shown that the endurance performance of soldiers is susceptible to decline during deployment (Dyrstad et al. 2007; Lester et al. 2010; Sharp et al. 2008), which may be due to detraining. It has been reported that complete detraining or even a few weeks of reduced training frequency can lead to a significant decrease in aerobic fitness, both in highly trained and recreationally active participants (Mujika & Padilla 2001). In the military context, Dyrstad et al. (2007) found that the average aerobic fitness of deployed Norwegian soldiers decreased during a 12-month operation in Kosovo. However, soldiers who reported active participation in endurance training during the deployment actually improved their aerobic capacity by 3.5% (Dyrstad et al. 2007). Sharp et al. (2008) found that soldiers in the two highest pre-deployment aerobic fitness quartiles decreased their endurance performance during a 9-month follow-up in Afghanistan, while no changes were observed in soldiers in the initially lowest fitness quartiles. Similar findings have been reported by Warr et al. (2012), who found that on average, endurance training performed at least three times a week was adequate to maintain or improve the aerobic fitness of soldiers during deployment. These previous findings, together with the results of the present study IV, suggest that increased endurance training frequency/volume likely reduces the incidence of decreased aerobic fitness during deployment. Thus, individual training history should be taken into account when implementing training plans for soldiers.

A probable explanation for the reduced endurance performance of the LoR group is that the total training load (i.e. the combination of volume, intensity and frequency) was insufficient to induce physiological responses required for improvement or maintenance of aerobic fitness (Burley et al. 2018; Mann et al. 2014). Montero & Lundby (2017) investigated adaptations to a 6-week endurance training program with a training frequency varying from one to five times per week. In the first part of the study, participants who performed a lower number of training sessions were more likely to be classified as "non-responders". For example, 81% of the participants who trained once a week showed a decrease in endurance performance, whereas in the group that performed four weekly training sessions, the respective proportion was only 18%. In the second part of the intervention, the non-responders completed two additional weekly training sessions for another six weeks. After the second part of the study, training adaptations were observed in all participants (Montero & Lundby 2017). Similar findings have been presented by Talsnes et al. (2020), who reported that in endurance athletes, factors separating low- and high-responders during the 6-month training period included higher overall weekly training loads and higher training motivation in high-responders. In the present study IV, soldiers who improved their 3000-m running time during the follow-up were able to maintain their pre-deployment endurance training frequency, whereas the endurance training frequency of the LoR group decreased during the operation. In addition, the decrease in endurance training frequency from the pre-deployment level was associated with an increase in 3000-m time during the deployment. Despite access to good training facilities in the present study, the motivation to train for some soldiers may have been suppressed by the continuous maintenance of vigilance and 24-hour shift-work associated with deployment. Intrinsic motivation has been shown to be an important reflector of positive training outcomes in athletes (Talsnes et al. 2020) and soldiers (Dyrstad et al. 2007). However, some obligatory physical training should be considered for soldiers with lower intrinsic training motivation to maintain the required occupational performance level during longer deployments.

In summary, high levels of muscular strength and aerobic fitness are the cornerstones of a soldier´s physical performance. Based on the findings of study IV, soldiers who are at greater risk of decreased aerobic fitness during prolonged military deployment with low operational tempo are leaner and fitter in terms of lower body strength and power at baseline. The emphasis of combined strength and endurance training of deployed soldiers should be varied individually and task-specifically. To attenuate decrements in aerobic fitness, the endurance training load should be at least as high as the level preceding the operation. On the other hand, continuous strength training is also important to maintain the necessary levels of muscular strength and power. Furthermore, properly designed strength training likely has additional positive effects on endurance performance.

Finally, increases in fat mass should be avoided to prevent decrements in endurance performance and operational readiness.

6.5 Methodological strengths and limitations

The main strength of the present study was that it was implemented during an actual military operation in Lebanon, and all objective measurements were performed during the operation. Most previous research conducted during military deployment has not included measurements in the real operation area, so the delay between the measurements and the operative work may have influenced the measured outcomes. In addition, three measurement points used in the present study provide valuable information about possible fluctuations in variables of interest within the 6-month follow-up period. Another strength of the study was objectively measured PA (Study I). There seems to be a lack of studies documenting longitudinal changes in the quantity of objectively measured PA during a military operation.

The implementation of the measurements during the military operation also included certain risks, such as the possibility of dropouts, as well as limitations related to the available measurement methods and the time required to perform the tests. Due to logistical constraints regarding the measurement devices, it was not possible to use more precise methods to measure body composition (e.g. dual energy X-ray absorptiometry) and aerobic fitness (e.g. direct maximal oxygen consumption measurement). Naturally, operative duties were prioritized over the measurements of the study, which may have negatively influenced the number of participants in some tests, especially during the MID measurement phase (Studies I, III and IV). Low adherence to the randomly selected training program can be regarded as a limitation of study III, while fifteen soldiers did not follow the prescribed strength-to-endurance emphasis. In order to analyze group changes reliably, modifications to the original group division had to be performed according to self-reported training diaries. On the other hand, this was an important finding that should be taken into consideration when implementing unsupervised training programs in the future. Another option would be supervised training sessions, which may be challenging during a military operation with rotating work shifts. Finally, dietary control might have provided further support for the interpretation of training adaptations in studies III and IV. However, the soldiers mainly lived inside the military base and were served the same food, maintaining similar energy balance during the follow-up (Nykänen et al. 2019).

Regarding Studies II-IV, the validity, reliability and reproducibility of the MST method can be questioned, as is the case for all respective simulations. Due to time constraints, the reliability and reproducibility of MST were not tested before the present study began. The MST track was designed to solely evaluate the anaerobic endurance capacity of soldiers, so procedures requiring specific skills and additional time to conduct (e.g. aiming, hitting a target with a grenade) were excluded from the protocol. Compared to a real-life scenario, this may weaken the relevance of the test method. However, all scenarios are generally theoretical in nature and the selected sub-tasks in the present test model include the most typical movement patterns for soldiers involved in combat (Silk & Billing 2013). The results presented in study II are based on the soldiers' first attempts at performing MST. Since they had no previous experience of the test, they were not able, for example, to develop pacing strategies for their performance. Thus, the associations presented in study II are more reliable indicators of performance predictors in suddenly changing real-life scenarios, whereas the following measurement phases may have been influenced by learning effects to some extent. Overall, the soldiers gave positive feedback about the test method, and MST was reported to be more occupationally relevant than other test methods used in this project.

The four studies of the present thesis did not include injury data. However, injury surveillance should be considered when implementing a training plan, as a large proportion (23%) of non-combat injuries have been reported to occur during sport activities (Sanders et al. 2005), especially during strength training (Roy et al. 2012). In the present study, all medical visits were registered and statistically analyzed after the study. Out of 154 medical visits, 16% (n = 25) were related to physical training or testing, and the visits were spread rather evenly throughout the duration of the study. The most common injuries were pain around the neck and shoulder (n = 9) and low-back (n = 4) region. Ten out of the 25 injuries were related to strength training. The injury rate was comparable to or lower than that of previous studies (Sanders et al. 2005; Roy et al. 2012) from military operations.

As noted earlier, the operational environment remained relatively calm throughout the study period, so the findings presented in this thesis cannot be generalized to actual combat operations. Nonetheless, the present study provides new insights into occupational physical workload during a crisis management operation.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions of the present thesis can be summarized as follows:

1) In general, the occupational physical load was low during all measurement phases, and hormonal changes reflected a shift towards a more anabolic state (Study I) during the 6-month military deployment in Lebanon. These observations were supported by objective PA measurements, revealing rather low volumes and intensities of daily activity. Only about 10% of the registered daily PA was categorized as moderate PA and less than one percent represented vigorous PA. This is logical because the security situation in the operative area of responsibility was rather low at the time of the study. However, soldiers were expected to maintain continuous vigilance and readiness throughout the operation, as the situation was constantly liable to change quickly. Indeed, operational measures also had negative effects on the study, as on some occasions soldiers were not able to take part in the measurements due to sudden changes in their duties. Regarding PA and exercise, the soldiers performed duties outside the military base mainly whilst sitting in an armored vehicle. In addition, moving outside the military base during free time was restricted. As such, the occupational PA alone was not adequate to maintain physical fitness and readiness at the required level during a sustained military operation.

2) The MST (Study II) demonstrated that during a critical combat-type situation, soldiers may be required to perform high-intensity actions which, in terms of heart rate, stress hormone and blood lactate values, increase the workload significantly in comparison with the previously described duties (Study I). For such actions, muscular power of the lower extremities, aerobic fitness (including aerobic and anaerobic components), muscle mass and muscular endurance of the upper extremities are important determinants of a soldier's performance.

3) As shown in study I, the operational demands did not increase the physical training load of soldiers excessively, which enabled the maintenance or development of physical performance during the deployment. The military base provided good facilities to perform strength and endurance training for Studies III and IV. For example, there were more than three kilometers of asphalt or gravel roads and two gym buildings inside the base, enabling both resistance and aerobic workouts. The groups of soldiers, who were provided with a combined strength and endurance training program (i.e. intervention groups), were able to maintain or improve all of the examined physical performance variables (Study III). Furthermore, when compared to the control group, the intervention groups were able to maintain their lower body muscular power and improve their lower body strength, which may be critical physical fitness attributes during combat, as demonstrated in Study II. In the present study it was not possible to make a clear distinction between the training programs regarding the optimal distribution of strength and endurance training. This may partly be due to the random allocation of soldiers into different training groups. For some individuals, a stronger emphasis on endurance training may have induced greater adaptations (Study IV), whereas other individuals may have benefitted more from a stronger focus on strength training.

4) Study IV demonstrated that individual characteristics such as baseline fitness, body composition, and changes in training status affected how aerobic fitness changed during the operation. Finally, analysis of the tasks and demands that soldiers may encounter during an operation should be the foundation of training prescription for deployment. Proper resources including training facilities, equipment, adequate time for training, and access to fitness professionals should be central parts of operative planning.

8 PRACTICAL APPLICATIONS

1) Guided physical training for soldiers should be implemented to minimize declines in physical performance and operative readiness during prolonged (≥ 6 months) military operations with low operational tempo. A physical instructor with knowledge of the relevant operational demands and the ability to organize strength and endurance training sessions should be positioned at the headquarters of the military base.

2) Standing long jump is a field-based fitness test that can be performed with limited test equipment (tape measure) and space, and thus could potentially be used to track changes in neuromuscular performance during deployment. This simple jump test provides a measure of explosive power of the lower extremities and combat readiness as it is well correlated with MST, as well as vertical jump performed with or without combat load.

3) Soldiers participating in crisis management operations should be encouraged or even required to perform strength and endurance training at least twice a week throughout the deployment. Furthermore, special attention should be paid to maintenance or development of lower body muscular strength and power, as well as aerobic fitness. Personal training preferences should be taken into account to ensure optimal training outcomes and the maintenance of readiness during sustained military operations. In addition, physical training should not rely solely on individual motivation and exercise habits, but should also take into account the demands of the operation and individual duties.

YHTEENVETO (SUMMARY IN FINNISH)

Tämän väitöskirjan tarkoituksena oli tutkia sotilastyön fyysistä aktiivisuutta ja kuormittavuutta sekä yhdistetyn voima- ja kestävyysharjoittelun vaikutuksia kehonkoostumukseen sekä fyysiseen suoritus- ja toimintakykyyn kuuden kuukauden kriisinhallintaoperaation aikana Libanonissa. Tutkimuksessa selvitettiin lisäksi sotilastyötehtäviä ja taistelukentällä vaadittavia liikesuorituksia simuloivan tehtäväradan suoritusaikaan yhteydessä olevia kehon koostumuksen ja fyysisen toimintakyvyn muuttujia. Tutkimuksen alkumittauksiin osallistui 91 vapaaehtoista miessotilasta. Veri- ja sylkinäytteenotto, monitaajuuksinen bioimpedanssianalyysi, lihasvoima- ja kestävyyskunto- sekä tehtäväratamittaukset ja fyysisen aktiivisuuden rekisteröinti toistettiin kolme kertaa operaation aikana.

Alkumittausten jälkeen sotilaat arvottiin satunnaisesti joko verrokkiryhmään tai yhteen kolmesta yhdistetyn voima- ja kestävyysharjoittelun ryhmistä, joissa voima- ja kestävyysharjoittelun määrän suhde vaihteli ohjelmien välillä. Verrokkiryhmälle ei annettu ohjeistusta fyysisestä harjoittelusta. Fyysisen kunnon ja kehon koostumuksen eroja tarkasteltiin myös jakamalla sotilaat ohjelmoidusta harjoittelusta riippumatta kahteen ryhmään, joista toinen paransi kestävyyskuntoaan operaation aikana ja toisessa ryhmässä kuntomuutosta ei tapahtunut tai muutos oli negatiivinen.

Tutkimustulokset osoittivat, että operaation aikana objektiivisesti mitatusta fyysisestä aktiivisuudesta vain noin 10 prosenttia ylitti kohtuukuormitteisen aktiivisuuden (MET $\geq$ 3,0) tason. Verinäyteanalyysien perusteella voitiin päätellä, että sotilaat eivät ylikuormittuneet operaation aikana. Kehonkoostumus ja fyysinen toimintakyky kyettiin pääsääntöisesti säilyttämään samalla tasolla kuin operaation alussa. Ohjelmoidun harjoittelun ryhmissä fyysinen kunto kehittyi tai säilyi lähtötilanteen tasolla kaikissa mitatuissa muuttujissa, mutta verrokkiryhmällä alaraajojen räjähtävä voimantuotto heikkeni.

Ryhmällä, jonka kestävyyskunto heikkeni operaation aikana, oli lähtötilanteessa parempi fyysinen kunto. Heillä oli lisäksi enemmän lihasmassaa ja vähemmän rasvamassaa kuin sotilailla, jotka kykenivät parantamaan kestävyyskuntoaan operaatioalueella. Sotilastyötehtäviä simuloivan testin lyhyempi suoritusaika oli yhteydessä suurempaan alaraajojen räjähtävään voimantuottoon ja lihasmassaan sekä lyhyempään 3000-m suoritusaikaan.

Väitöskirjan tulokset korostavat sotilaan monipuolisten kunto-ominaisuuksien kuten alaraajojen räjähtävän voimantuoton, kestävyyskunnon ja lihasmassan merkitystä operatiivisessa työssä. Kyseiset ominaisuudet ovat alttiita heikkenemään pitkien sotilasoperaatioiden aikana erityisesti hyväkuntoisilla sotilailla, ellei riittävästä harjoittelusta huolehdita. Tutkimustulokset puoltavat yksilöllisen yhdistetyn voima- ja kestävyysharjoitteluohjelman käyttöönottoa, ja erityisesti kestävyysharjoittelua tulisi jatkaa vähintään operaatiota edeltäneellä tasolla, jotta kestävyyskunto ja sotilaallinen valmius pystyttäisiin ylläpitämään nopeasti vaihtuvissa operatiivisissa olosuhteissa. Fyysisen toimintakyvyn ylläpidon varmistamiseksi yli kuusi kuukautta kestävien sotilasoperaatioiden henkilöstökokoonpa-

noon tulisi harkita lisättäväksi liikunta-alan ammattilaisen tehtävä, jossa vastuualueena olisi fyysisen kunnon seuranta, harjoittelun ohjelmointi ja johtaminen sekä fyysisen toimintakyvyn tilannekuvan luominen operaation johdolle. Tämän lisäksi tulisi harkita ohjatun fyysisen harjoittelun sisällyttämistä sotilaiden viikko-ohjelmaan.

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ORIGINAL PAPERS

I

EVALUATION OF OCCUPATIONAL PHYSICAL LOAD DURING A 6-MONTH INTERNATIONAL CRISIS MANAGEMENT OPERATION

by

Pihlainen Kai, Santtila Matti, Vasankari Tommi, Häkkinen Keijo & Kyröläinen Heikki, 2018

International Journal of Occupational Medicine and Environmental Health 31(2), 185-197

https://doi.org/10.13075/ijomeh.1896.01048

ORIGINAL PAPER

International Journal of Occupational Medicine and Environmental Health 2018;31(2)
https://doi.org/10.13075/ijomeh.1896.01048

EVALUATION OF OCCUPATIONAL PHYSICAL LOAD DURING 6-MONTH INTERNATIONAL CRISIS MANAGEMENT OPERATION

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Abstract
Objectives: Generally, operational military duties are associated with a variety of stressors, such as prolonged physical activity (PA). However, limited information is available on the occupational workload or changes in PA during international military operations. Thus, the aim of the study was to investigate the changes in body composition, stress biomarkers, PA, and heart rate (HR) responses of 79 male soldiers during a 6-month international crisis management operation. **Material and Methods:** Measurements were conducted 3 times in South-Lebanon during the operation. Body composition was assessed by the bioelectrical impedance method. Blood samples were analyzed for serum testosterone, sex-hormone binding globulin (SHBG), cortisol and insulin-like growth factor. Saliva sampling was used for analyzing stress biomarkers, cortisol and α-amylase. Heart rate and physical activity were monitored by a recordable belt and tri-axial accelerometer, respectively. **Results:** Increases in muscle mass (39.2±4.1 vs. 39.5±4.2 kg, $p < 0.05$) and testosterone (15.9±4.6 vs. 17.2±4 nmol/l, $p < 0.01$), and reductions in PA variables (e.g., daily step count 9472±2547 vs. 8321±2720, $p < 0.05$) were observed during the first half (i.e., PRE-MID) of the study. The increase in muscle mass remained significant during the latter half (PRE-POST, 39.2±4.1 vs. 39.6±4.4 kg, $p < 0.05$), but also fat mass increased (MID-POST, 10.6±4.6 vs. 11.0±4.7 kg, $p < 0.05$) while SHBG (MID-POST, 31.8±12.1 vs. 26.6±13.2 nmol/l, $p < 0.01$) and cortisol (MID-POST, 445±116 vs. 400±123 nmol/l, $p < 0.05$) decreased. With the exception of increased concentration of salivary α-amylase (PRE-POST, 36.5±33.7 vs. 55.1±39.7 U/ml), the acute stress biomarkers and HR responses remained unchanged. Furthermore, the low quantity of PA, low HR values and subjective ratings of exertion refer to rather light physical workload. **Conclusions:** Due to the operatively calm nature of the working environment, the present soldiers did not express any significant signs of physical overload during the study period. Int J Occup Med Environ Health 2018;31(2)

Key words:
Workload, Military personnel, Physical exertion, Occupational health, Military medicine, Accelerometry

Funding: The Scientific Advisory Board for Defence (Finland): and the National Defence Foundation (Finland).
Received: June 21, 2016. Accepted: January 2, 2017.
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INTRODUCTION

Many of the operational military duties have been characterized as prolonged, low intensity physical activity (PA) intermittent by shorter bouts of higher intensity activities [1,2]. Military tasks are often performed with extra loads and protective equipment such as body armor, which increase the energy expenditure of such activities [1,3–6]. In addition to physical strain, negative energy balance, sustained readiness and sleep deprivation, high ambient temperature, altitude and environmental toxins may all separately or in combination disturb homeostasis of the body and thus, increase stress of soldiers [1,2,7]. Consequently, these stressors may lead to degraded performance and increased risk for illnesses and task or mission failure [2,7].

Internal or external threats in a military environment may lead to acute stress modifying the function of the autonomic nervous system that may be indirectly evaluated by studying metabolic and neuroendocrine responses such as vagal activity of the heart and catabolic (e.g., cortisol) or anabolic biomarkers (e.g., testosterone, insulin-like growth factor-1) [2,8]. An increase in the concentration of catabolic hormones and stressful situations *per se* may activate immune function [8]. Prolonged stress may weaken the immune function and lead to various diseases or syndromes such as hypertension, atherosclerosis and metabolic syndrome [9].

Acute occupational physical workload may be assessed by several field measurements, such as recording of cardiorespiratory responses [5], analyzing stress biomarkers from blood and saliva samples [2,10–12] as well as quantifying PA by accelerometers [13,14]. In a follow-up of chronic stress development, the same methods may be used during military operations. In addition, changes in body mass or body composition constitute an essential part of the follow-up since many of the deleterious effects of the degraded performance are associated with body weight loss [1,2,10,11]. Most of the military studies examining occupational workload have focused on field exercises, while scientific information concerning the physical strain during international military operations seems to be limited.

Therefore, the purpose of this study was to investigate changes in body composition, blood and saliva stress biomarkers, volume and intensity of PA, and heart rate responses during the 6-month crisis management operation in the Middle East.

MATERIAL AND METHODS

Subjects and ethics

More than 250 soldiers were deployed for 6 months in the crisis management operation in the Middle East, out of whom 79 male soldiers took voluntarily part in this study. Before the deployment, the soldiers were examined by a physician. They were informed of the study design and gave written consents for their participation. The study was conducted in accordance to the guidelines of the Ethical Committee of the Central Finland Health Care District. All measurements were carried out 3 times, mainly inside the military base in South-Lebanon. The initial measures (PRE) were conducted after a 2-week acclimatization period. The respective measurements were repeated 9 (MID) and 19 (POST) weeks after the initial measures.

Study protocol and conditions

The soldiers served in a unit with the mission of monitoring the cessation of hostilities and supporting the government of Lebanon as well as the local population. The military base in which the soldiers were mainly accommodated was situated on a hill, 775 m above the sea-level.

The most typical task for operative soldiers was patrolling for 4–6 h/day by vehicles around the area of the operative responsibility. Typical operative duties also consisted in daily guarding of the military base for one to 8 h. Soldiers in the headquarters and logistic units worked mainly inside the base. The operative units worked in 3 shifts around the clock, while the logistic units worked mainly during a day-time. However, there were separate individual duties among all personnel groups that required 24-h readiness. The security situation at the operation area remained relatively calm throughout the study period. Nonetheless, the situation was continuously susceptible to rapid changes causing soldiers to conduct their daily duties in a peaceful environment while simultaneously being forced to remain vigilant of different types of threats.

The average ambient temperature, recorded in one-hour intervals throughout the 6-month study period (Thermochron iButton, Maxim Integrated, San Jose, California, USA) inside the military camp was 22.3±4.3°C (range: 11–36°C). The soldiers had air-conditioning in their accommodation, and no heat illnesses were reported during the study period.

Measurements

Body composition measurements and blood sampling were conducted in the morning after an overnight fast at a military hospital. Body height was measured to the nearest 0.1 cm by using a wall-mounted height board (Seca Bodymeter 206, Seca, Hamburg, Germany). Body mass (BM), skeletal muscle mass (SMM), fat mass (FATM) were determined to the nearest 0.1 kg by using the segmental multi-frequency bioimpedance analysis assessment (InBody 720, Biospace, Seoul, South Korea) in accordance with the manufacturer's guidelines.

Blood samples were drawn from the antecubital vein. Plasma and serum were separated from blood by using a centrifuge (1000 rpm, 8 min) and frozen below –20°C for the purpose of further transportation and analysis. Assays for serum testosterone (TES), sex-hormone binding globulin (SHBG), cortisol (COR) and insulin-like growth factor-1 (IGF1) were performed by Immulite 2000 XPi (Siemens Healthcare, Llanberies, UK) using commercial chemiluminescent enzyme immunoassay kits according to the manufacturer's guidelines. The inter-assay coefficients of variance (CV) for assays of TES, SHBG, COR and IGF-I were 7–7.2, 4.5–6.2, 4.6–5.8 and 3.7–7.4%, and that of sensitivity 0.5, 0.02, 5.5 nmol/l and 2.6 pmol/l, respectively.

The workload assessment was conducted by using heart rate (HR) recording, saliva sampling, and accelerometer to measure PA. The measurement methods were guided to the soldiers in advance at the military base but implemented during their duties in an operational environment.

Heart rate (HR) was recorded up to 3 days by a recordable memory belt (Memory belt, Suunto, Vantaa, Finland). Individual absolute and relative mean HR were analyzed for a 24-h period by a computer analysis software (Firsbeat PRO, Firstbeat Technologies, Jyväskylä, Finland).

Physical activity was recorded by a tri-axial accelerometer at a frequency of 100 Hz (Hookie AM20, Traxmeet, Espoo, Finland). The device was positioned to the left side of the trunk at the height of the hip with an elastic band. The soldiers were instructed to wear the accelerometer for 10 days at all times with the exception of sleeping and water activities (e.g., shower). Minimum requirement for the inclusion of accelerometer data for further analyses was 4 days with at least 10 h of wearing time each day. The accelerometer data was analyzed for metabolic equivalent (MET) intensities and step counts by using a mean amplitude deviation according to the previously published validation [15].

Saliva samples with concurrent ratings of perceived exertion (RPE) [16] were collected 6 times during one typical working day by using cotton swabs according to the manufacturer's guidelines (Salivette, Sarstedt, Nümbrecht, Germany). The saliva samples and RPE were instructed to be self-collected after a normal night's sleep, immediately at the time of wake-up followed by 30 min, 1 h, 4 h and 10 h after wake-up. The last sample was collected just before going to bed for a night-time sleep. With the exception of the first sample the soldiers were instructed to rinse their mouth with water 10 min prior to sampling. The soldiers were also informed to keep the sealed sample containers in a dry and, if possible, cool place during their duties. The samples had been delivered to the military base hospital on the following morning of sampling and stored at –20°C until they were transported in a frozen state for the purpose of further analysis. The samples were thawed and centrifuged at 3500 rpm for 10 min. Saliva cortisol (saCOR) and α-amylase (saAA), as potential determinants of stress [17,18], were analyzed.

Saliva cortisol was analyzed by Immulite 2000 XPi (Siemens Healthcare, UK) using chemiluminescent enzyme immunoassay kits, while saAA assays were performed by Konelab 20XTi (Thermo Fisher Scientific, Vantaa, Finland) using the enzyme photometric measurement method (inter-assay CV 13.2% and 3.2%, respectively). Daily mean values from all ratings (RPE) and samples (saCOR, saAA) were formed for the purpose of further statistical analyses.

Peak HR (HR_{peak}) was determined during a 3000-m running test inside the military base. The subjects were instructed to complete the test with a maximal effort and in the shortest possible time. Heart rate was continuously recorded by using the recordable memory belt (Memory Belt, Suunto, Vantaa, Finland). Peak heart rate was determined by the computer analysis software (Firsbeat PRO, Firstbeat Technologies, Jyväskylä, Finland) as the highest recorded HR during the running test.

Statistics

Commercial software (IBM SPSS 22.0.0, Chicago, USA) was used for the purpose of the statistical analyses. Data was analyzed by using repeated-measures ANOVA and t-tests when appropriate. If the model was statistically significant, pairwise group and time comparisons were performed. If assumptions were not to meet logarithm, transformations were applied, or finally nonparametric tests utilized. The relationships among relative changes of the measured variables were tested for linearity with Spearman's product moment correlation coefficients. The $p < 0.05$ was used for establishing statistical significance.

Soldiers were divided into 2 groups according to their tasks for group-wise comparison. The soldiers in the operative infantry units formed group A (N = 41) while headquarters and logistic units formed group B (N = 38). Due to the demands of high readiness, the present soldiers were not able to attend all the measurements. Therefore, a maximum number of soldiers who took part in all PRE-, MID- and POST-measurements were used in statistical analyses for each variable, and the results are also presented for the total subject group (i.e., group A+B). Physical characteristics of the soldiers are presented in the Table 1.

Table 1. Physical characteristics of male soldiers taking part in the 6-month international crisis management operation

Variable	Study group		
	total (N = 79)	A (operative infantry units) (N = 41)	B (headquarters and logistic units) (N = 38)
Age [years] (M±SD)	29.8±8.0	26.4±5.6	34.1±8.6
Body height [cm] (M±SD)	179.1±7.4	180.0±7.8	178.0±6.7
Body mass [kg] (M±SD)	79.4±8.1	79.1±7.1	79.9±9.2
Body mass index [kg/m²] (M±SD)	24.5±2.4	24.0±1.9	25.1±2.7

M – mean; SD – standard deviation.

RESULTS

Body composition and blood biomarkers

Body mass remained unchanged during the first half of the study period (from PRE-MID), while significant increases were observed during the latter part (from MID-POST) in the total subject group (A+B, 1±2%, $p < 0.01$) and in the group A (1±2%, $p < 0.05$). Skeletal muscle mass increased from PRE-MID by 1±3% in the total subject group ($p < 0.05$), while the increases from PRE-POST were significant in all groups (Table 2). The group B reduced FATM from PRE-MID (–4±24%, $p < 0.05$) and regained it from MID-POST (6±14%, $p < 0.05$). No differences between the groups were observed in BM and SMM during the study while FATM was higher in the group B in all comparison points. Individual increases in SMM were associated with individual decreases in SHBG ($r = –0.33$, $p < 0.05$, N = 60) as well as saAA ($r = –0.39$, $p < 0.05$, N = 41) from MID-POST.

Serum TES concentrations increased from PRE-MID in the total subject group (13±31%, $p < 0.01$) and the group A (12±24%, $p < 0.01$) (Table 2). In contrast, SHGB decreased in both groups from MID-POST (group A; –18±34%, $p < 0.01$, group B; –9±22%, $p < 0.05$) as well as from PRE-POST (group A; –19±35%, $p < 0.05$, group B; –14±24%, $p < 0.01$). Cortisol decreased significantly from MID-POST in the total subject group (–5±33%, $p < 0.05$) and the group A (–14±38%, $p < 0.01$). These changes led to significant increases in the TES-to-SHBG ratio (TES/SHBG) from PRE-POST as well as from MID-POST in all groups. The TES-to-COR ratio (TES/COR) increased accordingly, but only in the total subject group and in group A. A significant group difference was observed in the TES/SHBG ($p < 0.05$) and TES/COR ratios ($p < 0.01$) during POST. No changes in IGF1 were observed during the study in either group. However, the group A showed higher IGF1 con-

Table 2. Male soldiers' body composition and serum biomarkers in the beginning (PRE), middle (MID) and at the end (POST) of the 6-month international crisis management operation

Variable	PRE	MID	POST
Body mass [kg] (M±SD)			
total group (N = 79)	79.40±8.10	79.30±8.20	79.90±8.80*,**
group A (N = 41)	79.10±7.10	79.10±7.20	79.60±7.60**
group B (N = 38)	79.90±9.20	79.60±9.30	80.10±10.00
Skeletal muscle mass (SMM) [kg] (M±SD)			
total group (N = 79)	39.20±4.10	39.50±4.20*	39.60±4.40*
group A (N = 41)	39.80±4.00	40.00±4.10	40.10±4.30*
group B (N = 38)	38.60±4.20	38.80±4.30	39.00±4.50*
Fat mass (FATM) [kg] (M±SD)			
total group (N = 79)	11.00±4.80	10.60±4.60	11.00±4.70**
group A (N = 41)	9.70±3.70	9.50±3.70	9.90±3.70
group B (N = 38)	12.40±5.50#	11.70±5.20*,#	12.20±5.40**,#
Testosterone (TES) [nmol/l] (M±SD)			
total group (N = 59)[a]	15.90±4.60	17.2±4.00*	17.30±3.60
group A (N = 29)	16.30±5.40	18.0±4.10*	17.90±3.50
group B (N = 30)	15.50±3.80	16.5±3.90	16.80±3.80

Table 2. Male soldiers' body composition and serum biomarkers in the beginning (PRE), middle (MID) and at the end (POST) of the 6-month international crisis management operation – cont.

Variable	PRE	MID	POST
Sex-hormone binding globulin (SHBG) [nmol/l] (M±SD)			
total group (N = 59)[a]	32.30±12.00	31.80±12.10	26.60±13.20*,**
group A (N = 29)	31.00±13.40	32.40±15.70	25.50±16.40*,**
group B (N = 30)	33.60±10.50	31.20±7.50	27.70±9.30*,**
Testosterone to sex-hormone binding globulin ratio (TES/SHBG) [nmol/l] (M±SD)			
total group (N = 59)[a]	0.54±.020	0.60±0.21	0.80±0.43*,**
group A (N = 29)	0.58±.021	0.64±0.25	0.95±0.55*,**
group B (N = 30)	0.50±.019	0.55±0.16	0.65±0.18*,**,#
Insulin-like growth factor 1 (IGF1) [pmol/l] (M±SD)			
total group (N = 59)[a]	27.40±9.90	27.60±10.20	25.90±9.80
group A (N = 29)	31.90±9.20	33.00±9.00	28.80±10.80
group B (N = 30)	23.00±8.50#	22.30±8.60#	23.10±7.90#
Cortisol (COR) [nmol/l] (M±SD)			
total group (N = 59)[a]	425.00±101.00	445.00±116.00	400.00±123.00**
group A (N = 29)	420.00±108.00	476.00±127.00	368.00±138.00**
group B (N = 30)	429.00±96.00	414.00±98.00	430.00±99.00#
Testosterone to cortisol ratio (TES/COR) [nmol/l] (M±SD)			
total group (N = 59)[a]	0.04±0.02	0.04±0.01	0.05±0.02*,**
group A (N = 29)	0.04±0.02	0.04±0.01	0.05±0.02*,**
group B (N = 30)	0.04±0.01	0.04±0.01	0.04±0.01#

Group A – operative infantry units; group B – headquarters and logistic units.
[a] Due to the demands of high readiness, the soldiers (N = 79) were not able to attend all the measurements. Therefore, a maximum number of soldiers who took part in all PRE-, MID- and POST-measurements were used in statistical analyses for each variable.
* Within-group comparison: significantly different from PRE ($p < 0.05$).
** Within-group comparison: significantly different from MID ($p < 0.05$).
# Between-group comparison: significantly different from group A ($p < 0.05$).
Other abbreviations as in Table 1.

centrations at all time points as well as lower COR at POST ($p < 0.05$).

Workload assessment

The 24-h HR (HR^{24h}) responses of soldiers are presented in the Table 3. No changes within the groups were found in mean, minimum or peak HR^{24h} in relation to time. However, relative HR decreased in the total subject group (A+B) from PRE-MID (–2±8%, $p < 0.05$). The only difference between the groups was the higher mean HR^{24h} in the group A as compared to B during POST ($p < 0.05$). Individual increases in mean HR^{24h} were associated with individual decreases in IGF1 ($r = -0.46$, $p < 0.05$, N = 25) from PRE-MID.

No significant changes were observed in saCOR concentration. However, saAA increased from PRE-POST in the total subject group (108±203%, $p < 0.05$) as well as in the groups A (116±189%, $p < 0.05$) and B (103±217%, $p < 0.05$). While no differences were observed between

Table 3. Male soldiers' 24-h mean heart rate (HR) responses and saliva stress biomarkers in the beginning (PRE), middle (MID) and at the end (POST) of the 6-month international crisis management operation

Variable	PRE	MID	POST
HR_{mean}^{24h} [bpm] (M±SD)			
total group (N = 26)[a]	72±6	70±7	71±8
group A (N = 15)	70±6	70±8	71±10
group B (N = 11)	73±7	69±6	71±7
HR_{min}^{24h} [bpm] (M±SD)			
total group (N = 26)[a]	47±5	46±5	47±5
group A (N = 15)	47±6	47±5	48±6
group B (N = 11)	46±3	46±5	46±5
HR_{peak}^{24h} [bpm] (M±SD)			
total group (N = 26)[a]	147±18	139±21	148±19
group A (N = 15)	145±15	141±27	140±19
group B (N = 11)	149±20	138±17	153±18[#]
HR^{24h} [% HR_{peak}] (M±SD)			
total group (N = 26)[a]	37.6±3.8	36.5±3.9*	37.2±4.6
group A (N = 15)	36.1±3.2	36.1±4.7	36.7±5.4
group B (N = 11)	38.7±3.9	36.7±3.5	37.5±4.0
Saliva cortisol (saCOR) [nmol/l] (M±SD)			
total group (N = 34)[a]	14.2±5.4	15.0±6.3	17.4±7.1
group A (N = 14)	11.1±2.7	13.2±3.5	13.8±7.7
group B (N = 20)	16.4±5.7	16.3±7.5	19.9±5.4[#]
Saliva α-amylase (saAA) [U/ml] (M±SD)			
total group (N = 39)[a]	36.5±33.7	49.1±35.3	55.1±39.7*
group A (N = 16)	34.9±24.0	52.5±49.5	55.5±45.1*
group B (N = 23)	41.1±41.0	46.8±21.8	54.9±36.5*

Explanations as in Table 2.

the groups in saAA during the study, saCOR concentration was higher in the group B ($p < 0.05$) during POST (Table 3). A positive correlation in the individual changes between saCOR and SHBG ($r = 0.30$, $p < 0.05$, N = 43), as well as saAA and mean HR^{24h} ($r = 0.37$, $p < 0.05$, N = 41) were observed from PRE-POST.

The daily mean RPE of soldiers (group A+B, N = 24) remained unchanged (9±1) throughout the study and no within- or between-group differences were found. A positive correlation was observed in the MID-POST individual changes between RPE and COR ($r = 0.41$, $p < 0.05$, N = 25).

Physical activity

The accelerometer data was collected for 9.3±2.5, 9.6±3.1 and 9.6±2.8 days during PRE, MID and POST, respectively. The respective daily wearing times of the accelerometer were 14:27±1:39 h:min, 13:45±1:40 h:min and 14:13±1:47 h:min. In relative terms, the total subject group (A+B) spent 76±6% of wearing time at a level of sedentary behavior (MET < 1.5) during PRE (Table 4). The relative volume of sedentary time increased by 2±6% in the total subject group and by 3±6% in the group B from PRE-POST ($p < 0.05$). However, in absolute terms (h:min), the increased sedentary time was observed in the total subject group (A+B, 5±12%, $p < 0.05$) and the group A (4±9%, $p < 0.05$) from MID-POST.

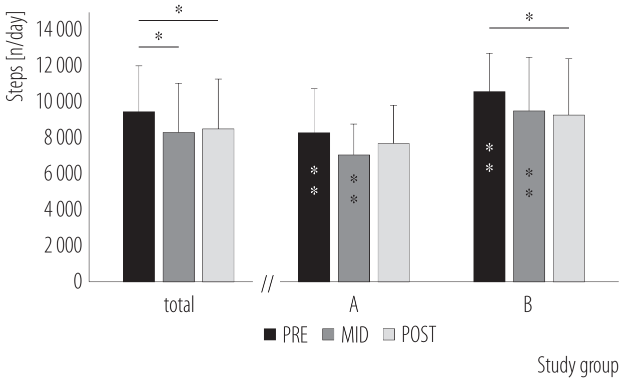
A significant reduction in the absolute volume of light PA (MET = 1.5–3) was observed only in group B (–12±29%) from PRE-MID ($p < 0.05$). Concurrent reductions in absolute and relative volumes of moderate PA (MET = 3–6) were observed in the total subject group and the group B (Table 4). Nonetheless, the group B was generally more active than group A in all PA levels.

The daily step count of soldiers (A+B) decreased from the initial levels by –10±24% (9472±2547 vs. 8321±2720, $p < 0.05$) from PRE-MID and by –7±29% (9472±2547 vs. 8517±2772, $p < 0.05$) from PRE-POST. In the group level, a significant reduction was observed in the group B (–12±25%, 10 594±2122 vs. 9288±3133, $p < 0.05$) from PRE-POST. Again, the PA of group B was significantly higher during PRE (10 594±2122 vs. 8291±2460, $p < 0.01$) and MID (9515±2985 vs. 7065±1720, $p < 0.01$) as compared to group A (Figure 1). The changes in running steps were non-significant in all comparisons (Figure 2). High

Table 4. Male soldiers' mean absolute and relative volume of physical activity in different metabolic equivalent (MET) intensities in the beginning (PRE), middle (MID) and at the end (POST) of the 6-month international crisis management operation

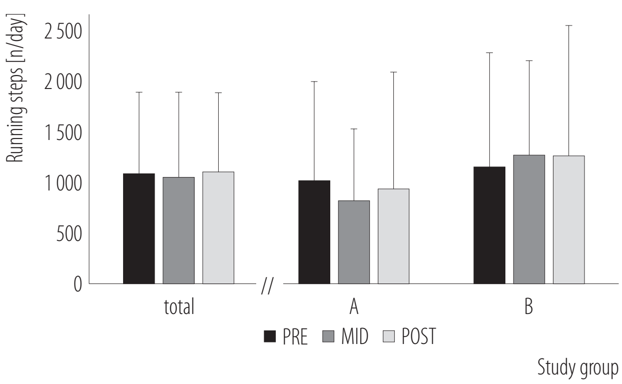
Variable	PRE		MID		POST	
	absolute [h:min] (M±SD)	relative[b] [%] (M±SD)	absolute [h:min] (M±SD)	relative[b] [%] (M±SD)	absolute [h:min] (M±SD)	relative[b] [%] (M±SD)
MET < 1.5						
total group (N = 39)[a]	11:04±1:44	76±6	10:41±1:41	78±5	11:08±1:42**	78±5*
group A (N = 19)	10:58±1:32	78±5	10:46±1:29	79±5	11:13±1:44**	79±5
group B (N = 20)	11:10±1:57	75±6	10:37±1:53	77±6	11:03±1:42	77±5*
MET 1.5–3.0						
total group (N = 39)[a]	1:45±0:26	12±3	1:38±0:22	12±3	1:39±0:25	12±3
group A (N = 19)	1:35±0:20	11±3	1:37±0:18	12±2	1:33±0:22	11±3
group B (N = 20)	1:55±0:26[#]	13±3	1:38±0:26*	12±3	1:45±0:27	12±3
MET 3.0–6.0						
total group (N = 39)[a]	1:27±0:23	10±3	1:17±0:21*	9±3*	1:16±0:22*	9±2*
group A (N = 19)	1:17±0:19	9±2	1:10±0:15	9±2	1:11±0:16	9±2
group B (N = 20)	1:36±0:24[#]	11±3	1:24±0:24*	10±3[#]	1:21±0:26*	9±3*,**
MET > 6.0						
total group (N = 39)[a]	0:10±0:09	1±1	0:09±0:08	1±1	0:10±0:09	1±1
group A (N = 19)	0:09±0:09	1±1	0:07±0:05	1±1	0:08±0:08	1±1
group B (N = 20)	0:12±0:09	1±1	0:11±0:09	1±1	0:12±0:09	1±1

[b] Presented as % of accelerometer wearing time.
Other explanations as in Table 2.



Respondents: total group (N = 39), group A – operative infantry units (N = 19), group B – headquarters and logistic units (N = 20).
Within-group comparison: marked with horizontal line (* p < 0.05, ** p < 0.01).
Between-group A and B comparison: marked inside the bars (* p < 0.05, ** p < 0.01).

Fig. 1. Male soldiers' volume of physical activity in daily step count in the beginning (PRE), middle (MID) and at the end (POST) of the 6-month international crisis management operation



Explanations as in Figure 1.

Fig. 2. Male soldiers' volume of physical activity in daily running step count in the beginning (PRE), middle (MID) and at the end (POST) of the 6-month international crisis management operation

inter-individual differences were observed in PA, as an example, the daily steps ranged between 3345 and 15 239 (running steps 18–5541) during the study.

Individual increase in the percentage share of time spent on moderate PA (MET = 3–6) from MID-POST was associated with simultaneous individual increase in BM (r = 0.53, p < 0.001, N = 41), SMM (r = 0.42, p < 0.01, N = 41), and decrease in TES (r = –0.35, p < 0.05, N = 35). In the PRE-POST comparison, associations were found between individual changes in BM and the percentage share of time spent on MET < 1.5 (r = –0.28, p < 0.05, N = 60), the percentage share of time spent on MET = 1.5–3 (r = 0.26, p < 0.05, N = 60), and the percentage share of time spent on MET = 3–6 (r = 0.27, p < 0.05, N = 60).

DISCUSSION

This study has demonstrated that soldiers either in the operative (group A) or in headquarter and logistic staff (group B) duties did not express symptoms of physical overload in terms of the measured variables. In fact, the occupational physical load of the soldiers was surprisingly low. The average daily PA of soldiers did not even exceed the population-wide activity guidelines (e.g., 10 000 steps/day) [19,20]. The measured mean relative HR values ranged between 36.5+3.9 and 37.5±3.8% HR_{peak}, and RPE values remained at the level of 9±1. The mean values (HR, RPE, MET) of this study refer to the light level of PA [21], at the most. Furthermore, the hormonal responses indicated an improved anabolic state. Taken together, the findings lead to a conclusion that the soldiers experienced rather a light physical workload during the study period.

During the study period overall security situation in South-Lebanon remained mainly calm without any hostilities. The nature of military duties in this study differed markedly from previous investigations [1,2,7], and this may partly explain the conflicting results. On the other hand, soldiers are required to maintain a high level of readiness for quickly changing security situations. This highlights the demands of the maintenance of physical performance by independent or guided exercise during the deployment.

The decreases in anabolic biomarkers were consistently found as a response to physical exertion combined with energy and sleep deprivation in several studies [2,10,11]. Nindl et al. [10] have shown that the 8-day military field exercise with negative energy balance induce a 50% decrease in total IGF-1 and TES concentrations. Similar findings have been demonstrated by Friedl et al. [11] in a military field exercise lasting for 8 weeks, where significant decreases in TES and IGF-1 concentrations were accompanied with increases in SHBG and COR. These changes were associated with marked reductions in body mass, and the adaptations were soon compensated, when energy balance was leveled [11].

In this study the average body mass of soldiers increased by 0.5 kg. The overall changes in BM of soldiers were modest and at the end of the study they were largely explained by increases in SMM. No decreases in anabolic biomarkers were observed, in fact, most of the changes in the measured blood biomarkers referred to the improved anabolic state. Therefore, it seems that soldiers were not physically overloaded during the mission, even though they additionally performed some recreational exercises. Furthermore, no significant associations between the individual changes in body composition and serum anabolic hormone concentrations were observed.

Cortisol and α-amylase have been suggested to reflect the sympathetic activation of the central nervous system as a consequence of physical or psychological strain [12,17]. The positive correlation between the individual changes in saAA and HR^{24h} supports these findings. With regard to physical strain, acute increase in cortisol has been observed in workloads exceeding > 60% maximal oxygen consumption (VO_{2max}) [22] even though psychological stress may accumulate the stress response during lower intensities [23]. Many studies have shown increases in basal levels of cortisol and α-amylase as a response to both acute and chronic stress [2,10,11,24,25].

Taverniers and de Boeck [26] have found a correlation between subjective distress and saAA as well as significant increases in saAA during a handgun practice in a simulated real-world environment with a sensation of probable threat by an opponent when compared to training with traditional card-board target.

In this study saCOR remained unaltered but saAA increased from PRE-POST in the both groups. It was obvious that the increase in saAA was more affected by psychological distress than physical overload. Furthermore, conflicting results from previous studies [27,28] complicate inference and highlight the importance of further studies on saAA alterations for humans suffering from chronic stress. Also, Thoma et al. [29] have found that daily mean saAA values of subjects suffering from the post-traumatic stress disorder (PTSD) do not differ from the control group, while the awakening samples are significantly lower for subjects with PTSD. In this study no changes in the awakening samples of saCOR or saAA have been observed between the studied time points (data not shown).

The obtained mean of 24-h HR responses and RPE values support the findings that the occupational workload was not physically demanding for the soldiers. Additionally, the HR responses were detected and calculated by the use of diaries throughout the study period during 3 typical military duties; patrolling (N = 13), guarding (N = 11) and logistics (N = 25), in which the absolute and relative HR values were 78±9 bpm (43±5% HR_{peak}), 80±8 (42±4), and 83±11 (40±5), respectively. The observed relative values below 50% HR_{peak} and RPE < 10 are classified as a very light level of physical load [21]. The results may be, at least partly, explained by the fact that both of the selected operative duties, patrolling and guarding, were performed mainly by sitting in a vehicle or standing at the military base gate, whereas logistic duties included various physical maintenance tasks such as plumbing, construction and electrical work. Moderate correlations were observed between the relative changes in mean HR^{24h} and COR from MID-POST suggesting that psychological and physiological factors changed parallel.

It has been proposed that physically active lifestyle may be quantified as at least 10 000 steps/day [19,20]. This amount was reached only in the group B during PRE. Compared to this study, even lower quantities of objectively measured PA was observed during a 4-month peacekeeping operation in Chad, where Rintamäki et al. [14] recorded fewer than 6000 steps during the one day measurement period. A study of Wyss et al. [13] showed that the average daily time spent on moderate (MET = 3–6) and light PA level (MET = 1.5–3) was more than 3 and 4 times higher for the Swiss army recruits as compared to the initial values of this study, respectively. On the contrary, sedentary time (MET < 1.5) was nearly 6 times higher in this study. Time performing military related activities on the vigorous activity level (MET > 6) during the military basic training (BT) period [13] was close to the present study.

However, the most typical military duties (e.g., marching 61±23 min/day, demanding materials handling 33±20 min/day) and running or sports activities (36±25 min/day) were not included in the MET values of Wyss et al. [13]. This means even a greater gap between the quantity of PA levels of MET = 3–6 and MET > 6 between this study and the military BT in the Swiss Armed Forces. Thus, the average volume of PA in this study was lower than the PA experienced during military BT [13]. It is noteworthy that the volume of PA in this study was significantly lower in the group A as compared to B, mainly due to the different occupational tasks. It has been proposed, on the other hand, that a higher volume of PA, in terms of physical training, is associated with higher intrinsic motivation [30] and health perception [31] during a military operation.

The overall study setting was unique in a sense that all the measurements were implemented in the operation area which may be regarded as one of the strengths of the study. To the best of our knowledge, there are no previous studies available about the changes in the quantity of objectively measured PA during military operations. On the other hand, the study setting included some limitations. One such example is the quantification of PA in respect to physical workload assessment in a military setting. Soldiers often perform operative tasks carrying equipment and wearing body armor, which increases the strain and energy expenditure but it is not detected by an accelerometer. In addition, some activities, such as resistance training, are often performed without any significant acceleration on the hip. The additional energy cost of the above mentioned activities must be taken into consideration when evaluating the workload of soldiers based on the PA data.

However, the general finding of the rather low total volume of PA is in coherence with other results of this study, such as the low HR responses. Another limitation of the study arose from the reduced number of participants. The priority of operative duties superseded the measurements of the study, which negatively influenced the number of participants, especially during MID. Nevertheless, with the given number of subjects and based on the used methods, the obtained results offer new insights to work physiology of military occupation in a crisis management operation during operatively calm period. Due to the varying stressors affecting the soldier performance during the deployment, it must be taken into consideration that the findings of this study cannot be generalized to all crisis management operations.

CONCLUSIONS

In conclusion, the findings have demonstrated that due to the operatively calm nature of the working environment, the soldiers expressed no significant signs of physical overload during the study. This was further supported by the low quantity of PA, low HR values and slight changes in biomarkers used in this study. As such, the demanded level of physical performance (e.g., functional reserve) may not be maintained during operations lasting several months just by performing the given military duties. Future studies focusing on training interventions, aiming to maintain or improve physical performance during military operations, are warranted.

ACKNOWLEDGMENTS
The authors appreciate Ms. Johanna Ihalainen, Ms. Mia Laakso and Ms. Moona Myllyaho for their assistance in data analysis, Mr. Pasi Ollila, Mr. Risto Puurtinen and Mrs. Aila Ollikainen for their blood and saliva analyses, and Mrs. Elina Vaara for statistical analyses.

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II

ASSOCIATIONS OF PHYSICAL FITNESS AND BODY COMPOSITION CHARACTERISTICS WITH SIMULATED MILITARY TASK PERFORMANCE

by

Pihlainen Kai, Santtila Matti, Häkkinen Keijo & Kyröläinen Heikki, 2018

Journal of Strength and Conditioning Research 32(4), 1089-1098

https://doi.org/10.1519/JSC.0000000000001921

III

EFFECTS OF COMBINED STRENGTH AND ENDURANCE TRAINING ON BODY COMPOSITION, PHYSICAL FITNESS, AND SERUM HORMONES DURING A 6-MONTH CRISIS MANAGEMENT OPERATION

by

Pihlainen Kai, Kyröläinen Heikki, Santtila Matti, Ojanen Tommi, Raitanen Jani & Häkkinen Keijo, 2020

Journal of Strength and Conditioning Research.
Epub ahead of print.

https://doi.org/10.1519/JSC.0000000000003902

Journal of Strength and Conditioning Research™

OPEN

Effects of Combined Strength and Endurance Training on Body Composition, Physical Fitness, and Serum Hormones During a 6-Month Crisis Management Operation

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[1]Training Division, Helsinki, Defence Command, Finland; [2]Neuromuscular Research Center, Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland; [3]Department of Military Pedagogy and Leadership, National Defence University, Finnish Defence Forces, Helsinki, Finland; [4]Finnish Defence Research Agency, Finnish Defence Forces, Tuusula, Tuusula, Finland; [5]Faculty of Social Sciences (Health Sciences), Tampere University, Tampere, Finland; and [6]UKK Institute for Health Promotion Research, Tampere, Finland

Abstract

Pihlainen, K, Kyröläinen, H, Santtila, M, Ojanen, T, Raitanen, J, and Häkkinen, K. Effects of combined strength and endurance training on body composition, physical fitness, and serum hormones during a 6-month crisis management operation. *J Strength Cond Res* XX(X): 000–000, 2020—Very few studies have examined the impact of training interventions on soldier readiness during an international military operation. Therefore, the present study investigated the effects of combined strength and endurance training on body composition, physical performance, and hormonal status during a 6-month international military deployment consisting of typical peacekeeping tasks, e.g., patrolling, observation, and on-base duties. Soldiers ($n = 78$) were randomly allocated to a control group (C) or one of 3 combined whole-body strength and endurance training groups with varying strength-to-endurance training emphasis (Es = 25/75%, *SE* = 50/50% or Se = 75/25% of strength/endurance training). Body composition, physical performance (3000-m run, standing long jump [SLJ], isometric maximal voluntary contraction of the lower [MVC lower] and upper extremities [MVC upper], muscle endurance tests), and selected serum hormone concentrations were determined prior to training (PRE), and after 9 (MID) and 19 (POST) weeks of training. Within- and between-group changes were analyzed using linear regression models. The average combined strength and endurance training frequency of the total subject group was 3 ± 2 training sessions per week. No changes were observed in physical performance variables in the intervention groups, whereas SLJ decreased by 1.9% in C ($p < 0.05$). Maximal voluntary contraction lower increased by 12.8% in the combined intervention group ($p < 0.05$), and this was significantly different to C ($p < 0.05$). Testosterone-to-cortisol ratio increased in *SE* and Se ($p < 0.05$), whereas no change was observed in C. The intervention groups maintained or improved their physical performance during deployment, which is beneficial for operational readiness. However, the high interindividual variation observed in training adaptations highlights the importance of training individualization during prolonged military operations.

Key Words: readiness, performance, soldier, resistance and aerobic training, military

Introduction

A high level of operational readiness is a prerequisite for soldiers during deployments. However, optimal occupational performance may be challenged during prolonged military operations by a combination of stressors, such as sustained physical activity without optimized recovery, sleep deprivation, energy deficit, dehydration, climate, and cognitive and emotional stress (4,26,27,30). Such an environment may disrupt homeostatic regulation and with insufficient recovery, decreases in serum concentrations of anabolic hormones and increases in catabolic hormones may lead to increased muscle protein breakdown and thus, decreases in muscle mass and physical performance (5,16). Cumulatively, these stressors may reduce the ability to successfully fulfil operative duties. Even though the overall operative physiological stress may be lower during prolonged crisis management operations than during intensive combat operations (34), soldier readiness should still be maintained at a high level, because the security situation can change quickly in both types of operations.

Although several studies have reported negative changes in body composition, hormonal status, and physical performance following prolonged military field exercises (12), fewer studies have been published related to peace enforcement or crisis management operations (10,30,34). The findings of studies concerning military deployments are partly contradictory regarding changes in body composition and physical performance. However, decreases in aerobic fitness (10,25,40,43) and increases in fat mass (11,25,40) have been observed in several studies. These changes may also be inter-

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (http://journals.lww.com/nsca-jscr).

Journal of Strength and Conditioning Research 00(00)/1–10

related (32,44), and they may compromise occupational physical performance (33), increase the prevalence of injuries (43), and thereby have a negative impact on operative readiness.

Several studies have shown that superior physical performance is related to more efficient job performance within the military context (14,41). Because many typical military tasks require a combination of strength and endurance, it is logical to assume that through properly planned training, improvements in physical fitness variables would be associated with improved military performance and readiness (14,23,24). For example, regular strength training enhances neural input and motor control during voluntary muscle actions, and it also increases muscle cross-sectional area (18,21). Together, these changes lead to increases in maximal strength and the rate of force development, especially when explosive strength training is included (8), but also in movement economy during submaximal workload (2). These are important determinants of various military tasks, such as rushes and loaded running (33). In addition, typical military tasks, such as maximal lifting capacity and repetitive lifting performance, can be improved by strength training (45). Low-intensity endurance training increases not only the capillary network density but also the mitochondrial and aerobic enzyme content of the trained muscle cells. Together, these adaptations improve fat oxidation and acid-base balance during prolonged submaximal exercise (17) such as marching. High-intensity endurance training results in central adaptations, such as higher maximal cardiac output (15), and thus increases the functional reserves for load carriage by enabling soldiers to operate at a lower percentage of their maximal capacity (9). High-intensity endurance training and high-intensity functional training may also enhance combat readiness by eliciting similar psychophysiological responses to high-stress combat situations (42). On the other hand, prolonged combined endurance and strength training seems to lead to interference, especially in explosive force development (19). Moreover, a high volume of endurance type military training may interfere with optimal strength and power development (38). Nonetheless, improvements in the abovementioned physical fitness attributes likely lead to superior occupational performance and enhanced tolerance of mental and physical stress (29).

Thus, physical performance may be enhanced by optimally periodized strength and endurance training in various military environments (24). However, studies focusing on the effects of combined strength and endurance training during international military operations are scarce. Therefore, the purpose of the present study was to investigate the effects of different combinations of strength and endurance training on body composition, physical performance, and serum anabolic and catabolic biomarkers during a six-month crisis management operation in the Middle East.

Methods

Experimental Approach to the Problem

A longitudinal study design was used to investigate the effects of combined strength and endurance training on body composition, physical performance and, selected serum hormonal concentrations during deployment in South Lebanon. The military duties of the soldiers included patrolling and observing possible hostilities outside the military base, and maintenance and headquarter duties inside the base. The average ambient temperature was 22.3 ± 4.3° C during the study period (34). According to previous studies from the same study population, energy balance was maintained with a self-reported average energy intake of 2,400–2,500 kcal·d^{-1} (31), and objectively measured physical activity data suggest that the daily average physical work load was light (34). However, the soldiers were obligated to maintain operative readiness at all times throughout the deployment, which may have increased their psychological stress (34).

All measurements were conducted inside the military base in South Lebanon. To determine adaptations to combined strength and endurance training, baseline (PRE) measures of body composition, blood biomarkers and physical performance variables were recorded before block-randomizing (1) of soldiers into 3 training groups and a control group. The respective measurements were repeated 9 (MID) and 19 (POST) weeks after the baseline measurements. Because of operational demands, the soldiers were not able to attend all the measurements. In addition, 2 subjects voluntarily ended their participation in the study during the operation. Thus, the final study sample within each variable only consisted of soldiers who participated in all 3 measurements.

Subjects

A rotation unit of approximately 250 soldiers was given the possibility to take part in the present study. Before the deployment, a medical doctor physically examined these soldiers. The exclusion criteria for the deployment included health limitations requiring permanent medication, and a score lower than 2,300 meters in the 12-minute running test (7). Finally, 78 male soldiers volunteered for the PRE measurements. The means ± *SD*s and ranges for age, height, body mass (BM), and BM index (BMI) of the soldiers were 29 ± 8 (20–51) years, 1.80 ± 0.07 (1.65–1.99) *m*, 79 ± 8 (60–97) kg, and 24 ± 2 (18–33) kg·m^{-2}, respectively. The soldiers were informed of the study design and possible benefits and risks of the investigation. Thereafter, the soldiers gave their written informed consent to participate in the study. The study was conducted in accordance with the statement of the Ethical Committee of the Central Finland Health Care District and accepted by the Finnish Defence Forces.

Procedures

The study measurements have been described previously in detail (31–34). Briefly, body composition measurements and blood sampling were conducted after a minimum of 10-hours of overnight fasting at a military hospital. Body mass, BMI, skeletal muscle mass (SMM), and fat mass (FATM) were determined using segmental multifrequency bioimpedance analysis (InBody 720, Biospace, Seoul, South Korea). Blood samples were analyzed for serum testosterone (TES), sex-hormone binding globulin (SHBG), cortisol (COR), and insulin-like growth factor-1 (IGF1). Thereafter, the TES to COR (TES:COR) and TES to SHBG (TES:SHBG) ratios were calculated.

Physical performance was assessed on separate days with a minimum of 24 hours between the strength, endurance, and occupational tests. Soldiers were advised to avoid any training the day before each test session. Maximal isometric force of the lower (MVC_{lower}) and upper (MVC_{upper}) extremity extensor muscles were measured (28) bilaterally in a sitting position using an electromechanical dynamometer (University of Jyväskylä, Jyväskylä, Finland). The MVC_{lower} measurement (18) was performed in a horizontal leg press position with knee and hip angles fixed at 107 and 110°, respectively. For the MVC_{upper}

measurement, the handle bar was adjusted to the height of the shoulders so that elbow angle was maintained at 90°. In both measurements, soldiers were instructed to perform 3 maximal efforts with a minimum of 30 seconds recovery between trials. The trial with the highest force output was selected for further analysis. A standing long jump (SLJ) was used to assess power production of the lower extremities, whereas the maximal number of sit-ups and push-ups in one minute, and the maximum number of pull-ups (no time limit), were used to assess dynamic muscle endurance of the trunk and upper extremities. The soldiers were familiar with these tests, because they have also been used during basic military training. A test supervisor demonstrated the correct technique before each test and registered the test results.

Endurance performance was assessed using the 3000-m running test (3000-m). Soldiers were instructed to complete the test with maximal effort and in the shortest possible time, which was the outcome measure. Heart rate was recorded for training purposes using chest-strapped monitors (Memory belt, Suunto, Vantaa, Finland).

The military simulation test (MST) (33) was designed to assess occupational physical performance during crisis-management in soldiers. The 243-m test track consisted of common movements (rushes, jumps, changes in movement direction, and crawling) and military tasks (load carriage and casualty drag), which the soldiers may theoretically have to perform in an ambush during a patrol or convoy in the deployment area. The test was performed in the shortest possible time wearing regular patrolling gear (combat dress uniform, boots, combat vest, ammunition, body armor, and helmet) and carrying a replica assault rifle. The total mass of the outfit including the weapon was 22.5 ± 1.0 kg. Performance time was the outcome measure.

After the PRE measurements, all participating soldiers were block-randomized to one of the 3 intervention groups or the control group (**C**) and provided with a training diary. The diaries of the 3 intervention groups included the combined strength and endurance training program with illustrated instructions of the exercises to be performed twice a week, whereas the diary of group **C** included only blank pages with instructions about how to complete the diary. Pihlainen et al. (32) recently presented the general description of the training program. The individual exercises of the training program were similar between the 3 groups, but the strength-to-endurance training emphasis varied. Group ***SE*** performed 2 strength and 2 endurance training sessions in 2 weeks (i.e., 50% strength training). During the same time period, group **Se** performed 3 strength and one endurance training sessions (i.e., 75% strength training), whereas group **Es** performed 3 endurance and one strength training sessions (i.e., 25% strength training). Furthermore, to avoid possible detraining, the soldiers were encouraged to at least maintain the training volume that they were accustomed to before the operation, but to follow the training program and adjust their strength-to-endurance training emphasis to match the given program.

The first half of the study focused on low-to-moderate-intensity exercises. Thereafter, the training intensity was increased, and volume was decreased during the latter half of the study period. For hypertrophic (3–5 × 8–10 repetitions) and maximal strength (4 × 2–4 repetitions) training, soldiers were instructed to select weights for each exercise (e.g., squat, bench press, and deadlift), so that the last repetitions in each set would proceed as close to concentric failure as possible. The correct performance techniques of the exercises were demonstrated for the intervention groups and practiced before starting the training program. For endurance exercises, peak heart rate (HR_{peak}) was determined as the highest measured value during the 3000-m run using Firstbeat PRO analysis (Firstbeat Technologies, Jyväskylä, Finland). Because of the nature of the operation, the soldiers performed the exercises and completed the diaries throughout the study without supervision.

At the end of the follow-up, the training diaries were collected and analyzed. In some cases ($n = 15$), the self-reported training did not match with the emphasis of the given program. To provide more accurate results regarding training adaptations, these soldiers were regrouped into the group that most closely matched the predetermined strength-to-endurance training emphasis for the purpose of statistical analyses. The training diary data were analyzed for relative strength and endurance training frequency (sessions·wk^{-1}). In addition, endurance training was analyzed for volume (minutes·wk^{-1}) spent in different intensity zones (low-intensity <75% HR_{peak}, moderate-intensity 75–85 HR_{peak}, high-intensity >85 HR_{peak}), and strength training for the lower- and upper-body volume load (kg·wk^{-1}).

Statistical Analyses

Descriptive statistics (mean, *SD*, 95% confidence interval [CI], percentages) are reported where appropriate. Differences in within- and between-group changes, including the intervention groups combined (i.e., ***SE*** + **Se** + **Es**), were analyzed using linear regression models. The purpose of combining the intervention groups was to investigate the possible effects of providing a training program in general. Models were adjusted for the baseline value of a given outcome, and group **C** was the reference group. Outliers (z-score < −3.3 or >3.3) were detected and removed separately in each model. Unstandardized regression coefficients were expressed with 95% CI (Tables 2–4 and see Table 1, Supplemental Digital Content 1, http://links.lww.com/JSCR/A242). Moreover, relationships were examined between explanatory variables (body composition, physical performance, and biomarkers) and the relative change from PRE to POST for SMM, FATM, 3000-m, and MVC_{lower}. Analyses were performed using backward linear regression with stepping method criteria $p = 0.05$ for entering and $p = 0.10$ for removing. Explanatory variables with $p < 0.05$ in the univariate analysis were included for backward linear regression. Stata 15.1 for Windows was used for statistical analyses, and $p < 0.05$ was used to establish statistical significance.

Results

During the deployment, the average strength and endurance training frequency of the whole subject group was 3.2 ± 1.5 training sessions per week, of which 1.5 ± 0.9 sessions focused on strength and 1.7 ± 1.2 focused on endurance training. The most active groups in the average weekly training frequency were ***SE*** (3.3 ± 1.2) and **C** (4.0 ± 2.0). Self-reported group-wise statistics from the training diaries are presented in Table 1.

Body Mass increased by 0.5% during MID-POST in the combined (***SE***, **Se**, **Es**) intervention group and by 0.9% in group **C**. An increase of 1.3% in BM was also observed in ***SE*** during PRE-POST. Skeletal muscle mass increased by 1.0% in the combined group and by 2.3% in ***SE*** during PRE-POST (Figure 1). In ***SE***, a 1.6% increase in SMM was also observed during the first half of the study. In addition, FATM increased in the combined group by 3.4% during MID-POST. Between-group comparisons showed that the decrease in SMM during PRE-POST was higher

Table 1

Group-wise weekly mean (*SD*) and range of the training frequency, volume of endurance training and volume load of strength training in the combined strength and endurance training groups and the control group during the operation.*

	SE		Se		Es		C	
Training variables	Mean (*SD*)	Range	Mean (*SD*)	Range	Mean (*SD*)	Range	Mean (*SD*)	Range
Endurance training frequency (times)	1.5 (0.6)	0.6–3.1	0.7 (0.6)	0.0–2.0	2.2 (0.8)	0.8–3.5	2.2 (1.7)	0.0–6.5
Strength training frequency (times)	1.6 (0.8)	0.4–2.8	1.7 (0.5)	1.1–2.4	0.8 (0.4)	0.0–1.4	1.8 (1.4)	0.0–4.7
Total training frequency (times)	3.1 (1.2)	1.2–5.0	2.4 (0.7)	1.4–3.7	3.0 (1.1)	0.8–4.4	4.0 (2.0)	1.6–8.6
LIT (<75% HR_{peak}) volume (min)	62 (30)	30–151	50 (18)	30–81	78 (32)	36–144	55 (37)	20–125
MIT (75–85% HR_{peak}) volume (min)	48 (13)	24–67	49 (17)	30–72	43 (12)	27–60	43 (15)	21–65
HIT (>85% HR_{peak}) volume (min)	38 (22)	16–77	30 (11)	22–38	33 (12)	23–53	17 (5)	13–20
LB strength training volume load (×1,000 kg)	15.7 (7.2)	3.0–31.1	16.8 (6.5)	4.4–26.8	16.2 (7.0)	4.7–27.7	10.8 (7.6)	3.4–34.9
UB strength training volume load (×1,000 kg)	11.2 (4.5)	4.2–20.8	10.0 (3.0)	6.2–15.0	10.1 (4.2)	1.8–17.3	15.0 (9.3)	3.8–34.5

**SE* = 50% strength training group; Se = 75% strength training group; Es = 25% strength training group; C = control group; LIT = low-intensity endurance training; MIT = moderate-intensity endurance training; HIT = high-intensity endurance training; LB = lower body; UB = upper body.

in **Es** compared with the control group **C** (coef. −0.7 kg, 95% CI −1.3 to −0.1 kg, $p < 0.05$). Within-group changes in body composition are presented in Supplemental Digital Content 1 (see Table 1, http://links.lww.com/JSCR/A242).

Although no within-group changes were observed in 3000-m time, all groups improved their MST time between every measurement point (Figure 1). No differences in the changes in 3000-m or MST were observed between the intervention groups and group C. Standing long jump decreased by −2.4% and −1.9% in group C during PRE-POST and MID-POST, respectively. In addition, MID-POST decrements in SLJ performance were observed in the combined group (−1.5%) and *SE* (−2.6%). MVC_{lower} increased in the combined group by 12.8% during PRE-POST. Significant PRE-POST increases in MVC_{lower} were also observed in all individual intervention groups. Between-group analysis (reference group **C**) showed a higher PRE-POST increase in the combined intervention group (coef. 415 N, 95% CI 97–733 N, $p < 0.05$) and **Se** (coef. 611 N, 95% CI 181–1040 N, $p < 0.05$). In addition, when comparing with **C**, the increase in MVC_{lower} was significantly higher during PRE-MID in **Se** (coef. 632 N, 95% CI 232–1031 N, $p < 0.05$), whereas in **Es**, the respective change was higher during MID-POST (coef. 353 N, 95% CI 10–696 N, $p <$

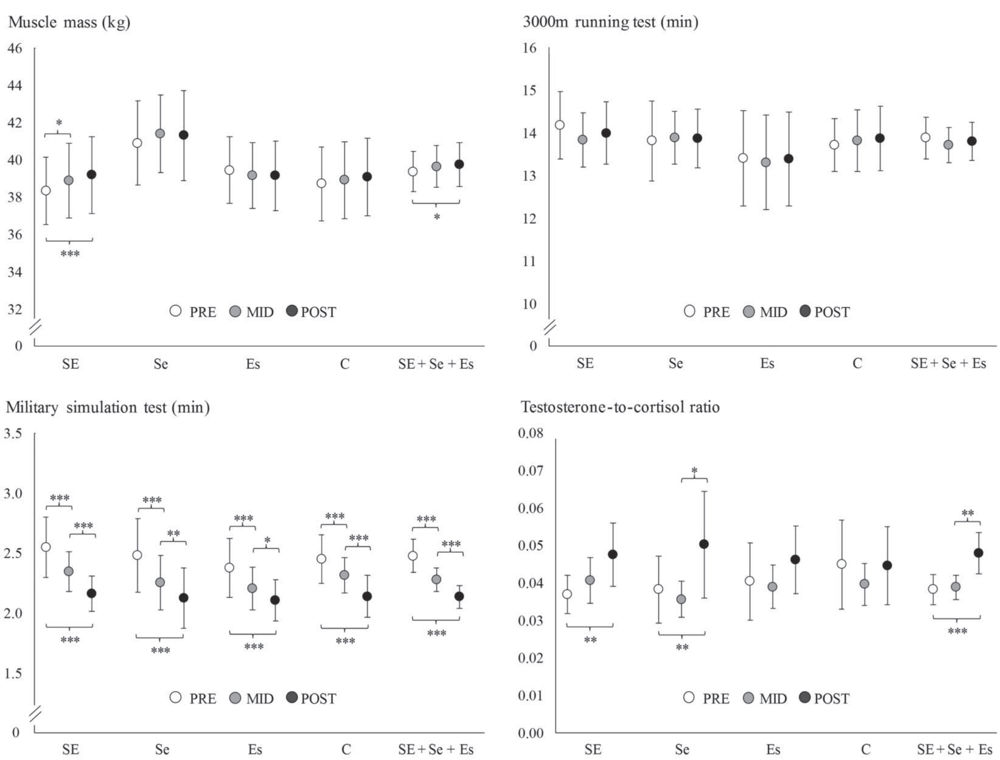

Figure 1. Within-group means and *SD*s for muscle mass, 3000-m running test, military simulation test and testosterone-to-cortisol ratio of the combined strength and endurance training groups and the control group during the operation. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Abbreviations: PRE, baseline; MID, first (9 weeks) follow-up measurement; POST, second (19 weeks) follow-up measurement; *SE*, 50% strength training group; Se, 75% strength training group; Es, 25% strength training group, C, control group.

0.05). MVC_{upper} increased during PRE-MID in the combined intervention group by 2.3%, whereas during MID-POST, a decrease of −3.4% was observed in **C**. Strength endurance tests (1-minute sit-ups and push-ups, maximum number of pull-ups) improved in all groups throughout the study. Within-group changes in physical performance are presented in Table 2.

Despite modest changes in the group mean values of body composition and some physical performance variables, interindividual variation in the magnitude and direction of changes was high (Figure 2).

TES increased by 10% and COR decreased by −8.7% in the combined intervention group during PRE-POST. TES also increased in **C** by 14.7% during PRE-MID and in **Es** by 16% during PRE-POST. The TES:COR ratio increased during the different phases of the study in the combined intervention group, **Se** and ***SE***, but not in **C** or **Es** (Table 3). No differences were detected in the abovementioned changes between the intervention groups and group **C**. No within- or between-group changes were observed in IGF1. The TES:SHBG ratio increased during PRE-POST in all groups, whereas between-group comparisons showed a PRE-MID decrease in **Se** compared with **C** (coef. −0.12 $nmol·L^{-1}$, 95% CI −0.24 to −0.01 $nmol·L^{-1}$, $p < 0.05$), but during MID-POST, the respective change was positive (coef. 0.23 $nmol·L^{-1}$, 95% CI 0.05–0.42 $nmol·L^{-1}$, $p < 0.05$). Within-group changes in serum anabolic and catabolic biomarkers are presented in Table 3.

Multiple linear regression with backward elimination for the relative increase in SMM resulted in a relationship with a higher strength training frequency (coef. 1.283, 95% CI 0.495 to 2.072, $p = 0.002$), and relative decreases in MST time (coef. −0.176, 95% CI −0.294 to −0.057, $p = 0.014$) and TES:SHBG ratio (coef. 0.011, 95% CI 0.000 to 0.023, $p = 0.052$), which together explained 32% of the variance in the change in SMM (Adj. $R^2 = 0.317$). For increased FATM, a relationship was found with higher LB strength training volume load (coef. 1.058, 95% CI 0.335 to 1.780, $p = 0.005$) and increased 3000-m time (coef. 2.303, 95% CI 1.285 to 3.321, $p < 0.001$), with an adjusted R^2 of 0.514. Similarly, a relationship with the relative increase in MVC_{lower} was found with the relative increase in SLJ (coef. = 0.863, 95% CI −0.126 to 1.851, $p = 0.086$) and the respective decrease in MST time (coef. = −0.559, 95% CI −1.106 to −0.012, $p = 0.045$) (Adj. $R^2 = 0.105$). Finally, the relative change in 3000-m time was related to respective changes in BMI (coef. = 0.694, 95% CI 0.434 to 0.954, $p < 0.001$), MST time (coef. = 0.236, 95% CI 0.092 to 0.380, $p = 0.002$), and pull-up repetitions (coef. = −0.017, 95% CI −0.037 to 0.003, $p = 0.089$), as well as PRE 3000-m time (coef. = −0.016, 95% CI −0.027 to −0.004, $p = 0.007$), which together explained 68% of the variance in 3000-m time (Adj. $R^2 = 0.675$). Univariate linear regression results showing significant relationships with relative changes in 3000-m, MVC_{lower}, SMM, or FATM are presented in Table 4.

Discussion

The present study showed that intervention groups that performed a combined strength and endurance training program were able to maintain or improve all of the examined physical performance variables. Thus, from a physical performance point of view, the soldiers were able to maintain their operative readiness during the study period. In addition, both TES:COR and TES:SHBG ratios increased during PRE-POST and MID-POST in the combined intervention group, indicating a shift to a more anabolic status, and thus providing a favorable physiological milieu for positive training adaptations. MVC_{lower} improved more in the combined intervention group than in group **C**. Although nonsignificant changes within the training groups occurred according to the specificity principle of training, large interindividual variations in training adaptations were

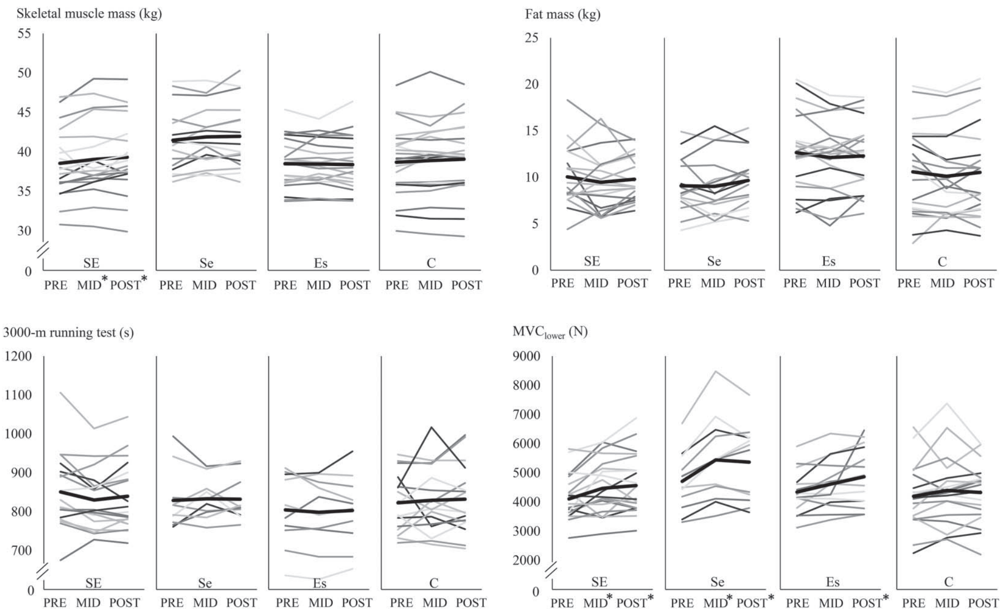

Figure 2. Individual and group mean (bolded line) changes in skeletal muscle mass, fat mass, maximal voluntary force of the lower extremities, and 3000-m running performance of the combined strength and endurance training groups and the control group during the operation. *Significant within-group change compared to PRE ($p < 0.05$). Abbreviations: PRE, baseline; MID, first (9 weeks) follow-up measurement; POST, second (19 weeks) follow-up measurement; *SE*, 50% strength training group; Se, 75% strength training group; Es, 25% strength training group, C, control group; MVC_{lower}, maximal voluntary force of the lower extremities.

Table 2

Physical performance variables (mean and *SD*) of the combined strength and endurance training groups and the control group at baseline (PRE), after 9 (MID) and 19 weeks (POST) and their changes within groups, based on unstandardized coefficients (Coef.) and 95% confidence intervals (CI) from linear regression models.*†

					Within groups		
					PRE-MID	PRE-POST	MID-POST
	n	PRE	MID	POST	Coef. (95% CI)	Coef. (95% CI)	Coef. (95% CI)
3000-m running test (min:s)							
SE	18	14:11 (1:36)	13:50 (1:17)	14:00 (1:29)	−0:16 (−0:36 to 0:04)	−0:08 (−0:27 to 0:11)	0:10 (−0:07 to 0:27)
Se	10	13:49 (1:18)	13:53 (0:52)	13:52 (0:57)	0:04 (−0:23 to 0:31)	0:03 (−0:22 to 0:28)	−0:01 (−0:23 to 0:21)
Es	10	13:25 (1:34)	13:18 (1:33)	13:23 (1:32)	−0:12 (−0:39 to 0:16)	−0:05 (−0:30 to 0:21)	0:04 (−0:19 to 0:27)
C	17	13:43 (1:12)	13:49 (1:24)	13:52 (1:28)	0:05 (−0:16 to 0:26)	0:09 (−0:11 to 0:28)	0:03 (−0:14 to 0:20)
SE, Se, Es	38	13:53 (1:31)	13:42 (1:15)	13:48 (1:22)	−0:10 (−0:23 to 0:04)	−0:04 (−0:17 to 0:08)	0:06 (−0:06 to 0:17)
Military simulation test (min:s)							
SE	15	2:33 (0:27)	2:21 (0:18)	2:10 (0:16)	**−0:11 (-0:14 to -0:07)**	**−0:22 (-0:26 to -0:17)**	**−0:11 (-0:15 to -0:06)**
Se	9	2:29 (0:24)	2:15 (0:18)	2:07 (0:20)	**−0:13 (-0:18 to -0:09)**	**−0:21 (-0:27 to -0:15)**	**−0:08 (-0:14 to -0:03)**
Es	11	2:22 (0:22)	2:12 (0:16)	2:06 (0:15)	**−0:13 (-0:17 to -0:08)**	**−0:18 (-0:24 to -0:13)**	**−0:06 (-0:11 to -0:01)**
C	12	2:27 (0:19)	2:19 (0:14)	2:08 (0:17)	**−0:09 (-0:13 to -0:04)**	**−0:19 (-0:24 to -0:14)**	**−0:11 (-0:15 to -0:06)**
SE, Se, Es	35	2:29 (0:25)	2:17 (0:17)	2:08 (0:16)	**−0:12 (-0:14 to -0:10)**	**−0:20 (-0:23 to -0:17)**	**−0:09 (-0:11 to -0:06)**
Standing long jump (cm)							
SE	18	234 (26)	237 (27)	231 (28)	2.8 (−0.9 to 6.6)	−3.2 (−7.8 to 1.4)	**−6.0 (-10.0 to -2.1)**
Se	12	238 (21)	238 (20)	236 (17)	−0.1 (−4.7 to 4.5)	2.1 (−7.8 to 3.5)	−2.0 (−6.9 to 2.8)
Es	15	238 (20)	241 (22)	238 (22)	3.1 (−1.0 to 7.3)	0.9 (−4.1 to 6.0)	−2.0 (−6.4 to 2.3)
C	19	236 (25)	235 (28)	230 (29)	−1.3 (−4.9 to 2.4)	**−5.6 (-10.0 to -1.1)**	**−4.4 (-8.3 to -0.6)**
SE, Se, Es	45	236 (22)	238 (23)	235 (25)	2.2 (−0.2 to 4.5)	−1.5 (−4.4 to 1.4)	**−3.6 (-6.1 to -1.1)**
Maximal voluntary force of the lower extremities (*N*)							
SE	19	4,216 (797)	4,547 (964)	4,651 (1,036)	**331 (83 to 580)**	**435 (168 to 702)**	97 (−130 to 324)
Se	12	4,168 (1,110)	4,997 (1,598)	4,908 (1,448)	**833 (520 to 1,146)**	**740 (404 to 1,077)**	−34 (−323 to 255)
Es	15	4,337 (735)	4,609 (828)	4,863 (982)	264 (−17 to 544)	**526 (225 to 827)**	256 (−0.1 to 511)
C	19	4,196 (1,081)	4,395 (1,191)	4,325 (1,013)	201 (−47 to 450)	129 (−138 to 397)	−98 (−326 to 131)
SE, Se, Es	46	4,243 (853)	4,684 (1,116)	4,787 (1,121)	**440 (272 to 608)**	**544 (372 to 716)**	115 (−31 to 262)
Maximal voluntary force of the upper extremities (*N*)							
SE	20	1,150 (261)	1,177 (263)	1,167 (263)	27 (−9 to 64)	18 (−23 to 60)	−9 (−42 to 25)
Se	11	1,121 (204)	1,142 (213)	1,163 (210)	20 (−29 to 69)	40 (−16 to 95)	18 (−27 to 64)
Es	15	1,199 (185)	1,228 (172)	1,204 (172)	33(-9 to 74)	12 (−36 to 59)	−19 (−58 to 20)
C	19	1,104 (253)	1,137 (250)	1,102 (232)	30 (−7 to 68)	−6 (−48 to 36)	**−37 (-72 to -3)**
SE, Se, Es	46	1,159 (223)	1,185 (223)	1,178 (220)	**27 (4 to 51)**	21 (−6 to 48)	−6 (−28 to 16)
Push-ups (repetitions in 1 minute)							
SE	20	40 (12)	41 (10)	44 (13)	0.7 (−2.0 to 3.5)	**4.3 (0.7 to 8.0)**	**3.6 (0.7 to 6.5)**
Se	11	37 (11)	41 (11)	46 (11)	2.7 (−1.0 to 6.4)	**8.7 (3.7 to 13.7)**	**5.9 (2.0 to 9.8)**
Es	15	44 (14)	46 (15)	50 (13)	2.1 (−1.1 to 5.3)	**6.7 (2.4 to 11.0)**	**4.8 (1.4 to 8.2)**
C	19	39 (13)	39 (12)	45 (16)	−0.2 (−3.0 to 2.6)	**5.7 (2.0 to 9.5)**	**5.9 (2.9 to 8.8)**
SE, Se, Es	46	41 (13)	42 (12)	47 (13)	1.6 (−0.2 to 3.4)	**6.2 (3.7 to 8.6)**	**4.5 (2.6 to 6.4)**
Sit-ups (repetitions in 1 minute)							
SE	20	45 (10)	47 (9)	48 (8)	**1.8 (0.3 to 3.4)**	**2.8 (0.8 to 4.7)**	0.9 (−0.6 to 2.4)
Se	12	46 (7)	47 (8)	49 (9)	0.6 (−1.4 to 2.7)	**2.7 (0.2 to 5.3)**	**2.1 (0.1 to 4.0)**
Es	15	48 (9)	50 (8)	50 (9)	**2.6 (0.8 to 4.4)**	**2.5 (0.2 to 4.8)**	−0.0 (−1.8 to 1.8)
C	19	46 (10)	46 (10)	48 (10)	−0.1 (−1.7 to 1.5)	1.8 (−0.3 to 3.8)	**1.8 (0.3 to 3.4)**
SE, Se, Es	47	46 (9)	48 (8)	49 (9)	**1.8 (0.8 to 2.8)**	**2.7 (1.4 to 3.9)**	0.9 (−0.1 to 1.9)
Pull-ups (repetition maximum)							
SE	20	9 (6)	11 (5)	12 (6)	**1.8 (0.7 to 2.8)**	**2.7 (1.4 to 4.0)**	0.9 (−0.0 to 1.9)
Se	12	9 (4)	10 (6)	12 (6)	0.8 (−0.5 to 2.2)	**2.9 (1.1 to 4.6)**	**2.0 (0.7 to 3.3)**
Es	15	12 (5)	13 (6)	15 (6)	**1.5 (0.3 to 2.7)**	**3.6 (2.0 to 5.1)**	**2.1 (0.9 to 3.2)**
C	19	9 (5)	11 (6)	12 (6)	**1.8 (0.8 to 2.9)**	**2.8 (1.4 to 4.2)**	0.9 (−0.1 to 2.0)
SE, Se, Es	47	10 (5)	11 (6)	13 (6)	**1.4 (0.8 to 2.1)**	**3.0 (2.2 to 3.9)**	**1.6 (0.9 to 2.2)**

*MID = first (9 weeks) follow-up measurement; POST = second (19 weeks) follow-up measurement; *SE* = 50% strength training group; Se = 75% strength training group; Es = 25% strength training group; C = control group.
†Bolded values, $p < 0.05$.

observed. Possible explanatory factors for not finding statistically significant differences include the low number of subjects in each study group and individual differences in baseline fitness levels, which should be taken into consideration when implementing a training program for soldiers during deployment.

Group *SE*, who performed an equal distribution of strength and endurance training (49% strength training), was the only group that showed an increase in SMM while simultaneously maintaining endurance performance during the operation. Increases in muscle mass during military operations have been

Table 3

Serum anabolic and catabolic biomarkers (mean and *SD*) of the combined strength and endurance training groups and the control group at baseline (PRE), after 9 (MID) and 19 weeks (POST) and their changes within groups, based on unstandardized coefficients (Coef.) and 95% confidence intervals (CI) from linear regression models.*†

					Within groups		
	n	PRE	MID	POST	PRE-MID Coef. (95% CI)	PRE-POST Coef. (95% CI)	MID-POST Coef. (95% CI)
Testosterone (nmol·L^{-1})							
SE	19	15.4 (3.9)	16.4 (3.7)	16.7 (2.9)	0.7 (−0.8 to 2.3)	0.9 (−0.5 to 2.3)	−0.3 (−1.8 to 1.2)
Se	11	15.4 (2.5)	15.9 (2.4)	17.4 (2.7)	0.2 (−1.8 to 2.2)	1.7 (−0.2 to 3.6)	0.7 (−1.3 to 2.7)
Es	12	16.9 (7.1)	18.0 (4.9)	19.0 (5.1)	1.5 (−0.4 to 3.5)	**2.7 (0.9 to 4.5)**	1.5 (−0.4 to 3.4)
C	16	16.3 (4.5)	18.6 (4.6)	17.2 (3.4)	**2.4 (0.8 to 4.1)**	1.1 (−0.5 to 2.7)	−0.5 (−2.2 to 1.1)
SE, Se, Es	42	15.9 (4.7)	16.7 (3.8)	17.6 (3.6)	0.8 (−0.2 to 1.8)	**1.6 (0.6 to 2.6)**	0.5 (−0.5 to 1.5)
Cortisol (nmol·L^{-1})							
SE	19	431 (74)	421 (127)	385 (130)	−7 (−61 to 47)	−44 (−98 to 9)	−55 (−113 to 2)
Se	11	430 (97)	459 (95)	402 (156)	31 (−40 to 102)	−27 (−98 to 43)	−48 (−123 to 27)
Es	12	455 (114)	453 (132)	409 (118)	20 (−49 to 88)	−33 (−101 to 35)	−39 (−111 to 33)
C	16	401 (118)	465 (109)	412 (105)	42 (−17 to 102)	−2 (−61 to 57)	−39 (−102 to 23)
SE, Se, Es	42	438 (91)	440 (120)	396 (131)	10 (−26 to 47)	**−37 (-72 to -1)**	**−49 (-87 to -11)**
Insulin-like growth factor-1 (nmol·L^{-1})							
SE	19	27.9 (9.3)	25.2 (10.2)	23.9 (8.6)	−2.6 (−5.7 to 0.5)	−3.9 (−7.9 to 0.05)	−2.3 (−6.1 to 1.5)
Se	10	27.4 (10.4)	27.6 (9.5)	26.8 (13.9)	0.0 (−4.3 to 4.3)	−0.7 (−6.2 to 4.7)	−0.7 (−5.9 to 4.6)
Es	12	29.8 (10.1)	30.7 (8.3)	28.0 (10.2)	1.6 (−2.3 to 5.6)	−0.7 (−5.7 to 4.3)	−1.3 (−6.2 to 3.5)
C	16	26.0 (9.1)	27.3 (8.5)	27.5 (7.2)	0.8 (−2.7 to 4.2)	0.7 (−3.7 to 5.0)	0.2 (−3.9 to 4.3)
SE, Se, Es	41	28.3 (9.6)	27.4 (9.5)	25.8 (10.4)	−0.7 (−2.8 to 1.4)	−2.2 (−4.9 to 0.5)	−1.6 (−4.1 to 0.9)
Sex-hormone binding globulin (nmol·L^{-1})							
SE	19	31.0 (10.2)	25.7 (8.3)	23.6 (10.4)	**−6.0 (-9.3 to -2.6)**	**−7.9 (-11.7 to -4.0)**	−2.8 (−6.7 to 1.1)
Se	11	32.4 (11.8)	35.6 (8.6)	22.5 (8.9)	3.2 (−1.2 to 7.7)	**−9.9 (−14.9 to −4.8)**	**−12.5 (−17.5 to −7.5)**
Es	12	34.7 (14.9)	32.8 (11.9)	30.9 (16.6)	−0.8 (−5.0 to 3.5)	−3.0 (−7.8 to 1.9)	−1.6 (−6.3 to 3.1)
C	15	32.2 (11.9)	32.4 (10.1)	27.2 (9.8)	0.1 (−3.7 to 3.9)	**−5.0 (−9.3 to −0.7)**	**−5.0 (−9.2 to −0.8)**
SE, Se, Es	42	32.4 (11.9)	30.3 (10.3)	25.4 (12.4)	−2.1 (−4.5 to 0.4)	**−7.0 (−9.6 to −4.4)**	**−5.0 (−7.8 to −2.3)**
Testosterone-to-cortisol ratio							
SE	18	0.037 (0.010)	0.041 (0.012)	0.047 (0.017)	0.001 (−0.003 to 0.006)	**0.010 (0.003 to 0.016)**	0.008 (−0.001 to 0.016)
Se	11	0.038 (0.013)	0.036 (0.007)	0.050 (0.021)	−0.004 (−0.010 to 0.002)	**0.011 (0.003 to 0.020)**	**0.012 (0.002 to 0.023)**
Es	11	0.040 (0.015)	0.039 (0.009)	0.046 (0.014)	−0.001 (−0.007 to 0.005)	0.006 (−0.003 to 0.014)	0.007 (−0.004 to 0.018)
C	15	0.045 (0.022)	0.040 (0.010)	0.045 (0.019)	−0.001 (−0.007 to 0.004)	0.001 (−0.006 to 0.008)	0.005 (−0.004 to 0.015)
SE, Se, Es	40	0.038 (0.012)	0.039 (0.010)	0.048 (0.017)	−0.001 (−0.004 to 0.002)	**0.009 (0.005 to 0.014)**	**0.009 (0.003 to 0.14)**
Testosterone to sex-hormone binding globulin ratio							
SE	17	0.50 (0.17)	0.63 (0.13)	0.75 (0.26)	**0.11 (0.04 to 0.18)**	**0.25 (0.16 to 0.34)**	**0.14 (0.03 to 0.25)**
Se	10	0.52 (0.20)	0.45 (0.08)	0.79 (0.25)	−0.07 (−0.16 to 0.02)	**0.28 (0.16 to 0.39)**	**0.33 (0.18 to 0.47)**
Es	11	0.52 (0.13)	0.55 (0.14)	0.64 (0.18)	0.03 (−0.06 to 0.12)	**0.12 (0.01 to 0.24)**	0.09 (−0.04 to 0.23)
C	16	0.55 (0.23)	0.58 (0.21)	0.68 (0.29)	0.06 (−0.02 to 0.13)	**0.13 (0.04 to 0.23)**	0.10 (−0.01 to 0.21)
SE, Se, Es	38	0.51 (0.16)	0.56 (0.16)	0.73 (0.24)	0.04 (−0.01 to 0.09)	**0.22 (0.16 to 0.28)**	**0.17 (0.10 to 0.25)**

*MID = first (9 weeks) follow-up measurement; POST = second (19 weeks) follow-up measurement; *SE* = 50% strength training group; Se = 75% strength training group; Es = 25% strength training group; C = control group.
†Bolded values, $p < 0.05$.

reported previously in 2 studies (25,44). Group ***SE*** also improved MST time, MVC_{lower}, 1-minute sit-up and 1-minute push-up performance, and pull-up performance during the deployment. These changes were accompanied by a decrease in SHBG and increases in the TES:COR and TES:SHBG ratios. When comparing the training and performance outcomes between ***SE*** and **C**, it seems that ***SE*** achieved essentially the same training effects with a slightly lower training frequency but with a higher volume and higher relative share of high-intensity endurance training than group **C**. Strength and endurance training were emphasized rather equally in both groups. However, the lower-body strength training load was higher than the upper-body strength training load in ***SE*,** whereas it was the opposite in **C**.

Group **Se** spent 77% of weekly training frequency performing strength training, and improved the same physical performance test results as group ***SE***, whereas other variables remained unchanged. Compared with group **C**, a larger improvement was observed in lower body strength in **Se** during PRE-MID and PRE-POST. In addition, although the TES:SHBG ratio decreased more in **Se** during PRE-MID, it also increased during MID-POST when compared with group **C**. As was the case for ***SE***, strength training volume load in **Se** was higher for the lower body than the upper body, suggesting that the soldiers focused training on more important muscle groups from a military occupational performance perspective (3,14,33).

The same positive training adaptations as those observed in ***SE*** and **Se** were also observed in **Es,** which included 75% endurance training. This group improved MST time, MVC_{lower}, and all repetitive strength endurance test results during the study. Despite the different planned and reported endurance training volumes,

Table 4

Unstandardized regression coefficients (coef.) with *p*-values <0.05 for the PRE-POST relative change in 3,000 m running test performance (3000-m), maximal isometric force of the lower extremity extensor muscles (MVC_{lower}), muscle mass (SMM), and fat mass (FATM).*†

	Δ % 3000-m			Δ % MVC_{lower}			Δ % SMM			Δ % FATM		
	n	Coef.	*p*	n	Coef.	*p*	n	Coef.	*p*	n	Coef.	*p*
Strength training frequency (times·wk^{-1})	43	2.16	<0.001				60	0.98	0.009			
LB strength training load (×1,000 kg)										54	0.99	0.002
Δ PRE-POST body mass index (%)	54	0.75	<0.001									
PRE FATM (kg)	55	−0.41	0.034									
Δ PRE-POST FATM (%)	54	0.11	<0.001									
Δ PRE-POST SLJ (%)				64	1.10	0.012						
Δ PRE-POST MST (%)	49	0.35	<0.001	58	−0.61	0.028	62	−0.11	0.027	62	0.83	0.009
Δ PRE-POST sit-up (%)	53	−0.10	0.042							72	−0.43	0.024
Δ PRE-POST pull-up (%)	53	−0.03	0.020									
PRE MVC_{lower} (N)	55	0.0013	0.046									
Δ PRE-POST MVC_{lower} (%)	53	−0.09	0.045									
Δ PRE-POST MVC_{upper} (%)							71	0.091	0.024			
Δ PRE-POST 3000-m (%)										64	1.87	0.001
Δ PRE-POST SHBG (%)							50	−0.029	0.021			
Δ PRE-POST TES:SHBG (%)	50	0.019	0.041									
PRE IGF1 (nmol·L^{-1})										50	−0.69	0.012
Δ PRE-POST IGF1 (%)										50	−2.15	0.003

*PRE = baseline measurement at the beginning of the operation; POST = final measurement at the end of the operation; LB = lower body; FATM = fat mass; kg = kilogram; SLJ = standing long jump; MST = military simulation test; MVC_{upper} = maximal isometric force of the upper extremity extensor muscles; SHBG = Sex-hormone binding globulin, TES:SHBG = Testosterone to sex-hormone binding globulin ratio; IGF1 = Insulin-like growth factor-1.

†Explanatory variables are adjusted for the baseline value of the outcome.

all groups were able to maintain their endurance performance during the operation. This is important especially from the perspective of the groups with lower endurance training volume, given that high mechanical loading from running may increase musculoskeletal injury risk and thereby reduce operative workforce during deployment (37). Overall, maintenance of endurance performance may be considered a positive adaptation during a military operation, because in many prior studies aerobic fitness has been shown to decrease during deployment (10,25,40,43).

Currently, there are no military standards for physical training during deployment in soldier populations. Because the soldiers in group **C** were not provided with any additional tools for improving physical performance, their exercise behavior and changes in body composition and physical performance reflect individual preferences, and are comparable to previous samples of military operation studies. Group **C** improved PRE-POST military-specific performance (MST) and muscle endurance of the trunk and arm flexors while maintaining endurance performance and body composition. Many previous studies of military operations have demonstrated positive changes in muscle endurance (10,37,40,44), whereas decrements in endurance performance have also been observed (10,26,41,44). In the present study, endurance performance was maintained at least at baseline levels. Similar results were reported after a 4-month military operation in Chad by Rintamäki et al. (36), and after a 6-month operation in Afghanistan by Fallowfield et al. (11). Interestingly, the highest average training frequency (4 ± 2 times per week), with 46% of the training sessions focusing on strength training, was reported in group **C**. On the other hand, the average lower body strength training volume load (kg·wk^{-1}) of group **C** was the lowest, and the respective upper body training volume load was the highest among all groups of this study. This suggests that the training programs performed by the intervention groups may have emphasized lower body strength training more during the operation. Despite the higher overall upper-body strength training volume, no PRE-POST changes but a decrease in MID-POST were observed in MVC_{upper} performance of group **C**. Furthermore, all other groups except **C** improved their lower-body strength during the study, whereas power of the lower extremities, assessed by SLJ, decreased only in group **C** between PRE and POST. This is important to note, given that lower body strength and power are very important physical abilities of a combat-armed soldier (3). It is possible that individual preferences do not necessarily reflect optimal training habits among tactical athletes, which may increase the risk of injury while on-duty or during training (35). These findings emphasize the role of strength and conditioning professionals in the prescription of periodized of strength and endurance training programs during crisis-management operations.

As mentioned earlier, strength and endurance constitute the basis of soldier physical performance (14,24,29). Optimally periodized combined strength and endurance training may improve muscle strength and endurance performance simultaneously without interference effects (19). It must be taken into consideration that higher (>3 times·wk^{-1}) endurance training frequency and volume, especially with high overall training volume, may have a negative influence on strength performance outcomes during concurrent training (38,46). In the present study, no interference effect on strength development was observed, but a weak correlation between increased strength training in relation to endurance training and increased 3000-m time was found in a previous study consisting of the same study sample (32). Similarly, a relationship between higher strength training frequency and increased 3000-m time was found with linear regression analyses in the present study. Increased 3000-m time was also associated with increased FATM. Thus, decreases in aerobic fitness and increases in fat mass, which have been observed in several military operation studies (11,25,40), seem to be at least partly linked. Furthermore, a relationship was observed between increased FATM and decreased MST time, which could be used from a physical performance perspective as an indirect measure of military readiness.

It has been suggested that during deployment, the training objective should be to maintain fitness levels, which can be achieved by performing strength training twice weekly, accompanied by anaerobic-aerobic endurance training one or 2 times per week (13). However, psychological stress induced by operative duties may accumulate internal training load, and should be taken into consideration in the daily training plan from a recovery perspective (13). In addition, other intrinsic factors such as age, individual fitness level and training status may affect internal training load, and thereby training adaptations (21,32). In the present study, baseline body composition (e.g., higher FATM) and physical performance (e.g., weaker MVC_{lower} result) showed weak but statistically significant relationships with training outcomes, namely, larger improvements in 3000-m time. Another study in conscripts (22) showed that despite the same standardized weekly program during basic military training, the highest internal training loads and the largest training adaptations were found in individuals with the lowest baseline fitness level and vice versa—the fittest individuals experienced the lowest internal training load. These results are in line with studies showing that untrained individuals seem to benefit from concurrent training similarly compared with training each mode separately, whereas individuals with a longer training background seem to be more susceptible to interference effects (6). In the present study, large variability in training adaptations may have been at least partly explained by the inadequate individualization of the training, which was because of randomization of the training groups. A previous study using the same study sample showed that soldiers with higher baseline levels of FATM and lower levels of SMM and lower-body strength were more likely to improve their endurance performance during the military operation (32). Obviously, individualization of training is challenging in the military context, because the number of soldiers is typically high within the same training session. Moreover, training possibilities are limited in many hazardous deployment environments.

All 3 measurement points of the present study were conducted in the deployment area during the crisis management operation. In most previous military operation studies, the measurements were performed before and after the deployment, and thus the delay between measurements and the deployment may have influenced the results. In addition, 3 measurement points provide valuable information about possible fluctuations in variables of interest within the follow-up period. A limitation of this study was low adherence to the randomly selected training program. As mentioned, 15 soldiers did not follow the prescribed strength-to-endurance emphasis. To analyze group changes reliably, modifications to the original group division had to be performed according to self-reported training diaries. On the other hand, this is an important finding to be taken into consideration when implementing an unsupervised training program. Another option would be supervised training sessions, which may be challenging during a military operation with rotating work shifts. In addition, one limitation was not using the gold standard in vivo methods to measure body composition (e.g., hydrostatic weighing or dual energy X-ray absorptiometry) and aerobic fitness (e.g., direct maximal oxygen consumption measurement). Implementing the study during an international crisis management operation limited the possibility to select the best possible measurement methods, and created logistical challenges regarding measurement devices and personnel. Finally, dietary control might have provided further support for interpretation of training adaptations.

Practical Applications

The present findings suggest that operational demands did not increase the internal training load of soldiers excessively during the present study, which enabled the maintenance or development of physical performance during the deployment. Maintenance of baseline BM and composition and endurance performance during deployment was achieved by performing combined strength and endurance training, on average 3 times a week. This average is in line with previous deployment studies (36,44) and recommended training frequency guidelines in this setting (13). During the follow-up period, the training group that performed an even volume of combined strength and endurance training (***SE***) was the only group to increase muscle mass, while simultaneously improving the same physical performance outcomes as the other intervention groups. Although individualized training prescription should take into account factors such as baseline fitness level, provision of a combined strength and endurance training program should encourage soldiers to focus training more on qualities related to their task demands, such as strength and power of the lower extremities. Finally, compulsory physical training or other supervised physical activities may help less fit and less motivated soldiers to avoid decrements in physical performance during longer operations.

Acknowledgments

The authors appreciate the financial support of the Centre for Military Medicine, Scientific Advisory Board for Defence (MATINE), the Defence Support Foundation and, the contribution of the participating soldiers.

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IV

DIFFERENCES IN TRAINING ADAPTATIONS OF ENDURANCE PERFORMANCE DURING COMBINED STRENGTH AND ENDURANCE TRAINING IN A 6-MONTH CRISIS MANAGEMENT OPERATION

by

Pihlainen Kai, Häkkinen Keijo, Santtila Matti, Raitanen Jani & Kyröläinen Heikki, 2020

International Journal of Environmental Research and Public Health 17(5), 1688

International Journal of
Environmental Research and Public Health

MDPI

Article

Differences in Training Adaptations of Endurance Performance during Combined Strength and Endurance Training in a 6-Month Crisis Management Operation

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Received: 19 February 2020; Accepted: 3 March 2020; Published: 5 March 2020

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Abstract: Decreases in aerobic fitness during military operations have been observed in several studies. Thus, differences in training adaptations during a 6-month crisis-management operation were compared by using the change in endurance performance as the outcome measure. Sixty-six male soldiers volunteered for the study, consisting of pre–post assessments of blood biomarkers, body composition, physical performance, and the military simulation test (MST) performance. Physical training volume was self-reported. After the follow-up, the data were divided based on individual changes in endurance performance. Endurance performance was improved in the high-responder group (HiR, n = 25) and maintained or decreased in the low-responder group (LoR n = 24). During the operation, the LoR group decreased while the HiR group increased their endurance training frequency from the pre-deployment level (Δ 28 ± 57% vs. −40 ± 62%, $p = 0.004$). Fat mass decreased (−7.6 ± 11.7% vs. 14.2 ± 20.4%, $p < 0.001$), and 1-min push-up (27.7 ± 21.9% vs. 11.7 ± 26.1%, $p = 0.004$) and MST performance improved (−13.6 ± 6.8% vs. −7.5 ± 6.5%, $p = 0.006$) more in the HiR group. No differences were observed in the changes of other physical performance test results or analyzed biomarkers. In conclusion, soldiers who were initially leaner and fitter in terms of lower body strength and power were more likely to decrease their aerobic fitness during the operation.

Keywords: soldier; combined training; cardiorespiratory fitness; bioimpedance; training response; adaptation

1. Introduction

The demands of operative duties constitute the basis for the development and maintenance of the physical performance of soldiers [1,2]. Typical military tasks such as marching, digging, manual material handling [1,2] are often performed in a prolonged manner, combined with environmental stress factors, which might accumulate fatigue in soldiers. Furthermore, soldiers commonly perform their operative duties wearing combat gear and carrying other equipment which might have negative impacts on job performance in relation to the weight of the carried load [3,4]. Thus, optimal occupational performance of a soldier requires a high level of combined strength and aerobic fitness.

Based on the requirements of military work, the development and maintenance of physical performance of soldiers should include combined strength and endurance training [5,6]. Aerobic fitness is an important contributor to optimal performance, in numerous military simulations of varying durations, both from the performance and recovery perspective [7]. Habitual endurance training has been shown to improve aerobic fitness through central (e.g., increased stroke volume) and peripheral (e.g., increased mitochondrial content) adaptations [8–11]. In addition, evidence from the literature suggests that improvements in neural [12,13] and hypertrophic pathways [14,15] lead to increases in muscle strength which might be a crucially important component of soldiers' physical performance, especially during intensive combat situations [16]. In certain tense situations, soldiers are required to rush and sprint short distances, interspersed with recovery periods [17,18]. The speed of such sprints has been associated with muscle strength and the power of the lower extremities [16]. All of the above-mentioned variables of occupational performance are modifiable through regular physical training. In a military environment, combined strength and endurance training might be a time-efficient method to simultaneously improve aerobic and muscle fitness [6,19]. Despite the known benefits of physical performance enhancement, studies focusing on combined strength and endurance training adaptations during a military operation are limited.

Physical stress induced by military field exercises has been documented extensively. For example, Ojanen et al. [20] observed deteriorated physical performance and hormonal balance in soldiers, during and after a three-week military field exercise. The results are well in line with an earlier study showing that an 8-week Army Ranger Course induced negative energy balance and >10 kg average weight loss, accompanied with decreases in serum testosterone, insulin-like growth factor-1 (IGF-1), and increases in cortisol (COR) concentrations [21]. In addition to military training, only a few studies have shown that international military operations might deteriorate physical performance, especially aerobic fitness, and could induce undesirable changes in body composition, such as an increase in fat mass [22]. These changes compromise occupational performance [7,23], increase a risk of injuries [24] and thereby, have negative impact on the mission readiness of soldiers.

Taken together, the physical performance of soldiers should be at a high level before military operations, as the physiological homeostasis, and thereby, the optimal status for the maintenance of fitness might be disturbed under tense operative circumstances. Nevertheless, especially during longer deployments, soldiers should engage with regular physical training in order to maintain their readiness for unexpected changes in security situations. Therefore, the purpose of the present study was to investigate differences in training responses and adaptations of endurance performance during combined strength and endurance training in a six-month crisis management operation in the Middle East.

2. Materials and Methods

Endurance performance adaptations to combined strength and endurance training were studied during a crisis-management operation in Southern Lebanon. Baseline body composition, physical performance, and serum biomarkers were studied before block-randomizing [25] the soldiers into three training groups (Figure 1A). The training groups were provided a standardized combined strength and endurance training program to be performed twice a week. Depending on the program, strength and endurance training frequency was set to either 1 + 3 (75% endurance training), 2 + 2 (50% endurance training), or 3 + 1 (25% endurance training) sessions in two weeks (Figure 1B). In addition, the soldiers were encouraged to maintain their habitual training frequency at the level of pre-deployment and to adjust their emphasis on the strength and endurance training to the given program. The training was self-reported by using training diaries. In addition, the soldiers were interviewed before and during the operation for achieving a better view of their training. The follow-up tests were performed five months after the baseline measurements. During the study, the soldiers performed their operative duties including typical military tasks, such as patrolling and observing outside the military base, as well as maintenance and headquarter duties inside the base. Recently, a more detailed description of the physical activity and work load [26] of the participants as well as their diet [27] has been published.

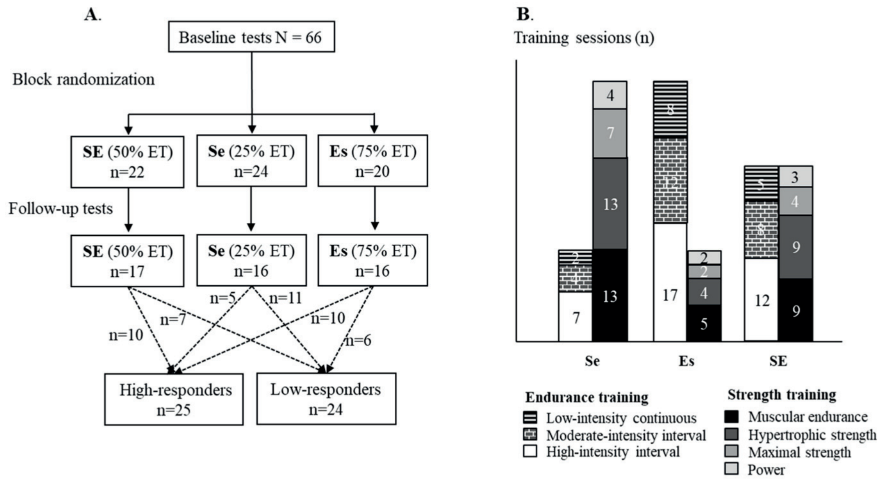

Figure 1. Study design (**A**) and the strength and endurance training plan of the groups (**B**). Se = strength emphasized training group; Es = endurance emphasized training group; SE = evenly balanced strength and endurance training group; and ET = endurance training.

Sixty-six voluntary male soldiers who were deployed for a crisis management operation in the Middle East took part in the baseline measurements. Before the deployment, the soldiers were examined by a physician. The exclusion criteria for deployment included health limitations with a need of permanent medication and aerobic fitness level lower than 2300 m in the 12-min running test [28]. The study was approved by and conducted in accordance with the statement of the Ethics Board of the Central Finland Health Care District (KSSHP E1/2013). The soldiers were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to voluntarily participate in the study.

The baseline means ± standard deviations (SD) with the range for age, height, weight, body mass (BM), and body mass index (BMI) of the participants were 29.8 ± 8.5 (20.4-51.2) years, 180 ± 7 (165-199) cm, 79.4 ± 8.2 (58.5-105.6) kg, and 24.5 ± 2.3 (21.1-32.8) kg/m^2, respectively.

The baseline measurements were carried out after two weeks of non-standardized acclimatization inside a military base in South-Lebanon. The measurements were repeated accordingly after the 5-month follow-up. The soldiers wore light underwear in the body composition measurements and shorts, and T-shirt and running shoes in the tests of endurance and neuromuscular performance. During the first day of the measurements, body composition measures and blood sampling were conducted in the morning, followed by the measurements of maximal strength in the evening. Thereafter, the soldiers were provided a minimum of 15 min for recovery before the muscle endurance tests. The assessment of strength, endurance, and military specific performance were performed on separate days, with a minimum of 24 h between the tests.

Assessment of body composition and blood sampling were performed in a military hospital in the morning after a 10-h overnight fast. Body height was measured by using a wall-mounted height board (Seca Bodymeter 206, Seca GmbH & Co, Hamburg, Germany). BM, skeletal muscle mass (SMM), and fat mass (FATM) were determined by using the segmental multi-frequency bioimpedance analysis (InBody 720, Biospace, Seoul, South Korea), in accordance with the guidelines of the manufacturer.

Blood samples were drawn from the antecubital vein and serum was separated from the blood using a centrifuge (1000 rpm, 8 min). The samples were frozen below −20 °C for further transportation and analysis. Assays for serum TES, sex-hormone binding globulin (SHBG), COR, and IGF-1 were performed by Immulite 2000 XPi (Siemens Healthcare, Llanberies, UK), using commercial chemiluminescent enzyme immunoassay kits, according to the manufacturer's guidelines. The inter-assay coefficients of variance (CV) for assays of TES, SHBG, COR, and IGF1 were 7.0%–7.2%, 4.5%–6.2%, 4.6%–5.8%, and 3.7%–7.4%; and that of sensitivity was 0.5, 0.02, 5.5 nmol·L^{-1}, and 2.6 pmol·L^{-1}, respectively.

Maximal isometric force of the lower and upper extensor muscles was measured bilaterally in a sitting position, using the electromechanical dynamometer [29] (University of Jyväskylä, Jyväskylä, Finland). In the lower extremity test, the seat was set to maintain knee and hip angles of 107° and 110°, respectively. In the upper extremity test, the handle bar was adjusted to the height of shoulders and the seat was set to maintain an elbow angle of 90°. The soldiers were instructed to exert their maximal force in all three trials, which were separated by a minimum of 30 s for recovery. The best performances with regard to maximal force output were selected for further analysis.

Maximal standing long jump (*SLJ*) was used to assess the maximal power production of the lower extremities [30]. The soldiers were familiar with the test since the same method has been used during their basic military training period. Before the three test attempts, the soldiers were provided with instructions on how to perform the jumps with the optimal technique preceding five to seven warm-up trials. The jumps were performed from a standing position, feet at pelvis to shoulder width apart on rubber mattresses designed for the purpose (Fysioline Co., Tampere, Finland). Explosive bilateral take-off was assisted by a powerful swinging of the arms and extension of the hip. The landing was performed bilaterally, and falling backwards led to a disqualification of the attempt. The result of the best jump was expressed as centimeters of the shortest distance from the landing point to the starting line.

Sit-up, push-up, and pull-up tests were used to assess the dynamic muscle endurance capacity of the trunk and upper extremities. A test supervisor showed the correct performance technique before each test. The soldiers were also informed that after a notice from the supervisor, incorrect repetitions would not be calculated to the test result.

Sit-ups were used to assess performance of the abdominal and hip flexor muscles [31]. In the starting position of the sit-up test, the soldier laid on his back, while his knees were bent at a 90° angle, elbows pointing upwards, and fingers interlocked behind the head. The ankles were supported by an assistant to keep the heels in contact with the ground during the test. From the starting position, the upper body was raised forward with the trunk muscles until the elbows reached the knee-level. One repetition was completed when the body was lowered until the bottom of the shoulder blades touched the ground. The test result was expressed as a number of consecutive repetitions in 60 s.

The push-up test was to evaluate performance of the arm and the shoulder extensor muscles [32]. The correct position for the push-up test was determined while the soldier was lying on the floor in a front-leaning rest position, feet parallel at pelvis-to-shoulder width and hands positioned so that the thumbs could reach the shoulders while the other fingers pointed forward. From this position, the soldiers were instructed to take the starting position by extending their arms straight, while keeping the body in a straight line from the shoulders to the ankles and maintaining the knee and hip angles steady, throughout the test. One repetition was counted when the soldier lowered his torso by bending his elbows until the upper arms were parallel to the floor and returned to the starting position by extending his arms. The test result was expressed as the number of consecutive correct repetitions during 60 s.

The pull-up test was used in order to measure the performance of the arm and shoulder flexor muscles. In the starting position of the pull-up test, the soldiers were hanging from a horizontal bar with an underhand grip, keeping the arms and feet straight. One repetition was performed when the body was raised by flexing the arms from the starting position until the chin exceeded the height of the bar level. The hip and legs were instructed to be extended throughout the test. The result of the test was expressed as the number of consecutive repetitions, until volitional exhaustion.

Aerobic endurance performance was assessed using the 3000-m running test (3000-m). Due to the time and logistical constraints, it was not possible to perform the direct assessment of aerobic capacity (e.g., oxygen consumption measurements) in the military base. The 3000-m test was performed on a standardized 1-km track covered with asphalt. The total ascent and descent of the track was 32 m. The soldiers were instructed to complete the test with maximal effort and in the shortest possible time. The duration of the test was recorded with a stopwatch (Select Sport, Glostrup, Denmark), while the heart rate was recorded by using chest-strapped monitors (Memory belt, Suunto, Vantaa, Finland) and analyzed with computer analysis software (Firstbeat PRO, Firstbeat Technologies, Jyväskylä, Finland).

Occupational physical performance and the anaerobic capacity of the soldiers was assessed by the military simulation test (MST) [23], which was designed to assess military-specific, high-intensity performance of crisis-management soldiers. The MST consisted of typical army soldier maneuvers (rushes, jumps, changes in movement directions, crawling) and tasks (load carriage, casualty drag) which might be performed in an ambush during a patrol or transport at the deployment area. The total length of the MST track was 243 m. The test was performed in the shortest possible time wearing a combat dress uniform, leather boots, and combat gear, including a body armor, helmet, and replica assault rifle. The total weight of the combat load, including the weapon replica, was 22.5 ± 1.0 kg. The performance time was recorded with a stopwatch (Select Sport, Glostrup, Denmark).

To assess the differences in habitual strength and endurance training before vs. during the operation, the soldiers were interviewed six weeks before the deployment, inquiring their endurance and strength training frequency from the preceding two months. The soldiers were asked "on average, how many times per week have you performed endurance-type of training, e.g., walking, running, swimming, cycling, during the preceding two months?" Similarly, for strength training, the soldiers were asked "on average, how many times per week have you performed strength-type of training, e.g., gym training, weight lifting, during the preceding two months?" The interview was repeated at the deployment area during the post measurements.

After the baseline measurements, the soldiers were randomly allocated to one of the three combined strength and endurance training groups. Training was recorded using the self-reported training diaries. The diaries of the three intervention groups included a progressive combined strength and endurance training program with illustrated instructions of the exercises. The actual exercises of all intervention groups were similar but the strength-to-endurance training ratio in the three groups varied between the groups, as mentioned earlier. For example, the training diary of the SE group consisted of two strength and two endurance training sessions in two weeks, while the diary of the Se group consisted of three strength training sessions and one endurance training session. Altogether, the training program included 50 standardized strength and endurance training sessions (Figure 1B). All exercises were demonstrated and practiced before the initiation of the intervention. Intensity and volume were determined individually for strength training. For hypertrophic and maximal strength training, the soldiers were instructed to select weights for each exercise so that the last predetermined repetitions in each set would proceed as close to concentric failure as possible. For endurance exercises, the peak heart rate was determined from the highest measured heart rate during the 3000-m run, utilizing the Firstbeat PRO analysis (Firstbeat Technologies, Jyväskylä, Finland). The soldiers were provided with a heart rate monitor for endurance training (M1, Suunto, Vantaa, Finland). Due to the nature of the operation, the soldiers performed the exercises without supervision. Despite the twice-a-week programming, the soldiers were encouraged to maintain the weekly training frequency, which they were accustomed to preceding the operation, but had to adjust the strength-to-endurance training ratio to match the program of their allocated group.

At the end of the follow-up, the training diaries were collected and analyzed. The available training data were analyzed for the relative strength and endurance training frequency (sessions/week). In addition, endurance training was analyzed for volume (minutes/week) of different intensity zones (low < 75% HR_{peak}, moderate 75–85 HR_{peak}, high-intensity > 85 HR_{peak}), and strength training for the lower and upper body volume load (kg/week). The training diary statistics for each group are presented in the supplemental material (Supplement Table S1).

Out of the 66 soldiers who initially took part in the study, the data were analyzed for those who participated in the 3000-m running test at the beginning and at the end of the operation (n = 49). The combined data of these soldiers were re-grouped to high responders (HiR, n = 25) and low responders (LoR, n = 24), according to the changes in endurance performance assessed by the 3000-m running test (Figure 2). The HiR group consisted of soldiers who decreased their 3000-m test time, while the soldiers in the LoR group either maintained or increased their running test time during the operation. Descriptive statistics (mean ± SD) were reported when appropriate. The relative changes were calculated on the basis of individual values. The significances of group differences were tested by using the Mann–Whitney test. In addition, the relationships between relative changes of the measured variables were tested with Spearman's rank correlation coefficient using all available data. IBM SPSS Statistics version 25 (Chicago, IL, USA) was used for all statistical analyses. The $p < 0.05$ was used to establish statistical significance.

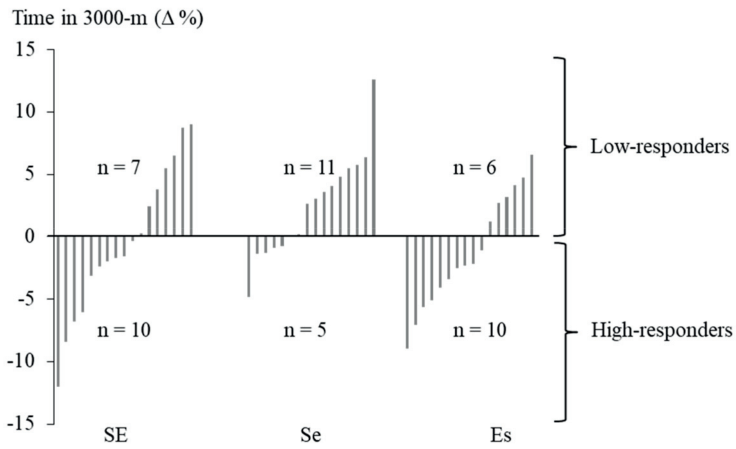

Figure 2. The classification into high-responders and low-responders. Soldiers who decreased their 3000-m running test time were termed high-responders, while the low-responders either maintained or increased their running test time during the operation.

3. Results

More than half (51%) of the soldiers improved their endurance performance and, thus, they were HiR in terms of combined strength and endurance training adaptation (Figure 2). Before the operation, no differences were observed in the endurance training frequency between the HiR and LoR groups, while the LoR group performed strength training more frequently than HiR (Mean ± SD: 1.8 ± 1.4 vs. 2.9 ± 1.2 times/week, $p = 0.008$). At baseline, the mean 3000-m test times of the HiR and the LoR groups did not differ (866 ± 106 vs. 822 ± 85 s, $p = 0.17$). Significant baseline differences between the HiR and LoR groups (Figure 3) were observed in SMM (38.0 ± 3.9 vs. 40.3 ± 4.1 kg, $p = 0.046$), FATM (12.8 ± 3.6 vs. 9.6 ± 5.7 kg, $p < 0.001$), maximal strength of the lower extremities (3959 ± 532 vs. 4564 ± 1116 N, $p = 0.049$), SLJ (227 ± 16 vs. 242 ± 27 cm, $p = 0.016$), and MST (156 ± 23 vs. 143 ± 24 s, $p = 0.028$). In addition, a trend for the lower baseline 1-min push-up test result of the HiR group (37 ± 12 vs. 44 ± 13 reps/min, $p = 0.053$) was observed. Group comparisons at baseline for all variables are presented in Table 1.

The training diary statistics showed that the HiR group performed their strength training of the lower body with a lower average volume (e.g., total amount of lifted weight/week) than the LoR group (14354 ± 6076 vs. 19489 ± 6202 kg/week, $p = 0.010$). In addition, a trend for a lower average strength training frequency in the HiR group (1.3 ± 0.7 vs. 2.1 ± 2.4 sessions/week, $p = 0.052$) was observed.

Significant differences in the relative changes of the measured body composition and physical fitness variables during the operation, favoring the HiR group (Figure 4), included BM (−1.0 ± 2.5% vs. 2.3 ± 2.8%, $p < 0.001$), FATM (−7.6 ± 11.7% vs. 14.2 ± 20.4%, $p < 0.001$), 1-min push-up (27.7 ± 21.9% vs. 11.7 ± 26.1%, $p = 0.004$), and MST (−13.6 ± 6.8% vs. −7.5 ± 6.5%, $p = 0.006$). In addition, interview-based training frequency revealed a relative decrease in endurance training (−40%) in the LoR group, while the HiR group increased their endurance training by 28% (group comparison, $p < 0.001$). The comparison of the training as well as relative changes in all available variables between the HiR and LoR groups is presented in Table 2.

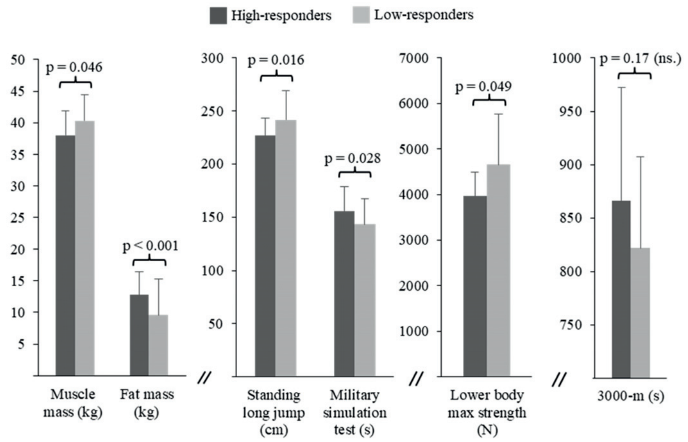

Figure 3. Comparison of body composition and physical performance between the high-responders and low-responders for endurance performance at baseline. ns.—non-significant.

Table 1. Group comparison of baseline characteristics, in terms of mean (SD).

	High-Responders	Low-Responders	*p*
n	25	24	
Age (years)	31.2 (7.9)	28.7 (9.4)	0.089
Stature (cm)	179.4 (5.4)	181.4 (6.9)	0.37
Body mass (kg)	79.3 (7.8)	79.7 (8.9)	0.79
Body mass index	24.6 (2.0)	24.2 (2.2)	0.28
Muscle mass (kg)	38.0 (3.9)	40.3 (4.1)	0.046
Fat mass (kg)	12.8 (3.6)	9.6 (5.7)	<0.001
Maximal isometric force of the lower body (N)	3959 (532)	4564 (1116)	0.049
Maximal isometric force of the upper body (N)	1139 (235)	1204 (223)	0.28
Sit-ups (repetitions in 1 min)	42.8 (10.5)	46.7 (8.5)	0.20
Push-ups (repetitions in 1 min)	37.4 (11.7)	43.5 (13.2)	0.053
Pull-ups (repetition maximum)	8.6 (4.9)	10.8 (5.3)	0.10
Standing long jump (cm)	226.7 (16.4)	241.5 (27.4)	0.016
Military simulation test (s)	155.8 (23.1)	143.2 (24.2)	0.028
Serum testosterone (nmol·L^{-1})	16.1 (4.3)	16.1 (5.7)	0.71
Serum sex-hormone binding globulin (nmol·L^{-1})	31.4 (9.9)	33.2 (14.1)	0.82
Serum insulin-like growth factor-1 (pmol·L^{-1})	26.2 (8.8)	29.5 (11.0)	0.21
Serum cortisol (nmol·L^{-1})	420.6 (108.7)	440.4 (78.7)	0.63
Interview-based endurance training (times/week) *	2.34 (1.40)	2.58 (1.58)	0.66
Interview-based strength training (times/week) *	1.79 (1.41)	2.90 (1.18)	0.008

* Interviewed before the operation.

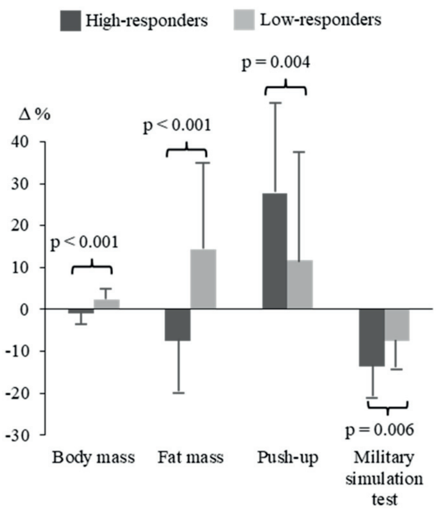

Figure 4. Comparison of differences in relative changes in variables with statistically significant group difference between the high-responders and low-responders of endurance performance.

Table 2. Group comparison in physical training and relative changes in measured variables during the operation, mean (SD).

	High-Responders	Low-Responders	p
n	25	24	
Training variables during the operation			
Endurance training (times/week)	1.7 (0.80)	1.9 (2.8)	0.22
Strength training (times/week)	1.3 (0.7)	2.1 (2.4)	0.052
Total training (times/week)	3.0 (1.0)	4.0 (5.0)	1.00
Low-intensity endurance training (min/week)	61.7 (22.9)	52.0 (18.4)	0.17
Moderate-intensity endurance training (min/week)	51.3 (11.2)	45.9 (16.4)	0.31
High-intensity endurance training (min/week)	32.7 (18.7)	37.4 (11.6)	0.27
Lower body strength training (kg/week)	14,354 (6076)	19,489 (6202)	0.010
Upper body strength training (kg/week)	10,428 (3272)	12,226 (4084)	0.31
Interview based endurance training (times/week)	2.41 (1.01)	1.38 (1.06)	0.002
Interview based strength training (times/week)	1.94 (1.07)	2.73 (1.51)	0.067
Relative change (%)			
Body mass (%)	−1.0 (2.5)	2.3 (2.8)	<0.001
Body mass index (%)	−1.0 (2.5)	2.3 (2.8)	<0.001
Muscle mass (%)	0.5 (3.0)	1.4 (2.7)	0.16
Fat mass (%)	−7.6 (11.7)	14.2 (20.4)	<0.001
Maximal isometric force of the lower body (%)	16.5 (17.5)	7.8 (13.3)	0.26
Maximal isometric force of the upper body (%)	2.1 (5.7)	1.9 (9.2)	0.67
Sit-ups (%)	6.3 (16.0)	5.5 (11.9)	0.91
Push-ups (%)	27.7 (21.9)	11.7 (26.1)	0.004
Pull-ups (%)	40.0 (49.8)	42.6 (66.1)	0.79
Standing long jump (%)	0.6 (9.2)	−1.0 (4.0)	0.89
Military simulation test (%)	−13.6 (6.8)	−7.5 (6.5)	0.006
Serum testosterone (%)	10.3 (31.9)	18.2 (33.1)	0.35
Serum sex-hormone binding globulin (%)	−18.3 (35.1)	−21.5 (26.3)	0.35
Serum insulin-like growth factor-1 (%)	−2.4 (42.8)	−3.5 (37.2)	0.69
Serum cortisol (%)	0.53 (48.2)	−9.9 (34.4)	0.52
Interview based endurance training frequency (%)	27.9 (56.7)	−40.1 (64.2)	0.001
Interview based strength training frequency (%)	8.7 (61.7)	14.7 (101.0)	0.73

In the total group of participants, the increase in the average strength training frequency correlated with the relative increase in BM ($r = 0.42$, $p = 0.004$), SMM ($r = 0.31$, $p = 0.036$), and FATM ($r = 0.35$, $p = 0.018$). In addition, the increase in the strength-to-endurance training ratio (%) correlated with the relative increase in BM ($r = 0.43$, $p = 0.034$) and also, a trend for decreased endurance performance (strength-to-endurance training ratio vs. 3000-m, $r = 0.33$, $p = 0.065$) was observed.

The relative increase in the weekly endurance training frequency during the deployment vs. pre-deployment correlated ($r = -0.57$, $p < 0.001$) with the relative reduction in 3000-m time (Figure 5). The relative increase in 3000-m time correlated with the respective increase in BM ($r = 0.41$, $p = 0.004$), as well as FATM ($r = 0.53$, $p < 0.001$). Finally, the relative increases in the MST time correlated with the respective increases in the 3000-m time ($r = 0.48$, $p < 0.001$).

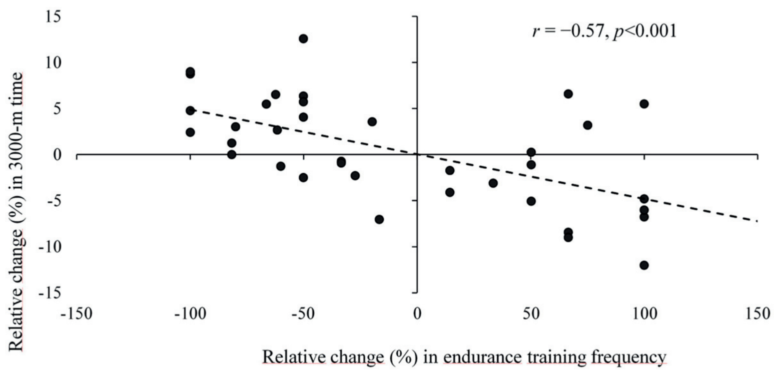

Figure 5. Relative increase in weekly endurance training frequency during the deployment vs. pre-deployment, plotted against relative reduction in 3000-m time ($r = -0.57$, $p < 0.001$).

4. Discussion

The present study showed that despite the similar endurance performance at baseline, soldiers who were more likely in a risk of decreasing their aerobic fitness, e.g., the LoR group, were initially leaner and they had a higher physical performance in terms of lower body strength and power. In addition, the LoR group was not able to maintain the average endurance training frequency at the level preceding the operation. Additionally, increased FATM was observed in the LoR group, whereas the HiR group decreased FATM during the operation. Relative increases in the 3000-m time correlated with respective increases in BM and FATM. Finally, the LoR group was not able to improve 1-min push-up and the MST performance to the same extent as the HiR group. From a physical performance perspective, many of these changes in the LoR group might reflect a reduction in military readiness, which is not desirable during the operation and should be avoided by providing more individualized strength and endurance training programs, during deployment. In addition to the operative task analysis, individualization should consist of factors like baseline physical performance, strength training and endurance training history, and body composition of soldiers.

Aerobic fitness seems to be an important component of soldiers' physical performance during prolonged physical activities, with extra loads (e.g., marching [7]) and intensive combat situations (e.g., rushes, casualty evacuation [7,23]). Aerobic fitness can be affected by endurance training, which leads to central and peripheral adaptations [8–11]. Low intensity endurance training increases the mitochondrial density and cellular level enzyme activity of the trained muscles, which lead to improved fat oxidation and decreased accumulation of lactate during submaximal effort [8,10]. High-intensity endurance training leads to strengthening of the left ventricle wall and, thus, increases in stroke volume and cardiac output [9]. Together, these adaptations lead to improved endurance performance and are also associated with decreased FATM [33,34], as observed in the present study.

On the other hand, progressive strength training leading to neuromuscular adaptations, e.g., an improved rate of force production, might develop endurance performance through improved exercise economy and sprinting ability [35]. Some concerns related to an interference effect of combined strength and endurance training have been presented, but they have mainly addressed the possible attenuating training effect on maximal strength development [19]. Only one study [36] has found a detrimental effect of combined training on aerobic fitness. More recent reviews have concluded that combined strength and endurance training improves aerobic capacity to the same extent and decreases fat mass even more than either training mode performed independently [19]. In the present study, the same absolute number (n = 10) of soldiers in the group of strength emphasized training and in the group of evenly balanced strength and endurance training improved their endurance performance during the study (Figure 2). Combined training might, therefore, be a superior training model for soldiers when compared to strength or endurance training only [6].

Previous studies have shown that endurance performance of soldiers is susceptible to decline during deployment [37–39], which might be due to detraining. It has been shown that already a few weeks of reduction in the training frequency or complete detraining can lead to a significant decrease in aerobic fitness, both in highly trained and recreationally active participants [40]. In the military context, Dyrstad et al. [37] found that the average aerobic fitness of deployed Norwegian soldiers decreased during a 12-month operation in Kosovo. However, soldiers who reported active participation in endurance training during the deployment, actually improved their aerobic capacity by 3.5% [37]. In the previous international military deployment study, Sharp et al. [39] found that soldiers in the two highest pre-deployment aerobic fitness quartiles decreased their endurance performance during a 9-month follow-up in Afghanistan, while no changes were observed in soldiers in the initially lowest fitness quartiles. Similar findings have been reported by Warr et al. [24] who found that endurance training performed at least three times a week was adequate to maintain or improve the aerobic fitness of soldiers during deployment. The previous findings support the present results, suggesting that increased endurance training frequency/volume would likely have reduced the number of soldiers with low training response. It is also important to note that individual training history should be taken into account when implementing training plans for soldiers.

Indeed, the reduced endurance performance in the LR group might have occurred simply because the total training volume was too low for the maintenance of their baseline aerobic fitness. A recent study [41] investigated adaptations to a 6-week endurance training program with a training frequency varying from one to five times per week. In the first part of the study, participants performing a lower number of training sessions were more likely to be determined as the "non-responders". For example, 81% of the participants who trained once a week decreased their endurance performance, whereas the respective proportion in the group of four weekly training sessions was only 18%. In the second part of the intervention, the non-responders completed two additional weekly training sessions for another six weeks. After the second part of the study, it was found that training induced positive adaptations in all participants [41]. In the present study, soldiers who improved their 3000-m running time during the study period were able to maintain their pre-deployment endurance training frequency, whereas the endurance training frequency of the LoR group decreased during the operation. In addition, the decrease in the endurance training frequency from the pre-deployment level was associated with an increase in 3000-m time during deployment. Despite the good training facilities, the motivation of some soldiers for physical training might have been suppressed by the continuous maintenance of vigilance and 24-h shiftwork when compared to the situation before the deployment. Therefore, some obligatory physical training should be considered to maintain minimum a physical training volume of the unmotivated soldiers.

The present study has several strengths and limitations. First, there is a limited number of studies which have been conducted in the actual area of international military operation. In most of the previous studies, the measurements have been performed in homelands, before and after the deployment, and thus, the transport as well as the delay between measurements and the deployment might have influenced the results. In the present study, all measurements were conducted in the deployment area during the crisis-management operation. However, implementing the study in the middle of the crisis management operation limited the possibility to select the best measurement methods and caused challenges to the logistics of the measurement devices as well as study personnel. Due to the priority of operative duties, all soldiers were not able to participate in every measurement, and thus, the number of soldiers was reduced in some of the tests. The same explanation might, at least partly, explain the discrepancy between interview and diary-based training frequencies. Except for patrolling and other observational duties, the soldiers mainly lived inside the military base and were served the same food during the follow-up. Furthermore, the present body composition and blood biomarker results did not reflect disturbances in hormonal balance either in the HiR or LoR group. These findings are supported by previously published results of rather low physical activity and work load [26], as well as well-maintained energy balance [27] during the same crisis management operation. Thus, there were no environmental or physiological barriers for the training adaptations during the operation.

5. Conclusions

High level of strength and endurance capacity forms the cornerstones of soldier's physical performance. Based on the present findings, soldiers who are more likely in a risk to decrease aerobic fitness during prolonged military operations are leaner and fitter in terms of lower body strength and power. The emphasis of combined strength and endurance training of the deployed soldiers should be varied individually and task-specifically. The volume of endurance training should be maintained, at least, at the level preceding the operation to attenuate performance decrements. On the other hand, continuous strength training is also important in order to maintain the necessary levels of strength and power performances, and it also has likely some positive additive effects on endurance performance. Finally, increases in fat mass should be avoided for preventing decrements in endurance performance and operational readiness.

Supplementary Materials: The following are available online at http://www.mdpi.com/1660-4601/17/5/1688/s1, Table S1: Group-wise weekly mean (±SD) and range of the training frequency and load during the operation.

Author Contributions: Conceptualizion, K.P., H.K., M.S., and K.H.; Methodology, K.P., H.K., K.H., M.S., and J.R.; Software, K.P. and J.R.; Validation, K.P., H.K, and J.R.; Formal analysis, J.R., K.P., K.H., H.K., and M.S.; Investigation, K.P., H.K., K.H., M.S., and J.R.; Recources, K.P., H.K., K.H., and M.S.; Data curation, K.P. and J.R.; Writing-original draft preparation, K.P., H.K., K.H., M.S., and J.R.; writing-review and editing, K.P., H.K., K.H., M.S., and J.R.; visualization, K.P. and J.R.; supervision, H.K., K.H., and M.S.; project administration, K.P. and H.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors appreciate the financial support of MATINE, the Scientific Advisory Board for Defence (Finland) and the Defence Support Foundation, Johanna Ihalainen, Mia Laakso, and Moona Myllyaho for their assistance in data analysis, and Risto Puurtinen and Aila Ollikainen for their blood analyses.

Conflicts of Interest: The authors declare no conflict of interest.

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