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MUSCULOSKELETAL DISORDERS IN THE SWEDISH ARMED FORCES MARINES:

BACK PAIN EPIDEMIOLOGY AND CLINICAL TESTS

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MUSCULOSKELETAL DISORDERS IN THE SWEDISH ARMED FORCES MARINES:
BACK PAIN EPIDEMIOLOGY AND CLINICAL TESTS

THESIS FOR DOCTORAL DEGREE (Ph.D.)

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ABSTRACT

The present work was conducted in order to lay the foundation for effective evidence-based prevention of one of the most common musculoskeletal disorders (MSDs) in the Swedish Armed Forces (SAF) marines. The overall aim of this thesis was therefore to estimate the occurrence of and identify risk factors for back pain and related limitations in work ability, at different stages of the SAF marine's career. The aim further included an evaluation of clinical useful tests and exposures assessment of occupational physical activity.

The work presented in this thesis is based on one study with a cross-sectional, population-based design (*study I,* n=272) and two studies with prospective observational cohort designs (*study III*; n=163, *study IV*; n= 53). These studies aimed to establish the occurrence of MSDs (*study I*) and back pain in SAF marines, and identify risks associated with back pain (*study I, III, IV*). A fourth study (*study II*; n=33) used a test-retest design to evaluate clinically- relevant movement-control tests with regard to their intra- and inter-observer reliability. Study participants were recruited from the main marine regiment in the SAF, the 1st Marine Regiment at Berga, Sweden. Included personal- and work-related potential risks were measured with structured self-report questionnaires (*study I, III,IV*), and clinical movement control (*study II, III, IV*) and muscular strength (*study IV*) tests. Occupational physical activity and worn load during the marine training course (*study IV)* were monitored using accelerometers combined with schedules and self-reports.

The results from these studies revealed that MSDs were common among SAF marines, limiting work ability to some extent in every other marine within six months. Here, the back (low and/or thoracic) emerged among the most prevalent pain regions, with more than 50% of active duty marines experiencing back pain within 12 months (*study III*). Additionally, 79% of the marines in the four-month long training course experienced back pain (*study IV*). Serving as a combat craft crew member (*study III*) or having work tasks that include occupational sitting (*study III*) and computer work (*study I*) emerged as associated factors for back pain. Of the risks related to personal factors, a history of previous back pain and body height emerged as risks for back (*study III*) and low back pain (*study IV*). While a lack of physical training (*study I, IV*) emerged as a risk for back/low back pain that limited work ability, only insufficient upper body strength, as tested with pull-ups (*study IV*), emerged from the clinical tests as related to back pain. In addition to a low predictive validity (*study III, IV*), while the movement control test showed good inter-observer reliability, the intra-observer reliability were lower (*study II*). While only addressing a limited part of the marine training course, results indicate that ambulation was low for parts of the course, but combat loads were carried for more than half of the work time.

In conclusion, MSDs are common in active duty SAF Marines, with the back among the most commonly reported pain region. Preventive actions targeting significant risks related to the work marines perform as well as the characteristics of marines – including physical training – are warranted to curb further back pain episodes. While pain history and demographic characteristics can be used to identify marines at risk, the specific relation of these risks to back pain needs to be further clarified. However, movement control tests do not seem to be valid for inclusion in preventive back pain screenings for marines.

SAMMANFATTNING

Detta arbete genomfördes för att lägga en grund till evidensbaserad prevention av ett av de vanligast förekommnade muskuloskeletala besvären i Svenska Försvarsmaktens (FM) Amfibiekår. Det övergripande syftet med denna avhandling var därför att kartlägga besvärsförekomst och riskfaktorer för såväl ryggbesvär som ryggbesvär med påverkan på arbetsförmågan bland svenska amfibiesoldater under olika faser i deras yrkeskarriär. Syftet var även att utvärdera kliniskt relevanta test och fysisk aktivitet i arbetet.

Arbetet bygger på en populationsbaserad tvärsnittsstudie (*studie I*; n=272) och två prospektiva observationsstudier (*studie III*; n=163, *studie IV*; n= 53). Dessa studier avsåg att kartlägga besvärsförekomsten av muskuloskeletala besvär generellt (*studie I*) och ryggbesvär specifikt (*studie I, III, IV*), samt risker kopplade till ryggbesvär (*studie I, III, IV*) hos FMs amfibiesoldater. I en fjärde studie (*studie II; n=33)* användes en test-retestdesign för att utvärdera rörelsekontrolltest med fokus på inter- och intrabedömarreliabilitet. Forskningspersoner rekryterades från Amfibieregementet, Berga. Potentiella individ- och arbetsrelaterade risker mättes med såväl frågeformulär (*studie I-IV*) som tester av rörelsekontroll (*studie III, IV*) och styrka (*studie IV*). Arbetsrelaterad fysisk aktivitet och personburen utrustning registrerades under ’Grundkurs Amfibie’ (*studie IV)* med hjälp av accelerometrar, scheman och självskattningsformulär.

Resultaten från dessa studier visade att muskuloskeletala besvär är vanliga hos FMs amfibiesoldater, och påverkar arbetsförmågan vid något tillfälle hos hälften av dem inom en period av sex månader. Rygg (länd- och bröstrygg) var bland de vanligaste kroppsområden som förknippades med smärta. Mer än hälften av amfibiesoldaterna hade haft ont i ryggen inom de senaste 12 månaderna (*studie III).* Av de amfibiesoldater som deltog i den fyra månader långa grundkursen uppgav 79% att de-upplevt ryggsmärta under kurstiden (*studie IV*). Att tjänstgöra som stridsbåtsbesättning (*studie III*) eller med arbetsuppgifter som innefattade sittande- (*studie III*) eller datorarbete (*studie I*) framkom som risker för att uppleva ryggbesvär. Av de individrelaterade riskerna framkom tidigare ryggbesvär och kroppslängd återkommande som risk för att uppleva rygg- (*study III*) eller ländryggbesvär (*studie IV*). Att utöva förhållandevis lite fysisk träning (*study I, IV*) framkom som en risk för rygg-/ ländryggs besvär som påverkar arbetsförmågan. Av testerna framkom trots det endast otillräcklig överkropps stryka, mätt med ”pull-ups” (*studie IV*), som risk för besvär med påverkan på arbetsförmågan. Rörelsekontrolltesterna hade låg prediktiv validitet för ryggbesvär (*studie III,IV*), och trots god interbedömarreliabilitet, uppvisade de relativt låg intrabedömarreliabilitet (*studie II*). Fysisk aktivitet mättes endast under en del av ’Grundkurs Amfibie’, och indikerade relativt låg genomsnittlig rörelseaktivitet. Stridsutrustning bars dock under mer än halva arbetstiden.

Sammantaget är muskuloskeletala besvär vanligt förekommande hos FMs amfibiesoldater, där ryggen är ett av de mest förekommande besvärsområden. Preventiva insatser riktade mot arbetsuppgifter och individuella risker, inkluderande fysisk träning, är befogat för att reducera risken för ryggbesvär. Besvärshistorik och kroppslängd kan användas för att identifiera soldater med ökad risk för ryggbesvär, men deras specifika relation till ryggbesvär måste klargöras. Däremot verkar inte rörelsekontrolltest vara valida att användas vid förebyggande undersökning av ryggbesvär hos amfibiesoldater.

LIST OF SCIENTIFIC PAPERS

I. Monnier A, Larsson H, Djupsjöbacka M, Brodin L-Å, Äng BO. **Musculoskeletal pain and limitations in work ability in Swedish marines: a cross-sectional survey of prevalence and associated factors.** *BMJ Open. 2015;5(10): e007943.*

II. Monnier A, Heuer J, Norman K, Äng B. **Inter- and intra-observer reliability of clinical movement-control tests for marines.** *BMC Musculoskeletal Disorders. 2012;13(1):263.*

III. Monnier A, Djupsjöbacka M, Larsson H, Norman K, Äng BO. **Risk factors for back pain in marines; a prospective cohort study.** *BMC Musculoskeletal Disorders. 2016;17(1):1-12.*

IV. Monnier A, Larsson H, Nero H, Djupsjöbacka M, Äng B, O. **Low back pain in the marine training course: A study of incidence, risk factors and occupational physical activit**y. *Manuscript*

Additional analyses are added in the thesis.

Study IV may not be the final version for publication.

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LIST OF ABBREVIATIONS

BKFO	The bent knee fall-out test
CBC	Combat craft (vehicle/boat)
CI	Confidence interval
CMCAR	Covariate missing completly at random
CPM	Counts per minute
DLL-ALE	The double leg lift-alternate leg extension test
DLL-L	The double leg lift-lower test
DSLL	The double straight leg lower test
HR	Hazard ratio
ICF	International Classification of Functioning, Disability and Health
LBP	Low back pain
MAR	Missing at random
MCAR	Missing completely at random
MI	Multiple imputation
MOS	Military occupation speciality
MSDs	Musculoskeletal disorders
OR	Odds ratio
PABAK	Prevalence-adjusted-bias-adjusted kappa
SAF	Swedish Armed Forces
SB	The standing bow test
SD	Standard deviation
SLKB+LL	The single leg small knee bend + lunge-lean test

FOREWORD

This project originated from this question asked by a marine commander (of undisclosed position) to his occupational health services Physiotherapists in 2009:

"Why do the combat craft crews experience so much back pain- is it related to the boat service, or is it due to being a marine?"

Having worked as a physiotherapist within the SAF for more than a decade, spending a large part of that time treating, testing and trying to prevent musculoskeletal pain in the SAF marines, this question has not escaped my memory throughout my engagement with this body of work. I take pride in having worked with the marines during all parts of their carrier, during basic and specific training, selections, active duty within the Swedish borders, and when deployed. Still, I could not answer this "simple" question, which left me, including my colleagues, with a feeling of "fumbling in the dark" with regard to our preventive work. In fact, like peeling an onion, the more I thought about it, the more questions (that I had been considering over the years) emerged, of which the following two were possible to put into words:

Is back pain more common than other type of disorders, and how does it affect the operational readiness?

Which marines get it, and why do not some of them get it?

I therefore embarked on this on this journey, with the hope of filling some of these knowledge gaps, and, as such, lay the foundation to effectively prevent MSDs in marines. While this journey I have undertaken has not yet answered all these questions, it has however equipped me with new skills and a box of tools to continue "peeling the onion" of MSDs in military personnel.

To date, I still see myself as a "clinician", but now with some growing research skills. I believe that the only tactic for successfully fighting MSDs within the military occupation lies within close collaboration between researchers, clinicians and military personnel alike, working bench-to-bedside. Therefore, to promote further integrated research on MSDs in military personnel, the most relevant methodological considerations of this work are briefly outlined in this thesis, thereby alerting the readers not only to focus on the results of this work but also accompanied benefits and pitfalls of different methods used.

I hope this work will foster further discussion between researchers, clinicians and military personnel on how to address these questions within the military community, with the goal of future reduction of MSDs in our society's armed forces personnel.

1 INTRODUCTION

Musculoskeletal disorders (MSDs) are common in all phases of the modern marine's career. It is well established that a general high level of MSDs during basic military training exist, both internationally (1) as well as within the Swedish armed forces (SAF) (2). During the last decade have MSDs in deployed personnel been given increased scientific attention. Here, in contrast to popular beliefs, MSDs have shown to be among the most common reasons for deployed marines to be medically evacuated from combat arenas, superimposed by a poor prognosis for return to operational duty (3). For elite military units, such as marines, back pain have been found to constitute a large portion of the experienced MSDs in some armed forces communities, and has further been linked to reduction in operational readiness by downgrading personnel to non-deployment status (4).

The SAF marines' primary task is to operate where water meets land, i.e. coastal zones, river deltas and harbour areas. However, these expeditionary units are trained to act in any type of environment, at any time. The main characteristics and strengths of marines are their flexibility and mobility to rapidly get into place. Furthermore, all marines, despite their main military occupation speciality – for example communication specialist and mechanics - are expected to possess the ability to act as a "marine rifleman". Because of these expected capabilities, the training of marines is considered comprehensive and very physically challenging. While back pain causes medical evacuation from combat arenas (3), it is also a significant medical and tactical problem during their normal service and training (1, 4-8). This is experienced daily by the SAF occupational health services, but the scientific understanding of back pain in the marines occupational contexts is not well elucidated. The main problem that has been extensively discussed in the SAF is the lack of systematic work published regarding the extent and consequences of MSDs as a whole, neither more specifically back pain within the SAF marines. In addition, a scarcity of scientific evidence exists on marines that are considered to be at increased risk of developing back pain, including on specific work exposures that could lead to such disorders. Hence, the SAF health care services lack answers to some of the most fundamental questions necessary for effective preventive work, such as: *What* is the magnitude and consequences of back pain and *who* are at risk of experiencing such a disorder?

While observational studies generally have the ability to provide such knowledge without interfering with normal activities, inference of the results is conditional based on chosen study methodology, which may differ on definition and assessment of back pain and potential risks.

The work conducted within this thesis may help fill such knowledge gaps by contributing with basic evidence derived from using an epidemiological study approach, i.e. the "*what*" and "*who"*, and test-retest reliability of clinical tests used in SAF marines. This approach is instrumental in providing translational understanding of basic and clinical research of the complex mechanisms underlying back pain in this group.

2 BACKGROUND

2.1 MUSCULOSKELETAL DISORDERS IN THE MILITARY SERVICES

Musculoskeletal disorders (MSDs) are often defined as health problems, including pain, of the musculoskeletal system. This includes muscles, nerves, tendons, bones and cartilage (9). Such disorders are often considered to be caused or aggravated by sudden or prolonged exposures to physical factors (9). In the epidemiological literature on military personnel, musculoskeletal pain, disorders and injury are used rather synonymously (3, 10).

Person-based MSD incidence rates during basic military training, i.e. the initial training where future soldiers get acquainted with the basics of their trade, range from 2.6 to 10.5 incidents per 1000 person/days (median 5.37) (11-21) and 6.2 to 11.7 incidences per 1000 persons days for subsequent occupation-specific training courses (22, 23). Although these courses vary in length and curriculum across countries, they most often span around three months, during which 28% to 58% of the participants reportedly experience at least one MSD episode (22-25). Here, the lower extremities, primarily the knee, are the most commonly affected anatomical region, followed by pain in the back (15, 17-19, 21, 26, 27).

While reported MSD incidence rates are markedly lower later in their career, i.e. for active duty soldiers focusing on national defence tasks and training, ranging around 1.5 to 3.5 MSDs per 1000 person days (28-33), some elite units still report rates as high as 17 MSDs per 1000 days (34). Based on the aforementioned, back pain is about as common as knee pain (28, 31, 35), but seems to become the primary reported region when these soldiers are deployed (36-38).

While the large variation in reported MSD occurrence could be related to differences in specific training and work tasks across study populations, it probably also reflects the great variety in outcome definitions and methods of retrieving data. The usefulness of comparing occurrence rates between different military populations is therefore limited, and preventive measures should be based primarily on systematic surveillance from respective military organizations (39).

Further, while back pain constitutes a large fraction of the MSDs experienced, most studies in the military context focus on pain in any location, with no specification of the anatomical locations. Hence, given the limited scientific evidence of this aspect in the military population, occurrence and risk factors for MSDs will be considered and also referred to in the present work with its focus on back pain.

2.2 BACK PAIN

The majority of people (up to 85%) will at some point during their lives experience an episode of back pain (40). It is therefore essential to address back pain epidemiology in civilian populations, in order to understand the nuances and specific role in the military context.

The nature of back pain is commonly multi-factorial and complex, with its aetiology often poorly understood. Pain, is defined by the International Association for the Study of Pain as:

"*an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage*"(41)

The term *"unspecific back pain"* is used, but has often been categorised as unrelated to any specific pathology, such as osteoporosis, infection or fracture (42), and may be considered a collection of symptoms rather than a specific disease (42). Back pain," *specific*" and "*unspecific*", can include "local" (i.e. within the back) pain, but also radicular pain spreading from the back into the lower extremities in a dermatological distribution and radiculopathy (disturbed neurological conduction from a spinal nerve or its root)(43, 44). Since back pain may arise from a wide variety of spinal structures, such as muscles, bones, intervertebral discs and neural structures (44), it may be of nociceptive or neuropathic character (45, 46). It can however also originate in, be reinforced by or interact with psychosocial factors or other co-morbidities, further complicating the identification of its source.

Globally, low back pain (LBP) is considered to be the musculoskeletal condition causing most disability (47, 48). As the prevalence of back pain is already considerable at relatively young ages (49), point-prevalence or temporality prevalence (48), i.e. occurrence over a specified time frame, might better describe the occurrence of back pain than reports of the incidence of first-ever back pain. However, heterogeneity across definitions and methods complicates, or even prevents, comparison or synthesis of back pain occurrences (42, 48). For example, Ozguler and colleagues showed a 37% difference in the six-month LBP prevalence when comparing one of the more common definitions of LBP, i.e. *pain lasting for at least a day*, with a definition that required sick leave (45% and 8% respectively) (50). With these uncertainties in mind, the average global (civilian) 12-month LBP prevalence is reported to be 38% (48), while the average point prevalence ranges from 9 to 19% (95% CI 9.0 to 9.8) (48, 51). In 2010 the highest age-standardised point prevalence was reported for Western Europe, at 15% (51). While the highest incidence of LBP reportedly occurs in the ages 30 to 40 years, the prevalence peaks beyond ages of 40 (48, 51).

Pain in the thoracic back has been reported less disabling than pain in the lower back, and the latter is reportedly up to four times as frequent (52). This might be one reason why back pain studies most often focus on the lower back. Still, despite efforts to standardize definitions (53-55), recent reviews show that many studies still refer to back pain rather than LBP (47). Within the scope of this thesis, pain in both the low (lumbar) and/or thoracic back will be referred to as *back pain* and otherwise explicitly specified as *low (lumbar) back pain* (LBP) or *thoracic back pain*.

The natural history of back pain, i.e. its development without any clinical actions taken, has long been considered favourable, and back pain considered to be a self-limiting condition for the majority of sufferers, with full recovery within six weeks (56). However, research within the past ten years has somewhat challenged this position, with studies showing recurrence within one year to be common (57, 58). Thus, LBP is nowadays to some extent, seen as a more chronic, recurring condition. Yet other studies have further concluded that few of those experiencing an LBP episode are fully recovered within one year (59). The discrepancy could be attributed largely to what is defined as recovery and “new” or ongoing episodes (57, 60). Even so, the average reduction of acute LBP, and related disability, occurs mainly within the first six weeks, with a low proportion experiencing pain and disability after one year (61). The individual clinical course of LBP recovery and relapse does not, however, necessarily follow the population-averaged course, and different trajectories have been identified for sub-categories of LBP (59, 62). However, as with reports of back pain occurrence, studies of recurrence display much heterogeneity in their definitions (63, 64), not only of what constitutes back pain, but also how recovery is operationalised, making comparison across studies treacherous.

2.2.1 Back pain in military populations

In contrast to studies in the civilian populations, relatively few studies explicitly address back pain in the military context. In addition, the outcome is often based on retrospective assessment of medical records (13, 14), records of medical evacuations from combat arenas (3) or attrition from military training (65). These may not reflect the full extent of back pain in the military services.

Nonetheless, pain in the low back constitutes a large fraction (10-21%) of reported MSDs in the military services (15, 17-19, 21, 27, 28, 31, 35-38), and is 2.5 to 5 times more common than thoracic pain (2, 66). Occurrence and locations vary between occupational groups, including whether they are deployed or “in garrison”. In general, back pain seems to constitute the highest proportion of reported MSDs in deployed personnel.

Single studies have reported that marines have lower back-pain incidence than other services (Navy, Air Force and Army) (67), while non-infantry marines (such as mechanics or maintenance personnel) are at higher risk than marines in combat occupations (68). Still, 1% of the yearly loss of total unit strength has been attributed to back pain in British marine commandoes (4), while US marines who have been evacuated due to spinal pain show lower likelihood of return to operational duty than colleagues from other branches (3).

2.3 RISK FACTORS FOR BACK PAIN

Risk factors are specific elements, for example anthropometric measurements or a specific work exposure, associated with development of back pain. However, inference on the causative relation to the outcome, i.e. whether back pain varies according to differences in exposure (all other factors constant), is limited largely by a fundamental problem: that observation is limited to one exposure level (at a time) per marine (69). However, evidence synthesis based on assessment of, among other things, *strength of the association*, *consistency*, *specificity*, *temporality* and *experimental evidence* (70) from different types of studies might still provide a basis for a plausible assumption about causality.

For the work in this thesis however, risk factors are considered to be factors with a significant, positive association with a subsequent experience of back pain, among the marines exposed to the risk under study (69). Causation is not expected to be proved solely on the basis of observational studies, and no attempts are made to prove causation in the present work. The factors here associated with back pain are simply referred to as risk factors when the temporal direction of associations can be established, and otherwise as "associated factors". The estimates of the relationship to the outcome should thus be considered associational, or conditional, risk-, odds- and hazard ratios (69).

Many personal and environmental factors have been associated with back pain, but the size of the risks identified is often modest, or giving contra-inductive results. In addition, a causal relationship is seldom established and a wide variety of risk factors are only explored in a few, or even single studies, which invalidate generalization to general populations.

Age is among the personal factors most often reported to be associated with back pain in the general population (71, 72), but contradictory results are found in samples from specific occupations (72). This could indicate that age, in certain occupations, acts as a proxy for other protective factors not controlled for, such as increased experience or less risk taking behaviour. Anthropometric characteristics, such as *obesity* (73, 74), are nowadays associated with increased risk of back pain, whereas the role of *height* still needs to be established due to conflicting results. Taller-than-average body height has been identified as a risk in a few studies (75, 76). Others have however not confirmed this association (77), or report inconsistent results (78, 79). This could reflect a personal characteristic that constitutes a risk for back pain only in certain contexts, for example in specific occupations, and under certain conditions, such as strenuous physical labour (80).

Some individuals might also be more predisposed to experiencing back pain, influenced by *genetic* and *heritable factors* (73). The genetic component seems, however, to be more closely connected with more severe or long-lasting forms of back pain (73). Such predisposition for back pain should not be seen as a static condition: it has been suggested that it is prone to change over time, due to the individual's interaction with the environment (81). On the other hand, modifiable health-related risk factors, such as *smoking* (82) or *obesity* (73, 74) may be confounded by a genetic component, given that some reported effects cannot be established in case-control twin studies adjusting for the effect of genetics (74).

The most reported individual risk for transitioning to an episode of back pain appears to be a previous history of such a disorder (72, 79). Even so, individual studies have further shown that a history of musculoskeletal pain in other parts of the body (83) is equally associated with a new episode, potentially indicating a general effect of previous pain as a pathway to back pain

2.3.1 Risk factors for work-related back pain

While as much as 37% of LBP may be attributed to work-related risks (84), its complex aetiology and strong relation to personal factors make the establishment of causality between specific work exposures and back pain hard. In addition, overall back pain incidence does not differ between occupational- and community-based cohort studies (72). Even so, and even though some systematic reviews have shown conflicting evidence regarding commonly identified risk factors (85-89), exposures from the working environment are repeatedly shown in individual studies and systematic reviews to be associated with back pain (90, 91).

Physical occupational exposures such as heavy physical work (92), whole-body vibrations (93) and lifting (94) are the most commonly reported occupational associations. Still, some evidence has also emerged linking work-related psychosocial factors to back pain (95).

2.3.1.1 In military populations

Few studies specifically address back pain in military contexts. Occupation-related risk factors are likely not the same for different sections of the services, or for different military occupational specialties. This may partly explain why few specific risks of back pain have been established for military occupations.

Prior pain episodes seem, as in civilian populations, to be the primary reported risk factor for development of back pain, as well as for “any MSD” also in the general military population (1, 13, 14, 96). Robinson, in a recently conducted narrative review, identified *smoking* and low *cardiorespiratory fitness* as the key identified risks for MSDs during infantry recruits’ training (97). As in previous reviews from basic military training (1, 98), also previous MSD history (1), high training dosage (1), self-rated physical fitness (1, 98) and older age (98) are considered associated with MSDs in infantry recruits.

In addition to pain history, several individual and health-related factors, and specific work-exposure, have been associated with back pain. Those emerging from the literature as rather consistent risks are presented in Table 1.

Despite some risks reported in most studies, knowledge of the pathways to back pain is still sparse for such “accepted” risks. Efficient use of information on previous pain history relies on knowledge of whether the risk of a new episode is region-specific (99), or is associated with preceding pain in any body region (96, 100). While clinically important, this is often not studied (36, 37) or specified in the military epidemiological literature (13, 101). This not only limits the use of such knowledge in clinical preventive work, but also makes it harder to indentify its specific role in development of back pain.

Table 1. Factors associated with back pain in a military context, as reported in some earlier studies.

Personal related factors	***Work related factors***
Age [†(67), ‡(102)]	MOS [†(67, 103), ‡(68, 99, 102)]
Sex [† (67, 104, 105)]	Rank [† (67, 103-105)]
Psychological capacity/Mental health [ǀ(106), † (104), ‡(102)]	Service (not being marine) [† (67, 103, 105)]
Musculoskeletal pain history [ǀ(106-108), † (104), ‡ (109)]	Protective equipment worn [‡ (37, 99, 109)]
	Specific work–exposures [‡ (37, 99, 102)]

MOS: Military occupation speciality
ǀ Factors identified in; military recruits/conscripts/basic trainees
† Factors identified in; active duty or reserve military personnel; not deployed
‡ Factors identified in; active duty or reserve military personnel; deployed

Further, while women are reported (and in the services generally considered) to be at greater risk of MSDs than men (67, 68), the evidence to support the specific influence of female sex on back pain is still insufficient (98). In addition, the identified risk differences between males and females are reduced, or even eliminated, once physical performance level is adjusted for (110). Further, while female marine recruits report higher levels of lower-extremity injures than their male colleagues, this risk difference diminishes when one adjusts for unreported injuries, indicating a potential difference between the sexes in symptom reporting behaviour (111). Hence, the larger occurrence of MSDs and back pain among females might largely represent insufficient physical capacity or difference in symptom reporting, rather than being attributed exclusively to their sex (98).

Other well established risk factors for MSDs and back pain, such as level of physical capacity, are primarily derived from soldiers entering basic military training (98), while less is known about the role of physical capacity as a risk factor for back pain later in the soldiers career. This limits the use of preventive work for active-duty marines.

2.3.2 Theoretical risk-factor framework for back pain in Swedish Armed Forces marines

Due to the vigorous physical demands placed upon armed forces marines, potential risk factors addressed in the present work concern largely physical exposures within the occupation. However, *personal-related* risk factors, such as *individual-characteristics, general* and *mental health*, and *environmental factors* may contribute to the development of pain from the spinal system. This path to back pain could be “direct” from physical reactions to external loads, or the perception thereof, and/or could act by reducing tolerance to experiencing loads.

To visualize, and potentially classify, theoretical risk factors, interactions and pathways to back pain, a “*conceptual model of risk factors for work related back pain*” was used as a framework in the present work. This model, initially proposed by the National Research

Council and the Institute for Medicine (112), and later refined in subsequent work on back (113) and neck pain (114), illustrates theoretical pathways of personal and work-related risk factors to back pain, through, or mediated by, the biomechanical load-tolerance relationship. This model was adapted for the present research (Figure 1). Here, *physical* and *psychosocial* exposures generated in work contexts and personal characteristics (*physical* and *psychosocial*) can act, direct, or interact, to induce back pain.

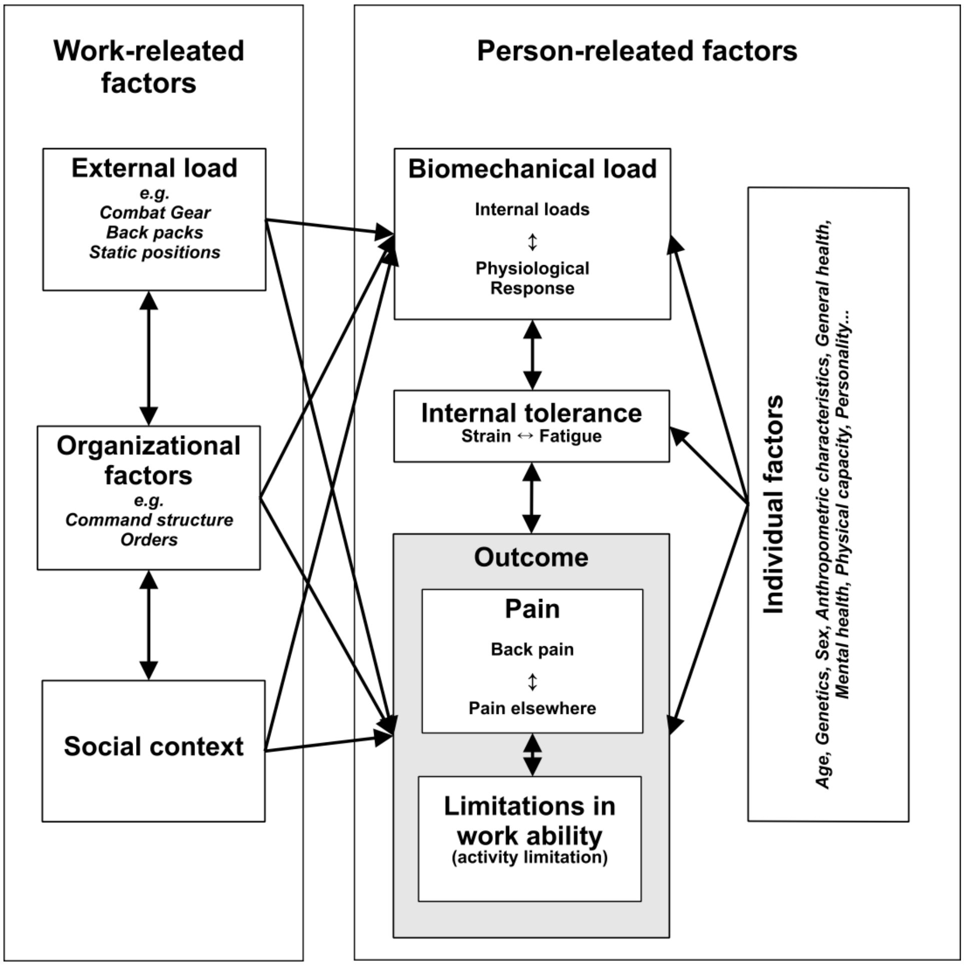

Figure1. Conceptual model of potential work- and person-oriented risk factors, relations and pathways to back pain in the SAF Marines. *Adapted and reprinted, with permission from Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities, 2001by the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.,* and *Marras WS. The working back: A systems view. 2008, John Wiley & Sons, Inc., Hoboken, New Jersey (Copyright © 2008 John Wiley & Sons, Inc.).*

Some of these factors can in addition act by increasing spinal load while simultaneously decreasing the individual's tolerance to load, thereby increasing the risk of back pain (115). For example, psychosomatic stress could act by both increasing the internal load by heightening physical response, at the same time reducing resilience to handle such loads (112). If an individual has a previous history of back pain, both internal tolerance, i.e. tissue tolerance and response to pain (resilience) might be further reduced and thereby interact with the physical load to increase the back pain experience (113). In addition, organizational demands for performing specific tasks regardless of available resources, could further directly increase the external load as well as the stress, thereby increasing the risk of back pain. This may well happen in a military context where back pain in one unit member will transfer the weight of group equipment, and potentially the whole task, to the rest of the group, especially significant in an elite context where this is considered the social norm.

This model is well aligned with the biopsychosocial model (116, 117), sharing the view that all health conditions can affect an individual at biological, psychological and social levels. It seems especially suitable for studies of populations such as the SAF marines. This is relevant because of their recurrent exposure to high biomechanical loading, but with differences in individual characteristics and in the spread of other work-related exposures.

While numerous studies exist on military recruits, groups with rather homogenous military-specific work exposures, the present work is based on data captured after the transition of the SAF from a conscript-based service to a professional service, with full- and part-time employed officers and other ranks. Some work tasks and exposures have consequently changed in comparison to our former "conscripted" armed forces, and for some marine positions this could increase the risk factors for back pain similarly to that of the civilian occupations. Therefore, identified work-related factors, or those considered (but not yet proved to be causally associated with or related to back pain) in the civilian population, for example occupational sitting (118) and exposure to whole-body vibration (93), were considered along with military-specific exposures.

The measurement necessary to draw conclusions from such associations is however more complex. To assess the level of back pain, including the determination of individual factors such as physical capacities and the quantification of work exposures, many methodological considerations need to be addressed.

2.4 ASSESSING AND DEFINING MUSCULOSKELETAL- AND BACK PAIN

Outcome measures of MSDs used in military medical literature are very largely based on medical records. These are often used alone or in combination with administrative data (e.g. medical downgrading, medical evacuation, attrition from training or work-absenteeism). Medical records may be very informative and relevant for specific research questions, especially if based on specific diagnostic criteria supported by objective measurements. However, most MSDs are probably treated at outpatient facilities, perhaps outside the military health care system, and will subsequently not be reflected in the data. Given the possibly negative impact on the soldier's career, a large fraction of MSDs are likely not seen by the military care provider at all, as seen in other occupations (119, 120). Further, fewer than 60% of those experiencing LBP in the general populations seek medical care, with experiencing disability far more associated with care-seeking than with pain intensity (121). Hence, care seeking may reflect an interaction between the disorder, personal characteristics and the environment, rather than the severity of the disorder itself. Subjective measures, such as self-reported pain experience may capture more disorders (122), but not without the risk of bias due to recollection (123) and inclusion of disorders of different magnitudes. For the purposes of the present research, MSDs, and back pain, are operationalized by self-reported musculoskeletal pain in marines at work.

When defining musculoskeletal pain based on self-reports, the anatomical *location*, *pain frequency*, *intensity* and *duration* needed to be addressed. Here, brief pain measurements, such as the bodily pain scale from SF-36 (124), the Örebro Musculoskeletal Pain Questionnaire (125) or, for the SAF the original version of the Musculoskeletal screening protocol (65), may in their designed be considered useful (126). However, some of these instruments lack the ability to specify pain intensity or activity interference for specific anatomical locations, which limit their usefulness in studies of specific pain sites, such as the focus of the present work. More comprehensive outcome measurements, such as the Roland Morris pain questionnaire (127), provide detailed information on pain intensity and related consequences for specific anatomical locations, but are more difficult to incorporate in population surveys with a wider focus. Furthermore, outcome measurements designed for general populations may lack the sensitivity needed for capturing LBP that is limiting specific military activities or tasks (128).

Averaging pain ratings over several intensity measures, such as worst and average pain over a specific time-period, has been advocated so as to gain precision over ratings (126). Such ratings are nonetheless relative to the end points used, e.g. the respondents´own experience of "worst possible pain". The same pain rating could therefore differ in meaning within a population, mainly due to the personal and nuanced experience attached to concepts.

Alternatively the concept "any reported pain" during a specified time period could be used. While such a definition might reduce the uncertainty of recall of pain intensity, it might at the same time lead to inflated prevalence, as even mild pain is reported as an occurrence of pain. Therefore, for certain musculoskeletal conditions, such as low back pain, an effect on the sufferer`s daily activity is advocated by some researchers as necessary to constitute a "relevant" pain episode (53).

For studies on work-related MSDs, such activity limitations are often reported as an effect on "work ability". In the present studies, the 'health-related abilities for the individual's specific occupation under investigation' is the essential outcome, and not sufficient ability to do "any" work (129). This concept refers to *"how able is he or she to do his or her work with respect to work demands, health and mental resources"* (130), with the response options ranging from slight limitations in work capacity to full reduction of work ability. Work ability is however often operationalised by "work absenteeism" in civilian occupations, based on the close association between work absenteeism and ill-health (131), or by lost training days in military and sport contexts (4, 11, 36). Such definitions will likely not reflect the majority of MSDs in occupations with high presenteeism, or as outlined by Clarsen (132), for overuse injuries in sports where individual adoptions of exposures are possible.

Given the dependence of pain on the specific environment and context of the sufferer, such activity limitations should neither be routinely interpreted as a reflecting the severity of the pain, nor as an automatic correlation with high activity limitations (126). In fact, low levels of self-rated pain might still constitute notable limitations in work ability for elite military personnel, as their perception of the anchor point of "worst possible pain" might affect their ratings. Furthermore, given the physical demands embedded in military service, even low levels of pain might have adverse effects on their ability to perform their duties.

2.4.1.1 Pain recall

Regardless of what definition is chosen, the risk of recall bias needs to be considered when basing outcomes on retrospective pain reports. While retrospective pain recall for up to three months has proven to give valid measurements (126), retrospective rating gives higher levels than averaged momentary ratings (133) and risks putting focus on the worst, or most recent, pain episode (133). In longitudinal studies, the number of times that pain is reported will therefore also affect the pain occurrence.

2.4.1.2 Back pain

As for other MSDs, definitions of what constitutes back pain vary greatly across studies with regard to the borders of anatomical regions, how pain is defined, or what constitutes a new or recurrent event or episode.

First, the region referred to as the back is often limited to the lower back, i.e. "from the twelfth rib to the lower gluteal folds"(47), which has been recommended for use in back pain prevalence studies (53). Still, some common outcome measurements do not define which part of "the back" they refer to (127), and could as such represent pain in either the lumbar and/or thoracic part of the back or pain along the entire spine. Here one could expect recall over longer periods to reduce the ability to accurately remember the specific location, and hence, might be a source of misclassification if many categories (areas of pain) are provided. Secondly, it is necessary to define back pain in terms of pain intensity or frequency, as described above. A common definition suggested is "*pain in the lower back within the past four weeks that has limited your usual activities for at least one day*" (53). This definition seems to be widely accepted by researchers , but used primarily as a guideline for question design. The severity criterion of "activity limitation" is often replaced by time of work in studies of occupational LBP (134), and by time "of training" in studies across military (4, 11, 36) or sports contexts (135). Such definitions might however report unrealistically low back pain occurrence, in that presenteeism is probably common in both elite military and sports contexts.

The definition of a "*new*" event also varies extensively between studies (63), but four pain-free weeks has been suggested as suitable criterion for the end of a pain episode (55, 134, 136). This is especially important when studying trajectories of back pain. Still, some evidence exists on how the duration of pain could affect pain-free periods (137). Symptom "flare ups" from an "ongoing" event, and experience of back pain as fluctuating states (60), could constitute important information for certain research aims. However, such phenomena might not be captured with a definition of “events” based on time since latest symptom, since this would not take into account pain-free episodes within the four weeks.

2.5 ASSESSING OCCUPATIONAL EXPOSURES

Assessment of occupational physical exposure as a risk factor for back pain requires quantification of its *type*, *intensity*, *frequency* and *duration*. Here, self-reported measurements are a cost-efficient and, logistically, relatively uncomplicated way of identifying possible risk factors. This is especially convenient in occupational populations whose work-tasks are hard to observe systematically in a “natural” context and environment. For example, 38% of occupational sedentary time has shown to be predicted in civilian workers, by only including a single question on sitting during working time (138). However, self-reports are often criticized for imprecision (139, 140), and for overrating of exposure levels by participants experiencing pain (141).

In studies of military populations, the “military occupational specialty” is often considered a proxy for occupational physical exposure. As different SAF marines units have very specific occupational tasks, this might partly serve as a valid proxy for the unique combination of risk factors within that unit.

Objective monitoring of physical activity, such as that obtained with accelerometers (e.g. *counts*, *steps* and *inclinometer* data)) and used in a widely in public health studies (142, 143), could also be a suitable means of quantifying the full work- and training-related physical activity in SAF marines. However, due to the variety of their tasks, continuous monitoring over longer periods is likely necessary to cover “habitual” occupational physical activities. Further, accelerometers alone will not capture the relative increase in energy expenditure induced by increased VO_2 demands as a response to increased born loads (144), e.g. protective equipment and weapon systems. Neither will accelerometers take into account the individual variation in aerobic fitness (work demands in relation to individual VO2 max capacity), nor correctly represent physical intensity when running faster than 9 Km/h (145) or non-ambulatory activities, such as strength training (146). Thus several assessment strategies combining sensors and subjective reports are necessary if a valid picture of the full occupational physical exposure within the marine setting is to be provided (147, 148).

2.6 ASSESSING PHYSICAL CAPACITY WITH CLINICAL TEST

In the SAF, general physical capacity is primarily quantified by measurements of aerobic and muscular endurance, tested yearly to ascertain the soldier’s physical capacity. In addition, the SAF marines have designed and implemented a marine-specific combat obstacle course and loaded speed marches to quantify “marine-specific” physical capacity. Also, individual clinical tests to screen marines' physical function and findings related to the development of back pain are conducted by the occupational health services.

Given the physical demands of service in the marines, screening physical function could be part of an appropriate preventive strategy if tests that reflect relevant physical demands are included. However, few clinical tests (results) have been scientifically identified as risks for back pain in this type of military personnel, and no systematic screening of active duty SAF marines' physical function have been systematically evaluated. Given the potential effect on the marines' operational status, the reliability and predictive validity of such tests need to be established before they may be systematically integrated in preventive work.

2.6.1.1 Movement control tests

Even though musculoskeletal pain can develop for numerous reasons, studies have demonstrated a link between pain and the inability to control bodily movement adequately. Such aberrant movement control may predict recurrence of musculoskeletal disorders in the civilian population (149-151) and injuries to the back and lower extremities in ballet dancers (152). Such tests of movement control are also believed (by marine health service personnel), based on clinical findings and empirical field observations, to adequately challenge weak-links in marines' musculoskeletal system relevant to their occupational tasks. However, the reliability and validity of such clinical tests have been given scant attention in civilian populations, and no published data on their reliability has previously been published for marines.

2.6.1.2 Physical test of strength, lifting- and load-carrying capacities

While assessment of aerobic capacity is commonly included in military physical evaluations (153), experts are nowadays considering muscular strength as one of the most critical fitness components required to successfully accomplish common military tasks (154, 155). A newly developed physical screening program in the SAF covers such areas by including global testing of upper body strength, lifting- and load-carrying capacities (156). Given these attributes and their relation to load carrying capabilities (157), and the association between load carrying and back pain in other military populations (99, 109, 158), these tests were also deemed potentially valid in the present context.

2.7 VALIDITY AND RELIABILITY

Validity testing in the present work is considered as a continuous gathering of the information necessary to evaluate the trustworthiness of inferences, and the justification for actions, based on the results of an instrument. However, the information is considered specific for this context and for this population under study (159-161). Here, the contents, response process, internal structure, relations to other variables and consequences of the instruments (160, 161) could be addressed to disentangle the *"degree to which evidence and theory support the* *interpretations of test scores entailed by the proposed uses of the tests"*, as stated in the Standards for Educational and Psychological Testing (162).

2.7.1 Validity testing

Different types of validity testing, often addressed as the three under constructs of validity - *criterion, content* and *construct* validity (159, 163) - could be used to answer such a question of "trustworthiness". In the present work, testing of *criterion validity* would refer to how well the test corresponds with the "gold standard" of measuring that phenomenon, i.e. the criterion (161, 163). Hence, knowing that a questionnaire item measuring work exposure highly correlates with direct observation of that exposure (*concurrent validity*) will aid in making an inference of the results using that questionnaire item. This will also be the case if the same item could predict the future consequences of such an exposure (*predictive validity*). By extension, addressing how well the specific questionnaire represents all domains and aspects of the exposure under study would be referred to as an evaluation of its *content validity*, meaning how well all items together cover the reality of the exposure in that specific context.

Most of the measurements included in the present study have been tested for some aspects of validity, either *criterion* or *concurrent* validity, but often also together with their reliability. However, most psychometric testing has been done for the civilian populations (164-171), and to a smaller extent in the military populations (65, 156). While the evidence of validity gained within these contexts might be limited for the present work, given that it is conducted in a "novel" population and under specific conditions, it still gives an indication of trust when interpreting the results.

2.7.2 Reliability testing

For any meaningful inference from a test or questionnaire answer, be it clinical or in research, one should form an opinion of the role and amount of error in the measurements. For clinical tests, variability that may influence such measurement is related to: *the observer, the instrument/ measuring procedure* and *the subject tested* (172). While this is most often referred to as reliability, widely varying of definitions exists (161, 173, 174), and the results will vary depending on whether, and how, the study design restricts potential variability. For example, the "reliability" measurements received from a test-retest design where a subject repeats a clinical test on two occasions include potential variability in the subject's performance. This source of variability will however be restrained if the test-retest procedure is conducted on repeated observations from only one occasion, for example using "video" recordings. Therefore, within this work, reliability is referred to as the level of agreement (i.e. not only its correlation), between two or more observers, that is, *inter-observer reliability*, and between the same observer over repeated occasions with repeated performance of the participants, i.e. *intra-observer reliability* (175).

For tests generating nominal level data, such as the movement control test used in *studies II, III* and *IV*, a suitable measurement of chance-adjusted agreement is Cohens kappa coefficient

(176), which is often reported together with overall agreement (i.e. agreement unadjusted for chance) for more comprehensive interpretation (174, 175).

Given that the kappa coefficient, by design, is affected by the prevalence of ratings (174, 175), such as the distribution of *"pass"* and *"fail"*, the inclusion of the maximal attainable kappa for that distribution (Kappa Max) may help interpretation (177). While the kappa coefficient should represent the "true" chance-adjusted agreement within the population under study (175, 178), inclusion of a "prevalence- and bias-adjusted kappa coefficient" (179) may aid in understanding how the test could perform in terms of reliability for a different population or context (175).

2.8 PREVENTION OF BACK PAIN

The present work, concerns the occurrence and risk factors for back pain, in order to contribute to the foundation of future evidence-based prevention (180, 181) of back pain in the marine population. Such knowledge could be seen as a contribution to prevention from both an individual perspective, here theorized within "*the ability process*"(182), and at population level, by planning and executing research in accordance with the translation "*public health model of injury prevention*"(180).

Back pain prevention can in principle be applied at any time during the development of back pain. It will however have a different meaning, and focus, depending on the stage of the disorder. *Primary prevention* aims to prevent the onset of back pain. In the military context, this is to be achieved by managing exposures (1), such as amount of load carried, and improving physical capacity after the detection of limitations (182). This can apply at group level, through policy decisions and organizational and equipment interventions, and at individual level.

Primary prevention can be very similar to *secondary preventive actions*, which seeks to reduce the consequences of back pain that has already occurred, for example by medical treatment, and by reducing the risk of a new episode: again, by reducing exposures or improving physical capacity (182). Therefore, once marines are symptom-free, they are again targets for the same, or at least very similar, preventive actions that are in function within primary prevention. However, marines with long-lasting or frequently recurring back pain episodes are likely candidates for *tertiary prevention*, where the focus is to handle ongoing back pain, often by symptom management and limiting the negative effect on the marines work ability.

2.8.1 Prevention of back pain in the Swedish Armed Forces

Prevention of back pain and MSDs when conducted within the military context often focuses on specific periods or tasks, such as initial physical entry standards or optimizing load progression during basic military training (1). Organized screening programs designed to reduce MSDs do exist in the SAF, but individual secondary preventive action for marines is most often initiated after a medical examination. These are commonly conducted in the SAF occupational health care system as general health appraisals typically at the start of training or before deployment. Similarly, periodical medical examinations, regulated by the Swedish Work Environment Act or military regulations, are conducted for certain military occupations, such as divers and boat crews. Here, identified risk factors for back pain could be used at individual level to guide back pain prevention.

Such information could also be employed for systematic, individual prevention, if used within *"the ability process"* for SAF marines. Originally developed following the sociomedical "*Disablement process*" (183), i.e. a conceptual model on the pathways and their accelerators or decelerators, from pathology to disability, the *"ability process*" was a theoretical framework to guide efforts to reduce attrition of military service among SAF conscripts (182). It has now evolved into an established process in the SAF to identify individuals at risk of MSDs, as well as an asset for promoting individual health and operational readiness. By comparing individual anamnestic data and testing function and physical performance (*capacity*) against individual job requirements (*demands*), potential gaps between personal capacities and job demands could be identified. Interventions could then be targeted to meet threats to operational readiness. However, this systematic approach relies heavily on knowledge of evidence-based risk factors and valid methods of assessing capacity. Also required are accurate knowledge of occupational physical demands and the identification of effective evidence-based preventive measures. The present results may, it is hoped, contribute with valid information and assessment methods for identifying marines at risk of back pain, and vital insights regarding occupational exposures for use in the *capacity* vs. *demands* analysis, (Figure 2).

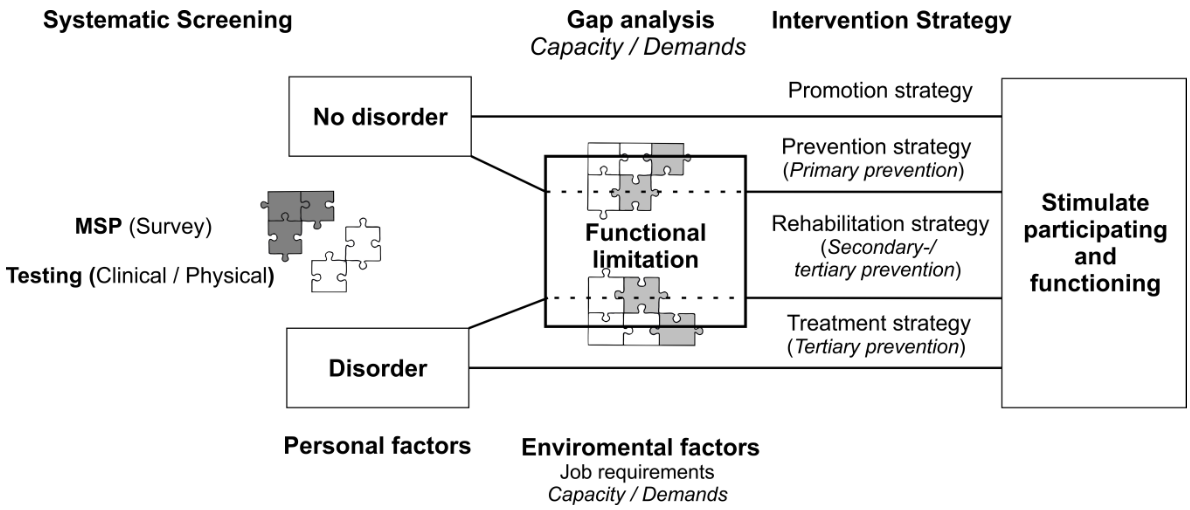

Figure 2. Potential knowledge gains, as illustrated by puzzle-pieces, by this thesis work in relation to "*the ability process*". Puzzle-pieces representing: dark grey; capacity information gained by testing, white; questionnaire or anamnesis information, light grey; work-related factors and exposures. *Adapted and reprinted, with permission from Larsson H. Premature discharge from military service: Risk factors and preventive interventions. Stockholm: Karolinska Institutet; 2009.*

2.8.2 The public health model of injury prevention

To handle the large burden of MSDs in the military setting, the use of the "*public health model of injury prevention*" (180); models developed from this original model (39, 184), or similar models (181, 185), have been used frequently (39, 184, 186). Working according to such models has given a structured approach to identifying the burdens and risk factors of MSDs, and implementing and evaluating appropriate preventive measures. The "p*ublic health model of injury prevention*", originating from Mercy et al. (180), is widely adopted in public health injury prevention (187), while similar translational models have evolved in other fields , such as sports medicine (181, 185, 188) and diabetes (189). Considering the resources required for implementing such an approach, projects that have considered evidence from such process have shown good results of MSDs reduction within different military occupations (190-192).

The "*public health model of injury prevention*" starts with identification of the extent of the problem, and then progresses to identification of related risks and causes. The present study aims and methods can primarily be seen as trying to fulfil the first two steps of this model for back pain in the SAF marines (Figure 3). The following steps of the model, however, not addressed here, concern design, implementation and evaluation of preventive measures for identified risks for the outcome in focus.

The the public health model, in its original form, can come about as unidirectional. Still it, or at least the models based on it, could be considered translational models (39, 184). Here, the final stage loops back to the first stage, using injury surveillance as the assessment of effectiveness. This is similar to a model used in sports medicine, as suggested by van Mechelen (181). More comprehensive translational models have been advocated (193), with respect to primarily the intervention, evaluation and implementation stages. Still, the initial steps of establishing the extent and aetiology of the problems remain unchanged, regardless of the overall model used

2.9 SUMMARY OF PERSPECTIVES, THEORETICAL FRAMEWORK AND CONCEPTUAL MODELS

The public health model of injury prevention is used to place the aims and results of this work along a continuum where its potential future use for reduction of back pain in the source population can be visualized, given continuing research and interventions. The results are also seen as means of addressing knowledge gaps hindering the effective use of the "*ability process*" for systematic back pain prevention in SAF marines. The *"conceptual model of potential work- and person-oriented risk factors, relations and pathways to back pain"* is used throughout the studies as a framework for selecting, theorizing and visualizing potential risk factors, their interaction, and theoretical pathways to back pain. In addition, the International Classification of Functioning, Disability and Health (ICF) model is included to conceptualize the domains to which the outcomes could be categorised. This framework integrates the biomedical and social model of human functioning and disability with the central part of recognizing the impact of disorders within an individual's personal and environmental contexts.

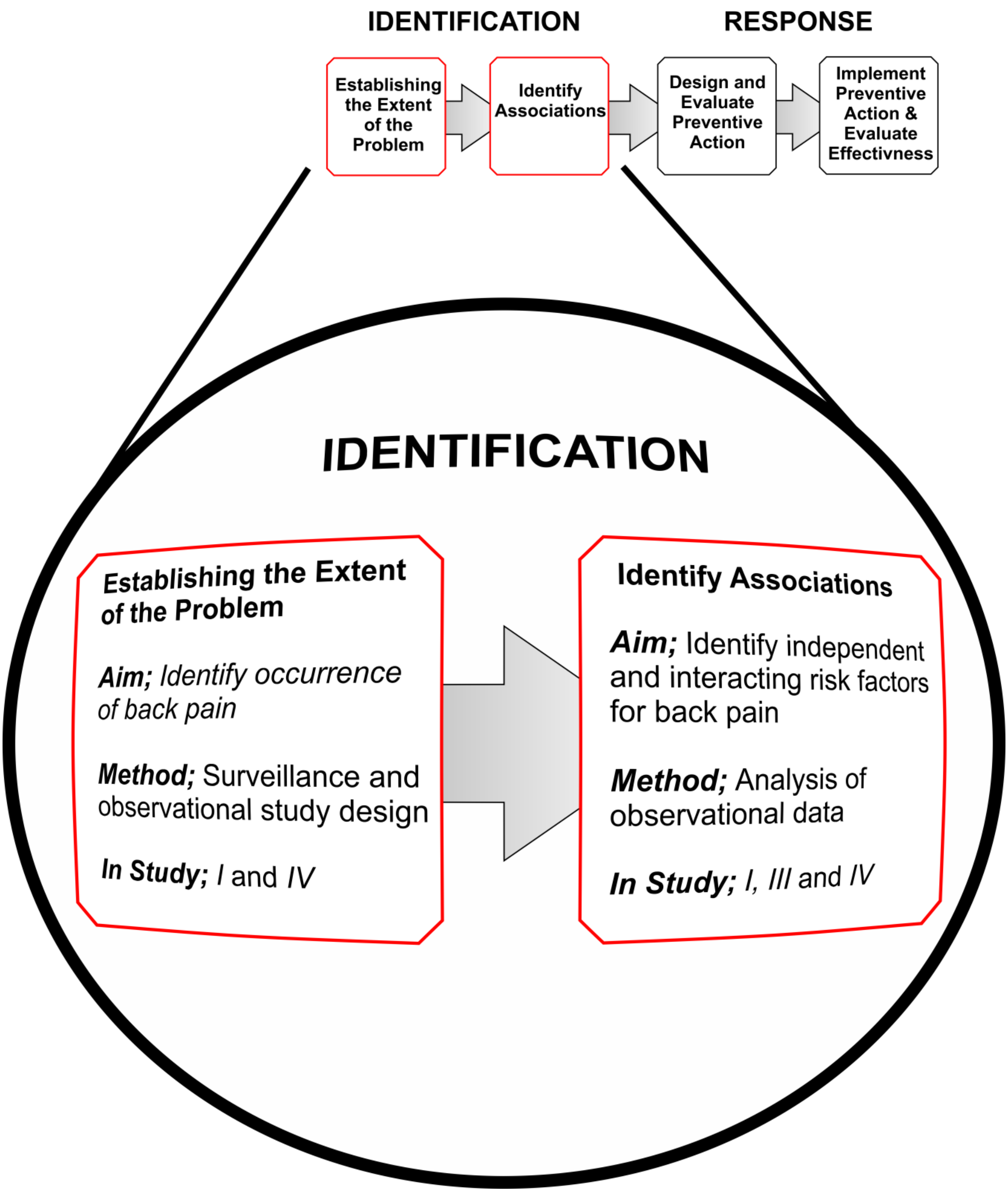

Figure 3. Locating the present aims and methods along the continuum of *"The public health model of injury prevention"*.

2.10 RATIONALE FOR THESIS

Back pain seems internationally to be common in all phases of the modern marine's career, starting to be at risk from basic training as well as before and during deployment. It has been shown to reduce both an individual's work and training ability, and as such has the potential to negatively affect operational readiness of military units. For this occupational group, any reduction in work ability might be regarded as important from a safety perspective, and as such, making prevention of back pain a major interest and top priority, from both a medical and an operational perspective (194).

While this problem, and its negative effect on work ability, might be as common in Sweden, the SAF marines health services lack answers to basic questions of necessity for a systematic and effective prevention program of back pain, specifically *what* the extent of the problem is, *who* is at risk and *why* they are at risk?

Here, disentanglement of the "*who*" and "*why*" questions relies, to some extent, on sufficient knowledge of the occupational demands, as means to interpret risks and the potential pathways to back pain. Furthermore, the systematic prevention program adapted by the SAF requires valid and reliable measurements of risks for back pain, including relevant physical and clinical tests to identify capacity limitations related to back pain development.

While unravelling all aspects of back pain epidemiology for marines are well beyond the scope of this thesis, it aims to, by means of an epidemiological as well as a clinical approach, to start filling the main knowledge gaps for the SAF marines and their occupational health care service, and lay the foundation for effective translational prevention of MSDs and back pain.

3 AIMS

Given the early identification of being among the most prevalent reported regions of pain, the overall aim of this thesis was to estimate the occurrence and risk factors for back pain and related limitations in work-ability, at different stages of the SAF marines career. Furthermore, an evaluation of clinical useful tests and the assessment of occupational physical activity exposures are included.

3.1 SPECIFIC RESEARCH QUESTIONS ADDRESSED IN THIS THESIS

3.1.1 Musculoskeletal pain in marines

What is the six-month prevalence of any musculoskeletal pain, and pain limiting work ability, in active duty SAF marines, and which are the most prevalent reported regions? (*study I*)

3.1.2 Occurrence of back pain in marines

What is the six-month prevalence of back pain and back pain limiting work ability in active duty SAF marines and marines entering the training course? (*study I, study IV*)

What is the six-, and 12-month prevalence of back pain and back pain limiting work ability in SAF active duty ranger-, infantry- and combat craft crew marines? (*study III, thesis*)

What are the weekly, and overall, prevalence and incidence of LBP, and related reduction in work ability, in marines during the training course? (*study IV)*

3.1.3 Work-related physical activity and occupational demands during the marine training course

What are the general levels of work related physical activity during this course. *(study IV)*

To what extent are body worn equipment worn during work activities of different physical intensity. *(study IV)*

3.1.4 Risk and associated factors for back pain in marines

Which individual-, health- and work-related factors are associated with back pain limiting work ability in active duty SAF marines? (*study I*)

Which individual-, clinical-tests, health- and work-related baseline factors increase the risk for back pain, and back pain limiting work ability, in SAF active duty ranger-, infantry- and combat craft crew marines within a six- and 12- month event window? (*study III*)

Which individual-, clinical-tests and health-related factors at baseline are associated with low back pain and low back pain limiting work ability in marines during the marine training course. (*study IV*)

3.1.5 Reliability and discriminative validity of clinical tests

What is the inter- and intra-observer reliability of clinically convenient tests assessing movement control of the back and hip in active duty SAF marines? *(study II)*

What is the discriminative validity of the best fitting combination of tests associated with back pain in active duty SAF marines? (*study II*)

4 METHODS

4.1 STUDY DESIGNS AND ETHICS

4.1.1 Design

The work presented in this thesis is based on one population-based study using a cross-sectional design (*study I*), one reliability study using a test-retest design (*study II*) and two studies with prospective observational cohort designs (*study III and IV*). *Study I, III* and *IV* focus on back pain epidemiology, i.e. occurrence and risk factors for back pain, in active duty marines and marines in the marine training course, respectively. They are however part of two larger projects aiming to investigate the occurrence and risk factors for musculoskeletal pain and associated limitation in work ability in SAF marines.

4.1.2 Ethical permissions

Due to the nature of the military profession, confidentially as well as voluntary participation, including the information stipulating the option to stop participating in the study at any time, have been heavily stressed during recruitment and enrolment for all work included in this thesis. Written, as well as oral, information was given prior to participation and signed informed consent was obtained from all participants entering any of the studies. All studies in this thesis were approved in advance by the regional board of ethics in Stockholm; *study I-III* dnr: 2010/728-31/2 (amendment dnr: 2011/1055-31) and *study IV*, dnr: 2014/1904-31/2 (amendment dnr: 2016/1135-32), as well as the SAF.

4.2 STUDY SAMPLES

General inclusion criteria for participants in all studies were planned service at the 2nd Amphibious battalion (*study I, III*) or 1st Marine regiment (*study II, IV*) during the study period. Additional inclusion and exclusion criteria are presented below for *study I-IV,* with participant recruitment (*study I-IV*) and retention in the study (*study III-IV*) illustrated in Figures 4-5, and demographic characteristics of participants included in Table 2.

Study I: Participants had to be on active service as a marine for the past six months, i.e. the exclusion of participants temporarily posted or under training at the battalion, and those that had not worked as a marine for the last six months due to leave, studies, etc.

Study II: Subjects on limited duty due to illness (full- or part-time sick leave), and those temporarily posted or under training at the 2nd Amphibious Battalion were excluded.

Study III: Male marines on active service as infantry, ranger or combat craft crews that were free of back pain (defined as <1 on numeric pain ratings for low and/ or thoracic back) at baseline were included.

Study IV: Marines planned to take part in the marine training course were included.

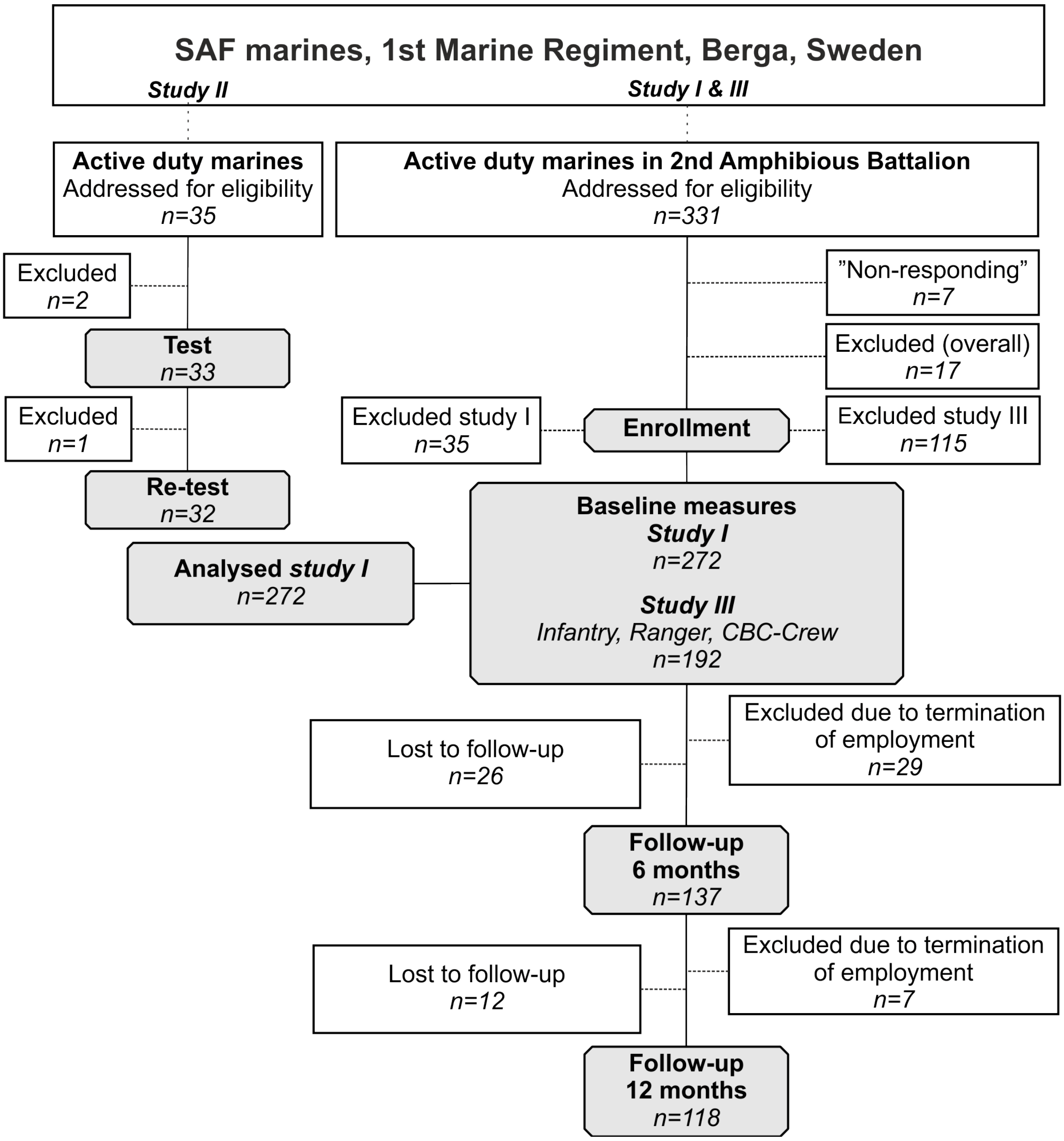

Figure 4. Illustration of recruitment procedure, number of subjects included, excluded, analyzed (*study I,III-IV*) and lost to follow-up (*study II-III*).

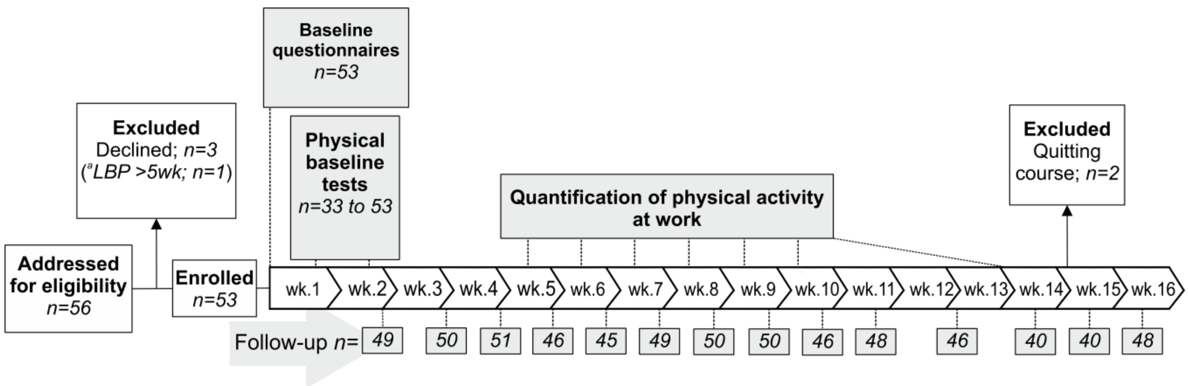

Figure 5. Recruitment and measurement procedure, number of marines included, excluded and weekly follow ups (wk) during the marine training course (*study IV*). [a]One subject excluded from analysis based on LBP incidence, due to LBP at baseline that lasted for more than additional five course weeks.

Table 2. Demographic characteristics of participants in the respective studies at baseline.

Study	***Statistics***	**Study *I***	**Study *II***	**Study *III***	**Study *IV***
Study sample		Active duty marines			
			Infantry, combat craft crews, rangers	Infantry, combat craft crews, rangers	Marines in the training course
Grade; *Officer/NCO*	*% (95% CI)*	31.9 (26.6-37.6)	100[a]	22.1 (16.4-29.1)	0
Demographic characteristics and health ratings					
Sex, male	*% (95% CI)*	97 (94.8-98.8)	97 (84.7-99.5)	100	90.6(79.8-95.9)
Age, yrs	*Mean (SD)*	25.3(6.7)	28.7 (5.9)	23.6 (4.3)	21.8 (3.4)
Weight, Kg	*Mean (SD)*	83.4 (10.7)	82.5 (9.4)	83.1 (10.1)	80.0 (10.1)
Height , m	*Mean (SD)*	1.82(0.07)	1.81 (0.06)	1.83 (0.01)	1.82 (0.07)
General Health; *Good/excellent*	*% (95% CI)*	94.4 (90.9-96.6)	n/a	95.6 (91.3-97.9)	96.2 (87.3-99.0)
MI-5[b]	*Mean (SD)*	85.1 (11.1)	n/a	87.7 (8.6)	n/a
GHQ-12[c]	*Mean (SD)*	n/a	n/a	n/a	1.8 (1.6)

n/a; not available, NCO; non-commissioned officer / specialist officers

[a] No Soldiers / Sailors employed within SAF marines at the time of testing

[b] The mental health domain from SF-36, ranging from 0 to 100 (best possible outcome)

[c] The General Health Questionnaire-12, overall score, ranging from 0 to 12 (where a score of 12 is the highest indicator of mental distress).

4.3 PROCEDURES

Study I: Self-assessment questionnaires were administered once to the participating marines, completed over the course of one year. Questionnaires addressed musculoskeletal pain and its effect on work ability, individual and health-related factors, and work exposures.

Study II: Self-assessment questionnaires addressing musculoskeletal pain and its effect on work ability, demographic characteristics and health-related factors were administered to 33 active duty marines. Thereafter they, following a standardized test procedure, performed six clinical tests of movement control. Test performance was rated by two observers and the test was repeated 7-10 days after.

Study III: Baseline measurements were conducted by use of questionnaires (same as *study I*) and movement-control tests over the course of one year with follow-ups after six and twelve months.

Study IV: Baseline measurements were conducted at the start of the training course, by use of questionnaires, addressing musculoskeletal pain and its effect on work ability, demographic characteristics and health-related factors Thereafter they performed clinical tests of strength and movement control. Incidence of LBP and its related effect on work ability were followed-up weekly during the course, and occupational physical activity was monitored by accelerometers, detailed schedules and self-reports for parts of the course, as presented in figure 5.

4.4 DATA COLLECTION INSTRUMENTS

Key data elements of relevance for these aims are presented in Table 3, structured by the overarching conceptual model of potential work- and person-oriented risk factors for back pain used. These data elements and methods of collection are, in addition, summarised below, and described in more detail within each study.

4.4.1 Questionnaires

Data on demographics, self-assessed musculoskeletal pain, general health, health-related quality of life or mental health, physical training habits, work ability and specific work exposures were collected at baseline in *study I-IV*, using questionnaires - previously used in Swedish public health cohorts (168, 195, 196) or within the SAF(182, 190). A summary of data elements used for the work included in this thesis is presented in Table 3, structured by the overarching *"conceptual model of potential work- and person-oriented risk factors, relations and pathways to back pain"*.

Table 3. Classification of data elements used in the present work.

Data element	Study	Data element	Study
Person related		***Work related***	
Age	*I, III[a], IV[a]*	Grade	*III*
Body weight	*I, III, IV*	Military experience	*I, III, IV*
Body height	*I[a], III, IV[a]*	MOS/MOF	*I, III*
Body mass index	*I, III[a], IV[a]*	Specific work -exposures	*I, III, IV*
Sex	*I[a], IV[a]*	Work ability	*III, IV*
Mental health	*I, III, IV*	Recovery	*III*
Musculoskeletal pain history	*III, II, IV*		
Non-musculoskeletal co-morbidity	*I[a], II[a]I, IV[a]*		
Physical training habits	*I, III, IV*		
Clinical tests	**Study**		
Movement control tests	*II, III, IV*		
Strength tests	*IV*		

[a]Addressed as potential confounder.

MOS/MOF; Military occupation speciality/ Military occupation function

4.4.2 Clinical tests

4.4.2.1 Movement control tests

In *study II, III* and *IV,* active movement-control tests, derived from descriptions by Comerford and Mottram (197, 198), were used to evaluate the ability to control the lumbar spine and hip at different loads. These tests were selected due to its clinical use within the SAF marines, and their ability to challenge weak-links in the musculoskeletal system as relevant for the marine occupation. These tests, summarised in Table 4, and described in detail in *study II,* were designed to evaluate the subjects' ability to control specified movements of the lumbar spine, and hip, while introducing loading of the hip/lower back by active movements of the lower legs. The included tests were classified as low and high load/threshold in relation to their postulated muscle activation levels (199), i.e. motor units primary recruited, and which are typically;

- ***Low load;*** non-fatiguing movement-control recruiting primarily slow-twitch motor units (low- threshold) (199, 200), and is often also referred to as motor-control tests (152, 201, 202).

- ***High load;*** movements with high fatiguing loads or speed, recruiting predominantly fast motor units (199, 200).

For the four tests performed in supine position, an air-filled pressure sensor (Pressure Biofeedback Unit, Chattanooga Group, Hixon, TN), developed for clinical monitoring of spinal movements (203, 204), was used to monitor lumbar deviations.

4.4.2.2 Strength tests

In *study IV,* physical tests focusing on muscle strength of the upper body, derived from a physical screening protocol for other units within in the SAF, were used. These tests, previously found to be reliable for use in SAF units (156) similar to the SAF marines were:

- *Kettlebells lift;* The number of "dead lifts" of a pair of kettlebells (2 x 16, 24 or 32Kg) conducted in one minute (156).

-*Pull up*; The maximum number of pull-ups (from hanging with a pronated grip, heaving the chin over the bar) in one sequence (156).

4.4.3 Continuous assessment of work-related physical activity and occupational demands in the training course

Data on occupational physical activity was captured from twenty-one marines from the inception cohort of *study IV*, by body worn tri-axial accelerometer GT3X+BT(Actigraph, Pensacola, FL), complemented by detailed weekly schedules and self-reported diaries covering occupational tasks and equipment worn, and physical training sessions conducted. Detailed information on data reduction are reported in *study IV.*

Table 4. Brief description of the movement control tests, their classification according to "load" and the study they were used in.

Movement control tests	Test classification ("load")	Used in study
The bent knee fall-out (BKFO) test	**Low**	***II***
Test position; Supine lying **Focus of test;** the ability to prevent rotation of the lumbar spine during abduction / lateral rotation of the hip.		
The standing bow (SB) test	**Low**	***II, III***
Test position; Upright standing **Focus of test;** the ability to maintain a neutral lumbar spine position (prevent lumbar flexion) while bending forward at hip to 50° flexion.		
The single leg small knee bend + lunge-lean (SLKB+LL) test	**Low**	***II, III***
Test position; Upright standing **Focus of test;** the ability to prevent flexion, extension, lateral flexion and rotation of the lumbar spine, and control movement of the hips during a lunge (a small knee bend), forward-lean of the trunk and elevation of the rear foot.		
The double leg lift-lower (DLL-L) test	**Low**	***II, III, IV***
Test position; Supine, crook lying (45° hip flexion) **Focus of test;** the ability to prevent extension and flexion of the lumbar spine while simultaneously lifting both feet, and legs to 90° hip flexion and then returning them to the starting position		
The double leg lift-alternate leg extension (DLL-ALE) test	**High**	***II, III, IV***
Test position; Supine, crook lying (45° hip flexion) **Focus of test;** the ability to prevent extension, flexion and rotation of the lumbar spine, and lateral flexion/rotation of the hip, while, firstly, simultaneously lifting both feet and legs to 90° hip flexion, then, one leg at a time, lowering and straightening out the leg to a fully extended position and returning it to 90° hip flexion, and then returning both leg simultaneously to the starting position.		
The double straight leg lower (DSLL) test	**High**	***II***
Test position; Supine, crook lying (45° hip flexion) **Focus of test;** the ability to prevent extension and flexion of the lumbar spine, while lifting both feet and legs to 90° hip flexion, and then, simultaneously, lowering and straighten out the legs to fully an extended position, thereafter returning them to 90° hip flexion, and then returning them to the starting position.		

4.5 OPERATIONAL DEFINITIONS OF MUSCULOSKELETAL PAIN

The occurrence of pain, within the last six months (*study I-III*) or week (*study IV*), was reported for nine anatomical areas (205), based on items used in Swedish public health cohorts, as; "*No pain*", "*Pain a couple a days per month or less*" and "*Pain a couple of days* *per week or more*" (*study I-III*) and "Yes/No" (*study IV*). When rating pain, participants were explicitly requested to further state related limitations in work ability as follow; "*not limited*", "*limited to some extent*" or "*limited to a large extent*". In *study I-IV*, pain was defined as the presence of "any pain", within the region of interest, and related limitations in work ability, in that the pain experience of the specific area, to at least some extent, had limited their work ability.

4.5.1 Outcome definitions

4.5.1.1 Back-/Low back pain

In *study I-III*, back pain, defined as the presence of any low (lumbar) and/or thoracic pain, as illustrated in Figure 6, within six (*study I-III*) and 12 months (*study III*) were used. In *study IV*, LBP was defined as the occurrence of any LBP within the preceding week. For the latter, recurrent events of LBP were analyzed, contingent upon marines not "under risk" for a new episode until pain free the following week, at which point they re-entered the analysis. Focusing primarily on pain, these outcomes could be seen as primarily representing an impact on "*body functions and structures*" according to the ICF framework.

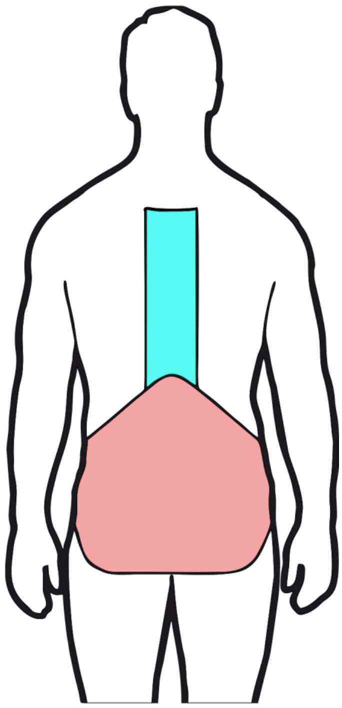

Figure 6 Questionnaire-mannequin illustrating defined anatomical areas for self-report of occurrence of musculoskeletal low back (red) and thoracic back (blue) pain. Adapted Monnier et al. Musculoskeletal pain and limitations in work ability in Swedish marines: a cross-sectional survey of prevalence and associated factors. BMJ Open. 2015;5(10):e007943. based on the regional definitions of Kuorinka et al.(205).

4.5.1.2 Back-/ Low-back pain limiting work ability

For all studies, related limitations in work ability were defined as pain in that specific area that had limited marines' work ability. For *study I* and *III*, marines with back pain limiting work ability were contrasted with marines with no back pain; hence, omitting marines reporting pain but not limiting their work ability in order to obtain distinct groups (cases vs. references) of them experiencing back pain that interferes with their ability to work. Such operationalization of the outcome was not possible in *study IV*, due to the recurrent event analysis used, and therefore marines with and without LBP limiting work ability was used as the secondary outcome. Taking both pain and the ability to conduct work in consideration, these outcomes represent, in addition to the impact on "*body functions and structures",* the execution of activities or interactions in occupational life areas, i.e. representing the "*activity*" as well as "*participation*" domains of the ICF.

4.6 DATA MANAGEMENT

4.6.1 Missing data

Loss of information due to *item* non-response (missing data from some participants on certain items under study) or *unit* non-response (missing data on all items for certain participants) is commonly referred to as missing data (206). In the work conducted in this thesis, only *"illegitimately"* loss of information, i.e. information that should have been present for participants, was considered "true" missing. As such, "*legitimately* " lost information, such as *item* non-response on pain intensity for those reporting no pain days, or *unit* non response, such as lost to follow-up response for those marines that quitted SAF during the course of the study (withdrawals, i.e. marines no longer meeting inclusion criteria's), was not considered as "missing data". Withdrawals were however analysed, as described below, using the same methods used for missing data mechanism as this could constitute valid information regarding the study population (207). For example, in *study III*, younger and non-officer marines, and those with non-musculoskeletal co-morbidity, were more likely to end their employment in SAF marines during the course of the study. While this could have represented a "healthy worker" effect" (208), no difference was identified with regard to MSD history.

For "illegitimately" loss of information, the reason and type of missing data, as well as assumptions of the missing mechanism (209) was analyzed and used to guide management of missing data. Table 5. presents the missing data mechanism for the work in this thesis, and the action taken to handle missing data. Here, data were consider to be *"missing completely at random"(MCAR)* if the reason for data to be missing was not dependent of the missing data itself (i.e. data on back pain not missing as a result of that the participant had experienced back pain), nor predicted by the independent variables included the analysis (206, 209, 210). Here, complete case analysis would likely be valid but consequently limit the power of the analysis. When the loss of information could be predicted by a independent variable from the planned analysis, but not from the variable itself, the missing mechanism was considered as *missing at random (MAR)* (206, 210) or *covariate missing at random (CMCAR)* (209). MAR/CMCAR should preferably be handled by Multiple imputation or Maximum likelihood techniques (206, 209) to represent a good estimate of uncertainty, i.e. correct standard errors (and as such p-values and confidence interval) and make use of all available information (206). The specification of the multiple imputations used in this thesis (in *study III* and *IV*), i.e. creation and analyzing of "*m"* number of completed data sets, by means of regressions, from which inference are based on pooled results, are presented within those papers.

Table 5. Missing data mechanism assumed and method of handling of missing data for regressions in *study I, III-IV*.

	Missing Mechanism	Method to handle missing	
		Complete case analysis	Multiple imputation
Study I		●	
Independent variables	MCAR		
Dependent variables	MCAR		
Study III		●[a]	●[b]
Independent variables	CMCAR		
Dependent variables	MCAR		
Study IV		●[c]	●[d]
Independent variables	MCAR		
Dependent variables	MCAR		

[a] On secondary outcomes (analysis method not supporting multiple imputation)
[b] Multiple imputation by chained equations (m=30) for primary outcomes
[c] ”Complete case analysis” on block 1 (No missing on independent variables)
[d] Markov-chain Monte Carlo (m=50) on block 2.

4.7 STATISTICAL ANALYSIS

Descriptive and inferential statistics used in the work complied in this thesis are presented in Table 6 and summarized below. For detailed information on statistics used, the reader is referred to the method sections of the individual studies of this thesis.

4.7.1 Musculoskeletal pain in Swedish Armed Forces marines

In *study I* the six month prevalence of pain, and pain limiting work ability, were reported as a percentage of the sample, with 95% confidence interval (CI), for the nine specific anatomical areas and four overall regions. Within this thesis, only the most prevalent regions identified are reported on, given its use in the rationale for the thesis.

4.7.2 Occurrence of back pain

4.7.2.1 Back pain prevalence at six months prior to baseline

In *study I,* the six month prevalence, derived from baseline measurements, of low and thoracic back, as well as back (thoracic and/or lower back) pain, and pain limiting work ability, was reported as a percentage of the sample, with 95% CI. For comparative purposes, the prevalence for *study II* and *IV* is also reported in this thesis.

Table 6. Statistics and procedures used in this thesis

Statistics	***Study I***	***Study II***	***Study III***	***Study IV***	***Thesis***[a]
Descriptive					
Counts	•	•	•	•	•
Percentage with CI	•	•	•	•	•
Mean with SD	•	•	•	•	•
Median with IQR	•	•	•	•	•
Inferential					
Prevalence proportions with CI	•	•	•	•	•
Finite population correction factor		•			
Incidents proportions with CI				•	
Incidents rate with CI				•	•
Cohen´s Kappa		•			•
PABAK		•			•
KappaMax					•
Agreement (percent)		•			
Sensitivity/Specificity		•			•
Predictive value					•
Man Whitney u test					•
McNemar		•			
Logistic regressions	•		•		
AikaIke autoregression		•			
Firth Logistic regressions			•	•	
Exact logistic regression	•		•	•	•
A-G recurrent event regressions				•	
Negative binomial regressions					•

[a] Additional analysis in thesis

SD=Standard Deviation; CI= Confidence Interval (95%); PABAK=Prevalence-Adjusted Bias-Adjusted Kappa

4.7.2.2 Difference in pain intensity for marines reporting pain or pain limiting work ability

The Man Whitney U test was applied to baseline data from *study I* to establish whether a significant difference exists for numeric pain ratings of worst and average back and thoracic pain within the past six months for marines only experiencing pain, compared to those experiencing pain that limits their work ability.

4.7.2.3 Pain prevalence from prospective follow-ups

Based on the follow-ups, the six-and twelve-month prevalence, presented as percentage with 95% CI, for the same anatomical areas are presented *for study III*, and for the four-month prevalence of the training course *(study IV).*

4.7.2.4 *Incidence*

The incidence rate, presented as episodes per 1000 person-days with corresponding 95% CI, of low and back (thoracic and/or lower back) pain, and pain limiting work ability, during the training course *(study IV)* was calculated based on number of episodes and time under risk (211). For comparison, these incidence rates were also calculated based on time to first event.

4.7.3 Work-related physical activity and occupational demands

Accelerometer data were analysed for weeks with sufficient wear time, defined as a minimum of 180 minutes per day for 3 days per work week. For valid wear-time, vertical counts per minute (cpm)- based on 10-seconds epochs - were extracted and reported as minutes and percentage of total work time, time with-, and time without, combat load carriage (≥18.5 Kg), in predefined categories: 0-99;100-2019; 2020-5998; and 5999- cpm (212). Here, the category of 2020-5998 cpm was considered to be comparable to slow to brisk walking (~3.8-7.5 km/h) (146, 213).

4.7.4 Analysis of factors associated with back pain

In *study I* and *III*, binary logistic regressions were used to estimate the association between potential risk factors and the outcomes, reported as odds ratio (OR) with corresponding 95% CI. Here, logistic regression based on maximum likelihood was used if not further specified. However, exact logistic regression and Firth (penalized likelihood) logistic regressions were used when appropriate, for example when low expected frequencies (<5) or risk for separation was present in the data (214, 215).

In *study IV* the association of the outcome with potential risk factors was examined using the Andersen-Gill repeated time-to-event regression method (211, 216). In this regressions model, discontinuous risk intervals (211) were used with the robust sandwich variance estimator (217), allowing for recurrent outcomes per participant and presented as hazard ratio (HR) with 95% CI. While using different regression methods, all studies used the "purposeful selection process" (215, 218), described below, to select variables for inclusion in the final model.

Additional analysis; To validate the accuracy of the selected discontinuous risk intervals in *study IV*, the model build was repeated using a negative binomial regression model, including exposure time. If no time-depending independent variables were included in the Andersen-Gill repeated time-to-event regression, a negative binomial model could be expected to yield similar results, whilst not taking time to event in consideration (219).

4.7.4.1 *Regression model building*

Variables for the final multiple regression models were selected by an iterative ("manual stepwise") process aiming to identify a final, well fitting model containing only significant independent variables, interactions and confounders (215, 218). At the first step, the selected independent variables were analyzed by univariate regressions (in *study I* adjusted for comorbidity). Independent variables associated with the dependent variable, at the level of $p<0.20$ (*study I* and *III*) or $p<0.25$(*study IV*), were included in a multivariable regression model. Thereafter followed an iterative process of deleting non-significant variables, $p > 0.05$, or non-confounding variables, including "a priori" consider confounders and variables not significant at the initial univariate regressions, and then refitting and verifying the model. This generated a preliminary main effects model, for which interactions between the variables in the model, between variables in the model and confounders and between variables in the final model and omitted variables (if plausible from a clinical perspective) were examined. Interactions were retained in the model at a significant level of $p<0.05$. Before interpreting the results, adequacy and good fit were reassessed for the final models (209, 215, 218, 220-222).

4.7.5 Measures of reliability and discriminative validity

4.7.5.1 Inter-and Intra observer reliability

The level of chance-adjusted inter- and intra-observer agreement was determined by calculating kappa coefficients with 95% confidence intervals. The confidence interval was based on the adjustment of variance for the sample size in relation to the finite SAF marine population (223), at the time of data collection. To guide interpretation, the standards proposed by Landis and Koch (224) were used for interpreting and reporting of kappa coefficient, as the percentage of agreed observations for each test, and overall agreement between, and within, the two observers and test occasions. A McNemar analysis was applied to identify any systematic differences between tests occasion one and two.

Additional analysis: To guide the interpretation on how the prevalence distributions affected chance-adjusted agreement, prevalence adjusted-bias adjusted kappa (PABAK) (179) was applied on agreements between and within observer A and B for test occasion1 and 2. Furthermore, maximal attainable kappa was calculated, given the marginal distributions of agreements between and within observer A and B for test 1 and test 2, i.e. Kappa Max. This was calculated to aid the interpretation of agreement levels (177).

4.7.5.2 Measures of discriminative validity

The discriminative validity of the movement control test in *study II* was investigated by identifying the best fitting combination of test/s for back pain during the past six months. For this, a best subset auto regression, based on the Akaike information criterion (AIC), was used on data, from both observers, on test session one. The AIC equation aims to "penalize" larger models (221), especially when adding variables that are not significantly associated with the dependent variable. Furthermore, for purposes of clinical value, the final model was decided to include a maximum of three tests. For this thesis, sensitivity, specificity, positive/negative predictive value and OR of the associations, based on exact logistic regressions, are presented for the best fitting combinations of tests.

5 RESULTS

Table 2 presents demographic characteristics as well as self-rated general health of the marines included in the respective studies. Good or excellent current health status was reported by 94-96% of the participants at baseline, with a mean (SD) score of mental health (MI-5) of 85.1 (11.1) out of a possible 100 (*study I*) and mean (SD) of 1.8(1.6), out of a possible 12, according to the GHQ-12 (*study IV*).

5.1 MUSCULOSKELETAL PAIN IN SWEDISH ARMED FORCES MARINES

In *study I*, musculoskeletal pain - somewhere in the body - was experienced by 78% of the active duty marines within a six-month period, with 50% of marines reporting that pain affected their work ability, to some extent. The overall regions most frequently reported to experience pain were the back (low- and/or thoracic back) and the lower extremity (hip and/or knee and/or foot) regions. With about the same prevalence, 36 and 35% respectively, the low-back and knee emerged as the most prevalent reported pain- specific anatomical areas.

5.2 OCCURRENCE OF BACK PAIN

5.2.1 Prevalence

5.2.1.1 Back pain within six months prior to baseline

As presented in Figure 7, pain in the back (the lumbar and/or thoracic back) within six months prior to baseline measurements was common for both active duty marines (*study I-III*), ranging from 46-55%, and marines participating in the training course (*study IV*), at 26%. Figure 7, also illustrates the pain prevalence of the lumbar and thoracic back within six months prior to baseline.

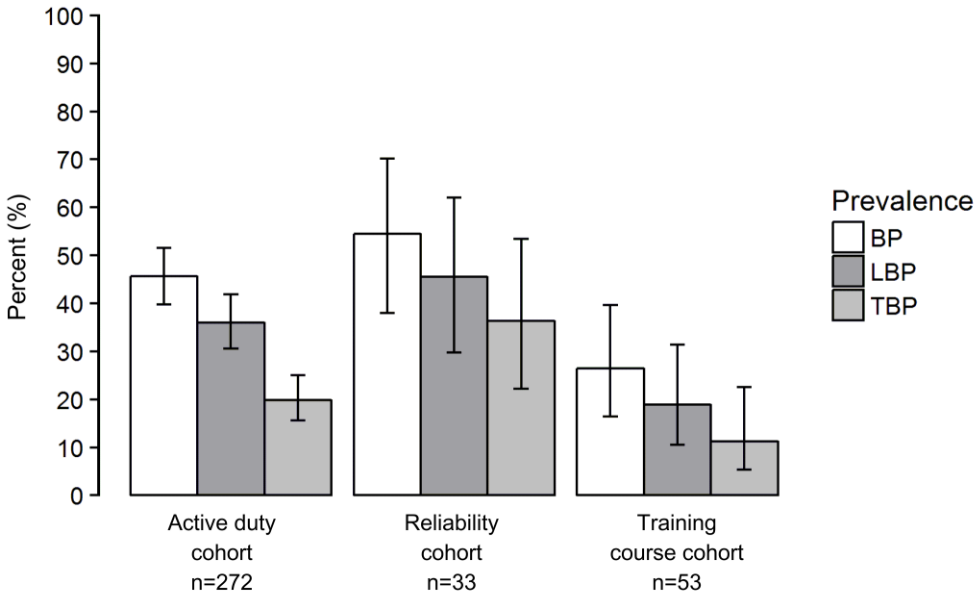

Figure 7. Back pain (BP), low back pain (LBP) and thoracic back pain (TBP), with 95% CI (error bars), within six months prior to baseline for the three cohorts in the studies.

5.2.1.2 Difference in pain intensity between active duty marines reporting pain and pain limiting work ability

Figure 8 presents average pain within the six months prior to baseline for marines reporting only pain, and marines further reporting related limitations in work ability in the lumbar and thoracic back. Here, marines experiencing back pain related limitations in work ability rated significantly higher on the numeric pain ratings for average (pain/pain limiting work ability, *mean*;1.3/2.3, *median*;1/2, p<0.001) and worst (p<0.001) LBP, as well as average (pain/pain limiting work ability, *mean*;1.4/3, *median*;1/3, p=0.002) and worst (p=0.002) thoracic back pain.

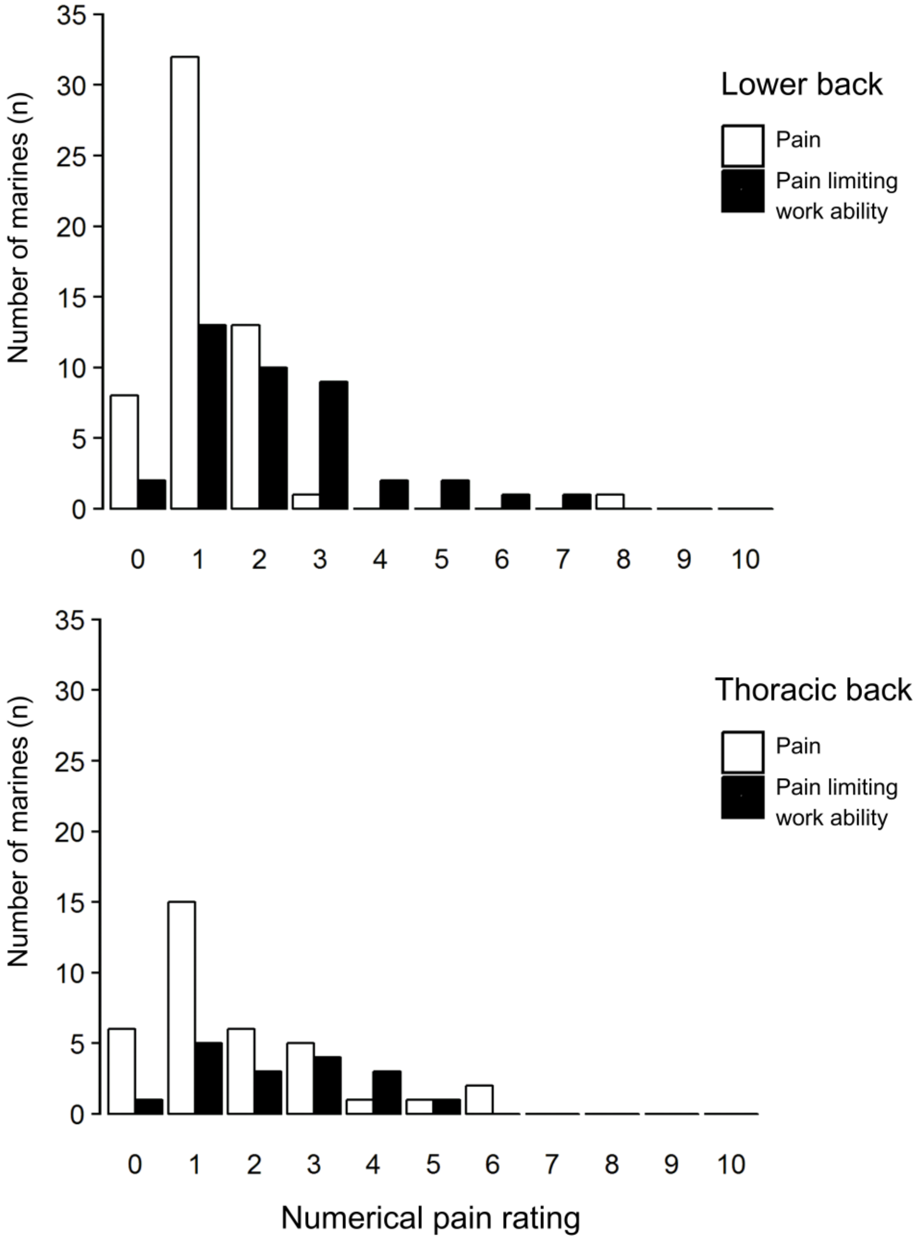

Figure 8. Number of marines reporting pain in the lower and thoracic back pain, compared to marines reporting pain that further limited work ability, presented per level of the numeric pain rating.

5.2.1.3 Pain prevalence from prospective follow-ups

Figure 9 presents the prevalence of back, lumbar and thoracic back pain and pain limiting work ability based on the prospective follow-ups carried out in *study III* (active duty rangers, infantry and combat craft crew marines) and *IV* (marines in the training course*)*. Here, the highest prevalence was reported during the four months of the marine training course, where 79% of the participants reported back pain, of whom 70% experienced LBP. Every other marine reporting pain further rated that it affected their work ability.

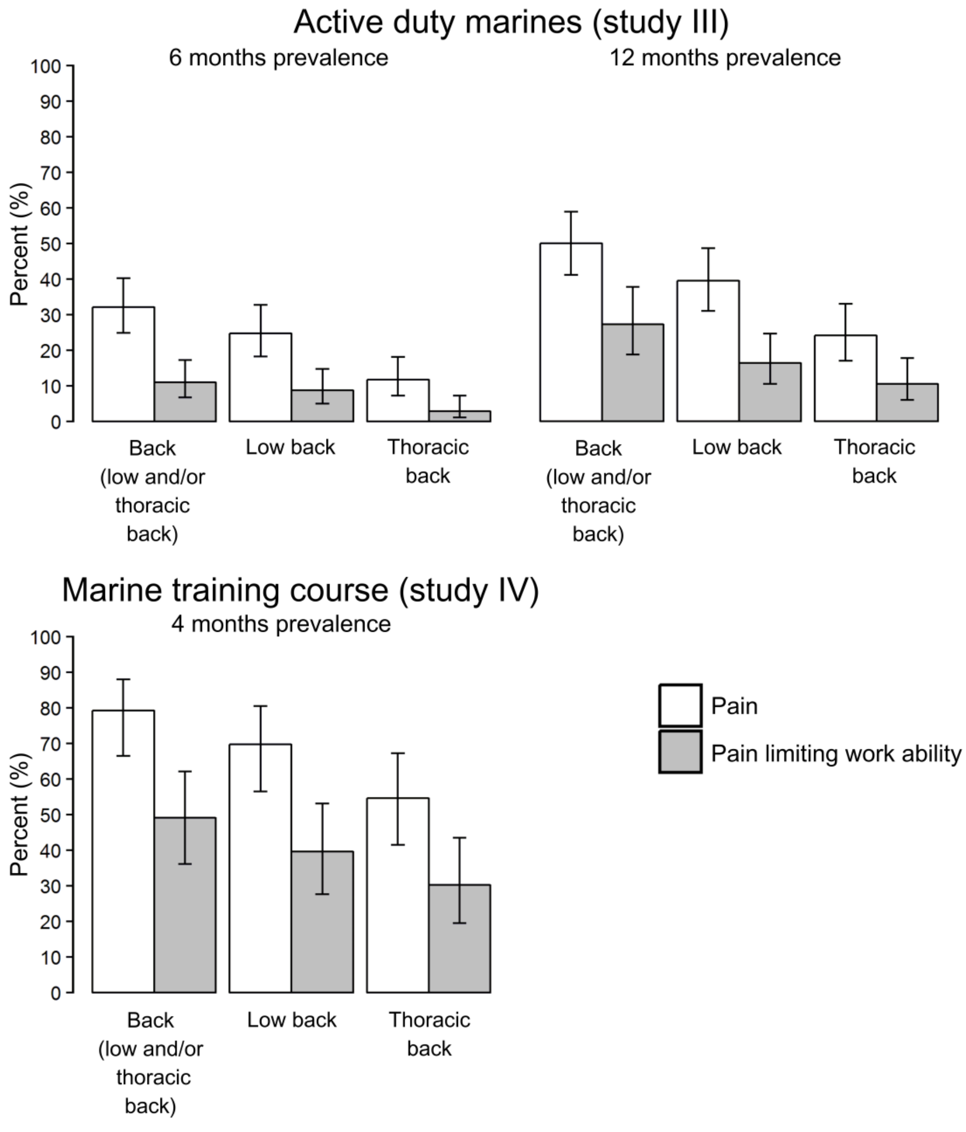

Figure 9. The prevalence of back, lumbar and thoracic back pain, and pain limiting work ability, within 6- and 12 months for active duty rangers, infantry and combat craft crew marines, and within four months for marines in the training course. Prevalence is reported as percentage with error bars indicates 95% confidence intervals.

5.2.2 Incidence of low back pain during the marine training course

At the end of the fifth week of the training course (*study IV*), one third of the marines had experienced at least one new episode of LBP, and one out of four an episode that had limited their work ability. Figure 10 presents the incidence rate for LBP and LBP limiting work ability per 1000 person days. For comparison, Figure 10 also includes incidence rates based on time to first LBP episode. The corresponding incidence rate for back pain (thoracic and/or lower back), based on recurrent events, during the course was 18.6 (95% CI 14.9-23.5) episodes per 1000 person days

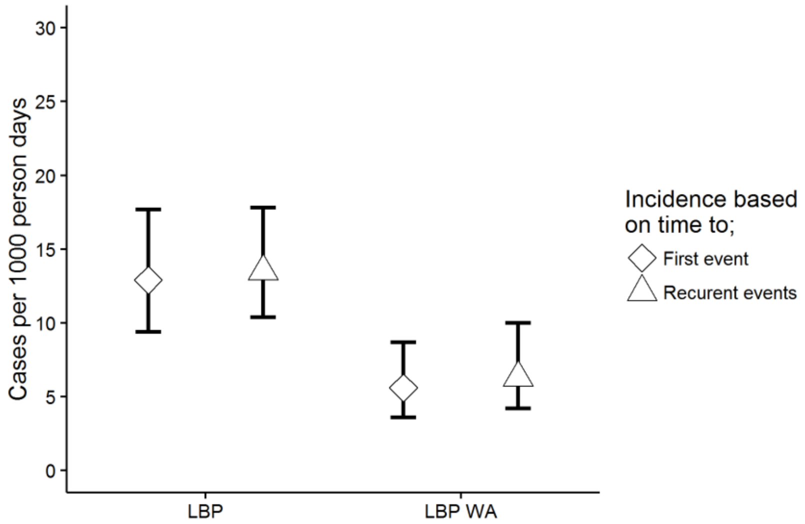

Figure 10. Episodes of LBP, and LBP limiting work ability (WA), per 1000 person days during the marine training course, reported for analyses based on recurrent events as well as based on time to first event, with 95% confidence intervals (error bars).

5.3 WORK-RELATED PHYSICAL ACTIVITY AND OCCUPATIONAL DEMANDS DURING THE MARINE TRAINING COURSE

Analyzing body worn accelerometer data, course schedules and logs, covering five of the 16 weeks of the marine training course, indicated that ambulation was modest (<2020 counts per minute) for most of the course times, but with, in average 73 minutes of the work day to be spent in moderate to vigour's ambulation (≥2020 counts per minute), not including planed prolonged ruck-marches, combat obstacle course- or aquatic-training sessions. Combat equipment (>18.5 Kg) was worn for more than 50% of the work time, relatively even spread within the weeks but with relatively large variation between weeks, spanning from four to 94%.

5.4 IDENTIFIED RISK FACTORS

5.4.1 Back pain

From the regressions analysis individual, health- and work-related risk factors for back pain were identified for active duty marines, and for LBP in marines during the training course. Table 7 presents the results of the final regression models for back pain within six and 12 months (*study III*) and LBP within the training course (*study IV*).

The most consistent risk factors were a previous back pain episode, which emerged as risk factor for back pain within six and 12 months in active duty marines, and for LBP for marines in the training course. Further, being among the taller marines (≥1.86m) emerged independently associated with back pain in active duty marines, while being among the shorter 1/3 of marines (≤1.80m) emerged as a risk for LBP during the training course. Here, performing less than four pull-ups also emerged as a risk for LBP.

5.4.1.1 Additional analysis

Previous back pain (incidence rate ratio 2.54, 95% CI 1.39-4.66) and shorter body height (incidence rate ratio 2.06, 95% CI 1.17-3.64) emerged as risk factors for LBP during the training course also when analyzed with negative-binomial regression models.

Table 7. Factors significantly associated with back pain (BP) and low back pain (LBP), reported as adjusted relative estimates (odds ratios (OR) or hazard ratios (HR)) and 95% confidence interval (CI).

	Study III				**Study IV**	
	BP within 6 months		**BP within 12 months**		**LBP within the MTC**	
	OR	95% CI	OR	95% CI	HR	95% CI
Demographic characteristics						
Body height; ≤1.80m					2.0[a]	1.2-3.3
Body height; ≥1.86m	2.8	1.2-6.8	2.8	1.2-6.3		
Health history						
Previous back pain	3.0	1.2-7.3	6.8	2.3-19.8	2.5[a]	1.4-4.3
Previous lower extremity pain	2.3	1.0-5.2				
Work related						
Sitting work	2.8	1.1-7.3				
Clinical tests						
Double leg lift-lower	0.3	0.1-0.8				
Pull-ups					1.9[b]	1.2-3.0

[a]Adjusted for sex, [b]Adjusted for body height and previous back pain

5.4.2 Back pain limiting work-ability

From the regressions analysis individual, health- and work-related risk factors for back pain limiting work ability were identified for active duty marines, and for LBP limiting work ability in marines during the training course. Table 8 presents the results of the final regression models for back pain limiting work ability within six (*study I, III*) and 12 months (*study III*), and LBP limiting work ability during the training course (*study IV*). Body height emerged associated with the outcomes in all three studies. However, while being among the taller marines (*study I* and *III*), or shorter marines (*study I*), emerged independently associated with back pain limiting work ability in active duty marines, while only being among the shorter 1/3 of marines (≤1.80m) emerged as a risk for LBP during the course (*study IV*). Back pain within the previous six months emerged as risk factor for back pain within 12 months in active duty marines (*study III*), and for LBP for marines in the training course (*study IV*). While no clinical tests emerged associated, the variable '*few weekly physical training sessions' w*as associated with back (*study I*) and low back pain limiting work ability (*study IV).*

Table 8. Factors significantly associated with back pain (BP) and low back pain (LBP) limiting work ability, reported as adjusted relative estimates (odds or hazard ratios) and 95% confidence intervals.

	Study I		**Study III**				**Study IV**	
	BP limiting work ability within 6 months		**BP limiting work ability within 6 months**		**BP limiting work ability within 12 months**		**LBP limiting work ability within the MTC**	
	OR	95% CI	OR	95% CI	OR	95% CI	HR	95% CI
Demographic characteristics								
Body height; ≤1.80m	5.0	1.6-15.1					4.5[c]	2.0-10.0
Body height; ≥1.86m	4.4	1.4-14.1	4.3[b]	1.3-14.1	4.6	1.5-13.6		
Health history								
Previous back pain	n/a				6.6	1.8-24.8	3.6[c]	1.4-8.9
Physical training(>20 minutes);								
≤1 days per week	5.3	1.7-16.8						
≤2 sessions per week							3.0[c]	1.2-7.4
Work related								
Computer work;								
>1/4 of work day	3.2	1.0-10.0						
>1/2 of work day	3.3	1.1-10.1						
Combat craft crew			5.9[b]	1.6-21.8				

[a]Adjusted for comorbidity (non-musculoskeletal), age and BMI, [b]Adjusted for previous back pain, [c]Adjusted for sex and neck/shoulder pain previous to course start

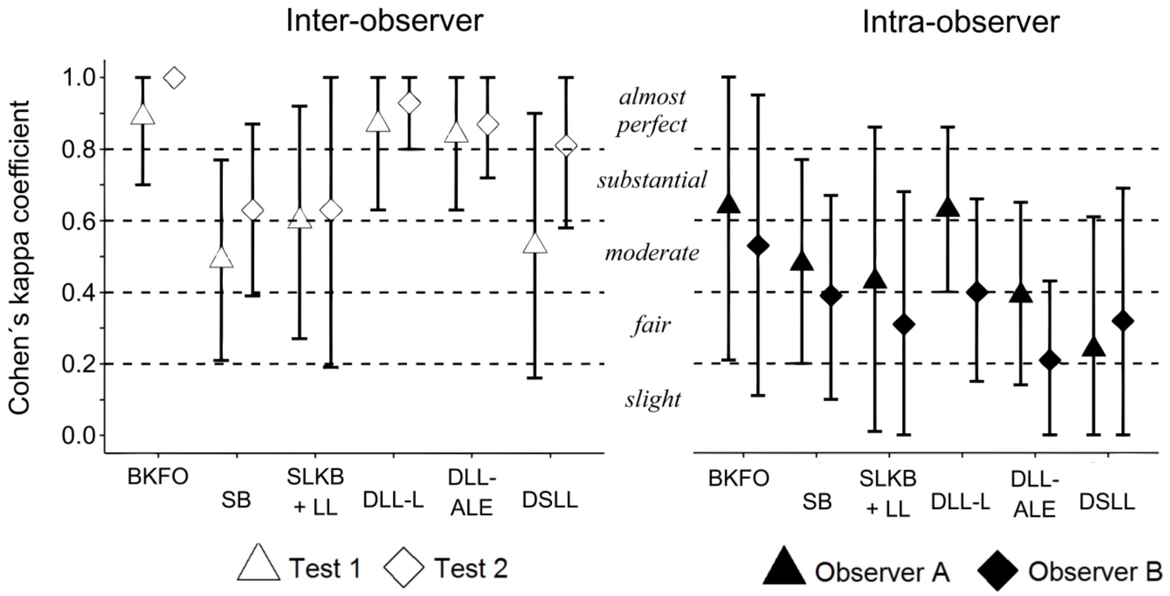

Figure 11. Inter-and intra-observer reliability presented as kappa coefficient, with 95% confidence intervals (error bars) and the strength of agreement according to the standards of Landis and Koch (224).

5.5 CLINICAL TESTS; RELIABILITY AND DISCRIMINATIVE VALIDITY

5.5.1 Reliability

Figure 11 presents the inter –and intra observer reliability of the movement control tests from *Study II*, and Table 9 the Prevalence Adjusted Bias adjusted kappa and Max possible Kappa for the given marginal distributions. The inter-observer reliability was fairly good on both occasions, with the averaged kappa coefficient reaching the level of "almost perfect" and the rest "substantial" or upper part of "moderate", by the standards of Landis and Koch (224). However, intra-observer reliability showed over all lower kappa coefficients, and, worth noting, lower level of the 95% CI not reaching 0.2 for the majority of the tests. For two of the tests, the DLL-L (observer B) and the DLL-ALE (observer A and B) significant more marines improved their results from test 1 to test 2.

5.5.2 Discriminative validity

Table 10 presents summary measurements of the discriminative validity of back pain within the previous six months, for both observers on the two tests that were included in the best fitting test combination, as well as summary measurements of validity for those final models.

Here, the BKFO and DSLL model discriminated prior back pain (observer A; OR 13.6, observer B OR 7.0) if the BKFO test was passed and the DSLL test failed. This was also consistent with the direction of the risks for both BKFO and the DSLL, i.e. a protective effect when failing the BKFO test and an increased risk when failing the DSLL test. Taken the distribution of back pain in consideration, passing BKFO and failing DSLL would indicate a 68-71% probability of having experienced back pain within the past six months.

Table 9. Inter-and intra-observer reliability presented as kappa coefficient and Prevalence Adjusted Bias adjusted kappa (PABAK) and Max possible Kappa (Kappa Max) for the given marginal distribution.

Inter-observer reliability	**Test 1**			**Test 1**		
Tests	Kappa	PABAK	Kappa Max	Kappa	PABAK	Kappa Max
Bent knee fall-out	0.89	0.94	0.89	1.0	1.0	1.0
Standing bow	0.49	0.52	0.87	0.63	0.63	0.75
Single leg small knee bend + lunge-lean	0.6	0.76	0.8	0.63	0.88	1.0
Double leg lift-lower	0.87	0.82	0.94	0.93	0.94	0.93
Double leg lift-alternate leg extension	0.84	0.88	0.84	0.87	0.88	0.87
Double straight leg lower	0.53	0.76	0.77	0.81	0.82	0.82
Intra-observer reliability	**Observer A**			**Observer B**		
	Kappa	PABAK	Kappa Max	Kappa	PABAK	Kappa Max
Bent knee fall-out	0.64	0.88	0.64	0.53	0.81	0.53
Standing bow	0.48	0.50	0.87	0.39	0.38	0.75
Single leg small knee bend + lunge-lean	0.43	0.75	0.72	0.31	0.63	0.54
Double leg lift-lower	0.63	0.63	0.63	0.40	0.38	0.52
Double leg lift-alternate leg extension	0.39	0.38	0.51	0.21	0.13	0.33
Double straight leg lower	0.24	0.56	0.68	0.32	0.56	0.90

Table 10. Summary measurements of discriminative validity of previous back pain, at a 55% prevalence, presented as percentage with 95% CI for test separately and combined (grey)

	Sensitivity % (95% CI)	**Specificity** % (95% CI)	**Positive predictive value** % (95% CI)	**Negative predictive value** % (95% CI)
Observer A				
BKFO (*fail*)	5.6 (0.1-27.3)	73.3 (44.9-92.2)	20 (0.51-71.6)	39.3 (21.5-59.4)
DSLL (*fail*)	100 (81.5-100)	26.7 (7.8-55.1)	62.1(42.3-79.3)	100 (39.8-100)
BKFO (*pass*) DSLL (*fail*)	94.4 (72.7-99.9)	46.7 (21.3-73.4)	68.0 (46.5-85.1)	87.5 (47.3-99.7)
Observer B				
BKFO (*fail*)	5.56 (141-27.3)	66.7 (38.4-88.2)	16.7(0.421-64.1)	37(19.4-57.6)
DSLL (*fail*)	88.9 (65.3-98.6)	26.7 (7.79-55.1)	59.3 (38.8-77.6)	66.7(22.3-95.7)
BKFO (*pass*) DSLL (*fail*)	83.3 (58.6-96.4)	60 (32.3-83.7)	71.4 (47.8-88.7)	75(42.8-94.5)

6 DISCUSSION

While constituting a relative young, primarily male occupational population, with, as identified in the present work, overall high general and mental health, MSDs that tend to limit work ability has for some time been perceived as a fairly common epidemiological and clinical problem in active duty marine communities (4, 20, 34). Therefore, the work presented in this thesis focused on establishing research evidence necessary for building MSD prevention for SAF marines. The approach involved three studies using observational methodology, at different stages of their military career, supported by a methodological study on clinical tests, as planned and gradually learned in a translational perspective (180). Results from the early phase showed that the low back was the most prevalent pain region (together with the knee). Important risks for back pain, both related to the person and work, were identified, underlining the multi-factorial origin of back pain and the importance of considering all dimensions affecting, or mediating back pain (112, 115). Given that previous back pain episodes were among the strongest, and most recurrent factor, associated with new episodes throughout the studies, systematic secondary back pain prevention is advocated for, to limit individual ill-health and retain high physical capacity and operational readiness in this occupational group.

6.1 FINDINGS

6.1.1 Occurrence of back pain

Considering the knowledge on LBP occurrence (47), it was somewhat surprising that the relative young, primarily male, full-time employed and physical active population of active duty marines reported LBP to the same extent as the average global 12 month pain prevalence (47), with the addition of thoracic pain prevalence in the size of those reported from civilian manual labourers (225). For active duty marines, low- and thoracic back pain affected work ability in approximately two out of five marines reporting pain. The proportion of thoracic back pain limiting work ability reported here is higher than civilian reports (52).

From the present results, it seems that the occurrence of both low and thoracic back pain is higher for marines in the ”marine training course”, compared to its active duty colleagues (*study I* and *III*), SAF recruits in basic training (2), other military cohorts (36) and civilian society alike (47). This could indicate the presence of a “healthy worker effect” (226) within the SAF marines, i.e. that the “younger workers” appear to be at greater risk compared to those remaining among the more seasoned workers. Here, the latter would represent the active duty marines that have remained in their trade, as they have been spared from back pain, i.e. representing those potentially more resilient to developing back pain. This reasoning could however be challenged, since an association between older age and the occurrence of back pain, (99, 102, 158) and MSDs (13, 14, 36), within military populations has been established.

The close follow-ups (123, 133), outcome definitions, i.e. self-reported pain (50), as well as analytical methods used (allowing for recurrent events) (227) in *study IV* will favour higher reported occurrence, as compared to studies with longer follow-up intervals, reviews of medical records, and analytics using only time to first back pain episode. Despite this, the overall occurrence of LBP appears high in comparison with other military cohorts. Based on the results from the present thesis, back pain that limits work ability could be assumed to represent a more severe form of back pain, i.e. higher pain ratings and activity limitations. This type of back pain could therefore be more comparable to reports that are based on medical records. Nonetheless, the 50% prevalence of back pain limiting work ability experienced during the training course, are of the same magnitude as any MSDs experienced by recruits in somewhat similar courses internationally (14, 21, 27). In addition, the incidence of 5.6 episodes per 1000 person days (based on time to first episode) of LBP limiting work ability is in the same size range as any MSDs reported internationally for recruits in general basic training (11, 15, 17, 19, 20), and one-and-a-half to three times more common than any MSDs for other active duty military personnel (28-32).

One potential explanation for the high reported occurrence of LBP during training could be related to the amount of load carriage throughout the course (addressed under 6.1.2). Here, the reported lower and thoracic back pain could reflect pain experienced while wearing heavy equipment, but that resolves after de-loading, as reported by the Israeli military (228). Such pain behaviour would likely be considered as pain, i.e. "*...an unpleasant experience... potentially related to tissue damage" (41),* but seemingly not be of the kind worth seeking medical attention for, and as such would not be reflected in studies of medical records.

For active duty marines, low- and thoracic back pain is reported to affect workability in 35 and 25% of the cases in six months (41 and 44% over 12 months respectively), compared to 57% and 55% of the cases in the four month training course. Accordingly, this may indicate that marines in this course have work tasks that are more affected by back pain, or that active duty marines have adapted to the occupational demands. It could also indicate a larger amount of flexibility for active duty marines to adapt their daily service to their current health status. The latter would exemplify how the context of work could affect ratings of "activity-limiting pain" within the military context (126). These results indicate, nonetheless, in contrast to civilian reports (52), that low and thoracic back pain affect work ability in approximately the same ratio (i.e. between pain and pain with activity limitation within the specific anatomical region).

Given that one-fifth of the active duty marines reported to have, within six months, experienced limitations to work ability due to back pain (*study I*), this may affect the overall operational readiness of SAF marines, and as such would motivate health protection efforts. Any incident of non-battle injuries that results in a reduction of the ability to work in one single marine may increase the work load for the rest of the unit, as seen in other military units (7). This could illustrate how organizational demands, i.e. in this scenario that the work task needs to be carried out regardless of available resources (i.e. regardless of the number of healthy marines), and social context, i.e. the acceptance by the marines to “take on” additional loads, may interact by increasing the overall exposure for the rest of the unit. This may potentially also increase their risk for back pain (113, 115).

The high prevalence of back pain reported within six month prior to baseline (*study I, III, IV*), together with the high occurrence during the marine training course, indicates active duty marines to be suitable targets for secondary prevention rather than primary prevention (defined as prevention of first ever back pain). It seems that a truly ‘initial’ episode of back pain is rare in those marines entering the marine training course, as a large fraction is likely to have experienced back pain within their preceding basic military training (2) or during their adolescence years (229).

6.1.2 Work-related physical activity and occupational demands during the marine training course

The data on occupational physical activity, covering approximately 30% of the marine training course, indicated modest ambulation for most of the course times, but with episodes of moderate to even vigorous ambulation occurring during work time. It is important to note that combat equipment (>18.5 Kg) was worn for more than 50% of the work time, and also during moderate to vigorous activities. It is paramount to consider this factor very carefully since operational load carriage has been associated with back pain and MSDs among deployed soldiers (99, 109, 158).

While both deployed soldiers and marines in training are likely to be wearing combat loads, sometimes continuously over a work shift, deployed soldiers may have higher levels of ambulation (primarily due to foot patrols (109)), whereas the training course includes a lot of teaching, briefings and observations. However, modern infantry assaults (e.g. military offensive movement, at foot, to engage and overtake enemy) also constitute of periods where ambulation is of moderate to low intensity, but with bursts of very high intensity movements, all while wearing combat loads. For example, an “standardised” dismounted assault task, lasting from 5 to 10 minutes, is conducted with a movement-to-standstill ratio of 1:4 (230), i.e. first covering ground by foot, with all equipment on, followed by an approximately three times as long period of standing, sitting or lying whilst covering movement or engaging with the enemy. Here, an increase load will, in addition to affecting tactical combat performance (231, 232), likely increase the load demands of the soldiers. While this could be associated with the development of back pain, either by itself or by accumulating load over time, more research is required since it has not yet been examined for other military populations, neither in this work.

The present results are also of interest, from an overall MSDs preventive planning perspective, to guide a sufficient, but still safe, progression of load carriage for marines in training. Here, in contrast to the authors’ expectations, the load carriage in the US Army´s basic military training was identified to be sufficiently lower than expected, both in context of physical ambulation and worn loads (233). If this would also be the case within the basic military training in the SAF (i.e. the training preceding the marine training course), the progression of load would, in contrast to recommendations (8), be very steep for those marines coming directly from that course (~50%) into the marine training course, and would as such constitute a risk for developing MSDs. Hence, it should be of interest to continuously monitor load progression from the basic training and throughout the continuous training of active duty marines.

6.1.3 Risk factors for back pain

The present results identified some specific, potentially modifiable, risks for back pain, such as being part of a combat craft crew, or work tasks such as occupational sitting, computer work and lack of physical training. Here, occupational driving (105) has been found to be related to back pain in other military populations as well, while such exposures like sitting (85, 234) and computer work (235) is, currently, not considered causally associated. While occupational sitting could represent low occupational physical activity (138), which may in itself be linked to the development of LBP (143), it might also indicate that some risk factors might be generic across civilian and military trades. Other risks seem to remain occupation-specific or represents of a combination of exposures, for example prolonged sitting with either body worn equipment, whole body vibrations and/or awkward postures.

Three risk factors emerged consistent through both the active duty- and marine training course cohorts, and are addressed bellow;

Previous back pain; In line with many studies on civilian and military populations, back pain (lumbar or thoracic) within the previous six months emerged as a risk for a new episode within the following six, and 12 months in active duty marines (*study III*), and for a similar episode of LBP in marines attending the training course (*study IV*). Importantly, these results continue to emerge as significant risks when adjusted for pain in other body regions, which may indicate that back pain is primarily specific to the anatomical region in its association with new episodes. Still, pain in other areas showed tendencies (significant at univariate level, but not when adjusted for previous back pain) to also be associated with back pain, with previous pain in the lower extremities (hip, knee or foot) emerging to be significantly and independently associated with back pain within six months in active duty marines. Plausible, but not yet addressed in this work, is for such previous pain to mediate future back pain by reducing physical capacity or training ability in marines that are affected. Given no statistical evidence for an effect measure modification between pain in different regions in the present studies; however, this would indicate potential differences in the underlying pathophysiology for back pain. In addition to ”central” effects of pain, such as pain hypersensitivity (236), it could also reflect remaining deficiencies of specific lumbar structures (or combinations of structures) such intervertebral discs, joints, ligaments, muscles, nerves or fascia (44).

Further exploration of this phenomenon is important, both from a clinical perspective, i.e. to guide treatment and secondary preventive measures, but also in an effort to delineate underlying pathways to back pain. Here, a clinical important step, as a first attempt to understand the complexity of back pain in this population, would be to address the time frame after a pain episode during which the risk is increased. While the present results indicate that an event window of at least six months needs to be considered, other studies conducted on deployed personnel have not specified duration since the last episode (99, 109), or even shown any association with a 12-month retrospective event window leading to new episodes of back pain(102). On the other hand, civilian studies has shown that adolescences experiencing back pain have an increased susceptibility to back pain during adulthood (229). The risk seems to increase with proximity in time (237) as well as by pain duration (229, 237). However, to effectively address such alteration within the risks of back pain in SAF marines, it is believed that analysis needs to be based on prospective data collected with very frequent follow-ups, in order to control for variations in competing exposures.

Body height: In the present studies, body height consistently emerged as a risk factor for back pain, or back pain limiting work ability, but with some discrepancies between the studies. *Study I* identified both the shortest and the tallest of the marines, i.e. those with a statue of 1.80m or less and those 1.86m or taller to be at greater risk for back pain limiting work ability. In *study III*, the tallest marines were at increased risk, whilst only the shortest marines showed increased risk during the training course. While differences in outcome definitions, sample size and analytics may explain these variations, other explanations need to be considered as well.

Firstly, the study sample in *study I* represented all military functions in the Amphibious Battalion, and *study IV* was limited to the direct recruitment base. *Study III* included a sub-sample of the Battalion, constituting of those marines most likely to be exposed to heavy sustained body worn loads (*infantry* and *rangers*) or prolonged time in operating combat crafts (*combat craft crews*). Hence, the participant from *study III* might have been exposed to potential risks for a longer duration which might interact with body height to induce back pain in the present context. Here, marines in the training course, i.e. in the beginning of their trade, might not yet have accumulated exposure time, for example in marine crafts (e.g. boat, cars, armoured personnel carriers), to exceed the potential ”safe” limit for interaction with tallness, as suggested for other work related interactions (238-240).

This discrepancy between the studies could potentially also represent a result of the introduction of new personal equipment (in the time between the studies), such as individually adjustable webbings and height adjustable back-packs, to the marines in the training course. Hence, with load-reducing functions fully functioning also for the tallest marines, and as such distributing the majority of the packs load from the shoulders to the hips (241), the risk for this group during the training course might have been attenuated. Still, this does not explain why shorter marines emerged at increase risk of back pain. While Walsh and colleges (80) identified the overall risk of LBP to increase with height, of those exposed to occupations with heavy physical loads (heavy lifting and digging) the shortest men showed the highest relative risk, indicating an interaction with specific work exposures. Body height as a risk for back pain is neither consistently reported in the literature from the general populations. This could indicate that these risks are reinforced in the presences of specific work exposures, such as high physical loads (80) or prolonged exposure to ergonomically unfavourable positions, potentially not fully accounted for in large population cohorts, hence not reflected in their exposure-outcome associations (240).

Physical training: Given the knowledge gained from numerous military studies (1, 98, 100), the results from *study I* and *IV*, identifying low weekly sessions of physical training to be associated with back /low back pain limiting work ability was not unexpected. While the direction of temporality could not be established in *study I*, hence not being able to differentiate whether the exposure preceded the effect, *study IV* used a prospective longitudinal design, where the results were also adjusted for sex and previous back, neck and shoulder pain. These results may therefore have the potential to serve as evidence to establish a causal link.

Taken together, these results emphasize the need to also promote regular physical exercise for elite military personnel such as the SAF marines, both as primary (242) and secondary preventive actions against back pain (243). Still, the present results regarding specific strength or aerobic fitness training habits did not assist in identifying which type of exercises is most beneficial from a preventive perspective. Yet, strength training has both been advocated for to improve soldiers' operational physical capacity (155), and proven useful in treating LBP (244). These beneficial effects could as such be considered a potential active ingredient in such a preventive program.

General- and mental health: Noteworthy to mention, none of the studies in the present work identified an association between measures of general- or mental-health and the outcomes. While the presence of MSDs has been associated with both reduced mental and general wellbeing among veterans and those never deployed alike (245), the SAF marines reported consistently high levels of general health (*study I, III,IV*), health-related quality of life (*study I, III,IV*), and low indices for mental distress (*study IV*). These results corroborate with reports from the US Marines and British Marine Commandoes, highlighting higher general mental health and lower level of psychiatric disorders for both non-deployed marines and those that had been exposed to combat (246, 247). One explanation is that the largest fraction of marines with mental ill-health are identified early in the basic training, and as such creates a "healthy warrior effect"(246), which would bias any comparison with other populations, civilian as well as military (208). While a risk for selection bias (further discussed under 2.6.6.1) exists when comparing results with general populations, the generalization of such a phenomenon to the SAF is however questionable, given the joint basic military training for recruits of all arms of the SAF (Army, Air Force and Navy (including Marines)).

6.1.4 Clinical tests

Movement control ability and core stabilization have been advocated for, both related to improving soldiers' physical function and as preventive measures (101, 248, 249). While showing good inter-observer reliability, the results from this thesis do, however, not support the use of any of the movement control tests under study to predict future back pain episodes in marines. Despite its popular clinical application, these results are in line with a few studies from the military population addressing the predictive validity of these types of tests for MSDs and back pain (27, 250). While the results on discriminative validity from *study II* adhere to those from previous studies that are in support of previous pain episodes leading to deficiencies in movement control (150, 151, 251), the results from *study III* and *IV* do not add any evidence in support of such deficiencies to be sensitive for back pain prediction in this population, which further hold for other core-stability or movement screening tests in the military (23, 27, 250).

Instead, tests of upper body strength, both proven to be associated with LBP in male marines under training (*study IV*), related to load carrying capabilities (157) and important for overall physical soldiering capacity (155, 156), might be more useful in a clinical screening battery used in prevention of back pain in marines. Nonetheless, specific parts of the reliability and validity results, from the examined movement control tests, are worth some further elaboration, as presented below.

6.1.4.1 Reliability of movement control tests

The results from *study II* indicate that ratings of marines performance in test used to screen movement control of the back and hip, has high chance-adjusted agreement between two independent observers, i.e. inter-observer reliability. However, when these tests are used in follow up interventions, i.e. for a repeated measure, the lower reproducibility yielded (intra-observer reliability) should be considered. Given that the inter-rater reliability showed high agreement between observers at both test occasions, this indicates that the variability leading to reduced intra-observer reliability may be related to variations within the participants' performance. Such a significant improvement between test occasions was indeed proven for two of these tests (*study II*). This could be one of the reasons why these results differ from other studies of intra-observer reliability testing of movement control where better intra-observer agreement is reported (252, 253). However, these studies made use of repeated video recording ratings of one occasion, i.e. omitting both the participants' variability as well as changing the context of ratings to a standardized two-dimensional view not normally used in clinical practice. The high inter-observer results from both test occasions in the present study indicate that such an approach would likely have raised the intra-observer kappa coefficients, but at the cost of the limiting transferability to clinical practice.

Another factor seemingly affecting the variability within the performance of the participants in the present work might, to some extent, reflect a learning effect from the initial test to the re-resting of the test performance. Here, more "training rounds" before each test could have resulted in a more stable performance. However, trade off would then have been between familiarization and total testing time. Furthermore, by including more feed-back on the test performance, one might at the same time risk to reduce the tests ability to predict LBP, as seen for other similar functional screening tests commonly used in military context (254).

However, if the predicted validity so strongly depends on the unfamiliarly of the test, its clinical use may be questioned.

While the kappa coefficient should represent the level of chance-adjusted agreement, it is by design prone to be affected by the prevalence of tests results. That is, if most people fail a tests, the observer are more likely to incorrectly categorize a subject as “failing” the test, in comparison to a situation where a 50-50 distribution of pass and fail exists (175). This is seen in the present results of intra-observer reliability, showing far better agreement for the BKFO, SLKB+LL and DSLL test when kappa statistics are based on a “theoretical” optimal prevalence and bias distribution. Interestingly, given the marginal distribution of pass/fail, the kappa coefficient for BKFO tests emerged as high as it possibly could be, potentially indicating its suitability for use in other contexts.

6.1.4.2 Validity of movement control tests

The focus of discriminative validity analysis in *study II* was to identify the simplest, yet the most sensitive and specific combinations of test, and not to address the sensitivity and specificity of each test separately. This was intended to reflect clinical practice where clinical conclusions are often based on combinations of information, some highly sensitive and some highly specific, rather than results from a single test. This is often also a solution for screening tests used in other medical contexts, where combinations of different markers are necessary (255). For this purpose, a “best subset stepwise regression model” was used.

While the AIC auto-regression is suggested to have the ability to accurately identify tests that are associated with the dependent variable, and at the same time provide the simplest, most parsimonious model, the present analyzes may have been affected by its low power (215), and as such lead to over fitting of the model that may increase the risk for a type I error. Furthermore, as proven by the present results, this model does not take the direction of the association of selected variables into consideration. This could be considered beneficial, as the model is not restrained by the researchers’ pre-assumptions, and as such, able to identify associations not previously considered. For example, the “protective effect” of both the BKFO test and the DLL-L test was not expected in *study II*, but the results showed similarities with the movement control tests association to the outcomes in *study III* and *IV*. Even so, before future use of this analysis to identify the best combinations of tests (with regard to sensitivity and specificity), potentially in conjunction with anamnestic information, one should, in accordance with the research question, pre-specify if all models should be evaluated. That is, should all models be interpreted, or should just those answering a very specific hypothesis, such as *“ when failing all included tests…”*, be considered.

As previously addressed *in study III*, notably, failing the “lighter” DLL-L test showed a surprising protective effect against back pain within six months. While not reaching significance at p=0.05, when addressed as a pass/fail dichotomy, the relatively “heavier” DLL-ALE test indicated an increased risk of back pain. These results have later been further confirmed by our research group when analyzed for specific movements, instead of a global assessment of several movements (*Monnier et al. in manuscript*), which could indicate abdominal muscle strength to have an important role in LBP prevention for this group of marines.

Reversing this statement: "*any exercise that grooves motor patterns, that ensure a stable spine, through repetition, constitutes a stabilization exercise*" by McGill and colleagues (256), high load movement control test could potentially be seen as a test of muscle strength, if sufficiently loaded. This would also be in line with the conclusion of the authors of a recent randomized controlled trial, where improvement of LBP was seen for both the "low load motor-control" exercise training arm and the "high load" strength training arm (257).

While the present work does not address the use of movement, motor control or core stability training from a back pain treatment perspective, it is, to date, to some extent, considered the "go to" treatment for people suffering from back pain and therefore deserve some brief attention here.

Based on how motor-/ movement-control or core training is defined, there are some evidence that motor control training, believing to target deep muscles, may have some additional effect in comparison with "general exercise", (258, 259) or minimal "intervention"(260) in the treatment of long-lasting LBP in the general populations. In more recent evidence synthesis, however with broader definitions of "core or stability training", stability exercise shows only additional improvement over general exercises within a shorter time frame, with no additional benefit in the long term (261). Still, core training might constitute a feasible treatment in sub groups of the heterogeneous back pain population and should therefore be considered.

The present results align with previous research on military personnel, where core stability is advocated for as a preventive measure, despite no obvious improvement over other training regimes targeting trunk muscles (262, 263). On the other hand, one could argue that since training regimes focusing on core stability give the same physical results as "classic" sit-up training (249) and traditional trunk strengthening exercise programs (262), it might be used equally well if better suiting the receiver.

6.2 ETHICAL CONSIDERATIONS

Several ethical issues have been considered in relation to the execution of the present studies. Those of most importance are therefore briefly addressed below.

Informed consent to participate: While it is considered one of the fundaments of "*the World Medical Association established recommendations guiding medical doctors in biomedical research involving human subjects* ", i.e. the *"Declaration of Helsinki",* participants in biomedical research are entitled to receive detailed information about the research they are asked to participate in, including the option to end their participation at any time. This, however, needs to be further considered in the military context. Given the nature of the military trade, where “orders” are natural part of work delegation, “volunteering” for research might be seen as a demand of the marines. Confidentiality as well as voluntary participation, including information (written as well as oral) on the option to end participation at any time, have therefore been heavily stressed during recruitment and enrolment for all work included in this thesis. Furthermore, data collection was conducted in such a way that “non participation” was not noted by commanding officers.

Risk of inflicting bodily harm at baseline clinical and physical testing: Conducting physical tests, especially when measuring max capacity, always include a risk of adverse effects and bodily harm. The tests under study were however regularly used in the SAF, with no known complications. The research protocol was planned to further minimize such risks, which was achieved by including systematic testing procedures (detailed instructions, warm-ups, recovery between tests, equipment and facilities used) and available medical resources in the case of adverse effects. Furthermore, participants in *study IV* were only allowed to do the baseline tests, during the first two weeks of the course, in an attempt to avoid maximal testing in combination with the progressive load of the course.

Revealing personal information: This might be experienced as intrusive by the respondents. Here, the confidentiality of data handling was stressed. With the exception of self-rated health status, the questionnaires contained no questions of sensitive nature. It is nonetheless possible that completion of the questionnaire could trigger thoughts about the risks of an individual’s health when serving as a marine. However, marines are trained and encouraged by their commanders to continuously perform risk assessments and to correctly evaluate their own “operational capacity”, and those reflections could as such be seen as increasing the marines’ “health literacy”(264) with regard to MSDs.

Imaginary over vulnerability and unrealistic optimism in regards to back pain; In accordance with the key assumptions of the “health believe theories” (265), an individual’s response to a potential threat of ill-health are largely affected by its prevalence and believed severity. If so, the result from the present work might, if exaggerating the extent and consequences of back pain, affect the marines perceived health status or their willingness to conduct certain work tasks. It could also potentially make marines with certain characteristics feel less vulnerable to back pain than others (266), and as such putting them in harm’s way. In the present work, efforts have been made to clearly describe methods and definitions used, in order to make it perfectly clear what has been evaluated, and as such limiting the exaggeration or underestimation of problems.

6.3 METHODOLOGICAL CONSIDERATIONS

Several methodological issues should be considered in relation to inference of the present results. These issues concern both to what extent these findings can be generalized to other populations or contexts, i.e. its *external validity*, as well as to how confident we can be in the study results, i.e. its *internal validity*.

6.3.1 External validity

The results in this thesis primarily extend to SAF marines on active national duty and in training. Still, the present results are believed to extend to other cohorts of light mobile infantry as well, given similar operational tasks and demographic characteristics (34, 267).

Given an equal MSD history and overall physical training habits for men and women in the present studies, one cannot assume that women are at greater risk for back pain than men only based on sex, aligned with results from other military cohorts (110, 268). Neither do results from civilian general populations support attributing occupational-related back pain to sex, but rather indicate that certain occupations, primarily conducted by women, have a high incidence of back pain (90). Hence, in order to represent the population of SAF marines, female marines were retained in all studies except for *study III,* where they were excluded based on statistical reasons (too few in this marine sub-population meeting the inclusion criteria and, as such, too few to control for a potential confounding effect). While this is in line with the distribution within the SAF marines, female marines still represent a relative small proportion of the cohorts, and the results might therefore mainly be driven by male marines. This should be considered when inferring the results to other military cohorts with higher proportions of females.

6.3.2 Internal validity

The trustworthiness of emerging results relies heavily on study design and its execution, definitions and assessments used, and information included or not included. While numerous definitions exist, thus giving rise to many types of deviations of the truth, so called bias, those of most concern in the present studies will be addressed here as related to; *selection, information* and *confounding* (269). For the latter I also address the potential effect of chance and unmeasured exposures on the present results. Since some of the methodological considerations regarding *study II* has already been addressed in the text above, the focus here will be on the epidemiological *studies I, III-IV*.

6.3.2.1 Selection bias

Study design: The epidemiological studies in the present work *(study I,III,IV*) included one cross-sectional design and two prospective observational designs. While the cross-sectional design enabled large coverage of the marine population, and as such, provide good estimations of the overall burden of MSDs and back pain, interpretation of the temporal sequence of identified associations were limited. *Study III* used a longitudinal design, with follow-ups at six and twelve months and focused on a sub cohort of marines. While aligned with the research focus of that study, this might constitute a risk for *selection bias* if results are generalized to all SAF marines. The prospective approach used permitted temporal exposure- outcome identification, such as allowing the examination of a previous pain episodes and its association with new episodes. However, the follow-up window of two six-month periods limited the analytic approach to “naive” multiple regression techniques (227), and, as such, potentially not fully reflecting the recurrent nature of back pain. Still, the selected follow-up periods replicate the “natural” intervals for different health appraisal within the SAF, and by cohering to the clinical reality the ecological validity of the results is strengthened. *Study IV* included the recruitment base of all parts of the SAF marines, with the weekly follow-ups making it possible to further model the recurrent nature of back pain, as well as taking the overall weeks affected by the disorders into account.

Missing data: Longitudinal studies based on self-reported outcomes, and not retrospective revision of medical records, need to consider the effect of lost to follow up of participants on the study results. If outcome data were systematically missing, this loss of outcome information could threaten the validity of the results, primarily by increasing the risk of falsely identifying an exposure as a risk factor, i.e. inducing a type I error. While, in *study III*, 16% and 24% of data for marines were missing at six- and 12-month follow-up, respectively, analysis gave no indication of data missing *“not at random”*, as recommended to assess before handling missing data (209, 270). Therefore, the main concern of the missing data in this instance is likely its reduction of analytic power.

Furthermore, a separate analysis of baseline characteristics for those marines excluded during the course of the study (due to leaving their employment), as suggested by Osborne (207), did not reveal any significant changes with regard to prior MSDs, which subsequently reduces the likelihood of a *selection bias* in the sample analysed. Still, marines experiencing back pain before the first follow-up could have transferred to other, physically-less exposed positions within SAF or the civilian society, potentially reducing the association of related risk factors with the outcomes (271), and risking to include a “healthy workers effect” if comparing the results to the overall general populations (208). The inclusion of only “marines at work” would also constitute a *“healthy worker effect*” risk if the results were generalized to all marines, or general populations. However, this issue is likely very modest in the present studies, given the very low sickness absenteeism (0,7%) within the SAF during the time of data collection (272).

Study IV had moderate levels of missing data on the outcomes. Still, 23% – 30% of the marines did not perform the two “heavy” physical strength tests. Here, multiple imputations were used in order to reduce unnatural reduction of variance in the sample. Even so, given that none of the female marines performed these tests, this could potentially have affected the inference of the results, assuming that none of the females included would have been able to pass the test. However, no relevant change in the results emerged from the sensitivity analyses that were based solely on men, indicating the validity of the present results for interpretation at the very least among male marines that were healthy enough to conduct these tests at the start of the course.

6.3.2.2 Information bias

Design: Study II used a test-retest approach with participants repeating the tests after 7-10 days, and as such included the important aspects of variability, i.e. related to *the observer*; *the* *instrument* / *measuring procedure*, and *the subject* tested (172), that could influence measurement reliability.

Outcome definitions: Throughout the studies in this thesis (*study I-IV*), pain outcome was defined as “any self-reported pain episode” for the specified area. This might seem too inclusive, in comparison to a pre-set cut-off based on averaged pain ratings (126). This was elected based on the perception that this population is prone to underestimating MSD occurrence and intensity, as seen in similar military populations (123). Nonetheless, the results of the present thesis suggest that the outcome of pain limiting work ability, included in *study I*, *II* and *III,* represents both an activity limitation and higher pain ratings, compared to “only” pain reported for the primary outcomes.

Merging lumbar and thoracic back pain for reporting prevalence as well as for use as an outcome of associated factors in *study I* and *III,* as seen in other studies on military personnel (158), was primarily based on clinical experience related to this population. I believe that there is a lower risk of recall bias for “back pain” in comparison to specifically distinguishing between lower and thoracic back for the preceding six months. For the same reason, the independent variable “back pain within the previous six months”, used in *study III* and *IV,* was classified accordingly.

The definition of a new event in this study stands in contrast to the suggestion that four pain-free weeks should pass before a pain experience should be considered a “new event”(55). However, aligned with the aims of the study, here a “new episode” only represented the transition from a pain-free state to a state of pain. As discontinues risk was used in *study IV* to reflect the duration of a pain episode during the course, marines experiencing pain for more weeks contributed fewer “event free” weeks under risk. Given an average of three pain free weeks in between two pain episodes in the present study, only counting “episodes” that were preceded by four-pain free weeks, i.e. a “wash out period” until they are considered at risk again, would constitute a severe overestimation of the LBP episodes impact on the course. Furthermore, the same independent risk factors emerged significant by the negative binomial regressions models, as with the recurrent event models, with only slightly attenuated risk estimates. This indicates that the discontinuing risk definition used in *study IV* accurately reflects the weeks with and without LBP during the training course.

Exposure assessment: Cases and non-cases were addressed the same way regarding self-ratings of occupational exposures, and as such limiting the risk of *differential misclassification.* On the other hand, marines experiencing pain might have rated those exposures they perceived to be associated with their pain to occur more frequently, as seen for other occupational cohorts (141).

The majority of self-rating items used to quantify the exposures in *study I* and *III* have been validated for use within Swedish general/occupational populations (164-166, 168, 169), and other parts of the SAF or other military cohorts (65). They have however not been specifically validated for SAF marines. While most of the questions used to cover general exposures, such as time spent with occupational sitting and time exposed to whole body vibrations or computer work, could be considered as generically designed, others might not capture marine-specific exposures. For example, the questions used covering "load handling" primary concerns load handled with the hands and not further specifying if the load was body worn, nor the duration and or activity during load carriage. Still, the complexity of this exposure might better be captured by combining information of the task conducted and equipment used, with objective measurements of ambulation.

In *study IV,* body worn accelerometers were used for this purpose, and to quantify and describe the common exposure of the cohort. Still, for logistical and safety reasons, only part of the course could be covered. Inference of results might therefore not be representative of the whole marine training course, but yet give valuable insights on the locomotion and load carriage during the course. For the complex military context, objective measures have shown to give more valid information than direct observations (148), which are normally considered to be more accurate within occupational epidemiology. Still, while a few studies have quantified physical occupational activity with objective measures, a lack of consensus still exists on what measures to use in order to correctly reflect the military reality. Given the complex nature of soldiering, a combinations of different sensors and/or subjective reports are likely necessary (147, 148), with longer episodes of monitoring, compared to civilian populations (273), if habitual occupational physical activity is to be sufficiently captured.

Self-reported anthropometric factors are logically also less accurate than objective measurements. However, self-rated body height (274) and weight have been found "accurate enough" to be included in epidemiological observational studies (275), with the trend of overestimation of body height and underestimation of body weight. Given these variations, the chance exists that body mass index will be underestimated (276). The use of the "standard" BMI categorization for overweight has however been suggested to be invalid for physically well-trained individuals, given the larger amount of muscle mass affecting the weight/height relation, and as such is of limited use within the present studies (277).

6.3.2.3 The effect of chance, sample size, confounding and unmeasured exposures.

While sample size may be a direct restriction when analyzing risk factors by multiple regressions, each of the present studies included more than 90% of the eligible marine sub-population in focus. However, caution has been taken to avoid over-fitting of statistical models (278) by including putative risks that are only based on empirical or scientific evidence (209, 215), applying researcher controlled model-building strategies (215, 218) and analytic methods suitable for our sample size (214). In addition, the model-fit and assumptions of all final models, in accordance with recommendations (209, 215, 218, 220, 222), has been carefully examined before inference of the results. Nonetheless, the effect of the sample size on precisions of the estimate is reflected in the somewhat wide confidence intervals, especially for the secondary analysis that was based on small sample regressions in *study III.* Furthermore, given multiple hypotheses testing during the model building process, single findings and borderline significant risks should be interpreted with caution.

While the analytic methods in *study IV* made use of the close follow-up design, the small sample size limited the full use of the recurrent event models, by reducing the numbers of variables suitable to include in the model. Given the multi-factorial origin of back pain, a wide variety of putative risk factors needed to be addressed, limiting the use of adjustment for time dependent confounding, such as co-occurring knee pain. This would likely have the most impact if such competing risk would have reduced the marines' participation in the course, and as such potentially limit the risk for developing work-related LBP. As such, it could constitute a risk for *differential misclassification*. While this could have been avoided by including the results from more than one training course, the homogeneity of the work-related exposures from only one course was deemed more important for the present aims.

While the present studies made use of multivariate techniques to adjust for confounding, the sample size limited exploration of effect measures modification and mediation beyond 2-way statistical interactions, hence limiting further exploration of mechanisms behind the identified risk factors. Still, no such interactions emerged significant during these analyses, despite the models were considered to have sufficient statistical power.

In my own opinion, unmeasured potential risks or confounders constitute the largest threats to the internal validity of the present studies. Hence, non-identification of a mediating exposure and an effect measure modification or a statistical interaction, might limit the inference about the mechanism behind LBP. Furthermore, unmeasured confounding could in the worst case lead to false identification of risk factors, inflated risk estimates and, as such, bias inference. While we have no way of insuring that this is not the case in the thesis, much effort has been made to include all relevant potential risk factors and to identify and test putative confounders and plausible interactions. As such I believe the primary effect of this is the reduced ability to fully explore the pathways to back pain for the identified independent risk factors.

6.4 CLINICAL IMPLICATIONS

The Marine commander is obligated, by the Swedish "Work Environment Act", to inform the marines about the potential health consequences of their trade. However, this needs to be done in such a way that it also supports the long term development of musculoskeletal health literacy among the marines. Hence, the knowledge gained needs to be communicated in such a way that the message is clear and understandable to marines, leaving no room for misinterpretation and misuse.

6.4.1 Occurrence of back pain

Given the relative high back pain prevalence identified for different parts of the marine occupation, the consequences on operational readiness need to be considered by SAF marine commanders at every level. To do so, access to medical personnel with updated knowledge of military MSD epidemiology and the characteristics of the marine occupation alike is a necessity to handle back pain when it is occurring. Furthermore should the role of trained "replacements" be considered, given that the ordered tasks will be executed regardless of specific unit's health status.

6.4.2 Risk factors associated with back pain

The present results identifie some specific risks for back pain, such as being part of a combat craft crew, or work tasks, such as occupational sitting, computer work, lack of physical training or insufficient upper body strength, that might be reduced by correct planning, i.e. *primary prevention,* or interventions, i.e. *secondary prevention*.

Even so, the risk factors consistently emerging for both cohorts of this thesis, i.e. body height and a history of previous back pain, need to be considered as *"non modifiable"* risks. At least until its role in back pain aetiology, potential interactions with certain parts of the marine occupation and equipment, or how it is mediated to finally cause back pain are further unravelled. One problem that exists, until the specific pathways to back pain are clarified, is that it does not inform the clinician what deficiencies to address. As such, the current use is limited to identifying "*individuals at risk*" (279), i.e. marines at increased risk for back pain due to their personal characteristics or health history.

Avoiding to hire persons presenting with these risk characteristics is however not likely to be an effective solution, which is also reflected in current perceptions among civilian occupations (280). First, the estimates of these risks for back pain are considered small-to-moderate, and not yet established for other MSDs of concern, such as knee, foot or shoulder pain. Neither has the association with work performance been explored for these risks, which could potentially be contradicting risk for back pain. For example, if marines possess certain characteristics to perform their work at a high level, they might also be exposed to such tasks more than other marines, and as such increase the risk of back pain. Hence, not employing such a marine would adversely affect operational ability.

Marines with identified risk characteristics, especially with a history of back pain, are however to be considered as candidates for closer monitoring, systematic medical examination, further research of the mechanism behind the risk factor and, if indicated, early secondary preventive actions, in order to reduce the effect on operational readiness. Still, what these preventive measures should include are still to be researched.

The identified risk characteristics needs also to be considered in the ongoing human factors integration work in the SAF, for example by ensuring that new equipment works as intended for all types of marines, regardless of physical characteristics

6.5 FUTURE RESEARCH

While the work conducted within this thesis may have helped fill some of the knowledge gaps covering the "identification phase" of back pain in marines, it has further identified important areas for future research necessary for the continuing the development of effective evidence-based preventions of MSDs within the SAF marines.

There is a need for

- exploration of the pathways to back pain in marines, by addressing interaction and mediation of individual characteristics, occupational physical activity and military-specific work exposures. This is likely most beneficial if conducted within an international collaboration.
- further identification of the occurrence and risk-factors for MSDs, starting with the knee.
- the use of prospective study designs and analysis mirroring the reality of MSDs and the nature of the complex military profession, by allowing incorporation of both trajectories of pain, its consequences and the variations in exposures over time.
- methods for field based, objective quantification of occupational physical activity and load.
- identification and validation of clinical useful tests, reflecting relevant marine-specific capacities
- controlled trials focusing on preventive exercise interventions and its effect on occurrence of musculoskeletal/back pain ("response"-phase according to the *public health model* (180))for active duty marines and before entering the marine training course. Such interventions needs to be design as to accommodate individual physical capacities, health- and physical training history, as previously shown to be key-aspects in military exercise interventions (190).

7 CONCLUSIONS

- MSDs are common in active duty SAF marines, with back and knee identified as most commonly reported regions of pain.
- Back pain is common among both active duty marines and marines in the training course, which limits work ability in every other case.
- Back pain limiting work ability should be seen as a more “severe” form of back pain, which represent higher pain ratings as well as activity limitations in SAF marines.
- A history of previous back pain seems to be primarily an anatomically region-dependent risk for new episodes, which may have implications for future prevention.
- Pain history and demographic characteristics can be used to identify marines at risk, suitable for further examination and secondary preventive actions, but its relationship to specific work exposures remains unclear.
- Marines with few weekly sessions of physical training, or marines presenting with insufficient upper body strength at the beginning of the training course, should be addressed with targeted physical training.
- Movement control tests of the back and hip do not seem to be valid for inclusion in back pain screenings for marines.
- Given the role of previous back pain as a risk for new pain episodes, together with a high occurrence of back pain before and during the marine training course, preventive actions for back pain in the basic military training are warranted.

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9 REFERENCES

1. Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: Surveillance, research, and prevention. Am J Prev Med. 2000;18(3):54-63.

2. Larsson H, Tegern M, Broman L. Rekrytering, urval och uppföljning. Första året med frivilia soldater. Solna: Karolinska Institutet, Instution för neurobilogi, vårdvetenskap och sammhälle. , 2013.

3. Cohen SP, Brown C, Kurihara C, et al. Diagnoses and factors associated with medical evacuation and return to duty for service members participating in Operation Iraqi Freedom or Operation Enduring Freedom: a prospective cohort study. The Lancet. 2010;375(9711):301-9.

4. Hayton J. Reducing medical downgrading in a high readiness Royal Marine unit. JR Army Med Corps. 2004;150:164-7.

5. Patzkowski JC, Rivera JC, Ficke JR, et al. The changing face of disability in the US Army: the Operation Enduring Freedom and Operation Iraqi Freedom effect. J Am Acad Orthop Surg. 2012;20:S23-S30.

6. Sanders JW, Putnam SD, Frankart C, et al. Impact of illness and non-combat injury during Operations Iraqi Freedom and Enduring Freedom (Afghanistan). The American journal of tropical medicine and hygiene. 2005;73(4):713.

7. Skeehan CD, Tribble DR, Sanders JW, et al. Nonbattle injury among deployed troops: an epidemiologic study. Mil Med. 2009;174(12):1256-62.

8. Bullock SH, Jones BH, Gilchrist J, et al. Prevention of physical training–related injuries: recommendations for the military and other active populations based on expedited systematic reviews. Am J Prev Med. 2010;38(1):S156-S81.

9. Luttmann A, Jäger M, Griefahn M. Preventing Musculoskeletal Disorders in the Workplace. WHO (World Health Organization).Geneva; 2003.

10. Cohen SP, Nguyen C, Kapoor SG, et al. Back pain during war: an analysis of factors affecting outcome. Arch Intern Med. 2009;169(20):1916.

11. Grier TL, Morrison S, Knapik JJ, et al. Risk factors for injuries in the US Army Ordnance School. Mil Med. 2011;176(11):1292-9.

12. Knapik JJ, Brosch LC, Venuto M, et al. Effect on injuries of assigning shoes based on foot shape in air force basic training. Am J Prev Med. 2010;38(1):S197-S211.

13. Knapik JJ, Graham B, Cobbs J, et al. A prospective investigation of injury incidence and injury risk factors among Army recruits in military police training. BMC Musculoskelet Disord. 2013;14(1):32.

14. Knapik JJ, Graham B, Cobbs J, et al. A prospective investigation of injury incidence and risk factors among army recruits in combat engineer training. J Occup Med Toxicol. 2013;8(1):5.

15. Knapik JJ, Sharp MA, Canham-Chervak M, et al. Risk factors for training-related injuries among men and women in basic combat training. Med Sci Sports Exerc. 2001;33(6):946-54.

16. Linenger J, West L. Epidemiology of soft-tissue/musculoskeletal injury among US Marine recruits undergoing basic training. Mil Med. 1992;157(9):491-3.

17. Taanila H, Suni J, Pihlajamäki H, et al. Musculoskeletal disorders in physically active conscripts: a one-year follow-up study in the Finnish Defence Forces. BMC Musculoskelet Disord. 2009;10(1):1.

18. Taanila H, Suni J, Pihlajamäki H, et al. Aetiology and risk factors of musculoskeletal disorders in physically active conscripts: a follow-up study in the Finnish Defence Forces. BMC Musculoskelet Disord. 2010;11(1):146.

19. Taanila H, Suni JH, Kannus P, et al. Risk factors of acute and overuse musculoskeletal injuries among young conscripts: a population-based cohort study. BMC Musculoskelet Disord. 2015;16(1):1.

20. Trone DW, Cipriani DJ, Raman R, et al. Self-Reported Smoking and Musculoskeletal Overuse Injury Among Male and Female US Marine Corps Recruits. Mil Med. 2014;179(7):735-43.

21. Wyss T, Von Vigier R, Frey F, et al. The Swiss Army physical fitness test battery predicts risk of overuse injuries among recruits. The Journal of sports medicine and physical fitness. 2012;52(5):513-21.

22. Jones SB, Knapik JJ, Jones BH. Seasonal variations in injury rates in US Army ordnance training. Mil Med. 2008;173(4):362-8.

23. O'Connor FG, Deuster PA, Davis J, et al. Functional movement screening: predicting injuries in officer candidates. Med Sci Sports Exerc. 2011;43(12):2224-30.

24. Havenetidis K, Kardaris D, Paxinos T. Profiles of musculoskeletal injuries among Greek Army officer cadets during basic combat training. Mil Med. 2011;176(3):297-303.

25. Havenetidis K, Paxinos T. Risk factors for musculoskeletal injuries among Greek Army officer cadets undergoing Basic Combat Training. Mil Med. 2011;176(10):1111-6.

26. Sharma J, Greeves JP, Byers M, et al. Musculoskeletal injuries in British Army recruits: a prospective study of diagnosis-specific incidence and rehabilitation times. BMC Musculoskelet Disord. 2015;16(1):1.

27. Wunderlin S, Roos L, Roth R, et al. Trunk muscle strength tests to predict injuries, attrition and military ability in soldiers. J Sports Med Phys Fitness. 2015;55(5):535-43.

28. Hauret KG, Jones BH, Bullock SH, et al. Musculoskeletal Injuries:: Description of an Under-Recognized Injury Problem Among Military Personnel. Am J Prev Med. 2010;38(1):S61-S70.

29. Knapik J, Ang P, Reynolds K, et al. Physical fitness, age, and injury incidence in infantry soldiers. J Occup Environ Med. 1993;35(6):598-603.

30. Smith TA. The incidence of injury in light infantry soldiers. Mil Med. 2002;167(2):104.

31. Wilkinson DM, Blacker SD, Richmond VL, et al. Injuries and injury risk factors among British army infantry soldiers during predeployment training. Inj Prev. 2011;17(6):381-7.

32. Knapik JJ, Spiess A, Grier TL, et al. Injuries and Physical Fitness Before and After Deployments of the 10th Mountain Division to Afghanistan and the 1st Cavalry Division to Iraq, September 2005-October 2008. the US Army Center for Health Promotion and Preventive Medicine, 2008 . TECHNICAL REPORT NUMBER 12-HF-05SR-05

33. Reynolds KL, Heckel HA, Witt CE, et al. Cigarette smoking, physical fitness, and injuries in infantry soldiers. Am J Prev Med. 1993;10(3):145-50.

34. Hollingsworth D. The prevalence and impact of musculoskeletal injuries during a pre-deployment workup cycle: survey of a Marine Corps special operations company. J Spec Oper Med. 2009;9(4):11.

35. Lynch JH, Pallis MP. Clinical diagnoses in a Special Forces Group: The musculoskeletal burden. J Spec Oper Med. 2008:76.

36. Roy TC, Knapik JJ, Ritland BM, et al. Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. Aviat Space Environ Med. 2012;83(11):1060-6.

37. Roy TC, Ritland BM, Knapik JJ, et al. Lifting tasks are associated with injuries during the early portion of a deployment to Afghanistan. Mil Med. 2012;177(6):716-22.

38. Glad D, Skillgate E, Holm LW. The occurrence and severity of musculoskeletal disorders in Swedish military personnel during peacekeeping operations in Afghanistan. Eur Spine J. 2012;21(4):739-44.

39. Jones BH, Perrotta DM, Canham-Chervak ML, et al. Injuries in the military: A review and commentary focused on prevention. Am J Prev Med. 2000;18(3, Supplement 1):71-84.

40. Schmidt CO, Raspe H, Pfingsten M, et al. Back pain in the German adult population: prevalence, severity, and sociodemographic correlates in a multiregional survey. Spine (Phila Pa 1976). 2007;32(18):2005-11.

41. "Part III: pain terms, a current list with definitions and notes on usage" (pp 209–214) Classification of chronic pain, second edition, IASP Task Force on Taxonomy. Merskey H, Bogduk N, editors. Seattle: IASP Press; 1994.

42. Balagué F, Mannion AF, Pellisé F, et al. Non-specific low back pain. The Lancet. 2012;379(9814):482-91.

43. Allegri M, Montella S, Salici F, et al. Mechanisms of low back pain: a guide for diagnosis and therapy. F1000Research. 2016;5.

44. Vora AJ, Doerr KD, Wolfer LR. Functional anatomy and pathophysiology of axial low back pain: disc, posterior elements, sacroiliac joint, and associated pain generators. Phys Med Rehabil Clin N Am. 2010;21(4):679-709.

45. Smart KM, Blake C, Staines A, et al. Mechanisms-based classifications of musculoskeletal pain: part 3 of 3: symptoms and signs of nociceptive pain in patients with low back (±leg) pain. Man Ther. 2012;17(4):352-7.

46. Smart KM, Blake C, Staines A, et al. Mechanisms-based classifications of musculoskeletal pain: part 2 of 3: symptoms and signs of peripheral neuropathic pain in patients with low back (±leg) pain. Man Ther. 2012;17(4):345-51.

47. Hoy D, Bain C, Williams G, et al. A systematic review of the global prevalence of low back pain. Arthritis Rheum. 2012;64(6):2028-37.

48. Hoy D, March L, Brooks P, et al. Measuring the global burden of low back pain. Best Practice & Research Clinical Rheumatology. 2010;24(2):155-65.

49. Jeffries LJ, Milanese SF, Grimmer-Somers KA. Epidemiology of adolescent spinal pain: a systematic overview of the research literature. Spine (Phila Pa 1976). 2007;32(23):2630-7.

50. Ozguler A, Leclerc A, Landre M-F, et al. Individual and occupational determinants of low back pain according to various definitions of low back pain. J Epidemiol Community Health. 2000;54(3):215-20.

51. Hoy D, March L, Brooks P, et al. The global burden of low back pain: estimates from the Global Burden of Disease 2010 study. Ann Rheum Dis. 2014:annrheumdis-2013-204428.

52. Niemeläinen R, Videman T, Battié MC. Prevalence and characteristics of upper or mid-back pain in Finnish men. Spine (Phila Pa 1976). 2006;31(16):1846-9.

53. Dionne CE, Dunn KM, Croft PR, et al. A consensus approach toward the standardization of back pain definitions for use in prevalence studies. Spine (Phila Pa 1976). 2008;33(1):95-103.

54. Pincus T, Santos R, Breen A, et al. A review and proposal for a core set of factors for prospective cohorts in low back pain: a consensus statement. Arthritis Care Res. 2008;59(1):14-24.

55. Stanton TR, Latimer J, Maher CG, et al. A modified Delphi approach to standardize low back pain recurrence terminology. Eur Spine J. 2011;20(5):744-52.

56. Van Tulder M, Becker A, Bekkering T, et al. Chapter 3 European guidelines for the management of acute nonspecific low back pain in primary care. Eur Spine J. 2006;15:s169-s91.

57. Marras WS, Ferguson SA, Burr D, et al. Low back pain recurrence in occupational environments. Spine (Phila Pa 1976). 2007;32(21):2387-97.

58. Pengel LH, Herbert RD, Maher CG, et al. Acute low back pain: systematic review of its prognosis. BMJ. 2003;327(7410):323.

59. Kongsted A, Kent P, Hestbaek L, et al. Patients with low back pain had distinct clinical course patterns that were typically neither complete recovery nor constant pain. A latent class analysis of longitudinal data. Spine J. 2015;15(5):885-94.

60. Young AE, Wasiak R, Phillips L, et al. Workers' perspectives on low back pain recurrence:"It comes and goes and comes and goes, but it's always there". PAIN®. 2011;152(1):204-11.

61. Costa LdCM, Maher CG, Hancock MJ, et al. The prognosis of acute and persistent low-back pain: a meta-analysis. Can Med Assoc J. 2012;184(11):E613-E24.

62. Axén I, Leboeuf-Yde C. Trajectories of low back pain. Best Pract Res Clin Rheumatol. 2013;27(5):601-12.

63. Stanton TR, Latimer J, Maher CG, et al. Definitions of recurrence of an episode of low back pain: a systematic review. Spine (Phila Pa 1976). 2009;34(9):E316-E22.

64. Stanton TR, Latimer J, Maher CG, et al. How do we define the condition ‘recurrent low back pain’? A systematic review. Eur Spine J. 2010;19(4):533-9.

65. Larsson H, Broman L, Harms-Ringdahl K. Individual risk factors associated with premature discharge from military service. Mil Med. 2009;174(1):9-20.

66. Roy TC, Piva SR, Christiansen BC, et al. Description of musculoskeletal injuries occurring in female soldiers deployed to Afghanistan. Mil Med. 2015;180(3):269-75.

67. Knox J, Orchowski J, Scher DL, et al. The Incidence of Low Back Pain in Active Duty United States Military Service Members. Spine (Phila Pa 1976). 2011;36(18):1492.

68. MacGregor AJ, Dougherty AL, Mayo JA, et al. Occupational correlates of low back pain among US Marines following combat deployment. Mil Med. 2012;177(7):845-9.

69. Hernan M. A definition of causal effect for epidemiological research. J Epidemiol Community Health. 2004;58(4):265-71.

70. Hill AB. The environment and disease: association or causation? Proc R Soc Med. 1965;58(5):295.

71. Kopec JA, Sayre EC, Esdaile JM. Predictors of back pain in a general population cohort. Spine (Phila Pa 1976). 2004;29(1):70-7.

72. Taylor JB, Goode AP, George SZ, et al. Incidence and risk factors for first-time incident low back pain: a systematic review and meta-analysis. The Spine Journal. 2014;14(10):2299-319.

73. Ferreira P, Beckenkamp P, Maher C, et al. Nature or nurture in low back pain? Results of a systematic review of studies based on twin samples. Eur J Pain. 2013;17(7):957-71.

74. Shiri R, Solovieva S, Husgafvel-Pursiainen K, et al. The Association between Obesity and the Prevalence of Low Back Pain in Young Adults The Cardiovascular Risk in Young Finns Study. Am J Epidemiol. 2008;167(9):1110-9.

75. Kujala UM, Taimela S, Viljanen T, et al. Physical loading and performance as predictors of back pain in healthy adults A 5-year prospective study. Eur J Appl Physiol Occup Physiol. 1996;73(5):452-8.

76. Leclerc A, Tubach F, Landre MF, et al. Personal and occupational predictors of sciatica in the GAZEL cohort. Occup Med. 2003;53(6):384-91.

77. Croft PR, Papageorgiou AC, Thomas E, et al. Short-term physical risk factors for new episodes of low back pain: prospective evidence from the South Manchester Back Pain Study. Spine (Phila Pa 1976). 1999;24(15):1556.

78. Heuch I, Heuch I, Hagen K, et al. Association between body height and chronic low back pain: a follow-up in the Nord-Trøndelag Health Study. BMJ open. 2015;5(6):e006983.

79. Adams MA, Mannion AF, Dolan P. Personal risk factors for first-time low back pain. Spine (Phila Pa 1976). 1999;24(23):2497.

80. Walsh K, Cruddas M, Coggon D. Interaction of height and mechanical loading of the spine in the development of low-back pain. Scand J Work Environ Health. 1991:420-4.

81. Dunn KM, Hestbaek L, Cassidy JD. Low back pain across the life course. Best Pract Res Clin Rheumatol. 2013;27(5):591-600.

82. Shiri R, Karppinen J, Leino-Arjas P, et al. The association between smoking and low back pain: a meta-analysis. Am J Med. 2010;123(1):87. e7-. e35.

83. Papageorgiou AC, Croft PR, Thomas E, et al. Influence of previous pain experience on the episode incidence of low back pain: results from the South Manchester Back Pain Study. Pain. 1996;66(2):181-5.

84. Punnett L, Prüss-Ütün A, Nelson DI, et al. Estimating the global burden of low back pain attributable to combined occupational exposures. Am J Ind Med. 2005;48(6):459-69.

85. Roffey DM, Wai EK, Bishop P, et al. Causal assessment of occupational sitting and low back pain: results of a systematic review. Spine J. 2010;10(3):252-61.

86. Roffey DM, Wai EK, Bishop P, et al. Causal assessment of workplace manual handling or assisting patients and low back pain: results of a systematic review. Spine J. 2010;10(7):639-51.

87. Roffey DM, Wai EK, Bishop P, et al. Causal assessment of awkward occupational postures and low back pain: results of a systematic review. Spine J. 2010;10(1):89-99.

88. Roffey DM, Wai EK, Bishop P, et al. Causal assessment of occupational pushing or pulling and low back pain: results of a systematic review. Spine J. 2010;10(6):544-53.

89. Roffey DM, Wai EK, Bishop P, et al. Causal assessment of occupational standing or walking and low back pain: results of a systematic review. Spine J. 2010;10(3):262-72.

90. SBU. Occupational exposures and back disorders. Stockholm: Swedish Council on Health Technology Assessment (SBU); 2014. SBU report no 227 (in Swedish)

91. da Costa BR, Vieira ER. Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. Am J Ind Med. 2010;53(3):285-323.

92. Driscoll T, Jacklyn G, Orchard J, et al. The global burden of occupationally related low back pain: estimates from the Global Burden of Disease 2010 study. Ann Rheum Dis. 2014:annrheumdis-2013-204631.

93. Burström L, Nilsson T, Wahlström J. Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis. Int Arch Occup Environ Health. 2015;88(4):403-18.

94. Coenen P, Gouttebarge V, van der Burght AS, et al. The effect of lifting during work on low back pain: a health impact assessment based on a meta-analysis. Occup Environ Med. 2014;71(12):871-7.

95. Hauke A, Flintrop J, Brun E, et al. The impact of work-related psychosocial stressors on the onset of musculoskeletal disorders in specific body regions: A review and meta-analysis of 54 longitudinal studies. Work Stress. 2011;25(3):243-56.

96. Mattila VM, Sahi T, Jormanainen V, et al. Low back pain and its risk indicators: a survey of 7,040 Finnish male conscripts. Eur Spine J. 2008;17(1):64-9.

97. Robinson M. Epidemiology of lifestyle behaviours and training injuries in British Army infantry recruits: Thesis (Doctor of Philosophy (PhD)). University of Bath; 2015.

98. Bulzacchelli MT, Sulsky SI, Rodriguez-Monguio R, et al. Injury during US Army basic combat training: a systematic review of risk factor studies. Am J Prev Med. 2014;47(6):813-22.

99. Roy TC, Lopez HP, Piva SR. Loads worn by soldiers predict episodes of low back pain during deployment to Afghanistan. Spine (Phila Pa 1976). 2013;38(15):1310-7.

100. Taanila HP, Suni JH, Pihlajamäki HK, et al. Predictors of low back pain in physically active conscripts with special emphasis on muscular fitness. Spine J. 2012;12(9):737-48.

101. Lisman P, O’Connor FG, Deuster PA, et al. Functional movement screen and aerobic fitness predict injuries in military training. Med Sci Sports Exerc. 2013;45(4):636-43.

102. Nissen LR, Marott JL, Gyntelberg F, et al. Deployment-Related Risk Factors of Low Back Pain: A Study Among Danish Soldiers Deployed to Iraq. Mil Med. 2014;179(4):451-8.

103. Ernat J, Knox J, Orchowski J, et al. Incidence and risk factors for acute low back pain in active duty infantry. Mil Med. 2012;177(11):1348-51.

104. George SZ, Childs JD, Teyhen DS, et al. Brief psychosocial education, not core stabilization, reduced incidence of low back pain: results from the Prevention of Low Back Pain in the Military (POLM) cluster randomized trial. BMC Med. 2011;9(1):1.

105. Knox JB, Orchowski JR, Scher DL, et al. Occupational driving as a risk factor for low back pain in active-duty military service members. Spine J. 2014;14(4):592-7.

106. Larsen K, Leboeuf-Yde C. Coping and back problems: a prospective observational study of Danish military recruits. J Manipulative Physiol Ther. 2006;29(8):619-25.

107. Moshe S, Zack O, Finestone AS, et al. The incidence and worsening of newly diagnosed low back pain in a population of young male military recruits. BMC Musculoskelet Disord. 2016;17(1):279.

108. Hestbaek L, Larsen K, Weidick F, et al. Low back pain in military recruits in relation to social background and previous low back pain. A cross-sectional and prospective observational survey. BMC Musculoskelet Disord. 2005;6(1):1.

109. Roy TC, Lopez HP. A comparison of deployed occupational tasks performed by different types of military battalions and resulting low back pain. Mil Med. 2013;178(8):e937-e43.

110. Bell NS, Mangione TW, Hemenway D, et al. High injury rates among female army trainees: a function of gender? Am J Prev Med. 2000;18(3):141-6.

111. Almeida SA, Trone DW, Leone DM, et al. Gender differences in musculoskeletal injury rates: a function of symptom reporting? Med Sci Sports Exerc. 1999;31(12):1807-12.

112. Barondess J, Cullen M, de Lateur B, et al. Musculoskeletal disorders and the workplace: Low back and upper extremities. Washington, DC: National Academy of Sciences. 2001:1-512.

113. Marras WS. The working back: A systems view: John Wiley & Sons; 2008.

114. Bongers P, Ijmker S, Van den Heuvel S, et al. Epidemiology of work related neck and upper limb problems: psychosocial and personal risk factors (part I) and effective interventions from a bio behavioural perspective (part II). J Occup Rehabil. 2006;16(3):272-95.

115. Marras WS. The Complex Spine The Multidimensional System of Causal Pathways for Low-Back Disorders. Hum Factors. 2012;54(6):881-9.

116. Mosey AC. An alternative: the biopsychosocial model. Am J Occup Ther. 1974.

117. Engel GL. The need for a new medical model: a challenge for biomedicine. Science. 1977;196(4286):129-36.

118. Lis AM, Black KM, Korn H, et al. Association between sitting and occupational LBP. Eur Spine J. 2007;16(2):283-98.

119. Silverstein BA, Stetson DS, Keyserling WM, et al. Work-related musculoskeletal disorders: comparison of data sources for surveillance. Am J Ind Med. 1997;31(5):600-8.

120. Pransky G, Snyder T, Dembe A, et al. Under-reporting of work-related disorders in the workplace: a case study and review of the literature. Ergonomics. 1999;42(1):171-82.

121. Ferreira ML, Machado G, Latimer J, et al. Factors defining care-seeking in low back pain–A meta-analysis of population based surveys. Eur J Pain. 2010;14(7):747. e1-. e7.

122. Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. J Electromyogr Kinesiol. 2004;14(1):13-23.

123. Carragee EJ, Cohen SP. Lifetime Asymptomatic for Back Pain: The Validity of Self-report Measures in Soldiers. Spine (Phila Pa 1976). 2009;34(9):978-83.

124. Sullivan M, Karlsson J, Taft C, et al. SF-36 Health Survey. Swedish manual and interpretation guide. Gothenburg: Sahlgrenska University Hospital. 2002.

125. Linton SJ. Manual for the Örebro Musculoskeletal Pain Screening Questionnaire: the early identification of patients at risk for chronic pain: Department of Occupational and Environmental Medicine, Örebro Medical Center; 1999.

126. Von Korff M, Jensen MP, Karoly P. Assessing global pain severity by self-report in clinical and health services research. Spine (Phila Pa 1976). 2000;25(24):3140-51.

127. Roland M, Morris R. A study of the natural history of back pain: part I: development of a reliable and sensitive measure of disability in low-back pain. Spine (Phila Pa 1976). 1983;8(2):141-4.

128. Roy TC, Fish KL, Lopez HP, et al. Preliminary Validation of the Military Low Back Pain Questionnaire. Mil Med. 2014;179(2):121-5.

129. Tengland P-A. The concept of work ability. J Occup Rehabili. 2011;21(2):275-85.

130. Tuomi K, Ilmarinen J, Eskelinen L, et al. Prevalence and incidence rates of diseases and work ability in different work categories of municipal occupations. Scand J Work Environ Health. 1991:67-74.

131. Marmot M, Feeney A, Shipley M, et al. Sickness absence as a measure of health status and functioning: from the UK Whitehall II study. J Epidemiol Community Health. 1995;49(2):124-30.

132. Clarsen B. Overuse injuries in sport: development, validation and application of a new surveillance method. Doctoral thesis. Norwegian school of sport sciences; 2015.

133. Broderick JE, Schwartz JE, Vikingstad G, et al. The accuracy of pain and fatigue items across different reporting periods. Pain. 2008;139(1):146-57.

134. de Vet HC, Heymans MW, Dunn KM, et al. Episodes of low back pain: a proposal for uniform definitions to be used in research. Spine (Phila Pa 1976). 2002;27(21):2409-16.

135. Bahr R. No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. Br J Sports Med. 2009;43(13):966-72.

136. Eklund A, Jensen I, Lohela-Karlsson M, et al. Absence of low back pain to demarcate an episode: a prospective multicentre study in primary care. Chiropr Man Therap. 2016;24(1):1.

137. Leboeuf-Yde C, Jensen RK, Axén I. Absence of low back pain in patients followed weekly over one year with automated text messages. Chiropr Man Therap. 2012;20(1):1.

138. Gupta N, Heiden M, Mathiassen SE, et al. Prediction of objectively measured physical activity and sedentariness among blue-collar workers using survey questionnaires. Scand J Work Environ Health. 2016;42(3):v+ 237-45.

139. Spielholz P, Silverstein B, Morgan M, et al. Comparison of self-report, video observation and direct measurement methods for upper extremity musculoskeletal disorder physical risk factors. Ergonomics. 2001;44(6):588-613.

140. Viikari-Juntura E, Rauas S, Martikainen R, et al. Validity of self-reported physical work load in epidemiologic studies on musculoskeletal disorders. Scand J Work Environ Health. 1996:251-9.

141. Balogh I, Ørbaek P, Ohlsson K, et al. Self-assessed and directly measured occupational physical activities—influence of musculoskeletal complaints, age and gender. Appl Ergon. 2004;35(1):49-56.

142. Parry S, Straker L. The contribution of office work to sedentary behaviour associated risk. BMC public health. 2013;13(1):296.

143. Thiese MS, Hegmann KT, Garg A, et al. The predictive relationship of physical activity on the incidence of low back pain in an occupational cohort. J Occup Environ Med. 2011;53(4):364-71.

144. Borghols E, Dresen M, Hollander A. Influence of heavy weight carrying on the cardiorespiratory system during exercise. Eur J Appl Physiol Occup Physiol. 1978;38(3):161-9.

145. Guinhouya CB, Hubert H, Dupont G, et al. Relationship between the MTI accelerometer (actigraph) counts and running speed during continuous and intermittent exercise. J Sports Sci Med. 2005;4(4):534.

146. Matthew CE. Calibration of accelerometer output for adults. Med Sci Sports Exerc. 2005;37(11 Suppl):S512-22.

147. Ward DS, Evenson KR, Vaughn A, et al. Accelerometer use in physical activity: best practices and research recommendations. Med Sci Sports Exerc. 2005;37(11 Suppl):S582-8.

148. Redmond JE, Cohen BS, Simpson K, et al. Measuring physical activity during US Army Basic Combat Training: a comparison of 3 methods. US Army Med Dep J. 2013(Oct-Dec):48-54.

149. Moseley GL, Hodges PW. Reduced Variability of Postural Strategy Prevents Normalization of Motor Changes Induced by Back Pain: A Risk Factor for Chronic Trouble? Behav Neurosci. 2006;120(2):474-6.

150. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain: a motor control evaluation of transversus abdominis. Spine (Phila Pa 1976). 1996;21(22):2640.

151. Luomajoki H, Kool J, de Bruin ED, et al. Movement control tests of the low back; evaluation of the difference between patients with low back pain and healthy controls. BMC Musculoskelet Disord. 2008;9(1):170.

152. Roussel NA, Nijs J, Mottram S, et al. Altered lumbopelvic movement control but not generalized joint hypermobility is associated with increased injury in dancers. A prospective study. Man Ther. 2009;14(6):630-5.

153. Nindl BC, Jaffin DP, Dretsch MN, et al. Human performance optimization metrics: consensus findings, gaps, and recommendations for future research. J Strength Cond Res. 2015;29:S221-S45.

154. Nindl BC, Alvar BA, Dudley JR, et al. Executive Summary From the National Strength and Conditioning Association's Second Blue Ribbon Panel on Military Physical Readiness: Military Physical Performance Testing. J Strength Cond Res. 2015;29:S216-S20.

155. Friedl KE, Knapik JJ, Häkkinen K, et al. Perspectives on Aerobic and Strength Influences on Military Physical Readiness: Report of an International Military Physiology Roundtable. J Strength Cond Res. 2015;29:S10-S23.

156. Larsson H, Tegern M, Monnier A, et al. Content Validity Index and Intra-and Inter-Rater Reliability of a New Muscle Strength/Endurance Test Battery for Swedish Soldiers. PLoS One. 2015;10(7):e0132185.

157. Knapik JJ, Harman EA, Steelman RA, et al. A systematic review of the effects of physical training on load carriage performance. J Strength Cond Res. 2012;26(2):585-97.

158. Konitzer L, Fargo M, Brininger T, et al. Association between Back, Neck, and Upper Extremity Musculoskeletal Pain and the Individual Body Armor. J Hand Ther. 2008;21(2):143-9.

159. Kane MT. Current concerns in validity theory. J Educ Meas. 2001;38(4):319-42.

160. Cook DA, Beckman TJ. Current concepts in validity and reliability for psychometric instruments: theory and application. Am J Med. 2006;119(2):166. e7-. e16.

161. Streiner D, Norman G. Health measurement scales: a practical guide to their development and use 4 edition Oxford University Press. New York. 2008.

162. AERA AN. Standards for Education and Psychological Testing. Washington DC: American Educational Research Association; 1999.

163. Coste J, Fermanian J, Venot A. Methodological and statistical problems in the construction of composite measurement scales: a survey of six medical and epidemiological journals. Stat Med. 1995;14(4):331-45.

164. Makowska Z, Merecz D, Moscicka A, et al. The validity of general health questionnaires, GHQ-12 and GHQ-28, in mental health studies of working people. Int J Occup Med Environ Health. 2002;15(4):353-62.

165. Stock SR, Fernandes R, Delisle A, et al. Reproducibility and validity of workers' self-reports of physical work demands. Scand J Work Environ Health. 2005:409-37.

166. Torgén M, editor Experiences of WAI in a random sample of the Swedish working population. International Congress Series; 2005: Elsevier.

167. Wiktorin C, Karlqvist L, Winkel J. Validity of self-reported exposures to work postures and manual materials handling. Scand J Work Environ Health. 1993:208-14.

168. Wiktorin C, Vingård E, Mortimer M, et al. Interview versus questionnaire for assessing physical loads in the population-based MUSIC-Norrtälje study. Am J Ind Med. 1999;35(5):441-55.

169. Aronsson G, Svensson L, Gustafsson K. Unwinding, Recuperation, and Health Among Compulsory School and High School Teachers in Sweden.Int J Stress Manag. 2003;10(3):217.

170. Kelly MJ, Dunstan FD, Lloyd K, et al. Evaluating cutpoints for the MHI-5 and MCS using the GHQ-12: a comparison of five different methods. BMC Psychiatry. 2008;8(1):10.

171. Sullivan M, Karlsson J. The Swedish SF-36 Health Survey III. Evaluation of criterion-based validity: results from normative population. J Clin Epidemiol. 1998;51(11):1105-13.

172. Bruton A, Conway JH, Holgate ST. Reliability: what is it, and how is it measured? Physiotherapy. 2000;86(2):94-9.

173. Streiner DL, Norman GR. “Precision” and “accuracy”: two terms that are neither. J Clin Epidemiol. 2006;59(4):327-30.

174. Tooth LR, Ottenbacher KJ. The κ statistic in rehabilitation research: An examination. Arch Phys Med Rehabil. 2004;85(8):1371-6.

175. Sim J, Wright CC. The kappa statistic in reliability studies: use, interpretation, and sample size requirements. Phys Ther. 2005;85(3):257.

176. Cohen J. A coefficient of agreement for nominal scales. Educ Psychol Meas. 1960;20(1):37-46.

177. Dunn G. Design and analysis of reliability studies: The statistical evaluation of measurement errors: Edward Arnold Publishers; 1989.

178. Hoehler FK. Bias and prevalence effects on kappa viewed in terms of sensitivity and specificity. J Clin Epidemiol. 2000;53(5):499-503.

179. Byrt T, Bishop J, Carlin JB. Bias, prevalence and kappa. J Clin Epidemiol. 1993;46(5):423-9.

180. Mercy JA, Rosenberg ML, Powell KE, et al. Public health policy for preventing violence. Health Aff (Millwood). 1993;12(4):7-29.

181. Van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. Sports Med. 1992;14(2):82-99.

182. Larsson H. Premature discharge from military service: Risk factors and preventive interventions.Thesis for doctoral degree (PhD). Stockholm: Karolinska Institutet; 2009.

183. Verbrugge LM, Jette AM. The disablement process. Soc Sci Med. 1994;38(1):1-14.

184. Sell TC, Abt JP, Crawford K, et al. Warrior Model for Human Performance and Injury Prevention: Eagle Tactical Athlete Program (ETAP) Part I. J Spec Oper Med 2009;10(4):2-21.

185. Finch C. A new framework for research leading to sports injury prevention. J Sci Med Sport. 2006;9(1):3-9.

186. Jones BH, Knapik JJ. Physical training and exercise-related injuries. Sports Med. 1999;27(2):111-25.

187. Hanson DW, Finch CF, Allegrante JP, et al. Closing the gap between injury prevention research and community safety promotion practice: revisiting the public health model. Public Health Rep. 2012:147-55.

188. Jones BH, Perrotta DM, Canham-Chervak ML, et al. Injuries in the military: a review and commentary focused on prevention. Am J Prev Med. 2000;18(3):71-84.

189. Narayan KV, Benjamin E, Gregg EW, et al. Diabetes translation research: where are we and where do we want to be? Ann Intern Med. 2004;140(11):958-63.

190. Äng BO, Monnier A, Harms-Ringdahl K. Neck/Shoulder Exercise for Neck Pain in Air Force Helicopter Pilots: A Randomized Controlled Trial. Spine (Phila Pa 1976). 2009;34(16).

191. Sell TC, Abt JP, Nagai T, et al. The Eagle Tactical Athlete Program Reduces Musculoskeletal Injuries in the 101st Airborne Division (Air Assault). Mil Med. 2016;181(3):250-7

192. Larsson H, Tegern M, Harms-Ringdahl K. Influence of the implementation of a comprehensive intervention programme on premature discharge outcomes from military training. Work. 2012;42(2):241-51.

193. Woolf SH. The meaning of translational research and why it matters. JAMA. 2008;299(2):211-3.

194. Braithwaite M, Nicholson G, Thornton R, et al. Armed Forces occupational health—a review. Occup Med. 2009;59(8):528-38.

195. Boström G, Nyqvist K. Objective and background of the questions in the national public health survey: Statens folkhälsoinstitut. Durham; 2010. Retrieved from: https://www.folkhalsomyndigheten.se/publiceratmaterial/publikationer/?so=&ph=&q=Objective+and+background+of+the+questions+in+the+national+public+health+survey. Latest accesed: 20161007.

196. Svensson AC, Fredlund P, Laflamme L, et al. Cohort profile: the Stockholm public health cohort. Int J Epidemiol. 2013;42(5):1263-72.

197. Comerford MJ. The Performance Matrix performance Profiling, risk assessment & training strategies for injury prevention & performance enhancement. UK: KC International / Movement Performance Solutions; 2008.

198. Comerford MJ, Mottram SL. Diagnosis of Uncontrolled Movement, Subgroup Classification and Motor Control Retraining of the Lumbar Spine. UK: KC International / Movement Performance Solutions 2010.

199. Lieber R. Skeletal muscle structure, function, & plasticity - The physiological basis of rehabilitation. 2 ed. United States of America: Lippincott Williams & Wilkins; 2002.

200. Mottram S, Comerford M. A new perspective on risk assessment. Phys Ther Sport. 2008;9(1):40-51.

201. Enoch F, Kjaer P, Elkjaer A, et al. Inter-examiner reproducibility of tests for lumbar motor control. BMC Musculoskelet Disord. 2011;12(1):1.

202. Roussel N, Nijs J, Truijen S, et al. Altered breathing patterns during lumbopelvic motor control tests in chronic low back pain: a case–control study. Eur Spine J. 2009;18(7):1066-73.

203. Jull G, Richardson C, Toppenberg R, et al. Towards a measurement of active muscle control for lumbar stabilisation. Aust J Physiother. 1993;39(3):187-93.

204. Richardson C, Jull G. Muscle control–pain control. What exercises would you prescribe? Man Ther. 1995;1(1):2-10.

205. Kuorinka I, Jonsson B, Kilbom A, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon. 1987;18(3):233-7.

206. Allison J, Paul D. Missing Data. In: Millsap R, E., Maydeu-Olivares A, editors. The SAGE Handbook of Quantitative Methods in Psychology. Thousand Oaks, CA: Sage Publications Inc.; 2009 p. 72-89.

207. Osborne JW. Best practices in data cleaning: A complete guide to everything you need to do before and after collecting your data: Sage; 2012.

208. Li C-Y, Sung F-C. A review of the healthy worker effect in occupational epidemiology. Occup Med. 1999;49(4):225-9.

209. Vittinghoff E, Glidden D, Shiboski S, et al. Regression methods in biostatistics: linear, logistic, survival, and repeated measures models. 2nd edn. New York: Springer; 2012.

210. Rubin DB. Multiple imputation after 18+ years.J Am Stat Assoc. 1996;91(434):473-89.

211. Guo Z, Gill TM, Allore HG. Modeling repeated time-to-event health conditions with discontinuous risk intervals: an example of a longitudinal study of functional disability among older persons. Methods Inf Med. 2008;47(2):107.

212. Troiano RP, Berrigan D, Dodd KW, et al. Physical activity in the United States measured by accelerometer. Med Sci Sports Exerc. 2008;40(1):181.

213. Nichols JF, Morgan CG, Chabot LE, et al. Assessment of physical activity with the Computer Science and Applications, Inc., accelerometer: laboratory versus field validation. Res Q Exerc Sport. 2000;71(1):36-43.

214. Firth D. Bias reduction of maximum likelihood estimates. Biometrika. 1993;80(1):27-38.

215. Hosmer DW Jr, Lemeshow S, Sturdivant RX. Applied logistic regression. 3rd edn. John Wiley & Sons, Inc., 2013.

216. Andersen PK, Gill RD. Cox's regression model for counting processes: a large sample study. The annals of statistics. 1982:1100-20.

217. Lin DY, Wei L-J. The robust inference for the Cox proportional hazards model. J Am Stat Assoc. 1989;84(408):1074-8.

218. Hosmer DW, Lemeshow S. May S.Applied Survival Analysis: Regression Modelling of Time to Event Data. 2nd ed. Hoboken: John Wiley & Sons; 2008.

219. Jahn-Eimermacher A. Comparison of the Andersen–Gill model with Poisson and negative binomial regression on recurrent event data. Computational Statistics & Data Analysis. 2008;52(11):4989-97.

220. Cleves MA, Gould WW, Gutierrez RG. et al. An introduction to survival analysis using Stata. 3rd edn. College Station, TX: Stata Press; 2010.

221. Hilbe JM. Logistic regression models: London, UK: Chapman & Hall/CRC Press; 2009.

222. Sarkar SK, Midi H, Rana M. Detection of outliers and influential observations in binary logistic regression: An empirical study. J Appli Sci. 2011;11(1):26-35.

223. Birnbaum D. Who is at risk of what? Infect Control Hosp Epidemiol. 1999;20(10):706-7.

224. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159.

225. Briggs AM, Bragge P, Smith AJ, et al. Prevalence and associated factors for thoracic spine pain in the adult working population: a literature review. J Occup Health. 2009(0):0903300066.

226. Pearce N, Checkoway H, Kriebel D. Bias in occupational epidemiology studies. Occup Environ Med. 2007;64(8):562-8.

227. Twisk JW, Smidt N, de Vente W. Applied analysis of recurrent events: a practical overview. J Epidemiol Community Health. 2005;59(8):706-10.

228. Milgrom C, Finestone A, Lev B, et al. Overexertional lumbar and thoracic back pain among recruits: a prospective study of risk factors and treatment regimens. J Spinal Disord. 1993;6(3):187-93.

229. Hestbaek L, Leboeuf-Yde C, Kyvik KO, et al. The course of low back pain from adolescence to adulthood: eight-year follow-up of 9600 twins. Spine (Phila Pa 1976). 2006;31(4):468-72.

230. Silk AJ, Billing DC. Development of a valid simulation assessment for a military dismounted assault task. Mil Med. 2013;178(3):315-20.

231. Hunt AP, Tofari PJ, Billing DC, et al. Tactical combat movements: inter-individual variation in performance due to the effects of load carriage. Ergonomics. 2016:1-10.

232. Billing DC, Silk AJ, Tofari PJ, et al. Effects of military load carriage on susceptibility to enemy fire during tactical combat movements. J Strength Cond Res. 2015;29:S134-S8.

233. Simpson K, Redmond J, Cohen B, et al. Quantification of physical activity performed during US Army Basic Combat Training. US Army Med Dep J. 2013;4:55-65.

234. Hartvigsen J, Leboeuf-Yde C, Lings S, et al. Review Article: Is sitting-while-at-work associated with low back pain? A systematic, critical literature review. Scand J Public Health. 2000;28(3):230-9.

235. Janwantanakul P, Sitthipornvorakul E, Paksaichol A. Risk factors for the onset of nonspecific low back pain in office workers: a systematic review of prospective cohort studies. J Manipulative Physiol Ther. 2012;35(7):568-77.

236. Woolf CJ. Central sensitization: implications for the diagnosis and treatment of pain. Pain. 2011;152(3):S2-S15.

237. Smedley J, Egger P, Cooper C, et al. Prospective cohort study of predictors of incident low back pain in nurses. BMJ. 1997;314(7089):1225.

238. Vandergrift JL, Gold JE, Hanlon A, et al. Physical and psychosocial ergonomic risk factors for low back pain in automobile manufacturing workers. Occup Environ Med. 2012;69(1):29-34.

239. Coenen P, Douwes M, van den Heuvel S, et al. Towards exposure limits for working postures and musculoskeletal symptoms–a prospective cohort study. Ergonomics. 2016:1-11.

240. van Dieën PhD JH. The effect of the presence and characteristics of an outlying group on exposure-outcome associations. Scand J Work Environ Health. 2015;41(1):65.

241. Knapik J, Harman E, Reynolds K. Load carriage using packs: a review of physiological, biomechanical and medical aspects. Appl Ergon. 1996;27(3):207-16.

242. Schaafsma FG, Anema JR, van der Beek AJ. Back pain: Prevention and management in the workplace. Best Practice & Research Clinical Rheumatology. 2015;29(3):483-94.

243. Bigos SJ, Holland J, Holland C, et al. High-quality controlled trials on preventing episodes of back problems: systematic literature review in working-age adults. Spine J. 2009;9(2):147-68.

244. Choi BK, Verbeek JH, Wai-San Tam W, et al. Exercises for prevention of recurrences of low-back pain. Occup Environ Med. 2010;67(11):795-6.

245. Kelsall HL, McKenzie DP, Forbes AB, et al. Pain-related musculoskeletal disorders, psychological comorbidity, and the relationship with physical and mental well-being in Gulf War veterans. PAIN. 2014;155(4):685-92.

246. Larson GE, Highfill-McRoy RM, Booth-Kewley S. Psychiatric diagnoses in historic and contemporary military cohorts: combat deployment and the healthy warrior effect. Am J Epidemiol. 2008;167(11):1269-76.

247. Sundin J, Jones N, Greenberg N, et al. Mental health among commando, airborne and other UK infantry personnel. Occup Med. 2010.

248. Roy TC, Springer BA, McNulty V, et al. Physical fitness. Mil Med. 2010;175(8S):14-20.

249. Childs JD, Teyhen DS, Benedict TM, et al. Effects of sit-up training versus core stabilization exercises on sit-up performance. Med Sci Sports Exerc. 2009;41(11):2072-83.

250. Teyhen DS, Shaffer SW, Butler RJ, et al. What risk factors are associated with musculoskeletal injury in US army rangers? A prospective prognostic study. Clin Orthop Relat Res. 2015;473(9):2948-58.

251. Luomajoki H, Moseley GL. Tactile acuity and lumbopelvic motor control in patients with back pain and healthy controls. Br J Sports Med. 2011;45(5):437-40.

252. Luomajoki H, Kool J, de Bruin ED, et al. Reliability of movement control tests in the lumbar spine. BMC Musculoskelet Disord. 2007;8(1):90.

253. Mischiati CR, Comerford M, Gosford E, et al. Intra and inter-rater reliability of screening for movement impairments: movement control tests from the foundation matrix. J Sports Sci Med. 2015;14(2):427.

254. Frost DM, Beach TA, Callaghan JP, et al. FMS Scores Change With Performers' Knowledge of the Grading Criteria—Are General Whole-Body Movement Screens Capturing "Dysfunction"? J Strength Cond Res. 2015;29(11):3037-44.

255. McIntosh MW, Pepe MS. Combining several screening tests: optimality of the risk score. Biometrics. 2002;58(3):657-64.

256. McGill SM, Grenier S, Kavcic N, et al. Coordination of muscle activity to assure stability of the lumbar spine. J Electromyogr Kinesiol. 2003;13(4):353-9.

257. Michaelson P, Holmberg D, Aasa B, et al. High Load Lifting Exercise and Low Load Motor Control Exercises As Interventions for Patients with Mechanical Low Back Pain: A Randomized Controlled Trial with 24-month Follow-up. J Rehabil Med. 2016;48(5):456-63.

258. Byström MG, Rasmussen-Barr E, Grooten WJA. Motor control exercises reduces pain and disability in chronic and recurrent low back pain: a meta-analysis. Spine (Phila Pa 1976). 2013;38(6):E350-E8.

259. Macedo LG, Maher CG, Latimer J, et al. Motor control exercise for persistent, nonspecific low back pain: a systematic review. Phys Ther. 2008.

260. Saragiotto BT, Maher CG, Yamato TP, et al. Motor Control Exercise for Non-specific Low Back Pain: A Cochrane Review. Spine (Phila Pa 1976). 2016.

261. Smith BE, Littlewood C, May S. An update of stabilisation exercises for low back pain: a systematic review with meta-analysis. BMC Musculoskelet Disord. 2014;15(1):1.

262. Teyhen DS, Childs JD, Dugan JL, et al. Effect of two different exercise regimens on trunk muscle morphometry and endurance in soldiers in training. Phys Ther. 2013;93(9):1211-24.

263. Childs JD, Teyhen DS, Casey PR, et al. Effects of traditional sit-up training versus core stabilization exercises on short-term musculoskeletal injuries in US Army soldiers: a cluster randomized trial. Phys Ther. 2010;90(10):1404-12.

264. Sørensen K, Van den Broucke S, Fullam J, et al. Health literacy and public health: a systematic review and integration of definitions and models. BMC Public Health. 2012;12(1):1.

265. Rosenstock IM. Historical origins of the health belief model. Health Educ Behav. 1974;2(4):328-35.

266. Weinstein ND. Unrealistic optimism about susceptibility to health problems. J Behav Med. 1982;5(4):441-60.

267. Munnoch K, Bridger RS. Investigation of the Operational Effectiveness of Hunter Company, Commando Training Centre, Royal Marines. Mil Med. 2008;173(2):129-33.

268. Blacker SD, Wilkinson DM, Bilzon JL, et al. Risk factors for training injuries among British Army recruits. Mil Med. 2008;173(3):278-86.

269. Grimes DA, Schulz KF. Bias and causal associations in observational research. The Lancet. 2002;359(9302):248-52.

270. Fox-Wasylyshyn SM, El-Masri MM. Handling missing data in self-report measures. Res Nurs Health. 2005;28(6):488-95.

271. Hartvigsen J, Bakketeig LS, Leboeuf-Yde C, et al. The association between physical workload and low back pain clouded by the "healthy worker" effect: population-based cross-sectional and 5-year prospective questionnaire study. Spine (Phila Pa 1976). 2001;26(16):1788-92.

272. Swedish Armed Forces; FÖRSVARSMAKTENS ÅRSREDOVISNING 2011, Bilaga 2. Retrieved from http://www.forsvarsmakten.se/siteassets/4-om myndigheten / dokumentfiler/arsredovisningar/arsredovisning-2011/bilaga2.pdf . Last accessed 20161007.

273. Wolff-Hughes DL, McClain JJ, Dodd KW, et al. Number of accelerometer monitoring days needed for stable group-level estimates of activity. Physiol Meas. 2016;37(9):1447.

274. Niedhammer I, Bugel I, Bonenfant S, et al. Validity of self-reported weight and height in the French GAZEL cohort. Int J Obes Relat Metab Disord. 2000;24(9).

275. Spencer EA, Appleby PN, Davey GK, et al. Validity of self-reported height and weight in 4808 EPIC–Oxford participants. Public Health Nutr. 2002;5(04):561-5.

276. Stewart AW, Jackson RT, Ford MA, et al. Underestimation of relative weight by use of self-reported height and weight. Am J Epidemiol. 1987;125(1):122-6.

277. Mazic S, Djelic M, Suzic J, et al. Overweight in trained subjects-are we looking at wrong numbers?(Body mass index compared with body fat percentage in estimating overweight in athletes.). Gen Physiol Biophys. 2009;28:200-4.

278. Vittinghoff E, McCulloch CE. Relaxing the rule of ten events per variable in logistic and Cox regression. Am J Epidemiol. 2007;165(6):710-8.

279. Leboeuf-Yde C. Back pain—individual and genetic factors. J Electromyogr Kinesiol. 2004;14(1):129-33.

280. Mahmud N, Schonstein E, Schaafsma F, et al. Pre-employment examinations for preventing occupational injury and disease in workers. The Cochrane Library. 2010.