doi:10.25143/prom-rsu_2024-05_dt

Rīga Stradiņš University

Darja Ņesteroviča-Petrikova

Biomechanical Aspects of Military Footwear Usage and their Relationship with Lower Extremity Overuse Injuries

Doctoral Thesis – set of publications – for obtaining the scientific degree “Doctor of Science (*PhD*)”

Sector Group – Medicine and Health Sciences
Sector – Basic Medicine
Sub-Sector – Medicinal Biomechanics

Riga, 2024

Darja Ņesteroviča-Petrikova

ORCID 0000-0003-1344-0067

Biomechanical Aspects of Military Footwear Usage and their Relationship with Lower Extremity Overuse Injuries

Doctoral Thesis – set of publications – for obtaining the scientific degree “Doctor of Science (*PhD*)”

Sector group – Medicine and Health Sciences

Sector – Basic Medicine

Sub-sector – Medicinal Biomechanics

Supervisor of the Doctoral Thesis:

Dr. med., Associate Professor **Ainārs Stepens**,
Rīga Stradiņš University, Latvia

Scientific Advisor:

Dr. med., Associate Professor **Signe Tomsone**,
Rīga Stradiņš University, Latvia

Riga, 2024

Abstract

Professional military service involves high-intensity physical training, including field training exercises and marching, which increase the risk of musculoskeletal injuries (MSKIs). In the military, MSKIs represent a significant medical concern, leading to an increased financial strain on military healthcare and a decrease in military preparedness. Acute and overuse lower extremity MSKIs are more common in the knee, lower leg, and foot. The role of military footwear in the development of overuse injuries is currently unresolved, and more research is suggested on the relationship between military footwear and overuse injuries.

The purpose of this work was to determine the incidence of overuse MSKI in the lower and investigate its possible relationship with military footwear usage among the Latvian Land Forces.

The research was carried out on infantry soldiers during their annual medical examinations at the Military Medical Support Centre of the Latvian National Army Logistic Command from 2018 to 2020. In a cross-sectional study on the epidemiology of MSKI, a total of n = 227 active duty infantry soldiers participated. Among study participants, 42.7 % had a history of lower extremity injuries, with a higher prevalence of overuse injuries in the lower leg. Study participants who wore inappropriate size of military boots reported lower comfort ratings for all parameters, irrespective of their history of injuries. Gait analysis was performed barefoot and wearing military boots during the case-control study (n = 66) where subjects were divided into groups according to their history of overuse injuries. Both groups showed an elevation in the foot contact angle, while simultaneously showing a reduction in the eversion of the rearfoot and the angular velocities of the ankle when wearing military footwear. The conditional logistic regression model revealed that stride time variability (OR = 2.71, 95 % CI 1.31 – 5.60) during barefoot gait demonstrated statistical significance in predicting the risk of lower leg overuse injury. The optimal threshold for stride time variability was determined to be 1.95 %, which could effectively predict the occurrence of lower leg overuse injuries, showing a sensitivity of 56 % and a specificity of 88 %.

Based on research findings, walking in military footwear improves stability and encourages gait symmetry, and the risk of overuse injuries to the lower extremities does not appear to be influenced by gait with footwear. The research results support the importance of further investigating gait variability as a possible risk factor for MSKI and lay the groundwork for the establishment of guidelines for medical gait and foot screening in the military.

Keywords: gait analysis, infantry boot, military personnel, musculoskeletal injuries, stride variability.

Anotācija

Militāro apavu valkāšanas biomehāniskie aspekti un to saistība ar apakšējo ekstremitāšu pārslodzes traumām

Profesionāls militārais dienests paredz augstas intensitātes fizisko slodzi, ieskaitot fiziskās sagatavotības treniņus, lauka taktiskās mācības un forsētus pārgājienus, kas paaugstina muskuloskeletālā traumatisma risku. Karavīru vidū muskuļu un skeleta traumas ir būtiska medicīniska problēma, kas ne tikai rada paaugstinātu finansiālu slogu uz militāro veselības aprūpi un samazina armijas kaujas gatavību, bet ir galvenais priekšlaicīgas atvaļināšanas medicīniskais iemesls NATO dalībvalstu armijās. Akūtas un pārslodzes kāju muskuloskeletālās traumas (MSKI) ir biežākas ceļa locītavas, apakšstilba un pēdas rajonā. Militāro apavu loma MSKI attīstībā pašlaik nav skaidra, un tiek ieteikta papildu pētījumu veikšana par saistību starp militāro apaviem un pārslodzes tipa traumām.

Šī darba mērķis bija noskaidrot apakšējo ekstremitāšu pārslodzes traumu biežumu Latvijas Sauszemes spēku karavīriem un noskaidrot to saistību ar militāro apavu izmantošanas paradumiem un pēdu uzbūves īpatnībām.

Epidemioloģiskie un klīniskie dati tika iegūti no 2018. līdz 2020. gadam. Šķērsgriezuma pētījumā par MSKI izplatību piedalījās n = 227 aktīvā dienesta karavīri un tas tika veikts ikgadējās medicīniskās pārbaudes laikā Nacionālo bruņoto spēku Nodrošinājuma pavēlniecības Medicīnas nodrošinājuma centrā. Iepriekš gūtas kāju MSKI bija sastopamas 42,7 % gadījumos, biežākās bija apakšstilba un pēdas pārslodzes traumas. Pētījuma dalībnieki, kuri izmantoja pēdas garumam neatbilstošus militāros zābakus, neatkarīgi no viņu traumu vēstures, apavu komfortu novērtēja zemāk. Gaitas analīze gan ar basām kājām, gan nēsājot militāros zābakus tika veikta gadījuma-kontroles pētījuma laikā (n = 66), grupās dalībnieki tika iedalīti atkarībā no viņu apakšstilba un pēdas pārslodzes traumu vēstures. Abās grupās novēroja, ka militāro apavu izmantošana palielina leņķi, kādā pēdas pieskarās pie atbalsta laukuma, vienlaikus stabilizē papēža kaulu un samazina pēdas locītavas kustību ātrumu. Nosacījuma loģistiskās regresijas modelis atklāja, ka tikai gaitas cikla ilguma mainība (OR = 2,71, 95 % CI 1,31–5,60), ejot basām kājām, var statistiski nozīmīgi prognozēt apakšstilba un pēdu pārslodzes traumu risku. Gaitas cikla ilguma mainības optimālā robežvērtība tika noteikta kā 1,95 %, kas ļauj paredzēt apakšstilba un pēdas pārslodzes traumu ar 56 % jutīgumu un 88 % specifiskumu.

Pētījumā tika secināts, ka militāro apavu izmantošana veicina gaitas stabilitāti un simetriju. Savukārt, militāru apavu izmantošana nav saistīta ar apakšstilba un pēdu pārslodzes traumu risku. Pētījuma datu parāda, ka gaitas cikla mainība ir potenciāls riska faktors kāju MSKI attīstībā, kas sniedz pamatojumu gaitas un pēdu skrīninga vadlīniju izveidei militārās medicīnas jomā.

Atslēgvārdi: gaitas analīze, gaitas mainība, karavīri, militāri zābaki, muskulo-skeletālās traumas.

Table of Contents

Abbreviations used in the Thesis

3D	Three-Dimensional
AI	Arch index
AUC	Area under curve
CI	Confidence interval
Cm	Centimetres
DN	Darja Nesterovica
DF	Dorsiflexion
EU	European Union
FPI	Foot Position Index
ICD-10	International Classification of Diseases, Tenth Revision
Kg	Kilogrammes
Ln	Natural Logarithm
LNAF	Latvian National Armed Forces
M	Metres
Mm	Millimetres
MSKI	Musculoskeletal injury
MTH	Metatarsal head
N	Newton
OR	Odds ratio
PF	Plantarflexion
ROC	Receiver Operating Characteristic
S	Seconds
SD	Standard deviation
SI	Symmetry (Robinson) index
STA	Soft tissue artefacts
US	United States of America
VAS	Visual analogue scale
WHO	World Health Organization

Introduction

Military service requires a high volume of physical activities, such as prolonged load carriage, marching, and running. Non-combat musculoskeletal injury (MSKI) in the military is one of the leading causes of medical discharge, increases the financial burden of military health care and reduces the readiness of the army (Dijksma et al., 2020; Fredette et al., 2021; Grimm et al., 2019; M. Lovalekar et al., 2021). MSKI is defined as any injury that affects any of the structures of the musculoskeletal system, such as bones, muscles, ligaments, nerves, or tendons, and results in pain and functional limitation (Sharma et al., 2015). Reported injury rates are consistently high despite years of military injury research and the implementation of injury prevention programmes. Multiple injury risk factors have previously been identified, such as load carriage, overweight, low physical fitness, female sex, and previous injury (Sammito et al., 2021). However, according to a recent meta-analysis, the evidence base for MSKI preventive strategies remains insufficient to provide strong recommendations for practice (Arslan et al., 2021). The overall reported incidence of MSKI among Swedish soldiers is 47 %, 49 % in the British army, and 53 % among US military personnel (T. Grier et al., 2020; Halvarsson et al., 2018; Sharma et al., 2015).

Throughout history, the infantry soldiers of the Land Forces have played a crucial and enduring role in the Latvian National Armed Forces (LNAF) (Andersons, 1992). Currently, the largest branch of the LNAF is the Latvian Land Forces, which comprises approximately 3,000 infantry soldiers with an average age of 34.5 years (2018). The monitoring of MSKI monitoring in LNAF is carried out by the National Army Medical Centre, according to medical reports provided monthly by regional military medical centres. The incidence of MSKI based on medical reports in 2018 among the Latvian National Armed Forces was 12.4 %; Most injured sites were lower legs (2.5 %), foot and toes (1.7 %) with only three cases of stress fractures reported (LNAF Joint Headquarters Medical Service, 2018). In contrast, a three-year (2017–2020) analysis of extremity MSKI from a Latvian regional medical centre found that extremity MSKI was common in 74 % of soldiers, which is consistent with findings from other military populations, but detailed analysis of types of injury (acute or overuse) or locations (upper or lower extremity) is not provided (Barovska, 2020).

The most common MSKI in the military with reported incidence from 70 % to 80 % are cumulative microtraumatic injuries (overuse injuries) of the lower part of the body, e.g. lower back, knee, calf, ankle and foot (Hauret et al., 2010; Molloy et al., 2020; Schwartz et al., 2018; Wilkinson et al., 2011). Such injuries are patellofemoral syndrome, Achilles tendinitis, plantar fasciitis, and stress fractures (Fredette et al., 2021; M. Lovalekar et al., 2021). Medical record-based injury rates in the LNAF are significantly lower than in other military populations, and it is not known whether injuries were concealed from medical professionals or reports were inaccurate, with only severe cases reported. However, systematic evaluation of MSKI incidence and long-term monitoring of acute and overuse injury trends are essential elements of the injury prevention strategy (Wardle & Greeves, 2017).

Footwear usage reduces lower extremity load, and this finding is promising in for reducing the MSKI rate in the lower leg (Zhang et al., 2013). The use of military footwear during combat training and in actual military scenarios varies between countries and military services (Andersen et al., 2016). Although the main purpose of footwear is foot protection from injury (Mawusi, 2019) and promotion of pain-free movement during locomotion (Menz & Bonanno, 2021). Moreover, military footwear should be comfortable and should assist a symmetrical gait cycle, provide mediolateral foot motion control and adequate stability on uneven terrain, therefore, protect against injuries (Hamill, 1996). Although a soldier may not prioritise footwear comfort and fit, it is crucial to address these aspects to achieve optimal gait stability, and they can significantly affect both physiological well-being and military job performance (Mawusi, 2019; Torrens et al., 2012). Additionally, footwear evaluation has been recommended as part of the relevant medical evaluation to prevent lower leg MSKI and improve overall foot health among the general population (Ellis et al., 2022). However, within military personnel, no routine assessment of shoe stability, fit and comfort is performed, along with an evaluation of foot posture. Several studies have reported an association between lower extremity injuries and military boots (Andersen et al., 2016; Joseph J Knapik et al., 2015; R. Orr et al., 2022), but a recent systematic review did not identify military boots as a possible risk factor for MSKI (Sammito et al., 2021). The role of military footwear in the development of overuse injuries remains unclear, and researchers suggest further investigation of the association between military footwear and overuse injuries (Baumfeld et al., 2015).

Foot interaction with footwear has a direct effect on gait kinetics, kinematics, and variability (Braunstein et al., 2010; S. J. Dixon et al., 2003; Franklin et al., 2015; Hollander et al., 2022). Decreased shock absorption and altered gait kinematics have been recognised as risk factors for overuse injuries in the lower leg and foot (Dowling et al., 2014; Willwacher et al., 2022). Plantar pressure evaluation can be used to examine foot function and motion during gait, although there is insufficient data linking plantar pressure values with risk of injury. Previous research on maximum plantar pressures among Royal Marine recruits and young Navy officers in the United Kingdom found that cases with high arch and greater plantar pressure on the medial side of the foot are more likely to sustain a metatarsal stress fracture and ankle inversion injury (S. Dixon et al., 2019; Rice et al., 2013). In a controlled training environment for Navy officers, elevated plantar pressure was found to be a prognostic factor in the development of lower extremity overuse injury (Franklyn-Miller et al., 2014).

Previous lower extremity MSKI in the military has been associated with subsequent injury and altered gait biomechanics (Andersen et al., 2016; Baida et al., 2018; Hamill et al., 2012; Toohey et al., 2017). Gait is a cyclic movement, and in healthy individuals, whether they are soldiers or civilians, complex fluctuations of unknown origin arise in the typical pattern (Hausdorff et al., 1995; Winter, 1984). Although significant variation in gait parameters is most observed in movement disorders (Ahsan et al., 2023), few studies have examined changes in gait variability as a risk factor or as a result of an injury among the military (Strongman & Morrison, 2020). Further research is required to promote evidence-based strategies that could minimise MSKI in the military across countries, and to establish medical gait and foot screening guidelines.

Previously, extensive anthropometric studies have been conducted in the military population of Latvia (Derums, 1940; Kokare, 1998). Derums (1940) have analysed body height, weight, and chest circumference among Latvian military recruits, while Kokare (1998) conducted an anthropometric study for various parameters among active-duty soldiers. Although systematic assessments of the foot types of soldiers have not been performed before and the role of foot posture and elevated plantar pressure as possible risk factors for lower extremity MSKI has not been well explored. Additionally, military footwear comfort, a critical element in soldiers' daily life, has not received prior research attention. Similarly, factors related to gait with footwear, despite their potential importance in injury prevention, remain relatively unexplored within the military setting. A comprehensive understanding of these interrelated factors is essential to improve the safety and well-being of military personnel.

Aim of the Thesis

The aim of this Doctoral Thesis was to determine the incidence of lower extremity overuse injury and investigate its possible relationship with the use of military footwear among Latvian Land Forces.

Objectives of the Thesis

To achieve this aim, four objectives were set:

1. Explore the incidence of lower extremity musculoskeletal injuries among Latvian Land Forces.
2. Investigate the relationship between a history of lower extremity overuse injury and the functional status of the foot.

3. Determine the association of lower extremity overuse injury with the use of military footwear.
4. Assess gait-related changes while walking with military footwear.

Hypothesis of the Thesis

- The incidence of musculoskeletal injuries in Latvian Land Forces is similar to other military populations.
- Previous lower extremity overuse injury is associated with elevated peak plantar pressure and non-neutral foot position.
- Military footwear comfort ratings are related to a history of lower extremity injury.
- Inadequate foot stability and lower foot and ankle angular velocities during gait with military footwear are risk factors for lower extremity overuse injury.

Novelty of the Thesis

Although there have been extensive studies on MSKI and gait-related risk factors among different military populations, there is still a need for a comprehensive view of the relationships of gait with military footwear and lower extremity overuse injury risk. The study focuses on a detailed analysis of both acute and overuse MSKIs, systematised using the Barell injury matrix, within a specific military population, infantry soldiers.

Data on foot posture and length, as well as footwear comfort ratings for the Latvian Land Forces, as well as for other armies of the Baltic States, are currently unavailable. This Thesis investigates foot posture and the biomechanical aspects of military footwear usage. Additionally, the Thesis explores potential military footwear usage and the non-neutral foot posture relationship with lower extremity overuse injuries among infantry soldiers.

The Thesis combines exploration of non-modifiable (history of injury, foot posture) and modifiable (military footwear, plantar pressure) lower leg overuse injury risk factors among infantry soldiers. To the best of the author's knowledge, for the first time, a case-control study aimed to assess shod and barefoot gait parameters as potential risk factors for lower leg overuse injuries among infantry soldiers.

Furthermore, a systematic assessment of perceived military footwear comfort was conducted for the first time, considering the cushioning and support provided by tactical boots. The Thesis contributes to a more profound understanding of the fit and comfort of military footwear by comparing infantry soldiers with and without previous injuries. The findings of this Thesis emphasise the importance of gait variability as a possible predictive risk factor for lower leg overuse injuries among infantry soldiers.

1 Literature review

1.1 Injury incidence and aetiology

Military training involves prolonged standing, load bearing, and long-distance running, which increases the risk of lower extremity MSKI (Scher et al., 2009; Taanila et al., 2015). Additionally, physiological stress during service time decreases immune response and increases the inflammatory response, which can increase injury susceptibility among the military (J. R. Hoffman et al., 2015).

Lower extremity injuries account for 40 to 60 % of all military MSKI, with the knee, lower leg, and foot being the most prevalent anatomic sublocations for injuries (Abt et al., 2014; M. Lovalekar et al., 2018; M. T. Lovalekar et al., 2016). Physical training has been associated with approximately 50 % of MSKIs among infantry personnel, with running being associated with 30 % of these injuries (T. A. Smith & Cashman, 2002).

Acute and overuse injuries are the two most common types of MSKI. Acute injury occurs suddenly due to blunt, crushing, or penetrating trauma (Iannotti JP, Parker RD, 2013), while overuse injury develops as a result of repeated overstretching, overloading, deformation, compression, or friction (J. R. Hoffman et al., 2015; Kernan et al., 2008). Sprains, strains, ligament ruptures, and joint dislocations, for example, are classified as acute injuries, while bursitis, fasciitis, and tendinopathies are classified as overuse injuries (Franklyn-Miller et al., 2014). In the case of acute injury, it is easy to determine when it started, but overuse injuries develop gradually and it is impossible to identify a single event that caused an injury (Roos & Marshall, 2014). Table 1.1 lists ICD-10 codes for lower extremity overuse injuries found in various military populations (World Health Organization, 2019). It should be noted that no established operational definition of an "overuse injury" is currently in use and existing injury surveillance systems may be under-reporting the occurrence of overuse injuries (Neil et al., 2018; Roos et al., 2019).

The incidence of lower extremity injury varies by service and country. For example, in Finland 51 % of young conscripts during the 6 months training programme sustained an overuse injury (Taanila et al., 2015), but the self-reported one-year incidence of MSKI among US infantry was 43 % (M. K. Anderson et al., 2015). The incidence of lower leg overuse injuries observed among Israeli Defence Forces ranged from 8 % in the foot to 22 % in the knee region and 34 % in the calf and ankle (Schwartz et al., 2018). In the US Army, the overall MSKI rate was 82 %, with a one-year incidence of lower extremity overuse injuries of 35 %. Overuse injuries were most common in the lower leg (57 %), followed by the foot (33 %), with patellar/Achilles tendinitis and plantar fasciitis being the most common injured body regions (Hauret et al., 2010).

Table 1.1

ICD-10 codes for musculoskeletal injuries in the military

Body region	ICD-10 diagnosis	Disease
Shoulder	M75.1	Rotator cuff syndrome or supraspinatus tear or rupture (complete)(incomplete), not specified as traumatic; supraspinatus syndrome
	M75.2	Bicipital tendinitis
	M75.4	Impingement syndrome of the shoulder
	M75.5	Bursitis of the shoulder
Elbow	M70.2	Olecranon bursitis
	M77.0/.1	Medial and lateral epicondylitis
Hand and wrist	G56.0	Carpal tunnel syndrome
	M70.1	Bursitis of the hand
Back	M54.5	Low back pain
Hip	M70.6	Trochanteric bursitis (trochanteric tendinitis)
	M70.7	Other hip bursitis (ischial bursitis)
Thigh	M76.3	Iliotibial band syndrome
Knee	M22.2	Patellofemoral disorders
	M70.4	Prepatellar bursitis
	M70.5	Other bursitis of the knee
	M76.5	Patellar tendinitis
Lower leg	M76.8	Other lower limb enthesopathies (anterior tibial syndrome; posterior tibial tendinitis)
	S86.9	Shin splints, medial tibial stress syndrome
Foot and ankle	M72.2 M76.6 M76.7 M77.4	Plantar fascial fibromatosis, plantar fasciitis Achilles tendinitis (bursitis) Peroneal tendinitis Metatarsalgia
Various	M84.3	Stress fracture not classified elsewhere

Source: adapted by author from ICD-10; WHO, 2019.

Table 1.2

Risk factors for lower extremity overuse injuries

Non-modifiable	Modifiable
• Female sex	• Muscle strength
• Age	• High volume of training
• Caucasians race	• Smoking
• Lower extremity morphology	• Footwear
• Previous injury	• Load carriage

Source: adapted by author from Andersen et al., 2016, M. K. Anderson et al., 2015, Fulton et al., 2014.

Lower extremity overuse injury is a multifactorial condition, with previously identified non-modifiable and modifiable risk factors (Table 1.2), including higher BMI, female gender, age, previous injury (Andersen et al., 2016; M. Anderson et al., 2015; Fulton et al., 2014), lower level of previous exercise (Cosman et al., 2013) and peak plantar pressure (Roberts et al., 2017).

The longer a soldier is absent from the military service, similar to professional sports, the greater the impact on the individual and unit mission. Returning too soon, before the individual has fully recovered, can put the individual at risk of sustaining another MSKI (Rhon et al., 2022). Inadequate recovery time combined with high-intensity training (overtraining syndrome) is a significant contributor to overuse injury in the military (Kaufman et al., 2000). Overtraining symptoms develop when training intensity or volume becomes excessive and is combined with insufficient recovery and rest time. Initially subjective fatigue appears and if overtraining continues, then performance decreases (J. Hoffman, 2014; J. R. Hoffman et al., 2015). If the amount of training is reduced and rest is provided, complete recovery can occur in 1–2 weeks (Kreider et al., 1998), and overcompensation and enhanced performance (functional overtraining) can occur (Meeusen et al., 2013). This training programme helps the competitive athlete to achieve peak conditioning for a specific period of time (e.g., competition season or championship). However, a tactical or military athlete (e.g., infantry soldier) is not focused on a known time frame and should remain at a high level of physical functioning throughout the period of service. If the balance between military training and recovery is inappropriate, overtraining can progress severely and the risk of overuse injuries is significantly increased (J. R. Hoffman et al., 2015).

1.2 Gait cycle

Gait is a cyclical series of highly synchronised movements of the entire body that incorporate pelvic sway and rotation, hip and knee swing, tibia rotation, and ankle joint flexion and extension (Haskell, 2020). The purpose of normal human gait is to enable movement from one point to another while minimising effort and maintaining sufficient stability in a wide range of walking circumstances (Webster & Darter, 2019). The spine requires a stable base in the lower extremities to provide both great mobility and the necessary stability when lifting the upper body during the gait cycle (McGregor & Hukins, 2009). However, no clear relationship between foot position and the spine during walking was previously found (Hmida et al., 2023).

The gait cycle is typically divided into two phases: the stance phase and the swing phase, which occur for each lower extremity (Dang, 2023). During walking, one lower extremity provides support (stance phase), while the other lower extremity advances forward (swing phase) and prepares to provide support. The stance phase makes up 60–65 % of the gait cycle and the swing phase makes up 35–40 % of the gait cycle (Magee & Manske, 2021). The stance consists of initial double limb support, single limb support, and terminal double limb support (Figure 1.1). During the swing phase, the reference limb is not in contact with the ground. A stride is a fundamental unit of the gait cycle. One stride is equivalent to one gait cycle (0–100 % gait) and occurs between the initial contact of one limb and the subsequent initial contact of the same limb (Haskell, 2020; Webster & Darter, 2019).

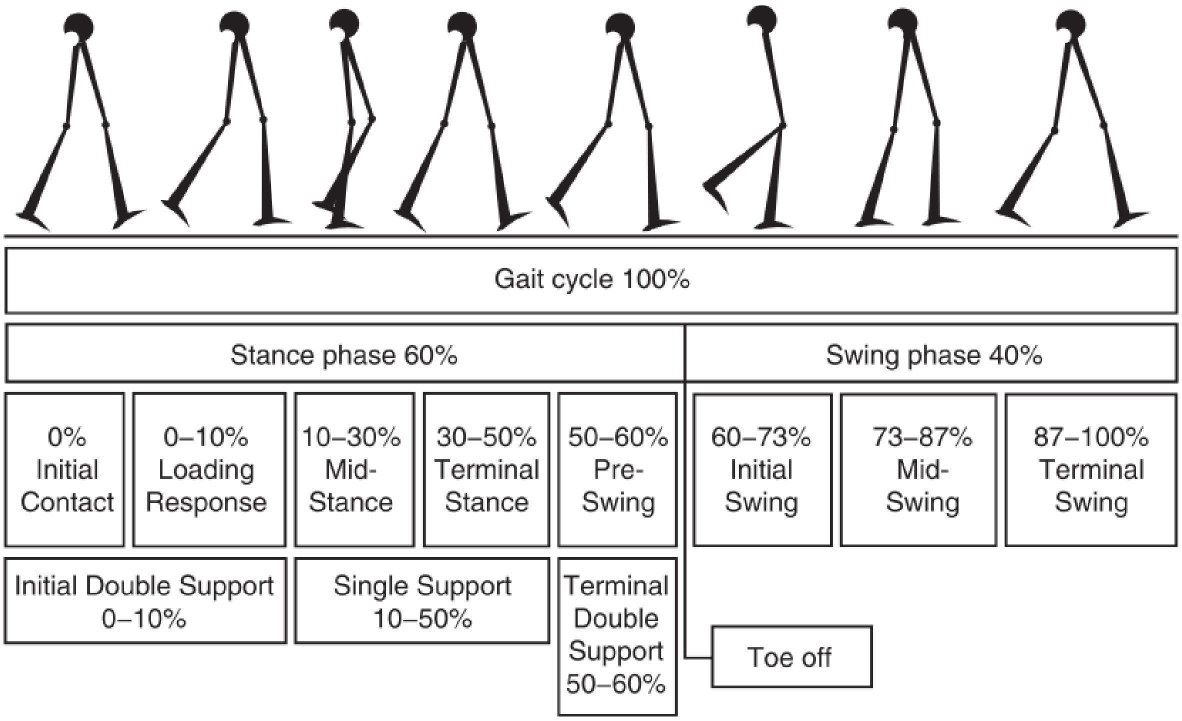

Figure 1.1 **Normal gait cycle periods and timing**

Source: Webster & Darter, 2019.

Spatiotemporal, kinematic and kinetic measures are used to describe the gait pattern. Phase timing, step length and width, number of steps per time period (cadence) and gait velocity are the basic spatio-temporal characteristics of the gait cycle. Gait kinematics describe joint angles and orientation of body segments. Gait kinetics are the forces and torques that occur throughout the body and can be assessed using ground reaction force and plantar pressure (Webster & Darter, 2019).

External loading is represented by ground reaction force, and according to Isaac Newton's third law of motion (Reinker & Ozburne, 1979), the same forces should be experienced internally. On the other hand, internal body structures of the musculoskeletal system are likely to experience forces differently and with a distinct risk of injury (Joseph J Knapik et al., 2015).

Plantar pressure measurement is test-retest reliable (Hafer et al., 2013), allows interpretation of the rate of loading of the foot and estimation of arch height in the military population (Goffar et al., 2013), correlates with foot posture index assessment, and has shown good intraclass correlation coefficients with ground reaction force data from force plate comparison (Low & Dixon, 2010). Plantar pressure correlates with intrinsic biomechanical abnormalities (Hagman et al., 2002) and the greater the perceived abnormality, the greater the risk of MSKI (De Cock et al., 2005). Gait interpretation based on dynamic pressure plate can be predictive of lower limb MSKI in the military; however, formal screening of initial military recruits is uncommon (Franklyn-Miller et al., 2014), and where it has been undertaken, it provides a possible injury prevention strategy (Reynolds et al., 2000).

Gait measures are individually specific and interrelated to each other. Due to variances in body segment length and mass distribution, each individual exhibits slight distinctive gait motion and muscular force differences (Haskell, 2020). The length of the gait phases is influenced by gait velocity; as walking velocity increases, the stance phase shortens, and the double support phase disappears during the transition from walking to running (Dang, 2023; Hombach-Klonisch et al., 2019; Webster & Darter, 2019). Furthermore, age, height, and gender, as well as the existence of disorders that cause pathologic gait patterns, can alter gait measures (Hof, 1996; Sekiya, 1996; Webster & Darter, 2019).

1.2.1 Gait variability

Although walking is a rhythmic and cyclical activity, each step is different from the previous or the following one (Pappas et al., 2018; Winter, 1984). Existing variations among subsequent strides (variability) are derived from the underlying gait-producing mechanisms (Stergiou et al., 2004). The standard deviation and coefficient of variation of kinematic or spatio-temporal measures are used to assess gait variability (Brach et al., 2005).

Individuals can modify step length and gait velocity to accommodate walking conditions, and can slow down or speed up without stopping, as well as increase foot clearance if an obstacle is present (Cavanaugh & Stergiou, 2020). Fluctuation of individual gait parameters or gait variability can be present even in a controlled environment (Cavanaugh & Stergiou, 2020). Gait variability alters with age (Kyvelidou et al., 2008), body composition (Y. Lee & Shin, 2022), load carrying, and fatigue (Qu, 2012). Significant gait variability shows a shift in gait parameters, which is most commonly found in individuals with neurological disorders (Moon et al., 2016; Patel et al., 2022), adults with a history of MSKI (Blyton et al., 2023; Nakayama et al., 2010) and patients with psoriatic arthritis (Walha et al., 2022). Higher fluctuation of stride time and step width, as well as increased variability of running gait parameters, has been observed previously (Nakayama et al., 2010; Niechwiej-Szwedo et al., 2007; Walha et al., 2022).

Although significant variation in gait parameters is most frequently reported in movement disorders, few studies have examined changes in the coefficient of variation of gait parameters as a risk factor or as a result of injury (Strongman & Morrison, 2020). A history of MSKI, according to the authors of a recent systematic review, could lead the neuromuscular system to explore alternate motor strategies and improve gait kinematic variability, which could protect musculoskeletal structures from further injury (Blyton et al., 2023).

1.2.2 Foot and ankle role during gait cycle

In theory, optimal biomechanical movement minimises the risk of injury by increasing the efficiency with which the body absorbs the load and responds to external stimuli (Hewett & Bates, 2017). The human foot is interconnected with other parts of the musculoskeletal system, and failure of one part to function effectively, whether caused by disease or external factors, will affect the functions of the other parts of the system during locomotion, such as walking or running. Suprapedal movements require certain functions of the foot and the way the foot functions may be reflected in movement patterns in other parts of the body. Likewise, changes in biomechanics above the foot caused by knee hyperextension or a stiff hip, may be expressed below by changes in foot motion (Haskell, 2020). The ability to adjust for undesirable movements can vary, allowing individuals to better adapt to suboptimal movement patterns than others and reduce their risk of injury. As a result, even if movement is poor, it may not always result in a higher risk of injury among individuals who can adapt effectively (Rhon et al., 2022).

The structures of the ankle and foot determine multiaxial mobility to assist human gait (Brockett & Chapman, 2016). Foot and ankle mobility are important determinants of gait economy (Saunders et al., 1953). The angular rotation of the foot around the lateral axis of the tibia is used to calculate ankle dorsiflexion and plantarflexion (Nair et al., 2010), and the alignment of the foot in the sagittal plane influences the angle of the ankle (Louey & Sangeux, 2016). After initial contact, ankle plantarflexion allows the foot to assume a flat foot position and decreases the rise of the centre of gravity; during terminal stance, ankle plantarflexion allows the heel to rise and prevents rapid tibial progression from causing a precipitous drop in the centre of gravity (Webster & Darter, 2019).

The main functions of the foot during gait are mobility for adaptability to uneven terrain, rotation of the tibia and fibula, and the capacity to serve as a rigid lever during push-off (Magee & Manske, 2021). Therefore, during locomotion, the lower leg, foot, and ankle joint act simultaneously as one functional group, and functional limitations of one component might lead to alterations in another. For example, disturbances of ankle mediolateral control decrease foot placement stability (van Leeuwen et al., 2020). Furthermore, disorders of the foot and ankle joint structures that provide shock absorption, static body support, and propulsion throughout the gait have a significant impact on individual levels of physical activity (Mojica & Early, 2019). Changes in foot and ankle mobility, for example, limited ankle dorsiflexion and increased hindfoot inversion observed among the Naval Forces of the United States Army, have been reported as significant risk factors for lower extremity MSKI (Kaufman et al., 1999).

1.2.3 Foot posture

The posture of the feet is related to gait. Sensory information on lower limb movement during walking is provided by the position of the foot and the forces applied to the foot (Arnold & Bishop, 2013; Landorf & Keenan, 2000). For example, forefoot instability functionally restricts the first metatarsophalangeal joint, making the stance phase of the gait inefficient (Payne & Dananberg, 1997). Changes in stance phase cause postural perturbations, prolongs forefoot inversion, and reduce pelvic stability during the gait cycle (Dananberg, 1993, 1997).

Foot posture index (FPI) is being used for the assessment of static foot and ankle position (Redmond et al., 2006). Previous research has indicated good FPI inter- and intrarater reliability regarding foot type (valgus, varus, neutral) quantification (Cornwall et al., 2008; Morrison & Ferrari, 2009; Redmond et al., 2006). Previously, a relationship between overuse lower leg MSKI and varus (pes cavus) and valgus (pes planus) foot postures was identified among the US Naval Forces (Kaufman et al., 1999). Valgus foot position results in excessive pronation during the stance phase of the gait and is associated with increased medial plantar load and strain of plantar fascia (Dananberg, 2000; Sánchez-Rodríguez et al., 2012). Excessive pronation has been linked to overuse injuries such as plantar fasciitis, stress fractures of the lower leg (Barnes et al., 2008; Kaufman et al., 1999; Neal et al., 2014) and patellofemoral pain syndrome (Levinger & Gilleard, 2007). The position of the varus foot and the high arched foot have been associated with a significantly higher risk of MSKI in the lower extremity due to increased lateral plantar pressure during the late midstance and propulsion phases (Ghani Zadeh Hesar et al., 2009; Riegger et al., 2022). The risk of lower leg MSKI is increased in non-neutral foot position in both barefoot and footwear conditions (T.M. Willems et al., 2006; Tine Marieke Willems et al., 2007).

1.3 Biomechanical effects of footwear on gait

Footwear usage is an external factor that interacts with the foot and acutely modifies gait kinematic and kinetic parameters (D'Août et al., 2009; Franklin et al., 2015; Haskell, 2020), as well as gait variability (Baumfeld et al., 2015; Hollander et al., 2022; R. Orr et al., 2022). Footwear also has the potential to be a tool to promote energy storage and release of the ankle during the gait cycle (Ogaya et al., 2022). Moreover, footwear influences foot position perception through the effect of plantar sensibility (Robbins et al., 1995).

The observed effects of footwear on the gait pattern depend on the design and material differences. During gait with common footwear, the range of ankle plantarflexion decreased, the maximum ground reaction forces were reduced, and the stride length increased compared to the gait with barefoot (Spencer, 2020). Furthermore, it has been reported that gait with common footwear reduces ankle stability (Ramanathan et al., 2011), increases plantar aponeurosis length (Lin et al., 2013), minimises peak Achilles tendon force, and reduces first metatarsophalangeal joint dorsiflexion angle (Greve et al., 2019). The gait with running footwear showed the same ankle dorsiflexion as the barefoot gait (Louey & Sangeux, 2016), while the gait with military boots demonstrated a restricted range of ankle mobility (Schulze et al., 2014). Unstable common footwear models showed reduced gait variability at the foot and ankle, but increased angles of spine rotation (Khoury-Mireb et al., 2019). Occupational footwear plays a role in postural stability (Chander et al., 2017), lower extremity impact (Chong et al., 2017) and lumbar biomechanics (Vu et al., 2017), and increases muscle activity in the lower extremities (Goto & Abe, 2017). Previous studies have also shown that occupational footwear can affect physiological parameters such as aerobic capacity, heart rate, temperature, muscle activity, and performance in selected occupations (Chander et al., 2017; R. Orr et al., 2022). Anderson et al. (2021) have pointed out the significance of focusing on the fit and comfort of occupational footwear when providing footwear to employees.

The occupational footwear used by military personnel while on duty is military (tactical) boots and running shoes, and shoe styles vary by country and service, making it difficult to identify inadequacies in military footwear design difficult to identify (Andersen et al., 2016). Military boots are designed for a specific activity and environment and can be used for marching and running (Hamill J, 1996). The contribution of military footwear to task performance is primarily protection and stability of the foot (Torrens et al., 2012). The use of military footwear leads to significant changes in foot motion and gait parameters (Majumdar et al., 2006; Morio et al., 2009), and, therefore, it may also be necessary to examine gait while barefoot.

1.4 Footwear comfort and fit

Footwear comfort is a complicated combination of characteristics such as proper fit, cushioning and support, interior temperature, humidity, plantar pressure distribution, and ground impact force (Jordan & Bartlett, 1994; Miller et al., 2000; West et al., 2019). Foot position, as well as footwear stiffness and cushioning, all contribute to the perception of footwear comfort (Miller et al., 2000).

The results of the systematic review showed that a considerable proportion of the common population wears ill-fitting shoes, leading to foot pain and foot disorders (Buldt & Menz, 2018). The appropriate footwear fit can help decrease or even avoid toe deformation and misalignment (Torrens et al., 2012). Foot skin and nail disorders such as corns, calluses, and blisters have been linked to improper footwear fit (Carr & Cropley, 2019). Skin disorders can also imply asymmetric lower limb behaviour during shod gait (Grouios, 2005). It has been discovered that improper footwear fit contributes to overuse injury of the lower extremity due to gait alterations (Finestone et al., 1992). Furthermore, footwear comfort has been identified as a key component in all MSKIs of the lower extremities caused by movement (Nigg et al., 2015; Tine Marieke Willems et al., 2019). However, military footwear, as well as other types of occupational footwear, appear to be developed for occupational safety without regard for comfort (Dobson et al., 2017),

Keratotic lesions of the plantar skin or foot blisters that result from friction, pressure, shearing, or a combination of these mechanisms between surface of the foot, sock, and insole of military footwear are common injury type sustained during load carriage (R. M. Orr et al., 2014; R. M. Orr & Pope, 2016). Uncomfortable military footwear, as well as inappropriate military footwear fit, is being reported to be a precursor to more serious issues of blisters (Torrens et al., 2012) and lower leg overuse injuries (Finestone et al., 1992). Although foot blisters are a minor condition, recruits who experienced foot blisters were found to be up to 50 % more likely to sustain additional training-related injury due to altered gait movement patterns caused by blisters (Bush et al., 2000). Furthermore, Grier et al. discovered that poor shoe fit and cushioning were related to foot pain and discomfort, but extra cushioned footwear did not reduce the incidence of MSKI in the military (T. L. Grier et al., 2011).

Previous military footwear research conducted in 1976 concentrated on various acute and overuse lower extremity MSKI without uniform injury definitions, while military footwear comfort data were not systematically evaluated (Bensel, 1976; Bensel & Kish, 1983). Muniz et al. reported only overall footwear comfort among Brazilian army recruits, with softer midsoles and lower military boot weight providing more comfort (Muniz & Bini, 2017). Paisis et al. assessed comfort perceptions in the Greek army, and the study demonstrated that participants preferred to walk in the lightest weight military boot. Reduced weight, increased stiffness, and the construction of military boots have all been indicated to be useful for increased footwear comfort (Paisis et al., 2013). Peak plantar pressures have been linked to military boot comfort, and military boot modifications based on plantar pressure variables can improve comfort while lowering the risk of foot overuse problems (Lange et al., 2009).

Despite previous studies on military footwear comfort, Dijksma et al. (2020) consider that previous footwear comfort research in military populations may no longer be applicable due to innovations in military boot design. Furthermore, the complexities of what makes well-fitted footwear more comfortable, as well as the impact of comfort of footwear on gait and injury, are still not well understood (Branthwaite & Chockalingam, 2019).

1.5 Injury prevention

To date, there is no current universal strategy for reducing MSKI in the military. The current evidence base for injury prevention strategies in the military population is broad, as MSKI is multifactorial in nature. In total, 57 different possible risk factors were discovered in a qualitative systematic evaluation of publications on risk factors for musculoskeletal injuries in the military that attempted to be all inclusive (Sammito et al., 2021). A methodology for prioritising risk factor classification was presented by Sammito et al. (2021) to help the development and implementation of intervention strategies, presenting the idea that targeting risk factors in a higher order will result in a greater risk reduction. Jones et al. (2018) suggested that the five-step public health strategy (Table 1.3) is an effective approach for use in the military. Although each step of this strategy is important, steps may not be taken in the order listed.

Table 1.3

Five-step public health method to develop and build an injury prevention program

1) Surveillance to define the magnitude of the problem
2) Research and field investigations to identify causes and risk factors
3) Intervention trials and systematic reviews to determine what works to address leading risk factors
4) Program and policy implementation to execute prevention
5) Program evaluation to assess effectiveness.

Source: Jones, B. H., Hauschild, V. D., & Canham-Chervak, M. Musculoskeletal training injury prevention in the US Army: Evolution of the science and the public health approach (2018).

MSKI rates can be reduced by improving leadership/supervision/awareness of injuries, as well as injury prevention initiatives (Farzadi et al., 2017; Wardle & Greeves, 2017). Any type of previous injury that can increase the likelihood of a variety of lower extremity injuries after injuries should be considered when establishing future preventive strategies (Toohey et al., 2017). When evaluating preventive methods, it is critical that they target the key factors that contribute to the risk of MSKI (Kaufman et al., 2000).

Physical fitness level before preadmission to the military service plays a role in overall MSKI rates (Wardle & Greeves, 2017). Musculoskeletal screening is recommended to target military recruits at elevated risk, such as those with insufficient muscular strength and flexibility (Andersen et al., 2016). To avoid overtraining, the physical limits of military personnel endurance must also be examined (Kaufman et al., 2000; R. Orr et al., 2010). The changes in the physical training programme for soldiers of various military occupational specialisations resulted in the most effective reduction in total injury rates (Bunn et al., 2022; J. J. Knapik et al., 2004; Wardle & Greeves, 2017).

Lower extremity biomechanical movement patterns that place individuals at increased risk for lower extremity MSKI may also be important targets for injury prevention interventions (Jacobs et al., 2014). MSKI among athletes can be significantly reduced by preventive biomechanical practices (Hewett & Bates, 2017), and it is similar for military athletes. Movement retraining interventions that target high-risk biomechanical movement patterns play a key role in the primary prevention of lower extremity MSKI (Dunn et al., 2018; Jacobs et al., 2014). Through gait retraining, vertical ground reaction forces in running shoes and military footwear can be significantly reduced (Zimmermann et al., 2019).

Changes in gait biomechanics with foot orthotics remain insufficient to reduce the incidence of lower limb injuries during military training. However, few studies have shown that foot orthotics could help reduce the occurrence of lower limb injury in the military (Bonanno et al., 2018, 2019; Schwellnus et al., 1990; Snyder et al., 2009). Furthermore, the results of the systematic review showed that foot and ankle bracing can be suggested for high-risk activities to minimise MSKI, but no clear indication of the benefit of footwear modification was found (Wardle & Greeves, 2017).

2 Materials

2.1 Study population

A study was carried out among Latvian Land Force soldiers at the Latvian National Army Logistic Command Military Medical Support Centre in 2018–2020. To mitigate possible variations in physical activity levels and routines, only active duty infantry soldiers were eligible for participation. Before starting the study, permissions from Rīga Stradiņš University Ethics Committee (Nr.40/26.10.2017) (Annex 5) and LNAF were admitted (Annex 6).

All available infantry soldiers were asked to participate in a research during the annual medical check-up. Participation was completely voluntary and the study results did not influence the results of the medical check-up or the functional status of the soldier.

The research was conducted in two stages: Stage I – cross-sectional study and Stage II – case-control study. The flow chart of the research design is illustrated in Figure 2.1. (Annex 3). In 12 consecutive interview sessions total, n = 228 or 16 % of all active duty infantry soldiers (males, n = 214; females, n = 14) were invited to participate. Written informed consent was provided for each study participant prior to starting the interview (Annex 7). For further activities, n = 227 infantry soldiers were selected, n = 1 person refused to participate and did not sign the informed consent.

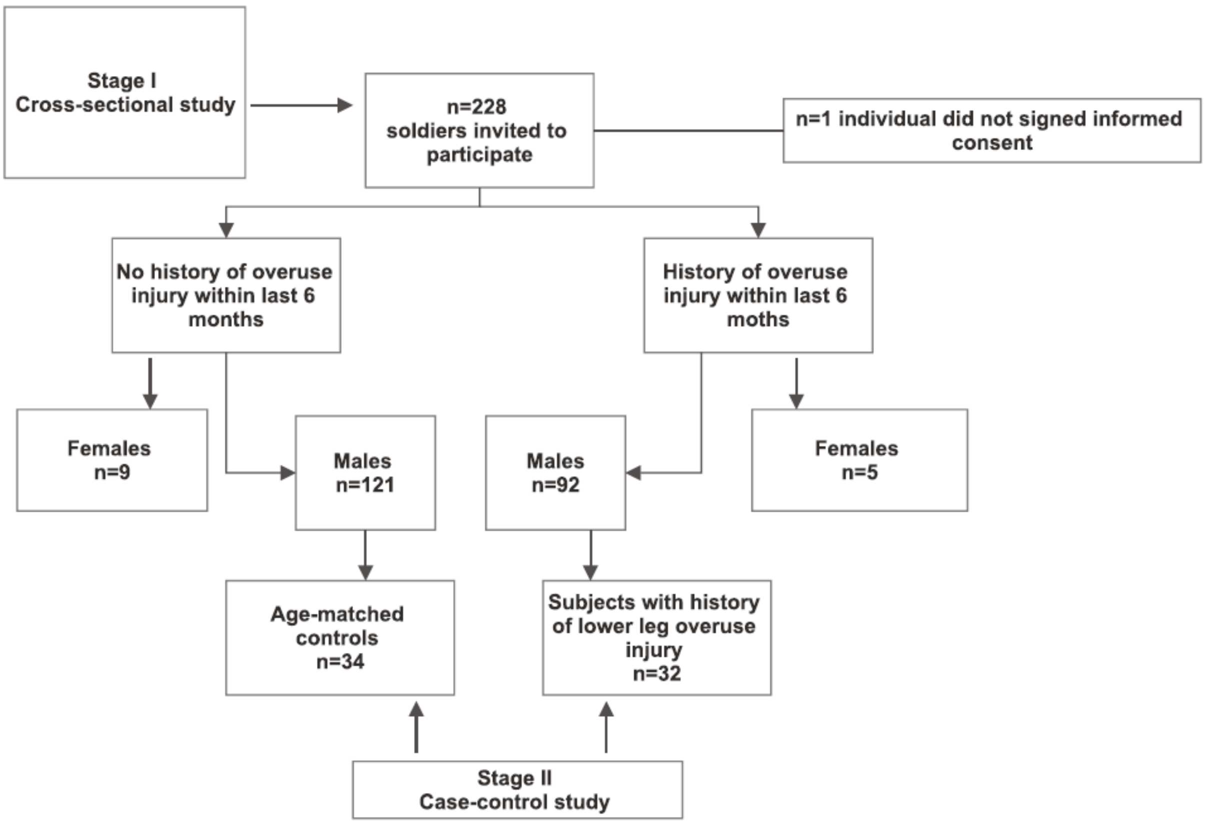

Figure 2.1 **Flow-chart of the research process**

3 Methods

3.1 Cross-sectional study

During the annual medical check-up, the soldiers were asked to recall all injuries during the last 6 months of service. The interviewer filled in (DN) the injury matrix and additional data from medical records (injury history, age of the individual, service time) was extracted.

The injury was considered if the soldier had a medical record or reported musculoskeletal injury (e.g. injury of bones, muscles, tendons), which did not allow participation in at least one activity during the last 6 months.

MSKIs were classified by type, acute or overuse, and by body regions according to the Barell injury matrix (Barell et al., 2002). Acute injuries are sprains, strains, ligament ruptures, and fractures (excluding stress fractures). MSKI caused by repetitive or forceful tasks resulting from repeated overstretching or overloading that occurred without a single identified event were defined as overuse injuries (Kernan et al., 2008; Nesterovica, 2020).

For injury coding and classification, ICD-10 was used (World Health Organization, 2019). The injury coding was performed by a person (DN). Acute injuries are coded with codes ICD-10 S00-T32, overuse injury codes are shown in Table 1.1. For example, ankle sprain was defined as acute injury (ICD-10 code S93.4) and posterior tibial syndrome (ICD-10 code M76.8) was defined as overuse injury. The aetiology and pathophysiology of medial tibial stress syndrome or shin splints (S86.9) have not been definitively established (Jamal et al., 2016; Milgrom et al., 2021; Zimmermann et al., 2017) and biomechanical factors related to running have been confirmed (Willwacher et al., 2022). Therefore, in this study, medial tibial stress syndrome was coded as overuse injury, but participants with this diagnosis were not included in the case-control study.

3.1.1 Military footwear comfort assessment

In stage I, study participants rated the comfort of their military boots. All participants were infantry soldiers who used the same personal protective equipment, including identical footwear. The same military boot models for hot and cold weather conditions were issued to all infantry soldiers during their service. Therefore, even in the event of a lower extremity injury, infantry soldiers were using the same military boot models. Latvia’s average annual air temperature is + 5.9 °C (Latvian Environment, Geology and Meteorology Centre), and for most of the year soldiers wear boots for hot weather conditions, so the comfort rating was assessed for this type of military boot only issued (Figure 3.1.).

Figure 1.1 **Military boot example**

Source: author's photograph.

1. **Overall military boot comfort**

Not comfortable at all — Most comfort imaginable

2. **Forefoot cushioning**

Not comfortable at all — Most comfort imaginable

3. **Arch cushioning**

Not comfortable at all — Most comfort imaginable

4. **Heel cushioning**

Not comfortable at all — Most comfort imaginable

Figure 3.2 **Footwear Comfort Tool Example**

Source: author's diagram adapted from Mills, K., Blanch, P., & Vicenzino, B. Identifying Clinically Meaningful Tools for Measuring Comfort Perception of Footwear (2010).

Military boot comfort rating tool was constructed accordingly to previously used methodology (MILLS et al., 2010). A VAS with a ten-centimetre length was used to rate overall boot comfort, forefoot, arch cushioning and heel cushioning, arch, and heel support. Best comfort (10) was at the right end and label 'not comfortable' (0) at the left end (Figure 3.2).

3.2 Case-control study

Cases and controls for the second stage of the research were identified from the cross-sectional study population. Groups were based on the injury status of the participants. Participants with a history of the lower leg, ankle, and foot overuse injuries n = 32 (14 %) were invited for more detailed testing. Participants with diagnosed medial tibial stress syndrome were not included. Controls n = 34 (15 %) were subjects without injury matched in age from the same population. The case-control matching procedure was performed using MedCalc Software Ltd (v.18.5, Belgium). During detailed testing study subjects' height, weight and size of the footwear used were documented. Foot posture, foot arch, and bare footprint length were assessed; additionally, plantar pressure, barefoot, and shod gait were examined. Two subjects in the control group did not participate in gait analysis.

3.2.1 Foot posture

Before foot posture assessment, visual inspection of the skin and nails of the foot was performed. The presence of blisters, calluses, or corns, as well as ingrown toenails and subungual haematoma, were documented according to the classification of Carr & Cropley (2019).

Foot posture was analysed according to FPI (Redmond et al., 2006). Each foot was assessed separately and each factor was rated from −2 to +2 (Table 3.1). The neutral FPI range is from 0 to +5, the pronated foot from +6 to +9, the highly pronated +10, the supinated FPI range from −1 to −4, the highly supinated foot from −5 to −12. For recording the FPI assessment, the data sheet adapted from Redmond et al.

Table 3.1

Foot Position Index Datasheet

	Factor	Plane
Rearfoot	Talar head palpation	Transverse
	Curves above and below the lateral malleolus	Frontal / transverse
	Inversion /eversion of the calcaneus	Frontal
Forefoot	Prominence in the region of the talonavicular joint	Transverse
	Congruence of the medial longitudinal arch	Sagittal
	Abd / Adduction forefoot on rearfoot	Transverse

For FPI usage in Latvian author's (professor Anthony Redmond) permission for translation was obtained. The adaptation of the FPI adaptation to Latvian was performed using forward-backward translation according to the recommendations of Beaton et al. (2007). For FPI measurement, subjects were asked to look straight forward and stand in a relaxed position with double-limb support (Redmond et al., 2006).

3.2.2 Footprint length and fit of the footwear

Digital image of the bare footprint for the length assessment was obtained using a pressure platform (2 m × 0.4 m × 0.02 m, RSscan International, Belgium). For the measurement procedure, participants were asked to stand on the platform in a relaxed manner. Calibration was performed before each measurement. Plantar pressure analysis software (Footscan® v.7.11, RSscan International) was used to detect the length of the foot arch and the length of the foot footprint in millimetres. Foot arch classification was performed using the arch index (AI): high-arch ($AI \leq 0.21$), normal arch ($0.22 < AI \leq 0.26$), low arch ($AI > 0.27$) (Cavanagh & Rodgers, 1987; Hernandez et al., 2007).

Footprint length was converted to shoe size according to the Mondopoint system (Celko, 2010). This system is an international metric footwear (sports shoes, military boots, skiing boots, etc.) system that is based on statistically constructed foot. According to the Mondopoint system, the shoe size is based on the length of the footprint in millimetres (*International Organisation for Standardisation*). If the lengths of the left and right footprint differ, the longer foot was chosen for the analysis of the footwear size. A comparison of the self-selected military shoe size with an appropriate shoe size was performed according to the length of the bare footprint. The appropriate fit of the military boot was defined if the used boot size matched the Mondopoint sizing, and toe clearance was not analysed.

3.2.3 Dynamic plantar pressure assessment

Plantar pressure was examined on the pressure platform described above. The platform was embedded in the centre of a 5-meter long walkway in the Rehabilitation Research Laboratory of Rīga Stradiņš University. Before each examination, weight calibration was performed. Study participants were instructed to walk barefoot at a comfortable and self-selected speed and not look at the ground. A two-step initiation protocol was used, so participants were placed 2 steps from the edge of the platform. This protocol was used to reduce the influence of walking speed on plantar pressure measurement. Few walking trials were used for acclimatisation and mean data from 3 successful trials were included in each foot plantar pressure analysis.

The plantar pressure analysis software measured plantar pressures in N/cm^2. Software automatically masks the foot into 10 regions: hallux, lesser toes, each metatarsal head (1^{st} MTH, 2nd MTH, 3rd MTH, 4th MTH, and 5th MTH), midfoot, medial, and lateral heel. After checking if the automatic masking was correct, peak plantar pressure values and contact area values were extracted. The plantar pressure symmetry for each region was determined between the right and left feet using the symmetry index (SI):

$$SI = \frac{|X_r - X_l|}{0.5 * (X_r + X_l)} * 100 \ \% \qquad (3.2)$$

where:

X_r and X_l are pressure parameters of the right and left foot. In case of perfect symmetry between the right and left foot SI value is 0, a higher value indicates higher asymmetry (Robinson et al., 1987; Wafai et al., 2015).

3.2.4 Gait analysis

Gait analysis was performed in the same laboratory mentioned before. During the gait evaluation procedure, study participants were instructed to wear shorts. All study participants used the same military boot model for hot weather conditions with 25 cm height (Figure 3.1.). The boot could not be used for gait evaluation if visual signs of attrition were found. Two familiarisation gait trials (Hamacher et al., 2017) were used for barefoot and shod gait conditions and were not included in the analysis.

For the gait assessment, participants had to walk at comfortable speed on the walkway barefoot and in military boots until full n = 50 gait cycles (König et al., 2014; Kroneberg et al., 2019) were video-recorded with two high-speed camera motion capture systems (100 samples/s). For two-dimensional kinematics and spatiotemporal gait analysis (Maykut et al., 2015; Zult et al., 2019), data from marker tracking and Quintic v31 biomechanics software (Quintic Consultancy Ltd., United Kingdom) were used. During the stance phase of the gait cycle, rearfoot eversion and ankle plantar/dorsiflexion angles were evaluated. The initial contact was defined as heel contact. The angle formed between the foot and the ground during a heel strike was defined as the foot contact angle (Pipkin et al., 2016). The anteroposterior distance between the left and right heel markers at each initial contact was used to calculate the length of the step.

Gait variability as well as spatio-temporal characteristics of straight walking patterns were statistically analysed. The definitions and calculations of the spatio-temporal gait parameters were the same as in a previous study among military recruits (Springer et al., 2016) (Table 3.2).

Table 3.2

Calculations of selected spatio-temporal gait parameters

Stride time variability	$100 \times \frac{stride\ time\ SD}{mean\ stride\ time}$
Stride length variability	$100 \times \frac{stride\ length\ SD}{mean\ stride\ length}$
Step length asymmetry	$100 \times \ln \frac{right\ step\ length}{left\ step\ length}$

ln, natural logarithm; SD, standard deviation.

All study participants were fitted with retroreflective spherical markers (n = 12) using double-sided tape for gait spatiotemporal analysis and for tracking lower leg motion during the gait cycle. A single examiner bilaterally marked the anatomical landmarks of the bare foot and shank: the middle shank, lateral and medial femoral epicondyles, lateral and medial malleoli, first, second, and fifth metatarsal heads, and posterior calcaneus. Markers were placed at the same locations as in previous studies of bare feet and shod (Chen et al., 2022; Peng et al., 2020). After palpation of the anatomical landmarks through the military boot, markers were inserted for evaluation of the gait with a shoe. The marker set of this study (n = 22) is identical to the conventional lower limb gait model marker set and has shown strong test-retest reliability (ICC > 0.80) (Molina-Rueda et al., 2021).

4 Statistical analysis

4.1 Sample size

Sample size calculation was determined by the medical-record based 1-year (2017, *Latvian National Army Logistic Command Military Medical Support Centre*) musculoskeletal lower extremity injury incidence among Latvian Land Forces (12.4 %) and same year population size of Latvian Land Forces (n = 1418). An open source calculator (OpenEpi, Open Source Statistics for Public Health) was used for representative sample size calculation (Kelsey L, Fleiss K, 2010). The statistical power was set to 0.9, $p < 0.05$ (two-tailed) was considered significant. To maintain statistical power, for the cross-sectional study, 150 participants were needed and 60 participants for the case-control study (n = 30 in each group).

4.2 Data analysis

For statistical analysis, IBM® SPSS® Statistics for Windows (Statistical Package for the Social Sciences), software version 22.0 was used. Categorical variables in the tables are presented as frequencies, and quantitative variables are presented as means ± standard deviation if not stated otherwise.

All variables were explored for distribution using the Kolmogorov-Smirnov test for the cross-sectional study and the Shapiro-Wilk test for the case-control study. The choice of the normality test was based on the sample size (Mishra et al., 2019) during different stages of the study. If data did not meet normal distribution assumptions, non-parametric tests (e.g. Mann-Whitney test, Kruskal-Wallis test) were applied.

In the article assessing MSKI injury incidence (Annex 1), relative and absolute frequency distributions were used. Injury incidence calculated as number of injuries divided by the population at risk of an injury in a one-year period, results were expressed as the number of injuries per 1000 person-years.

Logarithmic transformation was used in the case-control study for continuous gait-related variables if needed to obtain a normal distribution; If an approximately normal distribution after logarithmic transformation was not achieved, non-parametric tests were used. Within-group differences in gait were assessed by paired t test or Wilcoxon signed rank test (Breslow & Day, 1980).

For statistically significant gait-related differences between groups and between barefoot and shod conditions, an index of effect size point biserial correlation, r, is reported (Nakagawa & Cuthill, 2007); effect sizes were defined as 0.1 – small, 0.3 medium, and 0.5 large (Cohen, 2016).

Data from the right and left sides were used for plantar pressure analysis, stride time, stride length, and step asymmetry calculations; foot contact angle, rearfoot angle, and angular velocities from the right side only were used for statistical analysis.

The COXREG function in SPSS was used for conditional logistic regression analysis to investigate the effect of statistically significant gait-related factors on the likelihood of lower limb overuse injury. Additionally, for significant gait parameters, receiver operating characteristic (ROC) analysis was used to examine the area under the curve (AUC). Specificity, sensitivity, and cutoff value were based on the Youden index (Fluss et al., 2005).

5 Results

5.1 Cross-sectional study results

N = 227 active duty infantry soldiers participated in Stage I, 94 % of study participants were male (Table 5.1).

Table 5.1

Characteristics of the population of the cross-sectional study

	Total (n = 227)	**Males (n = 213)**	**Females (n = 14)**
Age, years*	29.5 ± 7.2	29.4 ± 7.0	32.1 ± 8.3
Service time, years	7.2 ± 6.4	7.1 ± 6.4	8.3 ± 6.5
Smoking, % (n)	43.2 (98)	45.1 (96)	14.3 (2)
History of lower extremity injury during service time, % (n)	42.7 (97)	43.2 (92)	35.7 (5)
Foot blisters after long marching, % (n)	46.3 (105)	46.5 (99)	42.9 (6)
Usage of foot orthotics, % (n)	4.9 (11)	4.7 (10)	7.1 (1)

*Continuous variables are presented as mean with standard deviation (SD); categorical variables are presented as % (n).

5.1.1 Incidence of self-reported injury

Active duty infantry soldiers reported 197 musculoskeletal injuries and the overall incidence rate of injuries in 2017 was 867.8 injuries per 1000 person-years (95 % CI 824.8–913.0). The incidence rate of acute injuries was 436.1 injuries per 1000 person-years (95 % CI 376.1–505.6); the incidence rate of overuse injuries was 431.7 injuries per 1000 person-years (95 % CI 371.8 – 501.2). 13 % of the study participants reported three or more injuries (n = 30), 26 % reported two injuries (n = 59), and 45.6 % of the participants reported only one injury (n = 108).

The most prevalent acute injuries were observed in the lower leg and ankle, knee, wrist, and shoulder regions. The most common acute injuries were sprains (n = 29), superficial contusion injuries (n = 24), fractures (n = 21), and joint dislocations (n = 21). Acute trunk and abdomen injuries, crush injuries, and amputations or blood vessel injuries were not reported. The Barell injury matrix with the acute and overuse injuries listed is shown in Annex 1 (Table 2).

Overuse injuries were reported by 43 % of the study participants (n = 98). The most common overuse injuries occurred in the lower back, knee, lower leg, and foot. Typical overuse injuries were lower back pain (n = 42), patellofemoral pain syndrome (n = 11), medial tibial stress syndrome (n = 9) and plantar fasciitis (n = 8). Stress fractures were reported in two cases.

5.2 Military footwear comfort rating

Differences in military boot comfort rating between male and female groups were independent of the history of overuse injury. The highest rating was 6.7 for overall comfort in the non-injured male group. Heel cushioning rating of 5.2 was the lowest and was observed among the non-injured female group for the heel cushioning. Mean military boot comfort ratings among males were higher across all dimensions, but the difference with the female group was not statistically significant (Table 5.2).

Table 5.2

Military footwear comfort ratings among infantry soldiers

	Males (n = 213)		**Females (n = 14)**		**P***
	with prior injury (n = 92)	**non-injured (n = 121)**	**with prior injury (n = 5)**	**non-injured (n = 9)**	
Overall comfort	6.3 ± 1.8*	6.7 ± 1.7	5.6 ± 2.1	6.1 ± 2.2	0.16
Forefoot cushioning	6.0 ±1.9	6.4 ±1.8	5.6 ± 1.7	5.7 ± 2.0	0.12
Arch cushioning	6.1±1.8	6.2 ± 2.0	5.6 ± 1.8	6.1 ± 1.7	0.67
Heel cushioning	6.2 ±1.8	6.2 ± 2.0	5.6 ± 1.3	5.2 ± 2.0	0.84
Arch support	6.0 ±1.9	6.4 ±1.9	6.0 ± 1.7	5.7 ± 1.9	0.19
Heel support	6.2 ±1.9	6.7 ± 1.8	5.8 ± 1.6	6.0 ± 2.4	0.05

*Comfort ratings with SD; one-way ANOVA test compared injured and non-injured groups.

5.3 Case-control study results

After stage I, n = 66 participants were assigned to the cases and control groups according to their history of overuse injuries (Table 5.3). The foot arch for the study subjects was classified as normal (AI = 0.26). The total FPI score ranged from –5 to 10 (median 3.00) for both groups. The pronated (n = 7) left foot was observed in both groups, the supinated posture (n = 6) of the left foot was observed more frequently between cases. The FPI values did not differ significantly between the feet or groups ($\chi2(1) = 0.15$, $p = 0.70$).

Table 5.3

Characteristics of the case-control study participants

		Cases (n = 32)	Controls (n = 34)	P*
Age, years		28.5 ± 5.2	30.24 ±5.4	0.07
Height, m		1.81 ± 0.08	1.77 ± 0.07	0.93
Weight, kg		80.5 ± 12.6	81.1 ± 12.6	0.93
BMI, kg/m^2		24.6 ± 2.7	25.7 ± 2.3	0.05
Footprint length, mm		275 ± 1.26	273 ± 1.28	0.15
Position of the left foot, n		–		0.70
–	Supinated foot	n = 6	n = 2	–
	Neutral foot	n = 19	n = 25	
	Pronated foot	n = 7	n = 7	
Left foot arch index		0.26 ± 0.06	0.26 ± 0.08	0.60
Position of the right foot, n		–		0.70
–	Supinated foot	n = 4	n = 1	–
	Neutral foot	n = 25	n = 27	
	Pronated foot	n = 3	n = 6	
Arch index of the right foot		0.26 ± 0.07)	0.26 ± 0.7	0.60

*P values based on the Mann-Whitney test, foot posture determined using FPI.

5.3.1 Footwear sizing analysis

To establish a possible relationship between shoe comfort and lower leg overuse injury, self-selected military footwear sizes were converted to millimetres using the Mondopoint system and compared with the foot length measurement of the Footscan® software (Table 5.4). The median difference in footprint length between the left and right foot was 1 mm (range 0–5 mm).

The sizes of the self-selected boot differed between the groups (p = 0.04). Footwear size analysis showed that 57.6 % (n = 38) of all study participants used inappropriate military boot size: 30.3 % among cases (n = 20) and 27.3 % in the control group (n = 18). Only n = 6 study participants used a larger boot size, others (n = 31) used a smaller boot size than would be recommended according to their footprint length.

Table 5.4

Military shoe size preferences among infantry soldiers

	Total (n = 66)	Cases (n = 32)	Controls (n = 34)	P*
Self-selected shoe size, EU	43 ± 1.5	43.5 ± 1.6	43 ± 1.4	0.04
Measured shoe size, EU	43.6 ±1.6	43.9 ± 1.6)	43.4 ± 1.5	< 0.01
Suitable shoe size usage, % (n)	42.4 (28)	37.5 (12)	47.1 (16)	0.16

*European footwear sizes (EU) compared using the Chi-square test; significant results are marked in bold.

5.3.2 Military footwear comfort and overuse injury history

Study participants who wore an inappropriate military footwear size among cases and controls showed lower perceived comfort ratings for military footwear in all dimensions, regardless of the history of lower extremity overuse injury (Table 5.5).

Table 5.5

Military footwear comfort rating comparison among study participants

	Subjects wearing inappropriate shoe sizes (n = 38) (SD)		**Subjects wearing suitable shoe sizes (n = 28) (SD)**		**$\chi^2(1)$**	**P***
	with prior OI* (n = 20)	**non-injured (n = 18)**	**with prior OI (n = 12)**	**non-injured (n = 16)**		
Overall comfort	6.69 ± 1.22	6.91 ± 1.11	7.29 ± 1.04	7.28 ± 1.33	5.23	**0.02**
Forefoot cushioning	6.24 ± 1.57	6.18 ± 1.78	7.00 ± 0.98	6.59 ± 1.72	4.17	**0.04**
Arch cushioning	6.24 ± 1.57	6.15 ± 1.79	6.88 ± 1.36	6.53 ± 2.00	3.61	0.06
Heel cushioning	6.29 ± 1.38	6.26 ± 1.52	6.92 ± 1.38	6.66 ± 1.66	5.06	**0.03**
Arch support	5.90 ± 1.79	6.15 ± 1.74	6.75 ± 1.59	6.63 ± 1.88	4.38	**0.04**
Heel support	6.38 ±1.61	6.47 ± 1.58	7.58 ± 1.02	7.19 ± 1.18	11.07	**< 0.01**

*OI – overuse injury; Kruskal Wallis test results, significant results are marked in bold.

5.3.3 Plantar pressure assessment

Plantar pressure distribution differences among forefoot, midfoot and rearfoot were observed between groups. Wide variation of peak plantar pressure values (Figure 5.1.) was observed in cases group. Higher and statistically different values have been observed in the forefoot and rearfoot regions (Table 5.6). Mean peak plantar pressure values of left and right foot among cases in the hallux region was 49.85 N/cm^2 (SD = 40.26) and at the medial and lateral rearfoot regions, 55.26 N/cm^2 (SD = 37.31) and 58.2 N/cm^2 (SD = 34.94) respectively.

Peak plantar pressure values in the midfoot appeared to be similar among both groups. Both groups showed higher mean peak plantar pressure values under the 3rd MTH, 50.38 N/cm^2 (SD = 38.53) and 45.43 N/cm^2 (SD = 28.12) respectively. Differences observed between the groups were not statistically significant except for the hallux ($\chi^2(1) = 6.8$; $p = 0.01$), for medial ($\chi^2(1) = 5.18$; $p = 0.02$) and lateral ($\chi^2(1) = 12.12$; $p < 0.01$) rearfoot.

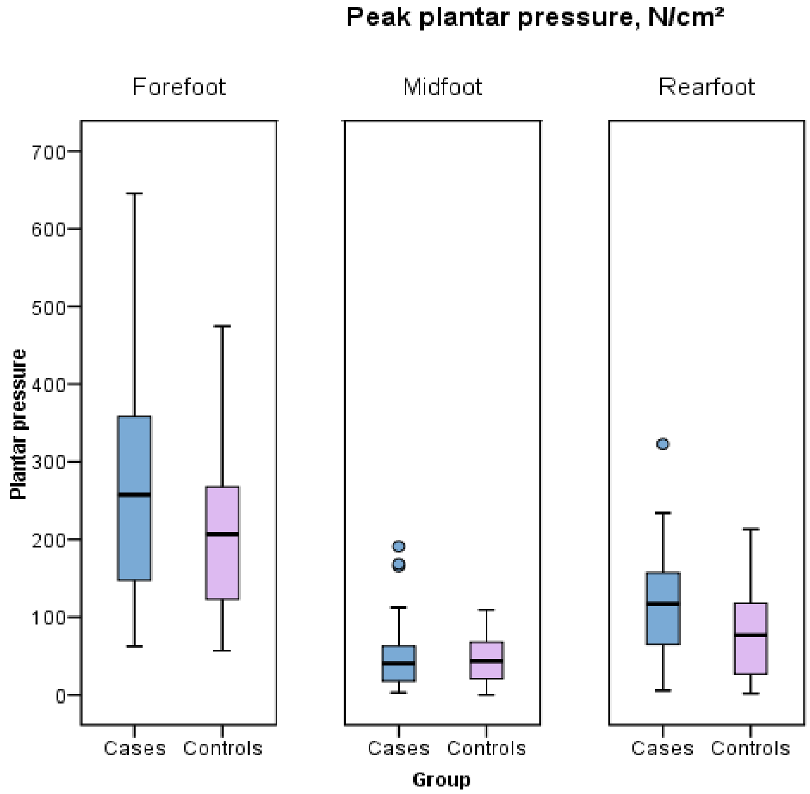

Figure 5.1 **Peak plantar pressure distribution during barefoot walking among cases and control groups for different foot regions**

Table 5.6

Peak plantar pressure values among the case and control groups for each foot

		Cases		Controls		$\chi^2(1)$	P*
		Foot					
		Left	Right	Left	Right		
Fore-foot	**Hallux**	**48.87 ± 42.22**	**50.82 ± 38.84**	34.39 ± 28.03	30.35 ± 26.55	6.8	**0.01**
	Lesser toes	23.40 ± 29.70	29.70 ± 32.07	29.09 ± 29.44	31.91 ± 29.95	1.47	0.23
	1st MTH	24.40 ± 27.10	33.95 ± 35.06	18.06 ± 26.56	17.72 ± 19.53	3.68	0.06
	2nd MTH	46.18 ± 33.83	49.53 ± 35.35	41.14 ± 32.75	42.85 ± 34.57	1.10	0.29
	3rd MTH	54.40 ± 33.83	46.37 ± 35.36	49.16 ± 28.87	41.70 ± 27.29	0.11	0.74
	4th MTH	41.11 ± 35.05	30.00 ± 32.18	36.22 ± 24.88	27.76 ± 23.66	0.001	0.98
	5th MTH	28.24 ± 37.01	25.25 ± 41.12	15.34 ± 19.72	15.15 ± 23.35	0.98	0.33
Midfoot		53.12 ± 37.59	43.77 ± 42.07	47.84 ± 29.97	41.82 ± 30.42	0	0.99
Rear-foot	**Medial heel**	**56.53 ± 40.79**	**53.99 ± 34.07**	40.62 ± 33.87	40.55 ± 29.90	5.18	**0.02**
	Lateral heel	**59.10 ± 37.98**	**57.30 ± 32.17**	37.06 ± 24.51	38.89 ± 29.35	12.12	< **0.01**

*All pressure values are in N/cm^2; Kruskal-Wallis test results, significant results are marked in bold; MTH – metatarsal head.

The median range of the degree of peak plantar pressure asymmetry (SI) in the case group was in the range of 1 % to 45 % in different foot regions, perfect symmetry was found in the medial heel. A lower range of SI values between ~7 % to 16 % was observed between 7 % and 16 % in the control group. Perfect symmetry was found for the peak plantar pressure below the 5th MTH in both groups, for the medial heel in the case group and under the lower toes and below the 3rd MTH in the control group (Table 5.7).

Table 5.7

Median peak plantar pressure asymmetry percentage

	Cases	Controls	P*
Hallux	–45.95 ± 67.87	–16.44 ± 63.70	0.40
Lesser toes	9.52 ± 96.26	0.00 ± 54.53	0.12
I MTH	**22.22 ± 91.23**	**0.00 ± 47.55**	**0.02**
II MTH	16.80 ± 54.67	13.12 ± 58.48	0.25
III MTH	–3.60 ± 50.54	–16.81 ± 59.80	0.51
IV MTH	–23.52 ± 71.60	–15.34 ± 40.37	0.11
V MTH	0.00 ±72.86	0.00 ± 34.41	0.95
Midfoot	–29.37 ± 62.37	–8.97 ± 57.36	0.22
Medial heel	0.00 ±57.91	13.65 ± 36.09	0.53
Lateral heel	–1.76 ± 54.24	7.82 ± 55.41	0.81

*Results of the Mann-Whitney test results; MTH – metatarsal head; negative value indicates higher pressure on the left foot; significant results are marked in bold.

5.3.4 Gait analysis results

Barefoot and shod gait characteristics differ significantly between both groups ($p < 0.001$). Shod gait stride was prolonged ($r = 0.64$), step asymmetry index was reduced and the stride time was less variable ($r = 0.52$) when comparing with barefoot gait among the cases and control groups (Table 5.8). The stride time ($p = 0.053$; $r = 0.31$) and the stride time variability ($p = 0.030$; $r = 0.85$) were statistically different between the study groups during the barefoot walk. During shod walk differences between the case and control groups were observed only for stride time ($p = 0.048$, $r = 0.36$).

Foot and ankle motion analyses during shod and barefoot walking differed in both groups, but no differences were found between cases and controls. During shod walking, the foot contact angle increased, but the eversion angle of the rearfoot and the angular velocities decreased (Table 5.9).

Table 5.8

Spatiotemporal gait parameters for the case and control groups

	Cases	Controls	P*
Walking barefoot			
Stride time	**1.11 ± 0.09**	**1.04 ± 0.12**	**0.05**
Stride variability, %	**1.98 ± 0.79**	**1.27 ± 0.66**	**0.03**
Step length asymmetry index	0.56 ± 5.55	0.42 ± 3.74	0.89
Stride length, m	1.14 ± 0.32	1.08 ± 0.33	0.18
Stride length variability, %	1.88 ± 1.72	1.97 ± 1.88	0.17

Table 5.8 continued

	Cases	Controls	P*
Shod walking			
Stride time	1.24 ± 0.01	1.19 ± 0.09	0.05
Stride variability, %	1.24 ± 0.85	1.21 ± 0.73	0.63
Step length asymmetry index	0.53 ± 4.56	0.12 ± 1.03	0.33
Stride length	1.34 ± 0.26	1.32 ± 0.30	0.57
Stride length variability, %	0.81 ± 0.73	0.72 ± 0.63	0.63

*Significant results are marked in bold.

Table 5.9

Foot and ankle complex kinematics

Barefoot	Group		P
	Cases	Controls	
Foot contact angle (°)	16.41 ± 5.86	17.04 ± 5.18	0.49
Rearfoot eversion (°)	5.64 ± 1.96	4.97 ± 1.65	0.69
Peak angular velocity, PF (°/s)	242.17 ± 36.71	256.4 ± 30.17	0.14
Peak angular velocity, DF (°/s)	157.38 ± 28.62	149.52 ± 14.04	0.20
Shod			
Foot contact angle (°)	25.31 ± 4.77	25.38 ± 4.63	0.90
Rearfoot eversion (°)	3.28 ± 1.10	2.88 ± 1.11	0.15
Peak angular velocity, PF (°/s)	157.47 ± 23.99	162.32 ± 26.79	0.48
Peak angular velocity, DF (°/s)	119.14 ± 36.36	120.07 ± 30.69	0.92

PF – plantarflexion, DF – dorsiflexion, s – seconds.

5.3.5 Regression analysis

Odds ratio was determined using the conditional logistic regression model. After univariate and multivariate analysis, stride time variability during barefoot gait was the only factor that statistically significantly can predict the risk of lower leg overuse injury (Table 5.10). To determine an optimal cut-off point of stride-time variability, a univariate ROC analysis and Youden index were used. The AUC for the ROC analysis of barefoot stride time variability was 0.77 (p = 0.001; 95 % CI 0.648–0.883). The optimal cut-off value for stride time variability, according to the Youden index, was 1.95 %, which could predict lower leg overuse injury with sensitivity 56 % and specificity 88 % (Figure5.2.).

Table 5.10

Summary of conditional logistic regression analysis

	Barefoot		Shod	
Variable	Unadjusted OR	Adjusted OR	Unadjusted OR	Adjusted OR
Stride time Variability (CI)	**2.59** (1.30 – 5.18)	**2.71** (1.31 – 5.60)	1.01 (0.99 –1.01)	1.00 (0.97 – 1.04)
p-value	**0.009**	**0.007**	0.928	0.131

OR – odds ratio, 95 % confidence interval (CI) is given in brackets.

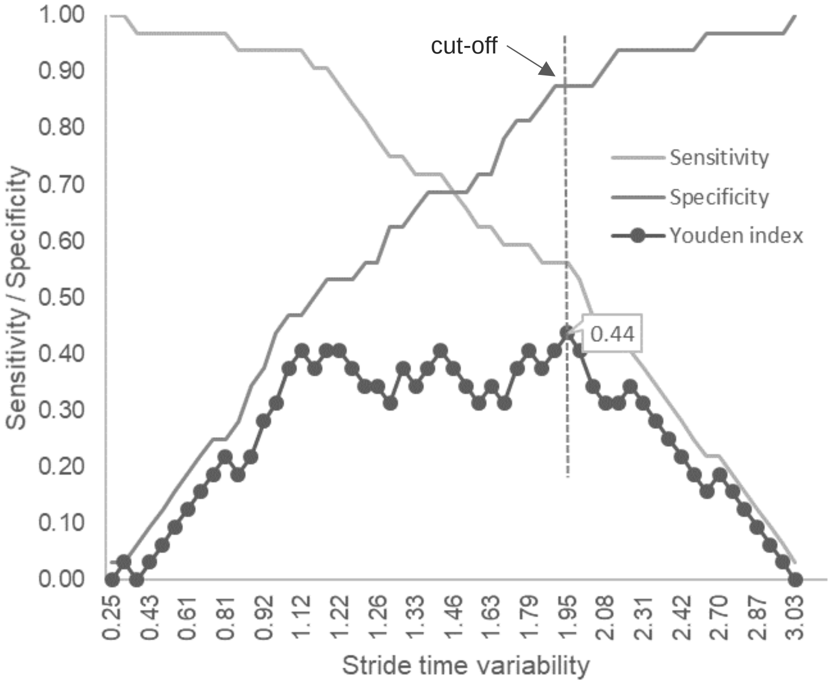

Figure 5.2 **Sensitivity, specificity, Youden index and cut-off value for stride variability**

6 Discussion

Musculoskeletal injury is the leading cause of disability among the military population that results in socioeconomic burden and negatively affects military readiness between different countries (Bulzacchelli et al., 2014; Molloy et al., 2020). Despite years of MSKI research in the military, the lower extremities remain the most common site of injury. Infantry soldiers' feet are continually exposed to large forces and must adapt to a variety of conditions. Therefore, the lower leg, especially foot health, is critical to the physical condition of soldiers.

Military personnel wear specialised occupational footwear appropriate for their service branch while on duty. For example, infantry soldiers wear military or tactical boots. Footwear usage has a direct impact not only on the foot and ankle complex, but also on gait kinematics. According to a recent systematic review, the role of footwear in the development of injuries in the military remains controversial (Lavigne et al., 2023), thus, recommendation for research that incorporates footwear usage and injury status (Baumfeld et al., 2015) remains necessary.

The purpose of this thesis was to evaluate the incidence of lower extremity overuse injuries and to analyse their probable association with the use of military footwear among infantry soldiers of the Latvian Land Forces. According to the study results, acute and overuse lower extremity injuries are still common in infantry soldiers. The use of military footwear significantly modified gait parameters and improved foot and ankle stability. The main finding of this thesis is that lower extremity overuse injuries are not related to the use of military footwear. Furthermore, after a thorough examination of the comfort of military footwear, it was discovered that inappropriate footwear sizing had an adverse effect on the comfort of the footwear regardless of the history of injury. Additionally, barefoot stride time variability was significantly associated with lower leg overuse injury in the military.

The findings of the present study contribute to the growing body of evidence on gait-related parameters in military personnel who have experienced lower leg overuse injuries, both while walking barefoot and while wearing tactical boots.

6.1 Injury incidence

The results of the present study provide survey-based acute and overuse MSKI data that were classified using the Barell injury matrix (Barell et al., 2002). The MSKI of the lower extremities remains most common among Latvian infantry soldiers, which is consistent with other study findings among British army infantry soldiers (Wilkinson et al., 2011). The lower back and lower extremities were the locations where most injured, and these findings are similar to those of the US Army Operational Forces and among the Netherlands Armed Forces (Abt et al., 2014; Dijksma et al., 2020). According to Abt et al. (2014), lower extremity overuse injuries, as well as dislocations and sprains, can be classified as preventable in nature and prevention strategies should be implemented. A high incidence of self-reported lower extremity injuries was also observed during marching with load carriage among the Australian Army Corps (R. M. Orr et al., 2017).

The most prevalent MSKI in the military occurs as a result of the cumulative effects of recurrent microtrauma, often known as overuse (Hauschild et al., 2019). The definition of overuse injury varies, but this study followed the definition that emphasises the gradual onset and underlying pathophysiology of overuse (Roos & Marshall, 2014). The overuse injury rate observed among study participants was 43 %, which is similar to 49 % reported among the US Air Forces (M. T. Lovalekar et al., 2016). The observed differences in the incidence of injuries could appear due to different research designs and assessed data types.

Higher injury rates among female soldiers compared to their male counterparts have previously been reported (B. H. Jones et al., 2017; Nye et al., 2016). A limited number of female soldiers participated in the cross-sectional study and the incidence of observed injuries may not be representative of other female military employees. Furthermore, based on the sample size calculation methodology (Section 4.1.), a group of n = 14 females is insufficient to achieve the required statistical power (0.9). More research on female soldiers is necessary because gender, specifically being female, is a risk factor for MSKI (Andersen et al., 2016; Geary et al., 2002).

The injury incidence rate calculation was based on self-reported data and helps to gain a more comprehensive understanding of the injury incidence. However, high accuracy of self-reported data has been revealed compared to medical record-based data (Schuh-Renner et al., 2019), and half of MSKI have been reported to have been concealed from medical personnel (L. Smith et al., 2016).

6.2 Functional status of the foot

Foot health status among infantry soldiers with and without a history of lower extremity overuse injury was assessed using FPI, SI, and peak plantar pressure data. Foot posture was not associated with a history of previous lower leg overuse injury, although a non-neutral foot position appeared in the case group more frequently compared to controls. This finding is in agreement with previous studies, where overuse injury was linked to a non-neutral foot position (Neal et al., 2014; Tong & Kong, 2013; Yates & White, 2004).

Plantar pressure data are practical for assessing foot function, but assumptions cannot be based solely on peak plantar pressure values. Wide variations in plantar pressure data have been observed among Latvian infantry soldiers, and the single plantar pressure value that could indicate the onset of foot MSKI is unknown (Wafai et al., 2015).

According to the study results, the peak plantar pressure differences in the hallux and heel regions between the cases and the control were statistically significant, which coincide with the non-neutral foot position, heel contact, and toe-off during the gait cycle. The larger range of motion in the healthy foot during walking is associated with lower plantar pressure values (Giacomozzi et al., 2014). Foot orthotics with different stiffness and cushioning components can be used for plantar pressure management (Bonanno et al., 2019; Chatzistergos et al., 2020). More research is needed to investigate how plantar pressures could be related to MSKI.

The motion of the lower extremities throughout the gait cycle among the healthy population has been considered universally symmetric (Sadeghi, 2003), and the range of plantar pressure symmetry (SI) in the control group was from 0 % to 16 %, which is comparable to the normal range of asymmetry in healthy individuals (10–18 %) (Wafai et al., 2015). The range of SI in the group of cases ranged from 0 % in the medial heel to 46 % in the hallux region. In 1st MTH, there was a statistically significant higher peak plantar pressure asymmetry between the cases (22 %) and the control group (0 %). The asymmetry between feet indicates an uneven load on the lower extremities and an imbalance during walking, which requires the attention of physiotherapists. Improving the aberrant biomechanical characteristics of the lower extremity during military training can help prevent lower extremity overuse injuries (Zhao et al., 2020). However, lower limb dominance is task dependent and could influence the roles of lower limbs during the gait cycle, contributing to local asymmetry. Plantar pressure was measured in a gait laboratory, and asymmetric patterns should not occur due to the even testing surface and the easy task of walking at the preferred speed.

6.3 Footwear size and comfort

Soldiers' feet are continually exposed to large forces and must adapt to a variety of conditions. Footwear should be comfortable to reduce the pressure, shear, and shock forces generated by the foot. Consequently, it is necessary to analyse foot function, as well as military footwear comfort, and proper footwear fit.

The Latvian Army's footwear sizes are self-selected by the soldier, and incorrect footwear size may have been used. The present study compared self-selected military footwear sizes with suitable sizes according to the universal Mondopoint footwear size measurement system for size conversion based on foot length in millimetres. Toe clearance was not analysed since there is no universal requirement for toe gap (P. Jones et al., 2020; McWhorter et al., 2003; Oke et al., 2015), but few studies recommend up to 20 millimetres between the foot and the length of the footwear (Byrne & Curran, 1998; Merriman, 2002; Nancarrow, 1999). According to the findings of the present study, 56 % of the study participants wore smaller footwear sizes and there was no toe gap, which is comparable to the findings of a study carried out among the Canadian Land Forces infantry, which found that the footwear size of the personnel was not appropriate according to the foot length and width (Dyck, 2000). Foot pain, toe abnormalities, and foot skin and nail problems have all been linked to poorly fitted footwear in the general population (Buldt & Menz, 2018; Carr & Cropley, 2019; Schwarzkopf et al., 2011). However, in this study, skin disorders were not prevalent and nail problems were more prevalent among cases that used inappropriate military shoe sizes. Furthermore, foot skin inspection should be done regularly since foot skin disorders could be an indicator of asymmetric motion of the lower extremities during gait (Grouios, 2005).

The overall comfort rating of the military footwear ranged from 6.69 to 7.29, which is comparable to the results of a previous study. The overall comfort of the footwear reported previously among Brazilian Army recruits ranged from 5.5 to 7.7 points (Muniz & Bini, 2017). Shock-absorbing insoles have been recommended to increase footwear comfort (T. L. Grier et al., 2011; Lullini et al., 2020), although what makes appropriate footwear size to be more comfortable and the impact of footwear comfort on gait disorders is not well understood (Branthwaite & Chockalingam, 2019). Significantly lower military footwear comfort ratings for all measured dimensions were observed among study subjects who used an inappropriate size. Previous studies have reported that inappropriate footwear size use leads to discomfort and could contribute to lower extremity overuse injury due to gait adaptations (Finestone et al., 1992). According to the results of the present study, no relationship was found between military footwear comfort and lower leg overuse injury history was found.

Footwear comfort ratings were provided for only one footwear model, and we did not inspect whether the same model was used for the last 6 months before the testing period. Although all soldiers of the Latvian Land Forces use the same military footwear model, comfort ratings were provided for the same military boot. Additionally, footwear comfort ratings can be distorted due to fatigue after physical activity (Hintzy et al., 2015) and for this reason, our study participants provided military footwear ratings during a day off. According to the study results, the fit of military footwear is a significant factor that leads to comfortable footwear usage. and it is difficult to develop a universal military footwear size recommendation system. Based on these results, foot dimension measures with the Brannock device or a 3D foot scan are needed to provide comfortable military or other occupational footwear usage. It is noteworthy that the preference for shoe fit and perception of footwear comfort is individual (Wannop et al., 2019). Establishing a universal footwear recommendation system requires the assessment of individual variances in foot shape and personal preferences for footwear comfort. This involves the development of an extensive database that integrates foot scan data and subjective evaluations related to fit and comfort of the specific target population (Nácher et al., 2006).

6.4 Changes of gait biomechanics during shod walk

An investigation of the gait pattern and foot ankle motion was performed to establish the association with the lower leg injury. Military footwear reduced stride time and stride length, and these findings correspond to previous studies (Franklin et al., 2015; Hollander et al., 2022). Previous studies indicated that military shoe design elements assisted in body balance (DeBusk et al., 2018; Hill et al., 2020).

Shod gait analysis revealed that military boots reduced ankle joint mobility, stabilised the rearfoot, and slowed ankle movement during walking, which is consistent with previous research on barefoot and shod gait while running and walking (Franklin et al., 2018; Hollander et al., 2022; Majumdar et al., 2006; Tine Marieke Willems et al., 2007). Compared to barefoot walking, gait with military footwear showed less variability. Despite less variable and more symmetric gait when walking with military footwear, stride variability remains a notable risk factor for overuse injury, considering that study participants gained injury while wearing tested footwear, and the use of military footwear does not change the potential risk of MSKI. The normal range of stride variability between healthy individuals varies from 0.6 % to 2.0 % (Tan et al., 2022). The mean stride time variability observed among cases with previous overuse MSKI in this study was 1.98 ± 0.79 which is within the normal range for the common population. Based on these results, a reference range restriction of stride time variability could be considered among military and other physically active populations.

Stride time variability was found to be significant in relation to previous lower leg overuse injury, according to the findings of the study. Stride time variability greater than 1.95 % can predict lower leg overuse injuries with 88 % specificity and 56 % sensitivity. Prediction based on stride time variability is not perfect, it should have high sensitivity (true cases, those who will experience an event) and high specificity (correctly identify true non-cases). In practice, higher specificity is important during military recruits screening for a low prevalence outcome. However, this study was not a prospective study and it cannot be confirmed that changes in stride time variability are a protective mechanism after sustaining an injury or a result of an overuse injury. However, this study finding is in accordance with prospective study results among soldiers of the Israeli Defence Forces who reported an association between stride time variability and overuse injury (Springer et al., 2016). On the contrary, a previous study among runners with patellofemoral pain syndrome has hypothesised that increased motion variability may aid recovery through varying tissue loading patterns (Bonacci et al., 2020). Additionally, increased variability in spatiotemporal gait parameters may also be a sensitive indicator of joint stiffness (Gouelle & Mégrot, 2016), which could occur due to incomplete rehabilitation after overuse of MSKI (Whittaker & Roos, 2019). Future prospective studies among healthy individuals are needed to assess stride time variability as an overuse injury risk factor.

6.5 Strengths and limitations

The present Thesis is pioneering in its investigation of gait biomechanics in lower extremity MSKI while also considering the usage of military footwear. A small number of research studies conducted in 1976 and 1983 investigated the impact of footwear on lower extremity MSKI in the military (Bensel, 1976; Bensel & Kish, 1983). The strength of this Thesis lies in its contribution to improving awareness of the biomechanical aspects of gait kinetics and kinematics, both with and without military boots, in terms of injury status. Furthermore, it offers valuable data on foot function, footwear comfort and fit, and gait variability by comparing groups of previously injured and noninjured infantry soldiers.

The studies included in the Thesis have few limitations, mainly related to the designs of the conducted studies. Causal sequences of gait-related parameters and overuse MSKI history cannot be established through cross-sectional and retrospective case-control studies. The strength of the cross-sectional study lies in its use of a highly homogeneous infantry population for the study, with a significantly larger and representative study population compared to the initial projected sample size (n = 150, n = 227, respectively). Therefore, the cross-sectional study sample is a subset of soldiers that accurately represents the characteristics of military personnel in the Latvian Land Forces. The grouping of the case-control study could change the results due to recall bias of the injury history, therefore, the analysis of medical records was performed to confirm the injury status. Furthermore, the author believes that the interview responses were true, since study participants were assured that the study results would not affect their annual medical check-up status and were granted a day off during the research period.

Calculating the incidence rate of the injury based on self-reported data is both a strength and a limitation. The survey is a cost-effective way to collect data from large populations and despite the constraints of a cross-sectional study, the strength of this study is that it presents self-reported incidence statistics of acute and overuse MSKI sites among Latvian Land Forces infantry personnel in a Barell injury matrix. Previous research found that self-reported injury data were more accurate than medical record data, supporting the use of survey data for injury assessment (Schuh-Renner et al., 2019). According to L. Smith et al. (2016), 50 % of musculoskeletal injuries among infantry populations are not reported to medical personnel (L. Smith et al., 2016). The number of self-reported injuries can include injuries for which the soldiers did not seek medical help or were hidden from the doctors at the Military Medical Support Centre, providing a more complete picture of the prevalence of MSKI. Therefore, systematic injury monitoring should continue as it allows implementation and assessment of the effectiveness of injury-orientated prevention strategies.

Evaluation of the functional status of the foot based on plantar pressure data should be considered with certain limitations. Although plantar pressure measurement is commonly used, it is not possible to make general assumptions based solely on plantar pressure levels. The utilised plantar pressure system (RSscan International, Belgium) can accurately measure the force directed perpendicular to the pressure sensor, but lacks the capability to measure other types of force, such as shear forces. Additionally, plantar pressure analysis software (Footscan® v.7.11) automatically executed the masking process, potentially causing a shift in foot region-specific plantar pressure values. Regardless the limitations, plantar pressure is a simple gait kinetic measurement that allows evaluating the symmetry of lower extremity loading during walking. Although wide variations in plantar pressure data have been observed among Latvian infantry soldiers, a single plantar pressure value that could indicate the onset of foot MSKI remains unknown (Wafai et al., 2015). The plantar pressure assessment showed a significant degree of asymmetry in previously injured infantry soldiers. This suggests that there is an uneven distribution of lower limb loads and an imbalance during the gait cycle, despite the fact that the evaluation was carried out in a controlled gait laboratory environment without external load, and all study participants had recovered from their injuries. Spine deformity could explain plantar pressure asymmetry, but posture assessment was not performed due to the inconsistency in the findings on gait parameter differences in patients with scoliosis, some studies reporting such differences, while others do not (Boulcourt et al., 2023; Schizas et al., 1998; Yang et al., 2013). Furthermore, a recent systematic review found that there is no significant connection between the feet and the spine during walking in healthy adults. (Hmida et al., 2023).

Furthermore, plantar pressure measurement and Footscan® software provided reliable digital footprint length measurement that is admitted to be similar to 3D foot scan measurement (Y.-C. Lee et al., 2014). Based on the Mondopoint system, the footprint length in centimetres was used to compare the appropriate size of self-selected military footwear. This comparison is limited to length alone, and foot width analysis was omitted because it had no effect on the measurement of the size of military shoes used.

Another strength of the current study is the systematic evaluation of the comfort of military footwear for different dimensions of footwear in the infantry soldier population. Furthermore, because the most comprehensive approach to footwear comfort was used for the first time to analyse military footwear comfort. The scores obtained for comfort, cushioning, and support of footwear in various areas of the military boot cannot be compared with previous studies. Study participants who wore the wrong shoe sizes had statistically significantly lower evaluations of perceived comfort of military footwear on all criteria, which implies that providing a proper fit is crucial for achieving more comfort. Several factors such as different military footwear models, wear and tear of the shoes, shock absorption capabilities, microclimate characteristics, width and weight of the shoes were not considered. Consequently, military footwear comfort ratings can only be applicable to tactical boots designed for hot weather conditions. While there are limitations to the application of comfort, the methodology used in footwear fit and comfort research is valuable for other military specialities, as well as for occupational footwear users such as firefighters, construction workers, and law enforcement personnel.

Gait kinematics assessment with motion tracking markers limits the precision of the results. Due to soft tissue artefacts (STA), markers can be a source of error in bare foot and ankle joint kinematic data. Additionally, shoe-mounted markers are unlikely to fully represent foot and ankle motion in shod analysis. To reduce potential errors during the study, a single examiner (DN) placed all markers according to a standardised marker placement scheme. Although heel markers were used to calculate spatiotemporal gait parameters such as step length and stride time, STA in the heel is likely to be small (Alcantara et al., 2018; Benoit et al., 2006), and rearfoot kinematic findings are consistent with earlier research (Chuter, 2010). Furthermore, for the evaluation of shod gait, a good accuracy of rearfoot and forefoot shoe marker placement was found without additional holes in the heel region (Alcantara et al., 2018; Bishop et al., 2011). A hole in the heel of the tactical boot is required for precise rearfoot motion; however, military boot with holes could not be worn by soldiers afterwards and would have to be replaced, raising study expenses, and causing issues for study participants.

Finally, variations in stride duration can result from anthropometric variances; however, gait biomechanical data were not adjusted or normalised for body height or foot sole length. This decision was made since no statistically significant variations in these parameters were identified between the study groups.

Conclusions

1. The knee, lower leg, and foot are the most common sites of musculoskeletal injuries among male soldiers of the Latvian Land Forces aged 20–49 years, and the incidence rate of 43 % is comparable to those reported in other countries.
2. Non-neutral foot posture and elevated peak plantar pressures are more prevalent in individuals with a history of lower leg injuries, while military footwear comfort ratings remain unaffected by foot position.
3. The comfort ratings of military footwear are influenced by improper size selection, regardless of an individual's history of lower extremity overuse injuries.
4. Wearing military footwear improves stability and encourages a more balanced gait, while the risk of the lower extremity overuse injuries is not related to the shod gait characteristics. Barefoot stride time variability of more than 1.95 % is the strongest indicator of lower leg overuse injury in male infantry soldiers.

Proposals

1. Implementing a Barell injury matrix-based monitoring system in the military to identify acute and overuse musculoskeletal injuries would facilitate the establishment and evaluation of injury prevention initiatives.
2. It is advisable to specify the foot posture evaluation criteria to assess possible injury risks and prevent individuals with overpronated or highly supinated feet from enlisting in the military.
3. Foot dimension measurement is recommended to provide adequate footwear size to ensure better military or other occupational footwear comfort.
4. During medical check-up, it is recommended to incorporate a plantar pressure assessment and barefoot gait variability analysis as tools to identify military personnel at an elevated risk of injury.

Publications and reports on topics of the Thesis

Publications

1. Nesterovica-Petrikova, D., Vaivads, N., Stepens, A. (2023). Increased Barefoot Stride Variability Might Be Predictor Rather than Risk Factor for Overuse Injury in the Military. International Journal of Environmental Research and Public Health, 20(15), Article 6449, http://dx.doi.org/10.3390/ijerph20156449 (Scopus) (Annex 4).
2. Nesterovica, D., Vaivads, N., Stepens, A. (2021). Relationship of footwear comfort, selected size, and lower leg overuse injuries among infantry soldiers. BMC Musculoskelet Disord. 2021 Nov 15; 22(1):952, https://doi.org/10.1186/s12891-021-04839-9 (Scopus) (Annex 3).
3. Nesterovica, D., Stepens, A., Vaivads, N. (2021). Peak plantar pressure as a risk factor for lower extremity overuse injury among infantry soldiers. Proceedings of the Latvian Academy of Sciences, Section B: Natural, Exact, and Applied Sciences, 75(1), 52–57, https://doi.org/10.2478/prolas-2021-0009 (Scopus) (Annex 2).
4. Nesterovica, D., Vaivads, N., Stepens, A. (2020). Self-reported musculoskeletal acute and overuse injuries among Latvian infantry soldiers. In V. Lubkina, A. Kaupužs, & D. Znotiņa (Eds.), Society. Integration. Education: proceedings of the international scientific conference (Vol. 6: pp. 354–360), https://doi.org/10.17770/sie2020vol6.5094 (Web of Science) (Annex 1).

Reports and theses at international congresses and conferences

1. Nesterovica-Petrikova, D., Vaivads, N., Stepens, A. (2023). Effects of Tactical Boots on Foot and Ankle Kinematics. In Y. Dekhtyar, & I. Saknite (Eds.), 19th Nordic-Baltic Conference on Biomedical Engineering and Medical Physics: Proceedings of NBC 2023, June 12–14, 2023, Liepaja, Latvia (Vol. 89, pp. 112–118). (IFMBE Proceedings; Vol. 89) Springer. https://doi.org/10.1007/978-3-031-37132-5_15 (Scopus).
2. Nesterovica, D., Vaivads, N., Stepens, A. (2023). Gait Variability during Barefoot and Shod Walk among Military Personnel. Rīga Stradiņš University International Conference on Medical and Health Care Sciences: Knowledge for Use in Practice, Riga, Latvia.
3. Nesterovica, D., Vaivads, N., Stepens, A. (2022). Evaluation of military boots effects on gait using symmetry coefficients. Abstract from 44th International Committee of Military Medicine World Congress: 44th ICMM World Congress, Brussels, Belgium.
4. Nesterovica, D., Vaivads, N., Stepens, A. (2022). Study of military footwear comfort, selected size, and lower leg overuse injuries. Abstract from OTWorld: International Trade Show and World Congress, Leipzig, Germany.
5. Nesterovica, D., Vaivads, N., Stepens, A. (2021). Evaluation of military boots effects on gait symmetry using ratio index, symmetry index, and gait asymmetry coefficient. Poster presented at 18th World Congress of the International Society for Prosthetics and Orthotics.
6. Nesterovica, D. (2020). Definition of the lower extremity overuse: A review. In L. Vilka, & J. Vike (Eds.), SHS Web of Conferences (Vol. 85). Article 02006, https://doi.org/10.1051/shsconf/20208502006.
7. Nesterovica, D. (2018). Incidence of exercise related musculoskeletal injuries in Latvian infantry soldiers. Abstract from 10th International Baltic Sports Medicine Congress, European Journal of Sports Medicine, vol.5 (Suppl.2), p.32; ISSN: 1792–4979, https://www.eujsm.eu/index.php/EUJSM/article/view/171/81.
8. Nesteroviča, D. (2018). Musculoskeletal overuse injury prevalence and comfort perception of military boots. In I. Kokina (Ed.), Proceedings of the International Scientific Conference of Daugavpils University (Part A: Natural Sciences, pp. 123–128) (EBSCOhost).

Reports and theses at local congresses and conferences

1. Nesterovica, D., Vaivads, N., Stepens, A. (2021). Fit and comfort of infantry boots in Land Forces of Latvia. RSU Research week 2021: Knowledge for Use in Practice, Riga, Latvia.
2. Nesterovica, D., Vaivads, N., Stepens, A. (2019). Musculoskeletal overuse injury prevalence and comfort perception of military boots. The International Scientific Conference on Medicine at the University of Latvia, Riga.

References

1. Abt, J. P., Sell, T. C., Lovalekar, M. T., Keenan, K. A., Bozich, A. J., Morgan, J. S., Kane, S. F., Benson, P. J., & Lephart, S. M. (2014). Injury Epidemiology of U.S. Army Special Operations Forces. *Military Medicine*, *179*(10), 1106–1112. https://doi.org/10.7205/milmed-d-14-00078
2. Ahsan, M., Abualait, T., Al-Subaiei, M., Al Muslem, W., Aldokhayyil, M., Nuhmani, S., & Alzahrani, A. (2023). Determining the characteristics of gait variability with a preferred walking speed in hypertensive and normotensive participants. *Clinical Epidemiology and Global Health*, *23*, 101344. https://doi.org/https://doi.org/10.1016/j.cegh.2023.101344
3. Alcantara, R. S., Trudeau, M. B., & Rohr, E. S. (2018). Calcaneus range of motion underestimated by markers on running shoe heel. *Gait & Posture*, *63*, 68–72. https://doi.org/10.1016/J.GAITPOST.2018.04.035
4. Andersen, K. A., Grimshaw, P. N., Kelso, R. M., & Bentley, D. J. (2016). Musculoskeletal Lower Limb Injury Risk in Army Populations. *Sports Medicine - Open*, *2*(1), 22. https://doi.org/10.1186/s40798-016-0046-z
5. Anderson, J., Williams, A. E., & Nester, C. (2021). Musculoskeletal disorders, foot health and footwear choice in occupations involving prolonged standing. *International Journal of Industrial Ergonomics*, *81*(January), 103079. https://doi.org/10.1016/j.ergon.2020.103079
6. Anderson, M. K., Grier, T., Canham-Chervak, M., Bushman, T. T., & Jones, B. H. (2015). Occupation and other risk factors for injury among enlisted U.S. Army Soldiers. *Public Health*, *129*(5), 531–538. https://doi.org/https://doi.org/10.1016/j.puhe.2015.02.003
7. Andersons, E. (1992). *Latvijas bruņotie spēki un to priekšvēsture / Armed Forces of Latvia and their historical background*. SIA "S" un "S."
8. Arnold, J. B., & Bishop, C. (2013). Quantifying foot kinematics inside athletic footwear: A review. *Footwear Science*, *5*(1), 55–62. https://doi.org/10.1080/19424280.2012.735257
9. Arslan, I. G., Dijksma, I., van Etten-Jamaludin, F. S., Lucas, C., & Stuiver, M. M. (2021). Nonexercise Interventions for Prevention of Musculoskeletal Injuries in Armed Forces: A Systematic Review and Meta-Analysis. *American Journal of Preventive Medicine*, *60*(2), e73–e84. https://doi.org/10.1016/j.amepre.2020.08.007
10. Baida, S. R., Gore, S. J., Franklyn-Miller, A. D., & Moran, K. A. (2018). Does the amount of lower extremity movement variability differ between injured and uninjured populations? A systematic review. *Scandinavian Journal of Medicine & Science in Sports*, *28*(4), 1320–1338. https://doi.org/10.1111/sms.13036
11. Barell, V., Aharonson-Daniel, L., Fingerhut, L. A., Mackenzie, E. J., Ziv, A., Boyko, V., Abargel, A., Avitzour, M., & Heruti, R. (2002). An introduction to the Barell body region by nature of injury diagnosis matrix. *Injury Prevention*, *8*(2), 91–96. https://doi.org/10.1136/ip.8.2.91
12. Barnes, A., Wheat, J., & Milner, C. (2008). Association between foot type and tibial stress injuries: a systematic review. *British Journal of Sports Medicine*, *42*(2), 93–98. https://doi.org/10.1136/bjsm.2007.036533
13. Barovska, S. (2020). *KARAVĪRU BIEŽĀK GŪTO TRAUMU ANALĪZE NACIONĀLO BRUŅOTO SPĒKU VESELĪBAS APRŪPES IESTĀDĒ LAIKA POSMĀ NO 2017. LĪDZ 2020. GADAM*. Latvijas Universitāte. https://dspace.lu.lv/dspace/handle/7/52100
14. Baumfeld, D., Raduan, F. C., Macedo, B., Silva, T. A. A., Baumfeld, T., Favato, D. F., de Andrade, M. A. P., & Nery, C. (2015). Shoe heel abrasion and its possible biomechanical cause: a transversal study with infantry recruits. *Journal of Orthopaedic Surgery and Research*, *10*(1), 179. https://doi.org/10.1186/s13018-015-0319-0
15. Beaton, D., Bombardier, C., Guillemin, F., & Ferraz, M. (2007). Recommendations for the Cross-Cultural Adaptation of the DASH & QuickDASH Outcome Measures Contributors to this Document. *Institute for Work & Health.*, *1*.
16. Benoit, D. L., Ramsey, D. K., Lamontagne, M., Xu, L., Wretenberg, P., & Renström, P. (2006).

Effect of skin movement artifact on knee kinematics during gait and cutting motions measured in vivo. *Gait and Posture*, *24*(2), 152–164. https://doi.org/10.1016/j.gaitpost.2005.04.012

17. Bensel, C. (1976). *The Effects of Tropical and Leather Combat Boots on Lower Extremity Disorders Among US Marine Corps Recruits*. 63. Retrieved from https://apps.dtic.mil/sti/citations/ADA025938 [Accessed on 03.03.2021].
18. Bensel, C., & Kish, R. (1983). *Lower Extremity Disorders among Men and Women in Army Basic Training and Effects of Two Types of Boots*. 99. Retrieved from https://apps.dtic.mil/sti/citations/ADA133002. [Accessed on 03.03.2021].
19. Bishop, C., Paul, G., Uden, H., & Thewlis, D. (2011). The development of a multi-segment kinematic model of footwear. *Footwear Science*, *3*(sup1), S13–S15. https://doi.org/10.1080/19424280.2011.575873
20. Blyton, S. J., Snodgrass, S. J., Pizzari, T., Birse, S. M., Likens, A. D., & Edwards, S. (2023). The impact of previous musculoskeletal injury on running gait variability: A systematic review. *Gait & Posture*, *101*, 124–133. https://doi.org/10.1016/j.gaitpost.2023.01.018
21. Bonacci, J., Fox, A., Hall, M., Fuller, J. T., & Vicenzino, B. (2020). Effect of gait retraining on segment coordination and joint variability in individuals with patellofemoral pain. *Clinical Biomechanics*, *80*, 105179. https://doi.org/https://doi.org/10.1016/j.clinbiomech.2020.105179
22. Bonanno, D. R., Ledchumanasarma, K., Landorf, K. B., Munteanu, S. E., Murley, G. S., & Menz, H. B. (2019). Effects of a contoured foot orthosis and flat insole on plantar pressure and tibial acceleration while walking in defence boots. *Scientific Reports*, *9*(1), 1–10. https://doi.org/10.1038/s41598-018-35830-5
23. Bonanno, D. R., Murley, G. S., Munteanu, S. E., Landorf, K. B., & Menz, H. B. (2018). Effectiveness of foot orthoses for the prevention of lower limb overuse injuries in naval recruits: a randomised controlled trial. *British Journal of Sports Medicine*, *52*(5), 298–302. https://doi.org/10.1136/bjsports-2017-098273
24. Boulcourt, S., Badel, A., Pionnier, R., Neder, Y., Ilharreborde, B., & Simon, A.-L. (2023). A gait functional classification of adolescent idiopathic scoliosis (AIS) based on spatio-temporal parameters (STP). *Gait & Posture*, *102*, 50–55. https://doi.org/10.1016/j.gaitpost.2023.03.002
25. Brach, J. S., Berlin, J. E., VanSwearingen, J. M., Newman, A. B., & Studenski, S. A. (2005). Too much or too little step width variability is associated with a fall history in older persons who walk at or near normal gait speed. *Journal of NeuroEngineering and Rehabilitation*, *2*(1), 21. https://doi.org/10.1186/1743-0003-2-21
26. Branthwaite, H., & Chockalingam, N. (2019). Everyday footwear: An overview of what we know and what we should know on ill-fitting footwear and associated pain and pathology. In *Foot* (Vol. 39, pp. 11–14). Churchill Livingstone. https://doi.org/10.1016/j.foot.2019.01.007
27. Braunstein, B., Arampatzis, A., Eysel, P., & Brüggemann, G. P. (2010). Footwear affects the gearing at the ankle and knee joints during running. *Journal of Biomechanics*, *43*(11), 2120–2125. https://doi.org/10.1016/J.JBIOMECH.2010.04.001
28. Breslow, N. E., & Day, N. E. (1980). Statistical methods in cancer research. Volume I - The analysis of case-control studies. *IARC Scientific Publications*, *32*, 248–279.
29. Brockett, C. L., & Chapman, G. J. (2016). Biomechanics of the ankle. *Orthopaedics and Trauma*, *30*(3), 232–238. https://doi.org/10.1016/j.mporth.2016.04.015
30. Buldt, A. K., & Menz, H. B. (2018). Incorrectly fitted footwear, foot pain and foot disorders: a systematic search and narrative review of the literature. *Journal of Foot and Ankle Research*, *11*(1), 43. https://doi.org/10.1186/s13047-018-0284-z
31. Bulzacchelli, M. T., Sulsky, S. I., Rodriguez-Monguio, R., Karlsson, L. H., & Hill, M. O. T. (2014). Injury during U.S. army basic combat training: A systematic review of risk factor studies. *American Journal of Preventive Medicine*, *47*(6), 813–822. https://doi.org/10.1016/j.amepre.2014.08.008
32. Bunn, P. D. S., Sodré, R. d S., Matos, M. I., Saliba, G. F., Silva, G. d P., Caldas, R., Esteves, J. d S., & Silva, E. B. (2022). Effects of prevention programmes on injury risk in military personnel:

a systematic review with meta-analysis. *BMJ Military Health*, e002098. https://doi.org/10.1136/bmjmilitary-2022-002098

33. Bush, R. A., Brodine, S. K., & Shaffer, R. A. (2000). The association of blisters with musculoskeletal injuries in male marine recruits. *Journal of the American Podiatric Medical Association*, *90*(4), 194–198. https://doi.org/10.7547/87507315-90-4-194
34. Byrne, M., & Curran, M.. (1998). The development and use of a footwear assessment score in comparing the fit of children's shoes. *The Foot*, *8*(4), 215–218. https://doi.org/10.1016/S0958-2592(98)90032-3
35. Carr, P. C., & Cropley, T. G. (2019). Sports Dermatology. *Clinics in Sports Medicine*, *38*(4), 597–618. https://doi.org/10.1016/j.csm.2019.06.001
36. Cavanagh, P. R., & Rodgers, M. M. (1987). The arch index: A useful measure from footprints. *Journal of Biomechanics*, *20*(5), 547–551. https://doi.org/10.1016/0021-9290(87)90255-7
37. Cavanaugh, J. T., & Stergiou, N. (2020). Chapter 8 - Gait variability: a theoretical framework for gait analysis and biomechanics. In Nick Stergiou (Ed.), *Biomechanics and Gait Analysis* (pp. 251–286). Elsevier. https://doi.org/10.1016/B978-0-12-813372-9.00008-7
38. Celko, J. (2010). Chapter 20 - Shoe Sizes. In J. Celko (Ed.), *Joe Celko's Data, Measurements and Standards in SQL* (pp. 167–168). Morgan Kaufmann. https://doi.org/https://doi.org/10.1016/B978-0-12-374722-8.00020-7
39. Chander, H., Garner, J. C., Wade, C., & Knight, A. C. (2017). Postural control in workplace safety: Role of occupational footwear and workload. *Safety*, *3*(3), 1–8. https://doi.org/10.3390/safety3030018
40. Chatzistergos, P. E., Gatt, A., Formosa, C., Farrugia, K., & Chockalingam, N. (2020). Optimised cushioning in diabetic footwear can significantly enhance their capacity to reduce plantar pressure. *Gait & Posture*. https://doi.org/10.1016/j.gaitpost.2020.05.009
41. Chen, S. F., Wang, Y., Peng, Y., & Zhang, M. (2022). Effects of Attrition Shoes on Kinematics and Kinetics of Lower Limb Joints During Walking. *Frontiers in Bioengineering and Biotechnology*, *10*, 824297. https://doi.org/10.3389/fbioe.2022.824297
42. Chong, H. C., Tennant, L. M., Kingston, D. C., & Acker, S. M. (2017). Knee joint moments during high flexion movements: Timing of peak moments and the effect of safety footwear. *The Knee*, *24*(2), 271–279. https://doi.org/10.1016/j.knee.2016.12.006
43. Chuter, V. H. (2010). Relationships between foot type and dynamic rearfoot frontal plane motion. *Journal of Foot and Ankle Research*, *3*(1), 9. https://doi.org/10.1186/1757-1146-3-9
44. Cohen, J. (2016). A power primer. In *Methodological issues and strategies in clinical research (4th ed.).* (pp. 279–284). American Psychological Association. https://doi.org/10.1037/14805-018
45. Cornwall, M. W., McPoil, T. G., Lebec, M., Vicenzino, B., & Wilson, J. (2008). Reliability of the modified foot posture index. *Journal of the American Podiatric Medical Association*. https://doi.org/10.7547/0980007
46. Cosman, F., Ruffing, J., Zion, M., Uhorchak, J., Ralston, S., Tendy, S., McGuigan, F. E. A., Lindsay, R., & Nieves, J. (2013). Determinants of stress fracture risk in United States Military Academy cadets. *Bone*, *55*(2), 359–366. https://doi.org/10.1016/j.bone.2013.04.011
47. D'Aoüt, K., Pataky, T. C., De Clercq, D., & Aerts, P. (2009). The effects of habitual footwear use: Foot shape and function in native barefoot walkers. *Footwear Science*, *1*(2), 81–94. https://doi.org/10.1080/19424280903386411
48. Dananberg, H. J. (1993). Gait style as an etiology to chronic postural pain. Part I. Functional hallux limitus. *Journal of the American Podiatric Medical Association*, *83*(8), 433–441. https://doi.org/10.7547/87507315-83-8-433
49. Dananberg, H. J. (1997). Lower back pain as a gait-related repetitive motion injury. In A. Vleeming, V. Mooney, C. J. Snijders, & T. A. Dorman (Eds.), *Movement, stability and low back pain: the essential role of the pelvis* (pp. 253–267). Churchill Livingstone.

50. Dananberg, H. J. (2000). Sagittal plane biomechanics. American Diabetes Association. *Journal of the American Podiatric Medical Association*, *90*(1), 47–50. https://doi.org/10.7547/87507315-90-1-47

51. Dang, D. Y. (2023). Biomechanics of the Foot and Ankle. In A. Haskell & M. J. Coughlin (Eds.), *Coughlin and Mann's Surgery of the Foot and Ankle* (pp. 1–27). Elsevier Health Sciences.

52. De Cock, A., De Clercq, D., Willems, T., & Witvrouw, E. (2005). Temporal characteristics of foot roll-over during barefoot jogging: reference data for young adults. *Gait & Posture*, *21*(4), 432–439. https://doi.org/10.1016/j.gaitpost.2004.05.004

53. DeBusk, H., Hill, C. M., Chander, H., Knight, A. C., & Babski-Reeves, K. (2018). Influence of military workload and footwear on static and dynamic balance performance. *International Journal of Industrial Ergonomics*, *64*, 51–58. https://doi.org/10.1016/j.ergon.2017.11.003

54. Derums, V. (1940). *Latviešu ķermeņa uzbūve laika perspektīvā*. Valters un Rapa.

55. Dijksma, C. I., Bekkers, M., Spek, B., Lucas, C., & Stuiver, M. (2020). Epidemiology and Financial Burden of Musculoskeletal Injuries as the Leading Health Problem in the Military. *Military Medicine*, *185*(3–4), e480–e486. https://doi.org/10.1093/milmed/usz328

56. Dixon, S. J., Waterworth, C., Smith, C. V., & House, C. M. (2003). Biomechanical analysis of running in military boots with new and degraded insoles. *Medicine and Science in Sports and Exercise*, *35*(3), 472–479. https://doi.org/10.1249/01.MSS.0000053733.64049.27

57. Dixon, S., Nunns, M., House, C., Rice, H., Mostazir, M., Stiles, V., Davey, T., Fallowfield, J., & Allsopp, A. (2019). Prospective study of biomechanical risk factors for second and third metatarsal stress fractures in military recruits. *Journal of Science and Medicine in Sport*, *22*(2), 135–139. https://doi.org/10.1016/j.jsams.2018.06.015

58. Dobson, J. A., Riddiford-Harland, D. L., Bell, A. F., & Steele, J. R. (2017). Work boot design affects the way workers walk: A systematic review of the literature. *Applied Ergonomics*, *61*, 53–68. https://doi.org/https://doi.org/10.1016/j.apergo.2017.01.003

59. Dowling, G. J., Murley, G. S., Munteanu, S. E., Smith, M. M. F., Neal, B. S., Griffiths, I. B., Barton, C. J., & Collins, N. J. (2014). Dynamic foot function as a risk factor for lower limb overuse injury: a systematic review. *Journal of Foot and Ankle Research*, *7*(1), 53. https://doi.org/10.1186/s13047-014-0053-6

60. Dunn, M. D., Claxton, D. B., Fletcher, G., Wheat, J. S., & Binney, D. M. (2018). Effects of running retraining on biomechanical factors associated with lower limb injury. *Human Movement Science*, *58*, 21–31. https://doi.org/10.1016/j.humov.2018.01.001

61. Dyck, W. (2000). *A study of the relationship between foot size and combat boot size in the Canadian forces* (DCIEM TR 2000-137).

62. Ellis, S., Branthwaite, H., & Chockalingam, N. (2022). Evaluation and optimisation of a footwear assessment tool for use within a clinical environment. *Journal of Foot and Ankle Research*, *15*(1), 12. https://doi.org/10.1186/s13047-022-00519-6

63. Farzadi, M., Nemati, Z., Jalali, M., Doulagh, R. S., & Kamali, M. (2017). Effects of unstable footwear on gait characteristic: A systematic review. *Foot*, *31*(April), 72–76. https://doi.org/10.1016/j.foot.2017.04.005

64. Finestone, A., Shlamkovitch, N., Eldad, A., Karp, A., & Milgrom, C. (1992). A Prospective Study of the Effect of the Appropriateness of Foot-Shoe Fit and Training Shoe Type on the Incidence of Overuse Injuries among Infantry Recruits. *Military Medicine*, *157*(9), 489–490. https://doi.org/10.1093/milmed/157.9.489

65. Fluss, R., Faraggi, D., & Reiser, B. (2005). Estimation of the Youden Index and its associated cutoff point. *Biometrical Journal. Biometrische Zeitschrift*, *47*(4), 458–472. https://doi.org/10.1002/BIMJ.200410135

66. Franklin, S., Grey, M. J., Heneghan, N., Bowen, L., & Li, F. X. (2015). Barefoot vs common footwear: A systematic review of the kinematic, kinetic and muscle activity differences during walking. In *Gait and Posture* (Vol. 42, Issue 3, pp. 230–239). Elsevier. https://doi.org/10.1016/j.gaitpost.2015.05.019

67. Franklin, S., Li, F.-X., & Grey, M. J. (2018). Modifications in lower leg muscle activation when walking barefoot or in minimalist shoes across different age-groups. *Gait & Posture*, *60*, 1–5. https://doi.org/10.1016/j.gaitpost.2017.10.027

68. Franklyn-Miller, A., Bilzon, J., Wilson, C., & McCrory, P. (2014). Can RSScan footscan® D3D™ software predict injury in a military population following plantar pressure assessment? A prospective cohort study. *Foot*, *24*(1), 6–10. https://doi.org/10.1016/j.foot.2013.11.002

69. Fredette, M. A., Roy, J.-S., Esculier, J.-F. ois, & Perreault, K. (2021). Most Military Runners Report Recent Changes in Running Parameters Before Lower Limb Injury Onset. *Military Medicine*, *186*(11–12), e1140–e1148. https://doi.org/10.1093/milmed/usaa524

70. Fulton, J., Wright, K., Kelly, M., Zebrosky, B., Zanis, M., Drvol, C., & Butler, R. (2014). Injury risk is altered by previous injury: a systematic review of the literature and presentation of causative neuromuscular factors. *International Journal of Sports Physical Therapy*.

71. Geary, K. G., Irvine, D., & Croft, A. M. (2002). Does military service damage females? An analysis of medical discharge data in the British armed forces. *Occupational Medicine*. https://doi.org/10.1093/occmed/52.2.85

72. Ghani Zadeh Hesar, N., Van Ginckel, A., Cools, A., Peersman, W., Roosen, P., De Clercq, D., & Witvrouw, E. (2009). A prospective study on gait-related intrinsic risk factors for lower leg overuse injuries. *British Journal of Sports Medicine*, *43*(13), 1057–1061. https://doi.org/10.1136/bjsm.2008.055723

73. Giacomozzi, C., Leardini, A., & Caravaggi, P. (2014). Correlates between kinematics and baropodometric measurements for an integrated in-vivo assessment of the segmental foot function in gait. *Journal of Biomechanics*. https://doi.org/10.1016/j.jbiomech.2014.05.014

74. Goffar, S. L., Reber, R. J., Christiansen, B. C., Miller, R. B., Naylor, J. A., Rodriguez, B. M., Walker, M. J., & Teyhen, D. S. (2013). Changes in dynamic plantar pressure during loaded gait. *Physical Therapy*, *93*(9), 1175–1184. https://doi.org/10.2522/ptj.20120103

75. Goto, K., & Abe, K. (2017). Gait characteristics in women’s safety shoes. *Applied Ergonomics*, *65*, 163–167. https://doi.org/10.1016/j.apergo.2017.06.012

76. Gouelle, A., & Mégrot, F. (2016). Interpreting Spatiotemporal Parameters, Symmetry, and Variability in Clinical Gait Analysis. In B. Müller, S. I. Wolf, G.-P. Brueggemann, Z. Deng, A. McIntosh, F. Miller, & W. S. Selbie (Eds.), *Handbook of Human Motion* (pp. 1–20). Springer International Publishing. https://doi.org/10.1007/978-3-319-30808-1_35-1

77. Greve, C., Schuitema, D., Otten, B., van Kouwenhove, L., Verhaar, E., Postema, K., Dekker, R., & Hijmans, J. M. (2019). Biomechanical effects of rocker shoes on plantar aponeurosis strain in patients with plantar fasciitis and healthy controls. *PloS One*, *14*(10), e0222388. https://doi.org/10.1371/journal.pone.0222388

78. Grier, T., Dinkeloo, E., Reynolds, M., & Jones, B. H. (2020). Sleep duration and musculoskeletal injury incidence in physically active men and women: A study of U.S. Army Special Operation Forces soldiers. *Sleep Health*, *6*(3), 344–349. https://doi.org/10.1016/j.sleh.2020.01.004

79. Grier, T. L., Knapik, J. J., Swedler, D., & Jones, B. H. (2011). Footwear in the United States Army Band: Injury incidence and risk factors associated with foot pain. *The Foot*, *21*(2), 60–65. https://doi.org/10.1016/j.foot.2010.12.002

80. Grimm, P. D., Mauntel, T. C., & Potter, B. K. (2019). Combat and Noncombat Musculoskeletal Injuries in the US Military. *Sports Medicine and Arthroscopy Review*, *27*(3), 84–91. https://doi.org/10.1097/JSA.0000000000000246

81. Grouios, G. (2005). Footedness as a potential factor that contributes to the causation of corn and callus formation in lower extremities of physically active individuals. *The Foot*, *15*(3), 154–162. https://doi.org/10.1016/j.foot.2005.05.003

82. Hafer, J. F., Lenhoff, M. W., Song, J., Jordan, J. M., Hannan, M. T., & Hillstrom, H. J. (2013). Reliability of plantar pressure platforms. *Gait & Posture*, *38*(3), 544–548. https://doi.org/10.1016/j.gaitpost.2013.01.028

83. Hagman, F. F., van Stef Stef Eijndhoven, & de Ven, V. (2002). *A mathematical model simulating the motion of the calcaneus from pressure plate measurements*.

84. Halvarsson, A., Hagman, I., Tegern, M., Broman, L., & Larsson, H. (2018). Self-reported musculoskeletal complaints and injuries and exposure of physical workload in Swedish soldiers serving in Afghanistan. *PloS One*, *13*(4), e0195548. https://doi.org/10.1371/journal.pone.0195548

85. Hamacher, D., Hamacher, D., Krowicki, M., & Schega, L. (2017). Between-day test–retest reliability of gait variability in older individuals improves with a familiarization trial. *Aging Clinical and Experimental Research*, *29*(2), 327–329. https://doi.org/10.1007/s40520-016-0536-3

86. Hamill, J., Palmer, C., & Van Emmerik, R. E. A. (2012). Coordinative variability and overuse injury. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology*, *4*(1), 45. https://doi.org/10.1186/1758-2555-4-45

87. Hamill J, B. C. (1996). Biomechanical analysis of military boots: Phase 1. Materials testing of military and commercial footwear. Technical Report. *Natick, MA: U.S. Army Natick Research; 1992. Report No.: NATICK-TR-93/006., April 1995*.

88. Haskell, A. (2020). Foot and Ankle Biomechanics. In M. D. Miller & S. R. Thompson (Eds.), *DeLee Drez & Miller's Orthopaedic Sports Medicine* (Fifth Edit, pp. 1359-1369.e2). Elsevier Inc. https://doi.org/10.1016/B978-0-323-54473-3.00110-2

89. Hauret, K. G., Jones, B. H., Bullock, S. H., Canham-Chervak, M., & Canada, S. (2010). Musculoskeletal injuries: Description of an under-recognized injury problem among military personnel. *American Journal of Preventive Medicine*, *38*(1 SUPPL.), S61–S70. https://doi.org/10.1016/j.amepre.2009.10.021

90. Hauschild, V. D., Schuh-Renner, A., Lee, T., Richardson, M. D., Hauret, K., & Jones, B. H. (2019). Using causal energy categories to report the distribution of injuries in an active population: An approach used by the U.S. Army. *Journal of Science and Medicine in Sport*, *22*(9), 997–1003. https://doi.org/10.1016/j.jsams.2019.04.001

91. Hausdorff, J. M., Peng, C. K., Ladin, Z., Wei, J. Y., & Goldberger, A. L. (1995). Is walking a random walk? Evidence for long-range correlations in stride interval of human gait. *Journal of Applied Physiology (Bethesda, Md. :1985)*, *78*(1), 349–358. https://doi.org/10.1152/jappl.1995.78.1.349

92. Hernandez, A. J., Kimura, L. K., Laraya, M. H. F., & Fávaro, E. (2007). Calculation of staheli's plantar arch index and prevalence of flat feet: A study with 100 children aged 5-9 years. *Acta Ortopedica Brasileira*. https://doi.org/10.1590/S1413-78522007000200001

93. Hewett, T. E., & Bates, N. A. (2017). Preventive Biomechanics: A Paradigm Shift With a Translational Approach to Injury Prevention. *The American Journal of Sports Medicine*, *45*(11), 2654–2664. https://doi.org/10.1177/0363546516686080

94. Hill, C. M., DeBusk, H., Knight, A. C., & Chander, H. (2020). Military-Type Workload and Footwear Alter Lower Extremity Muscle Activity during Unilateral Static Balance: Implications for Tactical Athletic Footwear Design. *Sports*, *8*(5). https://doi.org/10.3390/sports8050058

95. Hintzy, F., Cavagna, J., & Horvais, N. (2015). Evolution of perceived footwear comfort over a prolonged running session. *The Foot*, *25*(4), 220–223. https://doi.org/10.1016/j.foot.2015.08.003

96. Hmida, J., Tomschi, F., Strauss, A. C., & Hilberg, T. (2023). Relationship between foot pressure

and spinal parameters in healthy adults – A systematic review. *Gait & Posture*, *103*, 126–132. https://doi.org/10.1016/j.gaitpost.2023.05.006

97. Hof, A. L. (1996). Scaling gait data to body size. *Gait & Posture*, *4*(3), 222–223. https://doi.org/10.1016/0966-6362(95)01057-2
98. Hoffman, J. (2014). *Physiological aspects of sport training and performance*. Human Kinetics.
99. Hoffman, J. R., Church, D. D., & Hoffman, M. W. (2015). Overuse Injuries in Military Personnel. In Y. Gefen, A., Epstein (Ed.), *The Mechanobiology and Mechanophysiology of Military-Related Injuries. Studies in Mechanobiology, Tissue Engineering and Biomaterials* (Vol. 19, pp. 141–161). Springer. https://doi.org/10.1007/8415_2015_187
100. Hollander, K., Petersen, E., Zech, A., & Hamacher, D. (2022). Effects of barefoot vs. shod walking during indoor and outdoor conditions in younger and older adults. *Gait & Posture*, *95*, 284–291. https://doi.org/10.1016/j.gaitpost.2021.04.024
101. Hombach-Klonisch, S., Klonisch, T., & Peeler, J. (2019). Lower extremity. In *Sobotta Clinical Atlas of Human Anatomy* (pp. 153–222). Elsevier Health Sciences.
102. Iannotti JP, Parker RD (Ed.). (2013). Netter Collection of Medical Illustrations. In *Netter Collection of Medical Illustrations: Musculoskeletal System, Vol. 6.* (pp. 271–297). Elsevier.
103. *International Organization for Standardization*. Retrieved from https://www.iso.org/obp/ui/#iso:std:iso:9407:ed-2:v1:en [Accessed on 19.01.2020]
104. Jacobs, J. M., Cameron, K. L., & Bojescul, J. A. (2014). Lower Extremity Stress Fractures in the Military. *Clinics in Sports Medicine*, *33*(4), 591–613. https://doi.org/10.1016/j.csm.2014.06.002
105. Jamal, A., Ali, M. K., Mirza, T. M., Raza, M., Access, O., Related, S., Limbs, L., Scintigraphy, S., Article, O., Armed, P., Med, F., & Ali Jamal, M. (2016). PATTERNS OF STRESS RELATED INJURIES OF LOWER LIMBS IN MILITARY SETUP ON SKELETAL SCINTIGRAPHY. *Pak Armed Forces Med J*, *66*(5), 742–746.
106. Jones, B. H., Hauret, K. G., Dye, S. K., Hauschild, V. D., Rossi, S. P., Richardson, M. D., & Friedl, K. E. (2017). Impact of physical fitness and body composition on injury risk among active young adults: A study of Army trainees. *Journal of Science and Medicine in Sport*, *20 Suppl 4*, S17–S22. https://doi.org/10.1016/j.jsams.2017.09.015
107. Jones, B. H., Hauschild, V. D., & Canham-Chervak, M. (2018). Musculoskeletal training injury prevention in the U.S. Army: Evolution of the science and the public health approach. *Journal of Science and Medicine in Sport*, *21*(11), 1139–1146. https://doi.org/10.1016/j.jsams.2018.02.011
108. Jones, P., Bus, S. A., Davies, M. J., Khunti, K., & Webb, D. (2020). Toe gaps and their assessment in footwear for people with diabetes: a narrative review. *Journal of Foot and Ankle Research*, *13*(1), 70. https://doi.org/10.1186/s13047-020-00439-3
109. Jordan, C., & Bartlett, R. (1994). Relationship between plantar and dorsal pressure distribution and perception of comfort in casual footwear. *Gait & Posture*, *2*(4), 251. https://doi.org/10.1016/0966-6362(94)90145-7
110. Kaufman, K. R., Brodine, S. K., Shaffer, R. A., Johnson, C. W., & Cullison, T. R. (1999). The effect of foot structure and range of motion on musculoskeletal overuse injuries. *American Journal of Sports Medicine*, *27*(5), 585–593. https://doi.org/10.1177/03635465990270050701
111. Kaufman, K. R., Brodine, S., & Shaffer, R. (2000). Military training-related injuries: Surveillance, research, and prevention. *American Journal of Preventive Medicine*, *18*(3 SUPPL.), 54–63. https://doi.org/10.1016/S0749-3797(00)00114-8
112. Kelsey L, Fleiss K, F. P. (2010). *Methods in observational Epidemiology 2nd Edition, Statistical Methods for Rates and Proportion, formulas 3.18 and 19*. Methods in Observational Epidemiology 2nd Edition, Statistical Methods for Rates and Proportion, Formulas 3.18 and 19. http://www.openepi.com/SampleSize/SSCohort.htm
113. Kernan, M., Raja, B., & Matuszak, J. (2008). The Collegiate/Professional Male Athlete. In J. J. B. T.-C. M. H. Heidelbaugh (Ed.), *Clinical Men's Health* (pp. 485–522). Elsevier.

https://doi.org/10.1016/B978-141603000-3.10026-7

114. Khoury-Mireb, M., Solomonow-Avnon, D., Rozen, N., & Wolf, A. (2019). The effect of unstable shoe designs on the variability of gait measures. *Gait & Posture*, *69*, 60–65. https://doi.org/10.1016/j.gaitpost.2019.01.017

115. Knapik, J. J., Bullock, S. H., Canada, S., Toney, E., Wells, J. D., Hoedebecke, E., & Jones, B. H. (2004). Influence of an injury reduction program on injury and fitness outcomes among soldiers. *Injury Prevention*, *10*(1), 37–42. https://doi.org/10.1136/ip.2003.002808

116. Knapik, Joseph J, Jones, B. H., & Steelman, R. A. (2015). Physical Training in Boots and Running Shoes: A Historical Comparison of Injury Incidence in Basic Combat Training. *Military Medicine*, *180*(3), 321–328. https://doi.org/10.7205/MILMED-D-14-00337

117. Kokare, I. (1998). *Latvijas karavīru bioloģiskā statusa izvērtējums, pamatojoties uz 1939. un 1996. gada izpētes datiem*. Rīgas Stradiņa universitāte.

118. König, N., Singh, N. B., von Beckerath, J., Janke, L., & Taylor, W. R. (2014). Is gait variability reliable? An assessment of spatio-temporal parameters of gait variability during continuous overground walking. *Gait & Posture*, *39*(1), 615–617. https://doi.org/10.1016/J.GAITPOST.2013.06.014

119. Kreider, R. B., O'Toole, M. L., Fry, A. C., Kibler, W. B., Nieman, D. C., Whelan, J. P., & Lehmann, M. (1998). OVERTRAINING IN SPORT. *Medicine & Science in Sports & Exercise*, *30*(Supplement), 225. https://doi.org/10.1097/00005768-199805001-01277

120. Kroneberg, D., Elshehabi, M., Meyer, A. C., Otte, K., Doss, S., Paul, F., Nussbaum, S., Berg, D., Kühn, A. A., Maetzler, W., & Schmitz-Hübsch, T. (2019). Less is more - Estimation of the number of strides required to assess gait variability in spatially confined settings. *Frontiers in Aging Neuroscience*, *11*(JAN). https://doi.org/10.3389/FNAGI.2018.00435/FULL

121. Kyvelidou, A., Kurz, M. J., Ehlers, J. L., & Stergiou, N. (2008). Aging and partial body weight support affects gait variability. *Journal of NeuroEngineering and Rehabilitation*, *5*(1), 22. https://doi.org/10.1186/1743-0003-5-22

122. Landorf, K. B., & Keenan, A. M. (2000). Efficacy of foot orthoses. What does the literature tell us? *Journal of the American Podiatric Medical Association*. https://doi.org/10.7547/87507315-90-3-149

123. Lange, J. S., Maiwald, C., Mayer, T. A., Schwanitz, S., Odenwald, S., & Milani, T. L. (2009). Relationship between plantar pressure and perceived comfort in military boots. *Footwear Science*, *1*, 30–32. https://doi.org/10.1080/19424280902977129

124. *Latvian Environment, Geology and Meteorology Centre*. (n.d.). Climate of Latvia. Retrieved from https://www.meteo.lv/en/lapas/environment/climate-change/climate-of-latvia/climat-latvia?id=1471&nid=660 [accessed on 15.10.2017]

125. Lavigne, A., Chicoine, D., Esculier, J.-F., Desmeules, F., Frémont, P., & Dubois, B. (2023). The Role of Footwear, Foot Orthosis, and Training-Related Strategies in the Prevention of Bone Stress Injuries: A Systematic Review and Meta-Analysis. *International Journal of Exercise Science*, *16*(3), 721–743.

126. Lee, Y.-C., Lin, G., & Wang, M.-J. J. (2014). Comparing 3D foot scanning with conventional measurement methods. *Journal of Foot and Ankle Research*, *7*(1), 44. https://doi.org/10.1186/s13047-014-0044-7

127. Lee, Y., & Shin, S. (2022). The Effect of Body Composition on Gait Variability Varies with Age: Interaction by Hierarchical Moderated Regression Analysis. *International Journal of Environmental Research and Public Health*, *19*(3), 1171. https://doi.org/10.3390/ijerph19031171

128. Levinger, P., & Gilleard, W. (2007). Tibia and rearfoot motion and ground reaction forces in subjects with patellofemoral pain syndrome during walking. *Gait & Posture*, *25*(1), 2–8. https://doi.org/10.1016/j.gaitpost.2005.12.015

129. Lin, S.-C., Chen, C. P. C., Tang, S. F. T., Wong, A. M. K., Hsieh, J.-H., & Chen, W.-P. (2013). Changes in windlass effect in response to different shoe and insole designs during walking. *Gait & Posture*, *37*(2), 235–241. https://doi.org/10.1016/j.gaitpost.2012.07.010

130. Louey, M. G. Y., & Sangeux, M. (2016). Shod wear and foot alignment in clinical gait analysis. *Gait and Posture*, *49*, 144–147. https://doi.org/10.1016/j.gaitpost.2016.06.032

131. Lovalekar, M., Hauret, K., Roy, T., Taylor, K., Blacker, S. D., Newman, P., Yanovich, R., Fleischmann, C., Nindl, B. C., Jones, B., & Canham-Chervak, M. (2021). Musculoskeletal injuries in military personnel – Descriptive epidemiology, risk factor identification, and prevention. *Journal of Science and Medicine in Sport*, *24*(10), 963–969. https://doi.org/10.1016/j.jsams.2021.03.016

132. Lovalekar, M., Johnson, C. D., Eagle, S., Wohleber, M. F., Keenan, K. A., Beals, K., Nindl, B. C., & Connaboy, C. (2018). Epidemiology of musculoskeletal injuries among US Air Force Special Tactics Operators: an economic cost perspective. *BMJ Open Sport & Exercise Medicine*, *4*(1), e000471. https://doi.org/10.1136/bmjsem-2018-000471

133. Lovalekar, M. T., Abt, J. P., Sell, T. C., Nagai, T., Keenan, K., Beals, K., Lephart, S. M., & Wirt, M. D. (2016). Descriptive Epidemiology of Musculoskeletal Injuries in the Army 101st Airborne (Air Assault) Division. *Military Medicine*, *181*(8), 900–906. https://doi.org/10.7205/milmed-d-15-00262

134. Low, D. C., & Dixon, S. J. (2010). Footscan pressure insoles: Accuracy and reliability of force and pressure measurements in running. *Gait & Posture*, *32*(4), 664–666. https://doi.org/10.1016/j.gaitpost.2010.08.002

135. Lullini, G., Giangrande, A., Caravaggi, P., Leardini, A., & Berti, L. (2020). Functional Evaluation of a Shock Absorbing Insole During Military Training in a Group of Soldiers: A Pilot Study. *Military Medicine*, *185*(5–6), e643–e648. https://doi.org/10.1093/milmed/usaa032

136. Magee, D. J., & Manske, R. C. (2021). Lower Leg, Ankle, and Foot. In *Orthopedic Physical Assessment* (pp. 990–1095). https://doi.org/10.1007/s00117-020-00664-8

137. Majumdar, D. D., Banerjee, P. K., Majumdar, D. D., Pal, M., Kumar, R., & Selvamurthy, W. (2006). Temporal spatial parameters of gait with barefoot, bathroom slippers and military boots. *Indian Journal of Physiology and Pharmacology*, *50*(1), 33–40.

138. Mawusi, E. P. S. (2019). *20 - Shoes and Shoe Modifications* (J. B. Webster & D. P. B. T.-A. of O. and A. D. (Fifth E. Murphy (Eds.); pp. 229-232.e1). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-323-48323-0.00020-2

139. Maykut, J. N., Taylor-Haas, J. A., Paterno, M. V, DiCesare, C. A., & Ford, K. R. (2015). Concurrent validity and reliability of 2d kinematic analysis of frontal plane motion during running. *International Journal of Sports Physical Therapy*, *10*(2), 136–146.

140. McGregor, A. H., & Hukins, D. W. L. (2009). Lower limb involvement in spinal function and low back pain. *Journal of Back and Musculoskeletal Rehabilitation*, *22*(4), 219–222. https://doi.org/10.3233/BMR-2009-0239

141. McWhorter, J. W., Wallmann, H., Landers, M., Altenburger, B., LaPorta-Krum, L., & Altenburger, P. (2003). The effects of walking, running, and shoe size on foot volumetrics. *Physical Therapy in Sport*, *4*(2), 87–92. https://doi.org/10.1016/S1466-853X(03)00031-2

142. Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., Raglin, J., Rietjens, G., Steinacker, J., & Urhausen, A. (2013). Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Medicine and Science in Sports and Exercise*, *45*(1), 186–205. https://doi.org/10.1249/MSS.0b013e318279a10a

143. Menz, H. B., & Bonanno, D. R. (2021). Footwear comfort: a systematic search and narrative

synthesis of the literature. *Journal of Foot and Ankle Research*, *14*(1), 63. https://doi.org/10.1186/s13047-021-00500-9

144. Merriman, L. (2002). Footwear assessment. In L. M. Merriman & W. Turner (Eds.), *Assessment of the Lower Limb* (Second Edi, pp. 245–265). Elsevier. https://doi.org/10.1016/B978-0-443-07112-6.50015-8

145. Milgrom, C., Zloczower, E., Fleischmann, C., Spitzer, E., Landau, R., Bader, T., & Finestone, A. S. (2021). Medial tibial stress fracture diagnosis and treatment guidelines. *Journal of Science and Medicine in Sport*, *24*(6), 526–530. https://doi.org/10.1016/j.jsams.2020.11.015

146. Miller, J. E., Nigg, B. M., Liu, W., Stefanyshyn, D. J., & Nurse, M. A. (2000). Influence of foot, leg and shoe characteristics on subjective comfort. *Foot and Ankle International*, *21*(9), 759–767. https://doi.org/10.1177/107110070002100908

147. MILLS, K., BLANCH, P., & VICENZINO, B. (2010). Identifying Clinically Meaningful Tools for Measuring Comfort Perception of Footwear. *Medicine & Science in Sports & Exercise*, *42*(10), 1966–1971. https://doi.org/10.1249/MSS.0b013e3181dbacc8

148. Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive statistics and normality tests for statistical data. *Annals of Cardiac Anaesthesia*, *22*(1), 67–72. https://doi.org/10.4103/aca.ACA_157_18

149. Mojica, M. N., & Early, J. S. (2019). Foot Biomechanics. In *Atlas of Orthoses and Assistive Devices* (Fifth Edit). Elsevier Inc. https://doi.org/10.1016/b978-0-323-48323-0.00019-6

150. Molina-Rueda, F., Fernández-González, P., Cuesta-Gómez, A., Koutsou, A., Carratalá-Tejada, M., & Miangolarra-Page, J. C. (2021). Test-Retest Reliability of a Conventional Gait Model for Registering Joint Angles during Initial Contact and Toe-Off in Healthy Subjects. *International Journal of Environmental Research and Public Health*, *18*(3). https://doi.org/10.3390/ijerph18031343

151. Molloy, J. M., Pendergrass, T. L., Lee, I. E., Chervak, M. C., Hauret, K. G., & Rhon, D. I. (2020). Musculoskeletal Injuries and United States Army Readiness Part I: Overview of Injuries and their Strategic Impact. *Military Medicine*, *185*(9–10), e1461–e1471. https://doi.org/10.1093/milmed/usaa027

152. Moon, Y., Sung, J., An, R., Hernandez, M. E., & Sosnoff, J. J. (2016). Gait variability in people with neurological disorders: A systematic review and meta-analysis. *Human Movement Science*, *47*, 197–208. https://doi.org/10.1016/j.humov.2016.03.010

153. Morio, C., Lake, M. J., Gueguen, N., Rao, G., & Baly, L. (2009). The influence of footwear on foot motion during walking and running. *Journal of Biomechanics*, *42*(13), 2081–2088. https://doi.org/10.1016/j.jbiomech.2009.06.015

154. Morrison, S. C., & Ferrari, J. (2009). Inter-rater reliability of the Foot Posture Index (FPI-6) in the assessment of the paediatric foot. *Journal of Foot and Ankle Research*. https://doi.org/10.1186/1757-1146-2-26

155. Muniz, A. M. S., & Bini, R. R. (2017). Shock attenuation characteristics of three different military boots during gait. *Gait and Posture*, *58*(July), 59–65. https://doi.org/10.1016/j.gaitpost.2017.07.037

156. Nácher, B., Alemany, S., González, J. C., Alcántara, E., García-Hernández, J., Heras, S., & Juan, A. (2006, July 4). A Footwear Fit Classification Model Based on Anthropometric Data. *Digital Human Modeling for Design and Engineering Conference Proceedings*. https://doi.org/10.4271/2006-01-2356

157. Nair, S. P., Gibbs, S., Arnold, G., Abboud, R., & Wang, W. (2010). A method to calculate the centre of the ankle joint: A comparison with the Vicon® Plug-in-Gait model. *Clinical Biomechanics*, *25*(6), 582–587. https://doi.org/10.1016/j.clinbiomech.2010.03.004

158. Nakagawa, S., & Cuthill, I. C. (2007). Effect size, confidence interval and statistical significance: a practical guide for biologists. *Biological Reviews*, *82*(4), 591–605. https://doi.org/10.1111/j.1469-185X.2007.00027.x

159. Nakayama, Y., Kudo, K., & Ohtsuki, T. (2010). Variability and fluctuation in running gait cycle of trained runners and non-runners. *Gait & Posture*, *31*(3), 331–335. https://doi.org/10.1016/j.gaitpost.2009.12.003

160. Nancarrow, S. (1999). The footwear suitability scale: a measure of shoe-fit for people with diabetes. *Australasian Journal of Podiatric Medicine*, *33*(2), 57–63.

161. Neal, B. S., Griffiths, I. B., Dowling, G. J., Murley, G. S., Munteanu, S. E., Franettovich Smith, M. M., Collins, N. J., & Barton, C. J. (2014). Foot posture as a risk factor for lower limb overuse injury: a systematic review and meta-analysis. *Journal of Foot and Ankle Research*, *7*(1), 55. https://doi.org/10.1186/s13047-014-0055-4

162. Neil, E. R., Winkelmann, Z. K., & Edler, J. R. (2018). Defining the Term “Overuse”: An Evidence-Based Review of Sports Epidemiology Literature. *Journal of Athletic Training*, *53*(3), 279–281. https://doi.org/10.4085/1062-6050-84-16

163. Nesterovica, D. (2020). Definition of the lower extremity overuse: A review. In L. Vilka & J. Vike (Eds.), *SHS Web of Conferences* (Vol. 85). https://doi.org/10.1051/shsconf/20208502006

164. Niechwiej-Szwedo, E., Inness, E. L., Howe, J. A., Jaglal, S., McIlroy, W. E., & Verrier, M. C. (2007). Changes in gait variability during different challenges to mobility in patients with traumatic brain injury. *Gait & Posture*, *25*(1), 70–77. https://doi.org/10.1016/j.gaitpost.2006.01.002

165. Nigg, B., Baltich, J., Hoerzer, S., & Enders, H. (2015). Running shoes and running injuries: mythbusting and a proposal for two new paradigms: ‘preferred movement path’ and ‘comfort filter.’ *British Journal of Sports Medicine*, *49*(20), 1290–1294. https://doi.org/10.1136/bjsports-2015-095054

166. Nye, N. S., Pawlak, M. T., Webber, B. J., Tchandja, J. N., & Milner, M. R. (2016). Description and Rate of Musculoskeletal Injuries in Air Force Basic Military Trainees, 2012-2014. *Journal of Athletic Training*, *51*(11), 858–865. https://doi.org/10.4085/1062-6050-51.10.10

167. Ogaya, S., Okubo, S., Utsumi, T., Konno, F., & Kita, S. (2022). Effects of flat-flexible shoes on lower limb joint kinetics and kinematics in gait. *Journal of Biomechanics*, *141*, 111216. https://doi.org/10.1016/j.jbiomech.2022.111216

168. Oke, F., Branthwaite, H., & Chockalingam, N. (2015). Footwear mismatch – do we wear correct-sized shoes? *Footwear Science*, *7*(sup1), S76–S77. https://doi.org/10.1080/19424280.2015.1038617

169. Orr, R. M., Coyle, J., Johnston, V., & Pope, R. (2017). Self-reported load carriage injuries of military soldiers. *International Journal of Injury Control and Safety Promotion*, *24*(2), 189–197. https://doi.org/10.1080/17457300.2015.1132731

170. Orr, R. M., & Pope, R. (2016). Gender differences in load carriage injuries of Australian army soldiers. *BMC Musculoskeletal Disorders*, *17*(1), 488. https://doi.org/10.1186/s12891-016-1340-0

171. Orr, R. M., Pope, R., Johnston, V., & Coyle, J. (2014). Soldier occupational load carriage: a narrative review of associated injuries. *International Journal of Injury Control and Safety Promotion*, *21*(4), 388–396. https://doi.org/10.1080/17457300.2013.833944

172. Orr, R., Maupin, D., Palmer, R., Canetti, E. F. D., Simas, V., & Schram, B. (2022). The Impact of Footwear on Occupational Task Performance and Musculoskeletal Injury Risk: A Scoping Review to Inform Tactical Footwear. *International Journal of Environmental Research and Public Health*, *19*(17), 10703. https://doi.org/10.3390/ijerph191710703

173. Orr, R., Pope, R., Johnston, V., & Coyle, J. (2010). Load Carriage: Minimising Solider Injuries through physical conditioning - a narrative review. *Journal of Military and Veteran’s Health*, *18*, 31–38.

174. Paisis, P., Hanley, B., Havenetidis, K., & Bissas, A. (2013). Cypriot and greek army military boot cushioning: ground reaction forces and subjective responses. *Military Medicine*, *178*(4), e493-7. https://doi.org/10.7205/MILMED-D-12-00432

175. Pappas, E., Xergia, S. A., Zampeli, F., Ristanis, S., Moraiti, C., Georgoulis, A., & Stergiou, N. (2018). Motion Analysis in Anterior Cruciate Ligament Deficient and Reconstructed Knees. In *The Anterior Cruciate Ligament* (Second Edi, pp. 558-564.e2). Elsevier. https://doi.org/10.1016/B978-0-323-38962-4.00139-9

176. Patel, P., Enzastiga, D., Casamento-Moran, A., Christou, E. A., & Lodha, N. (2022). Increased temporal stride variability contributes to impaired gait coordination after stroke. *Scientific Reports*, *12*(1), 12679. https://doi.org/10.1038/s41598-022-17017-1

177. Payne, C. B., & Dananberg, H. J. (1997). Sagittal plane facilitation of the foot. *Journal of the American Podiatric Medical Association*, *31*(1), 7–11.

178. Peng, Y., Wong, D. W. C., Wang, Y., Chen, T. L. W., Tan, Q., Chen, Z., Jin, Z., & Zhang, M. (2020). Immediate Effects of Medially Posted Insoles on Lower Limb Joint Contact Forces in Adult Acquired Flatfoot: A Pilot Study. *International Journal of Environmental Research and Public Health*, *17*(7). https://doi.org/10.3390/IJERPH17072226

179. Pipkin, A., Kotecki, K., Hetzel, S., & Heiderscheit, B. (2016). Reliability of a Qualitative Video Analysis for Running. *The Journal of Orthopaedic and Sports Physical Therapy*, *46*(7), 556–561. https://doi.org/10.2519/jospt.2016.6280

180. Qu, X. (2012). Uncontrolled manifold analysis of gait variability: Effects of load carriage and fatigue. *Gait & Posture*, *36*(2), 325–329. https://doi.org/10.1016/j.gaitpost.2012.03.004

181. Ramanathan, A. K., Parish, E. J., Arnold, G. P., Drew, T. S., Wang, W., & Abboud, R. J. (2011). The influence of shoe sole's varying thickness on lower limb muscle activity. *Foot and Ankle Surgery*, *17*(4), 218–223. https://doi.org/10.1016/j.fas.2010.07.003

182. Redmond, A. C., Crosbie, J., & Ouvrier, R. A. (2006). Development and validation of a novel rating system for scoring standing foot posture: The Foot Posture Index. *Clinical Biomechanics*, *21*(1), 89–98. https://doi.org/10.1016/j.clinbiomech.2005.08.002

183. Reinker, K. A., & Ozburne, S. (1979). A comparison of male and female orthopaedic pathology in basic training. *Military Medicine*, *144*(8), 532–536.

184. Reynolds, K., Williams, J., Miller, C., Mathis, A., & Dettori, J. (2000). Injuries and risk factors in an 18-day Marine winter mountain training exercise. *Military Medicine*, *165*(12), 905–910.

185. Rhon, D. I., Teyhen, D. S., Kiesel, K., Shaffer, S. W., Goffar, S. L., Greenlee, T. A., & Plisky, P. J. (2022). Recovery, Rehabilitation, and Return to Full Duty in a Military Population After a Recent Injury: Differences Between Lower-Extremity and Spine Injuries. *Arthroscopy, Sports Medicine, and Rehabilitation*, *4*(1), e17–e27. https://doi.org/10.1016/j.asmr.2021.09.028

186. Rice, H., Nunns, M., House, C., Fallowfield, J., Allsopp, A., & Dixon, S. (2013). High medial plantar pressures during barefoot running are associated with increased risk of ankle inversion injury in Royal Marine recruits. *Gait and Posture*. https://doi.org/10.1016/j.gaitpost.2013.02.001

187. Riegger, M., Müller, J., Giampietro, A., Saporito, A., Filardo, G., Treglia, G., Guidi, M., & Candrian, C. (2022). Forefoot Adduction, Hindfoot Varus or Pes Cavus: Risk Factors for Fifth Metatarsal Fractures and Jones Fractures? A Systematic Review and Meta-Analysis. *The Journal of Foot and Ankle Surgery: Official Publication of the American College of Foot and Ankle Surgeons*, *61*(3), 641–647. https://doi.org/10.1053/j.jfas.2021.11.002

188. Robbins, S., Waked, E., & Mcclaran, J. (1995). Proprioception and stability: Foot position awareness as a function of age and footware. *Age and Ageing*, *24*(1), 67–72. https://doi.org/10.1093/ageing/24.1.67

189. Roberts, A., Roscoe, D., Hulse, D., Bennett, A. N., & Dixon, S. (2017). Biomechanical differences between cases with chronic exertional compartment syndrome and asymptomatic controls during walking and marching gait. *Gait and Posture*, *58*(November 2016), 66–71. https://doi.org/10.1016/j.gaitpost.2017.07.044

190. Robinson, R. O., Herzog, W., & Nigg, B. M. (1987). Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. *Journal of Manipulative and Physiological Therapeutics*, *10*(4), 172–176.

191. Roos, K. G., Kucera, K. L., Golightly, Y. M., Myers, J. B., Rosamond, W. D., & Marshall, S. W. (2019). Variability in the identification and reporting of overuse injuries among sports injury surveillance data collectors. *Athletic Training & Sports Health Care*, *11*(3), 143–146. https://doi.org/10.3928/19425864-20190214-01

192. Roos, K. G., & Marshall, S. W. (2014). Definition and Usage of the Term "Overuse Injury" in the US High School and Collegiate Sport Epidemiology Literature: A Systematic Review. *Sports Medicine*, *44*(3), 405–421. https://doi.org/10.1007/s40279-013-0124-z

193. Sadeghi, H. (2003). Local or global asymmetry in gait of people without impairments. *Gait & Posture*, *17*(3), 197–204. https://doi.org/10.1016/S0966-6362(02)00089-9

194. Sammito, S., Hadzic, V., Karakolis, T., Kelly, K. R., Proctor, S. P., Stepens, A., White, G., & Zimmermann, W. O. (2021). Risk factors for musculoskeletal injuries in the military: a qualitative systematic review of the literature from the past two decades and a new prioritizing injury model. *Military Medical Research*, *8*(1), 66. https://doi.org/10.1186/s40779-021-00357-w

195. Sánchez-Rodríguez, R., Martínez-Nova, A., Escamilla-Martínez, E., & Pedrera-Zamorano, J. D. (2012). Can the Foot Posture Index or their individual criteria predict dynamic plantar pressures? *Gait & Posture*, *36*(3), 591–595. https://doi.org/10.1016/j.gaitpost.2012.05.024

196. Saunders, J. B., Inman, V. T., & Eberhart, H. D. (1953). The major determinants in normal and pathological gait. *The Journal of Bone and Joint Surgery. American Volume*, *35-A*(3), 543–558.

197. Scher, C. D. L., Belmont, L. C. P. J., Bear, M. R., Mountcastle, S. B., Orr, J. D., & Owens, M. B. D. (2009). The Incidence of Plantar Fasciitis in the United States Military. *The Journal of Bone and Joint Surgery-American Volume*, *91*(12), 2867–2872. https://doi.org/10.2106/JBJS.I.00257

198. Schizas, C. G., Kramers-de Quervain, I. A., Stüssi, E., & Grob, D. (1998). Gait asymmetries in patients with idiopathic scoliosis using vertical forces measurement only. *European Spine Journal*, *7*(2), 95–98. https://doi.org/10.1007/s005860050037

199. Schuh-Renner, A., Canham-Chervak, M., Grier, T. L., & Jones, B. H. (2019). Accuracy of self-reported injuries compared to medical record data. *Musculoskeletal Science and Practice*, *39*(June 2018), 39–44. https://doi.org/10.1016/j.msksp.2018.11.007

200. Schulze, C., Lindner, T., Woitge, S., Schulz, K., Finze, S., Mittelmeier, W., & Bader, R. (2014). Influence of footwear and equipment on stride length and range of motion of ankle, knee and hip joint. *Acta of Bioengineering and Biomechanics*, *16*(4), 45–51. https://doi.org/10.5277/ABB-00043-2014-02

201. Schwartz, O., Malka, I., Olsen, C. H., Dudkiewicz, I., & Bader, T. (2018). Overuse Injuries in the IDF's Combat Training Units: Rates, Types, and Mechanisms of Injury. *Military Medicine*, *183* (3–4), E196–E200. https://doi.org/10.1093/milmed/usx055

202. Schwarzkopf, R., Perretta, D. J., Russell, T. A., & Sheskier, S. C. (2011). The Journal of Foot & Ankle Surgery Foot and Shoe Size Mismatch in Three Different New York City Populations. *The Journal of Foot & Ankle Surgery*, *50*(4), 391–394. https://doi.org/10.1053/j.jfas.2011.04.030

203. Schwellnus, M. P., Jordaan, G., & Noakes, T. D. (1990). Prevention of common overuse injuries by the use of shock absorbing insoles: A prospective study. *American Journal of Sports Medicine*. https://doi.org/10.1177/036354659001800614

204. Sekiya, N. (1996). The invariant relationship between step length and step rate during free walking. *Journal of Human Movement Studies*, *30*, 241–257.

205. Sharma, J., Greeves, J. P., Byers, M., Bennett, A. N., & Spears, I. R. (2015). Musculoskeletal

injuries in British Army recruits: A prospective study of diagnosis-specific incidence and rehabilitation times Epidemiology of musculoskeletal disorders. *BMC Musculoskeletal Disorders*. https://doi.org/10.1186/s12891-015-0558-6

206. Smith, L., Westrick, R., Sauers, S., Cooper, A., Scofield, D., Claro, P., & Warr, B. (2016). Underreporting of Musculoskeletal Injuries in the US Army. *Sports Health: A Multidisciplinary Approach*, *8*(6), 507–513. https://doi.org/10.1177/1941738116670873

207. Smith, T. A., & Cashman, T. M. (2002). The incidence of injury in light infantry soldiers. *Military Medicine*, *167*(2), 104–108.

208. Snyder, R. A., DeAngelis, J. P., Koester, M. C., Spindler, K. P., & Dunn, W. R. (2009). Does shoe insole modification prevent stress fractures? a systematic review. *HSS Journal*, *5*(2), 92–98. https://doi.org/10.1007/s11420-009-9114-y

209. Spencer, S. (2020). Biomechanical Effects of Shoe Gear on the Lower Extremity. *Clinics in Podiatric Medicine and Surgery*, *37*(1), 91–99. https://doi.org/10.1016/j.cpm.2019.08.008

210. Springer, S., Gottlieb, U., & Lozin, M. (2016). Spatiotemporal Gait Parameters as Predictors of Lower-Limb Overuse Injuries in Military Training. *Scientific World Journal*, *2016*. https://doi.org/10.1155/2016/5939164

211. Stergiou, Nicholas, Buzzi, U., Kurz, M., & Heidel, J. (2004). Nonlinear Tools in Human Movement. In Nicholas Stergiou (Ed.), *Innovative Analyses of Human Movement* (pp. 63–90). Human Kinetics Champaign.

212. Strongman, C., & Morrison, A. (2020). A scoping review of non-linear analysis approaches measuring variability in gait due to lower body injury or dysfunction. *Human Movement Science*, *69*(December 2019), 102562. https://doi.org/10.1016/j.humov.2019.102562

213. Taanila, H., Suni, J. H., Kannus, P., Pihlajamäki, H., Ruohola, J.-P., Viskari, J., & Parkkari, J. (2015). Risk factors of acute and overuse musculoskeletal injuries among young conscripts: a population-based cohort study. *BMC Musculoskeletal Disorders*, *16*(1), 104. https://doi.org/10.1186/s12891-015-0557-7

214. Tan, A. M., Weizman, Y., Van Netten, J. J., & Fuss, F. K. (2022). Comparing the applicability of temporal gait symmetry, variability and laterality in bilateral gait conditions: A feasibility study of healthy individuals and people with diabetic neuropathy. *Clinical Biomechanics*, *91*, 105530. https://doi.org/10.1016/j.clinbiomech.2021.105530

215. Tong, J. W. K., & Kong, P. W. (2013). Association between foot type and lower extremity injuries: systematic literature review with meta-analysis. *The Journal of Orthopaedic and Sports Physical Therapy*, *43*(10), 700–714. https://doi.org/10.2519/jospt.2013.4225

216. Toohey, L. A., Drew, M. K., Cook, J. L., Finch, C. F., & Gaida, J. E. (2017). Is subsequent lower limb injury associated with previous injury? A systematic review and meta-analysis. *British Journal of Sports Medicine*, *51*(23), 1670–1678. https://doi.org/10.1136/bjsports-2017-097500

217. Torrens, G., Campbell, I., & Tutton, W. (2012). Design issues in military footwear and handwear. In *Advances in Military Textiles and Personal Equipment* (pp. 139–164). Elsevier. https://doi.org/10.1533/9780857095572.1.139

218. van Leeuwen, A. M., van Dieën, J. H., Daffertshofer, A., & Bruijn, S. M. (2020). Active foot placement control ensures stable gait: Effect of constraints on foot placement and ankle moments. *PLOS ONE*, *15*(12), e0242215. https://doi.org/10.1371/journal.pone.0242215

219. Vu, V., Walker, A., Ball, N., & Spratford, W. (2017). Ankle restrictive firefighting boots alter the lumbar biomechanics during landing tasks. *Applied Ergonomics*, *65*, 123–129. https://doi.org/10.1016/j.apergo.2017.06.006

220. Wafai, L., Zayegh, A., Woulfe, J., Mahfuzul, S., & Begg, R. (2015). Identification of foot pathologies based on plantar pressure asymmetry. *Sensors (Switzerland)*. https://doi.org/10.3390/s150820392

221. Walha, R., Gaudreault, N., Dagenais, P., & Boissy, P. (2022). Spatiotemporal parameters and gait variability in people with psoriatic arthritis (PsA): a cross-sectional study. *Journal of Foot and*

Ankle Research, *15*(1), 19. https://doi.org/10.1186/s13047-022-00521-y

222. Wannop, J. W., Stefanyshyn, D. J., Anderson, R. B., Coughlin, M. J., & Kent, R. (2019). Development of a Footwear Sizing System in the National Football League. *Sports Health*, *11*(1), 40–46. https://doi.org/10.1177/1941738118789402

223. Wardle, S. L., & Greeves, J. P. (2017). Mitigating the risk of musculoskeletal injury: A systematic review of the most effective injury prevention strategies for military personnel. *Journal of Science and Medicine in Sport*, *20*, S3–S10. https://doi.org/10.1016/j.jsams.2017.09.014

224. Webster, J. B., & Darter, B. J. (2019). Principles of Normal and Pathologic Gait. In *Atlas of Orthoses and Assistive Devices* (Fifth Edit, pp. 49-62.e1). Elsevier. https://doi.org/10.1016/B978-0-323-48323-0.00004-4

225. West, A. M., Schönfisch, D., Picard, A., Tarrier, J., Hodder, S., & Havenith, G. (2019). Shoe microclimate: An objective characterisation and subjective evaluation. *Applied Ergonomics*, *78*, 1–12. https://doi.org/10.1016/j.apergo.2019.01.010

226. Whittaker, J. L., & Roos, E. M. (2019). A pragmatic approach to prevent post-traumatic osteoarthritis after sport or exercise-related joint injury. *Best Practice & Research Clinical Rheumatology*, *33*(1), 158–171. https://doi.org/10.1016/j.berh.2019.02.008

227. Wilkinson, D. M., Blacker, S. D., Richmond, V. L., Horner, F. E., Rayson, M. P., Spiess, A., & Knapik, J. J. (2011). Injuries and injury risk factors among British army infantry soldiers during predeployment training. *Injury Prevention*. https://doi.org/10.1136/ip.2010.028233

228. Willems, T.M., De Clercq, D., Delbaere, K., Vanderstraeten, G., De Cock, A., & Witvrouw, E. (2006). A prospective study of gait related risk factors for exercise-related lower leg pain. *Gait & Posture*, *23*(1), 91–98. https://doi.org/10.1016/j.gaitpost.2004.12.004

229. Willems, Tine Marieke, De Ridder, R., & Roosen, P. (2019). Is consumer behaviour towards footwear predisposing for lower extremity injuries in runners and walkers? A prospective study. *Journal of Foot and Ankle Research*, *12*(1), 43. https://doi.org/10.1186/s13047-019-0354-x

230. Willems, Tine Marieke, Witvrouw, E., De Cock, A., & De Clercq, D. (2007). Gait-related risk factors for exercise-related lower-leg pain during shod running. *Medicine and Science in Sports and Exercise*, *39*(2), 330–339. https://doi.org/10.1249/01.mss.0000247001.94470.21

231. Willwacher, S., Kurz, M., Robbin, J., Thelen, M., Hamill, J., Kelly, L., & Mai, P. (2022). Running-Related Biomechanical Risk Factors for Overuse Injuries in Distance Runners: A Systematic Review Considering Injury Specificity and the Potentials for Future Research. In *Sports medicine (Auckland, N.Z.)* (Vol. 52, Issue 8, pp. 1863–1877). https://doi.org/10.1007/s40279-022-01666-3

232. Winter, D. A. (1984). Kinematic and kinetic patterns in human gait: Variability and compensating effects. *Human Movement Science*, *3*(1–2), 51–76. https://doi.org/10.1016/0167-9457(84)90005-8

233. World Health Organization. (2019). International statistical classification of diseases and related health problems, 10th revision (ICD-10). *World Health Organization*.

234. Yang, J. H., Suh, S.-W., Sung, P. S., & Park, W.-H. (2013). Asymmetrical gait in adolescents with idiopathic scoliosis. *European Spine Journal*, *22*(11), 2407–2413. https://doi.org/10.1007/s00586-013-2845-y

235. Yates, B., & White, S. (2004). The Incidence and Risk Factors in the Development of Medial Tibial Stress Syndrome among Naval Recruits. *The American Journal of Sports Medicine*, *32*(3), 772–780. https://doi.org/10.1177/0095399703258776

236. Zhang, X., Paquette, M. R., & Zhang, S. (2013). A comparison of gait biomechanics of flip-flops, sandals, barefoot and shoes. *Journal of Foot and Ankle Research*, *6*(1), 45. https://doi.org/10.1186/1757-1146-6-45

237. Zhao, Y., Zhang, Z., Luo, D., Li, M., Wang, J., Fang, J., Jiang, W., Feng, Y., Peng, J., Xu, W., Wang, Y., Wang, A., & Zhang, M. (2020). Risk factors for stress fracture of lower limbs and future research direction. *Chinese Journal of Tissue Engineering Research*. https://doi.org/10.3969/j.issn.2095-4344.2460

238. Zimmermann, W. O., Helmhout, P. H., & Beutler, A. (2017). Prevention and treatment of exercise related leg pain in young soldiers; A review of the literature and current practice in the Dutch armed forces. *Journal of the Royal Army Medical Corps*, *163*(2), 94–103. https://doi.org/10.1136/jramc-2016-000635

239. Zimmermann, W. O., Van Valderen, N. R. I., Linschoten, C. W., Beutler, A., Hoencamp, R., & Bakker, E. W. P. (2019). Gait retraining reduces vertical ground reaction forces in running shoes and military boots. *TRANSLATIONAL SPORTS MEDICINE*, *2*(2), 90–97. https://doi.org/https://doi.org/10.1002/tsm2.62

240. Zult, T., Allsop, J., Tabernero, J., & Pardhan, S. (2019). A low-cost 2-D video system can accurately and reliably assess adaptive gait kinematics in healthy and low vision subjects. *Scientific Reports*, *9*(1), 18385. https://doi.org/10.1038/s41598-019-54913-5

Acknowledgements

First of all, we would like to thank all the **infantry soldiers** who participated in this study and **the Joint Headquarters Medical Service Centre of the Latvian National Armed Forces** for the support in organising this investigation.

I am very grateful to my supervisor Associate Professor **Ainārs Stepens** for your enormous influence, your advice and encouragement helped me develop as a researcher.

Thank you, Associate Professor **Signe Tomsone,** for all your support and motivation throughout these years.

Thank you, Professor **Aivars Vētra,** for helping me with laboratory equipment and giving me more research opportunities in the field of gait biomechanics.

I express my deepest gratitude to Surgeon General **Normunds Vaivads**, thank you for your guidance and knowledge.

A special thank you for inspiring me, Dr. **Gundars Rusovs**, I was lucky to have your friendship, and I am so grateful for all your wise advice.

Thank you to my wonderful **Mumin & Nikita** for their love and support, I am so grateful for both of them.

Annexes

SOCIETY. INTEGRATION. EDUCATION
Proceedings of the International Scientific Conference. Volume VI, May 22th -23th, 2020. 354-360

SELF-REPORTED MUSCULOSKELETAL ACUTE AND OVERUSE INJURIES AMONG LATVIAN INFANTRY SOLDIERS

Darja Nesterovica
Riga Stradinš University, Military medicine research and study center, Latvia

Normunds Vaivads
National Armed forces, Joint Medical Service Headquarters, Latvia

Ainars Stepens
Riga Stradinš University, Military medicine research and study center, Latvia

Abstract. *Musculoskeletal injury is the leading cause of disability among different military populations that results in socioeconomic burden and negatively affects military readiness. Study aim was to describe self-reported musculoskeletal injuries among Latvian infantry soldiers during one-year period. Survey-based cross-sectional study was carried out. Data was assessed using survey about injuries that occurred in one-year period during annual medical check-up. Musculoskeletal injuries were classified according to body regions as it is in Barell injury matrix and by injury type – acute or overuse. Study results showed in one-year injury incidence rate was 867.8 cases per 1000 person-years (95% CI 824.8 – 913.0) with total 197 musculoskeletal injuries reported among active duty infantry soldiers. Typical acute injuries were superficial contusion injuries (n=24), fractures (n=21), joint dislocations (n=21) and sprains (n=29). Typical overuse diagnoses were lower back pain (n=42), patellofemoral pain syndrome (n=11), medial tibial stress syndrome (n=9), plantar fasciitis (n=8). Present study showed high incidence of overuse back injuries and overuse and acute lower leg injuries. Mostly of reported injuries could be classified as preventable and should be reduced through injury reduction programmes.*
Keywords: *Barell matrix, military personnel, musculoskeletal injuries, occupational health.*

Introduction

Musculoskeletal injuries remain leading cause of disability among military population that results in socioeconomic burden and negatively affects military readiness among different countries. Half of all outpatient medical visits in U.S. appear to be due to injuries (Knapik et al., 2004). In the United Kingdom, musculoskeletal injuries are the primary cause of medical discharge among military population (UK Ministry of Defence, 2018).

Studies conducted in military injury epidemiology field usually are based on medical-record analysis; however, recent study showed high self-reported injury

http://dx.doi.org/10.17770/sie2020vol6.5094

data accuracy when comparing with medical-record based data (Schuh-Renner et al., 2019).

Important aspect of injury prevention process is systematic injury surveillance, which monitors injury rates and trends (Jones et al., 2010; Schuh et al., 2017). For better understanding impact of injury reducing strategies, long-term monitoring of injury rates is recommended by Wardle & Greeves (2017).

Latvian Land forces is the biggest branch of Latvian National Armed forces and infantry soldiers have consistently high physical demands. No epidemiologic data on musculoskeletal injuries among Latvian infantry soldiers have been published previously and first step for injury rates monitoring is survey usage for injury rate assessment. Therefore, purpose of this study is to describe self-reported musculoskeletal injuries among Latvian infantry soldiers during one-year period.

Methods

To assess self-reported musculoskeletal injury data we performed survey-based cross-sectional study. Latvian infantry soldiers were asked to fill in the survey about injuries that occurred in one-year period during annual medical check-up in State Military Medicine Centre. Participation was voluntary and written informed consent was retrieved after providing information on study purpose. Approvals for this research from Riga Stradinš university Ethics committee (Nr.40/26.10.2017) and Land forces of Latvia were admitted. Musculoskeletal injury was defined as an injury of any musculoskeletal system elements (bones, muscles, tendons etc.). Injuries were classified according to body regions as it is in Barrel injury matrix (Barell et al., 2002) and by injury type – acute or overuse. Barrel injury matrix is a basic tool for injury analysis; it displays twelve types of injury in columns and thirty six body regions in rows.

Musculoskeletal injuries due to blunt, crushing or penetrating trauma were classified as acute (Iannotti & Parker, 2013). Injury caused by repetitive and/or forceful tasks as the result of repeated overstretching, overloading, deformation, compression, friction, or ischemia was classified as overuse injury (Kernan 2008; McCarty et al., 2017). For example, strains, sprains, ligament ruptures and fractures are acute injuries and overuse injuries are different tendinitis, bursitis etc. Stress fractures were included in overuse injury group due to micro-traumatic aetiology.

To describe injury incidence relative and absolute frequency distribution was used. Injury incidence calculated as number of injuries divided by the population at risk of an injury in a one-year period, results expressed as the number of injuries per 1000 person-years. For non-normally distributed data median values with standard deviation was reported.

SOCIETY. INTEGRATION. EDUCATION
Proceedings of the International Scientific Conference. Volume VI, May 22th -23th, 2020. 354-360

Results

Totally 227 soldiers participated in survey, 94% of survey participants were males at the mean age of 29.6 ± 7.2 years and with mean service time 7.1 ± 6.4 years. Participant characteristics are shown in Table1.

Table 1 ***The demographics of the subjects***

	Total n=227	Age, years ± SD	Service time, years ± SD	Foot blisters, % (n)	Smoking		
					Non-smokers, % (n)	<10 cigarettes per day	11< cigarettes per day
Males	213	29.6 ± 7.2	7.1 ± 6.4	43,7 (93)	54.9 (117)	34.7 (74)	10.4 (22)
Females	14	29.8 ± 7.4	7.4 ± 6.6	42,3 (6)	85.7 (12)	7.14 (1)	7.14 (1)

Overall, incidence rate reported 867.8 injuries per 1000 person-years (95% CI 824.8 – 913.0) with total 197 musculoskeletal injuries reported in 2017 among active duty infantry soldiers. 45.6% of participants reported only one injury (n=108), 26% reported two injuries (n=59), and others reported three or more injuries (n=30).

Acute injury rate was 436.1 injuries per 1000 person-years (95% CI 376.1 – 505.6); reported overuse injury rate was 431.7 injuries per 1000 person-years (95% CI 371.8 – 501.2). Barrel injury matrix with listed acute and overuse injuries is in Table 2. Most common acute injury sites were lower leg and ankle, knee, wrist and shoulder.

Typical acute injuries were superficial contusion injuries (n=24), fractures (n=21), joint dislocations (n=21) and sprains (n=29). Acute injuries of abdomen and trunk, as well as any crush injuries, amputations or blood vessel injuries were not reported.

Overuse injuries were reported in 43% of cases (n=98). Most commonly injured locations due to overuse were lower back, knee, lower leg and foot. Typical overuse diagnoses were lower back pain (n=42), patellofemoral pain syndrome (n=11), medial tibial stress syndrome (n=9), plantar fasciitis (n=8). Metatarsal (n=1) and fibular (n=1) stress fractures were not common in this study.

Table 2 ***Barrel injury matrix for acute and overuse injuries***

Body region of injury			Acute injuries by type							Total acute injuries, n	Total overuse injuries, n
			Fracture	Dislocation	Sprains and strains	Open Wound	Contusion or superficial	Burns	Nerves		
Torso		Chest (thorax)	1	-	-	-	-	-	-	1	1
Torso		Pelvis and urogenital	-	-	-	-	1	-	-	1	-
Torso		**Back and buttock**	-	-	1	-	2	-	-	3	**42***
Extremities	Upper	**Shoulder and upper arm**	3	4	2	-	1	-	-	**10**	4
Extremities	Upper	Forearm and elbow	-	-	2	-	4	-	-	6	6
Extremities	Upper	**Wrist, hand, and fingers**	3	1	1	2	2	1	-	**10**	1
Extremities	Lower	Hip	-	-	-	-	1	-	-	1	-
Extremities	Lower	Upper leg and thigh	-	-	1	-	4	-	1	6	-
Extremities	Lower	**Knee**	-	2	5	-	5	-	-	**12**	**15**
Extremities	Lower	**Lower leg and ankle**	11	14	16	-	-	-	-	**41**	**17**
Extremities	Lower	Foot and toes	3	-	1	-	4	-	-	8	**12**
Total by injury type			21	21	29	2	24	1	1	99	98

*Note: *Injuries with incidence ≥10% are highlighted in bold*

Discussion

Present study assessed self-reported musculoskeletal injury data among infantry soldiers. To authors' knowledge, this is the first descriptive study on epidemiology of injury data among Latvian infantry soldiers. Current research data provides information about most common acute and overuse injury types and locations based on survey data among infantry soldiers.

Acute and overuse injuries of lower extremity remain common among military populations, especially in infantry soldiers which is consistent with this study findings (Knapik et al., 2006). Most commonly lower back, knee, lower leg and foot were injured and these findings are similar to Abt et al. findings in US Army Operational Forces and Dijksma et al. recently reported injury locations in Netherlands Armed Forces (Abt et al., 2014; Dijksma et al., 2019). Orr et al. at self-reported injury study found bones and joints of lower extremity injuries as most commonly injured structure where most injuries occurred during marching (Orr et al., 2017). In this survey, few female soldiers participated and it reduces representativeness of injury rates found in this study. However, it has been reported that in military population females are have higher injury risks when comparing to males (MoD, 2018).

Acute musculoskeletal injuries, such as dislocations and sprains, according to Abt. et al. (2014), as well as overuse injuries identified in this study among infantry soldiers are classified as preventable in nature and prevention strategies should appear.

Observed overuse injury rate among all body regions at present study was 43%, which is similar to 49% reported by Lovalekar et al. in 2018 for U.S. Air Forces (Lovalekar et al., 2016).

Among all locations, lower extremity overuse has been reported with higher rates and it is similar to another study findings. For example, Ruscio et al. reported lower extremity overuse as the leading cause of limited duty in U.S. army (Ruscio et al., 2006).

Injury incidence rate calculation based on self-reported data is a strength and weakness at the same time. Smith et al. report, that approximately half of musculoskeletal injuries among infantry populations are not reported to medical personnel (Smith et al., 2016). However, self-reported injury data can also include injuries for which soldier did not seek any medical help or which were concealed from State Military Medicine centre doctors, so it helps to gain more comprehensive insight of injury prevalence.

Cross-sectional study design is a serious limitation in interpretation due to relatively small and heterogeneous study population, recall bias and honesty. Using surveys remain cost-effective method to gain data from large populations so in spite of study limitations, strength of this research is that it helps to gain insight to musculoskeletal acute and overuse injury sites. Recent study showed high self-reported injury data accuracy when comparing with medical-record based data, thereby additionally supporting survey data usage for injury assessment (Schuh-Renner et al., 2019).

Conclusions

Overall self-reported injury incidence rate was 867.8 injuries per 1000 person-years. Present study showed high incidence of back and lower leg injuries. Reported injuries could be reduced through injury reduction programmes and in order to evaluate effectiveness of these programmes it is important to report injuries regularly and compare injury trends over time. Continuing injury monitoring allows implementing injury-oriented prevention strategy and assessing it effectiveness.

Acknowledgement

The author would like to thank soldiers who participated in the study and State Military Medicine Centre for the support.

References

Abt, J.P., Sell, T.C., Lovalekar, M.T., Keenan, K.A., Bozich, A.J., Morgan, J.S., Kane, S.F., Benson, P.J., & Lephart, S.M. (2014). Injury Epidemiology of U.S. Army Special Operations Forces. *Military Medicine*, *179*(10), 1106–1112. DOI: https://doi.org/10.7205/milmed-d-14-00078

Barell, V., Aharonson-Daniel, L., Fingerhut, L.A., Mackenzie, E.J., Ziv, A., Boyko, V., Abargel, A., Avitzour, M., & Heruti, R. (2002). An introduction to the Barell body region by nature of injury diagnosis matrix. In *Injury Prevention*, *8*(2), 91–96. DOI: https://doi.org/10.1136/ip.8.2.91

Dijksma, C.I., Bekkers, M., Spek, B., Lucas, C., & Stuiver, M. (2019). Epidemiology and Financial Burden of Musculoskeletal Injuries as the Leading Health Problem in the Military. *Military Medicine*. DOI: https://doi.org/10.1093/milmed/usz328

Jones, B.H., Canham-Chervak, M., & Sleet, D.A. (2010). An evidence-based public health approach to injury priorities and prevention: Recommendations for the U.S. Military. *American Journal of Preventive Medicine*, *38*(1 SUPPL.). DOI: https://doi.org/10.1016/j.amepre.2009.10.001

Knapik, J.J., Bullock, S.H., Canada, S., Toney, E., Wells, J.D., Hoedebecke, E., & Jones, B.H. (2004). Influence of an injury reduction program on injury and fitness outcomes among soldiers. *Injury Prevention*, *10*(1), 37–42. DOI: https://doi.org/10.1136/ip.2003.002808

Knapik, Joseph J., Darakjy, S., Hauret, K.G., Canada, S., Scott, S., Rieger, W., Marin, R., & Jones, B.H. (2006). Increasing the Physical Fitness of Low-Fit Recruits before Basic Combat Training: An Evaluation of Fitness, Injuries, and Training Outcomes. *Military Medicine*, *171*(1), 45–54. DOI: https://doi.org/10.7205/milmed.171.1.45

Lovalekar, M.T., Abt, J.P., Sell, T.C., Nagai, T., Keenan, K., Beals, K., Lephart, S.M., & Wirt, M.D. (2016). Descriptive Epidemiology of Musculoskeletal Injuries in the Army 101st Airborne (Air Assault) Division. *Military Medicine*, *181*(8), 900–906. DOI: https://doi.org/10.7205/milmed-d-15-00262

Neal, B.S., Griffiths, I.B., Dowling, G.J., Murley, G.S., Munteanu, S.E., Franettovich Smith, M.M., Collins, N.J., & Barton, C.J. (2014). Foot posture as a risk factor for lower limb overuse injury: A systematic review and meta-analysis. *Journal of Foot and Ankle*

Research, *7*(1), 1–13. DOI: https://doi.org/10.1186/s13047-014-0055-4

Orr, R.M., Coyle, J., Johnston, V., & Pope, R. (2017). Self-reported load carriage injuries of military soldiers. *International Journal of Injury Control and Safety Promotion*, *24*(2), 189–197. DOI: https://doi.org/10.1080/17457300.2015.1132731

Ruscio, B., Smith, J., Amoroso, P., Anslinger, J., Bullock, S., Burnham, B., Campbell, J., Chervak, M., Garbow, K., & Garver, R. (2006). DoD Military Injury Prevention Priorities Working Group: Leading Injuries, Causes and Mitigation Recommendations. *DTIC Document*, *ADA458257*, 88. DOI: http://www.dtic.mil/get-tr-doc/pdf?AD=ADA458257

Schuh-Renner, A., Canham-Chervak, M., Grier, T.L., & Jones, B.H. (2019). Accuracy of self-reported injuries compared to medical record data. *Musculoskeletal Science and Practice*, *39*, 39–44. DOI: https://doi.org/10.1016/j.msksp.2018.11.007

Schuh, A., Canham-Chervak, M., & Jones, B.H. (2017). Statistical process control charts for monitoring military injuries. *Injury Prevention*, *23*(6), 416–422. DOI: https://doi.org/10.1136/injuryprev-2016-042089

Smith, L., Westrick, R., Sauers, S., Cooper, A., Scofield, D., Claro, P., & Warr, B. (2016). Underreporting of Musculoskeletal Injuries in the US Army: Findings From an Infantry Brigade Combat Team Survey Study. *Sports Health*, *8*(6), 507–513. DOI: https://doi.org/10.1177/1941738116670873

Wardle, S.L., & Greeves, J.P. (2017). A systematic review of the most effective injury prevention strategies for military personnel. *Journal of Science and Medicine in Sport*, *20*, S3–S10. DOI: https://doi.org/10.1016/j.jsams.2017.09.014

PROCEEDINGS OF THE LATVIAN ACADEMY OF SCIENCES. Section B,
Vol. 75 (2021), No. 1 (730), pp. 52–57.
DOI: 10.2478/prolas-2021-0009

PEAK PLANTAR PRESSURE AS A RISK FACTOR FOR LOWER EXTREMITY OVERUSE INJURY AMONG INFANTRY SOLDIERS

Darja Ņesteroviča[1,#], Ainārs Stepens[1], and Normunds Vaivads[2]

[1] Military Medicine Research and Study Centre, Rīga Stradiņš University, 14 Baložu Str., Rīga, LV-1048, LATVIA

[2] Joint Medical Service Headquarters, National Armed Forces, LATVIA

[#] Corresponding author, darja.nesterovica@rsu.lv

Communicated by Modra Murovska

The majority of reported injuries among military populations are injuries due to cumulative repetitive microtrauma — overuse injuries. Plantar pressure measurement is a simple tool to analyse lower limb biomechanics through the assessment of forces applied to the foot. This study aimed to determine the relation between peak plantar pressure and lower extremity overuse. Sixty-six active-duty infantry male soldiers, with mean age 29.7 years (range 22–40 years), and mean service time 5.2 years (range 1–15 years) participated. The highest peak plantar pressure (PPP) at the forefoot occurred at the hallux (cases: 50.82 n/cm^2, SD = 38.84; control: 34.39 n/cm^2, SD = 28.03) and 3rd metatarsal head (cases: 54.40 n/cm^2, SD = 33.83; control: 49.16 n/cm^2, SD = 28.87). The study demonstrated elevated PPP among cases. Statistically significant results were found at the hallux ($\chi2(1) = 6.8$; $p = 0.01$), medial heel ($\chi2(1) = 5.18$; $p = 0.02$) and lateral heel ($\chi2(1) = 12.12$; $p < 0.01$) regions. The results show that plantar pressure assessment could be used as a useful screening tool for early lower extremity overuse injury detection.

Key words: *military personnel, cumulative trauma disorder, baropodometry.*

INTRODUCTION

Sustaining an injury reduces military readiness, increases the financial burden of additional health care and is a leading cause of medical discharge among military personnel (Geary *et al.*, 2002; Jones *et al.*, 2010; Ruscio *et al.*, 2010; Lovalekar *et al.*, 2018). Musculoskeletal injuries (MSKI) are common among different countries and the reported injury rates are consistently high. Reported acute and overuse injury incidence in the British army is 49% and it is 53% for military personnel in the USA (Sharma *et al.*, 2015; Grier *et al.*, 2020). The majority of reported MSKI among different military populations are injuries due to cumulative repetitive microtrauma (Hoffman *et al.*, 2015). Repetitive high-intensity training with a short recovery period is a significant contributor to injury with gradual onset — overuse injury (Kaufman *et al.*, 2000). For example, it has been reported that 51% of young conscripts in Finland during six months sustained an overuse injury (Taanila *et al.*, 2015).

Previous studies showed that a history of injury is a strong risk factor for the next injury (Knapik *et al.*, 2003; Fulton *et al.*, 2014). For this reason, systematic injury rate assessment and long-term injury trend monitoring are important parts of the injury prevention process (Wardle and Greeves, 2017). Regional Logistics Command (LC) military medical care centres in Latvia provide written acute musculoskeletal injury monthly reports to the National Armed Forces LC Military Medical Support Centre. Medical reports contain data on the injured person, injury date and place, injured body part and side, and injury type similar to the Barell injury matrix (Barell *et al.*, 2002). Medical-record based on one-year injury incidence in the Latvian Army is 12.4%; most injured locations are lower legs (2.5%), foot and toes (1.7%) with only three cases of stress fractures reported.

The Latvian Land Forces are one of the biggest military branches of the Latvian Army, with three thousand soldiers involved at average age 34.2 years. A large portion of the Latvian Army is formed by infantry soldiers, also known as "foot soldiers". According to survey results among infantry soldiers, the lower extremity is the most injured body site (56%), where self-reported lower extremity overuse injury occurs in 45% subjects. In comparison, self-reported upper extremity overuse injury occurrence is only 11% (Nesterovica, 2018).

Foot health for infantry is essential in not only providing adequate shock-absorbing and normal gait cycle on uneven terrain, but also in maintaining good health status and the highest state of military readiness. Foot type as well as forces applied to the foot are important. Studies have shown good Foot Posture Index (FPI) inter- and intra-rater reliability with the ability to quantify foot type (Redmond *et al.*, 2006; Cornwall *et al.*, 2008; Morrison and Ferrari, 2009) . Plantar pressure measurement with a pressure plate is a simple method to assess the direction and force applied to the foot and it is a key tool to analyse lower limb biomechanics (Landorf and Keenan, 2000). For plantar pressure management, foot orthotics with different stiffness and cushioning components have been used among pathological and healthy populations (Bonanno *et al.*, 2019; Chatzistergos *et al.*, 2020). Different foot orthotics have shown good results in lower limb injury incidence reduction during military training (Snyder *et al.*, 2009; Bonanno *et al.*, 2018).

Limited evidence regarding plantar pressure values and injury risk exists. Few studies previously investigated peak plantar pressure among injured and healthy Royal Marines recruits and young Navy officers. High arch and greater peak plantar pressure at the medial side of the foot increased risk for a metatarsal stress fracture and ankle inversion injury among Royal Marines; Dixon *et al.*, 2019). Plantar pressure has been reported to be a predictive factor of sustaining an overuse injury of the lower limb in a controlled training environment of Navy officers (Franklyn-Miller *et al.*, 2014).

This study aimed to investigate the relation between peak plantar pressure and lower extremity overuse injuries among Latvian infantry soldiers.

MATERIALS AND METHODS

Subjects. Sixty-six active-duty infantry soldiers participated in the case-control study, all were males at mean age 29.7 years (range 22–40 years) and with mean service time 5.2 years (range 1–15 years). Cases were soldiers with prior lower leg (knee, ankle, or foot) overuse injury during the last six month period (cases); persons who did not sustain any lower extremity injury during the same period were the control group). Overuse injury was defined as MSKI caused by repetitive and/or forceful tasks or appeared as a result of repeated overstretching or overloading (Cheron and Scanff, 2016). Overuse lower limb injuries included in this definition were: plantar fasciitis, metatarsalgia, Achilles tendinopathy, stress fracture, medial tibial stress, patellofemoral syndrome, chronic exertional compartment syndrome, and iliotibial band syndrome.

Information about injuries was obtained from surveys during the annual medical check-up and from medical record data. During the data collection period, all of the participants were not injured and were free of any musculoskeletal pain. Participation was voluntary and all study subjects provided written informed consent. Ethical approval was obtained from the Ethics Committee of Rīga Stradiņš University (No. 40/26.10.2017).

Procedure and data extraction. A pressure platform (2 m × 0.4 m × 0.02 m, RSscan International, Belgium) was embedded in the centre of a 5-metre long walkway. Firstly, weight calibration was performed. Participants were asked to walk barefoot in a relaxed manner at a self-selected comfort speed, and not to look at the ground. To minimise walking speed influence on plantar pressure measurement, a two-step initiation protocol was used, such that participants were positioned two steps from the platform edge. Two walking trials were used for acclimatisation; mean data from three successful trials were analysed for each foot.

Plantar pressure analysis software (Footscan v.7.11, RSscan International) was configured to measure plantar pressures in n/cm^2. Software masks the foot into 10 regions: hallux, lesser toes, each metatarsal head (1st MTH, 2nd MTH, 3rd MTH, 4th MTH, and 5th MTH), midfoot, heel medial and heel lateral. Peak plantar pressure (PPP) values, contact area, and foot length values were extracted. The degree of plantar pressure asymmetry for each region was determined between the left and right foot in both groups using the symmetry index (Robinson *et al.*, 1987; Wafai *et al.*, 2015). A value of 0 indicates perfect symmetry between feet plantar loading, while a higher value indicates higher asymmetry in plantar loading.

For FPI measurement, the subjects were asked to stand in a relaxed stance position with double-limb support, arms relaxed and looking straight forward. Additionally, foot arch types were classified based on arch index (AI) measurement. Three categories were used based on values in previous studies: high-arch ($AI \leq 0.21$), normal arch ($0.22 < AI \leq 0.26$), low arch ($AI > 0.27$) (Cavanagh and Rodgers, 1987; Hernandez *et al.*, 2007). All measurements were made by the same examiner.

Data analysis. Statistical analyses were performed using the SPSS 22.0 software package. Firstly, all data were assessed for normality using the Shapiro-Wilk test. Mostly, data were not normally distributed; nonparametric tests were applied in order to determine differences between groups. Data are presented as means with standard deviation if not stated otherwise. The Mann–Whitney test was used to determine SI differences among groups. The significance level was set to $p < 0.05$ (two-tailed).

RESULTS

In total, 32 subjects were included in the case group and 34 subjects were included in the control group. Case and control group characteristics are shown in Table 1. Both group demographic characteristics as well as foot posture vari-

Table 2. Peak plantar pressure values among cases and controls for each foot, n/cm2, (SD)

		Cases		Controls			
		Foot				$\chi^2(1)$*	*p*-value
		Left	Right	Left	Right		
Forefoot	**Hallux**	**48.87** (42.22)	**50.82** (38.84)	34.39 (28.03)	30.35 (26.55)	6.8	**0.01**
	Lesser toes	23.40 (29.70)	29.70 (32.07)	29.09 (29.44)	31.91 (29.95)	1.47	0.23
	1st MTH	24.40 (27.10)	33.95 (35.06)	18.06 (26.56)	17.72 (19.53)	3.68	0.06
	2nd MTH	46.18 (33.83)	49.53 (35.35)	41.14 (32.75)	42.85 (34.57)	1.10	0.29
	3rd MTH	54.40 (33.83)	46.37 (35.36)	49.16 (28.87)	41.70 (27.29)	0.11	0.74
	4th MTH	41.11 (35.05)	30.00 (32.18)	36.22 (24.88)	27.76 (23.66)	0.001	0.98
	5th MTH	28.24 (37.01)	25.25 (41.12)	15.34 (19.72)	15.15 (23.35)	0.98	0.33
Midfoot		53.12 (37.59)	43.77 (42.07)	47.84 (29.97)	41.82 (30.42)	0	0.99
Rearfoot	**Medial heel**	**56.53** (40.79)	**53.99** (34.07)	40.62 (33.87)	40.55 (29.90)	5.18	**0.02**
	Lateral heel	**59.10*** (37.98)	**57.30** (32.17)	37.06 (24.51)	38.89 (29.35)	12.12	**0.01**

*Kruskal Wallis test results; SD, standard deviation; MTH, Metatarsal head; significant results are marked in bold; differences relate to both left and right feet.

Table 3. Median peak plantar pressure assymetry percentage in case and control groups with standard deviation

	Cases	Controls	
	Median assymetry, %		*p*-value
Hallux	–45.95 (67.87)	–16.44 (63.70)	0.40
Lesser toes	9.52 (96.26)	0.00 (54.53)	0.12
1st MTH	**22.22 (91.23)**	**0.00 (47.55)**	**0.02**
2nd MTH	16.80 (54.67)	13.12 (58.48)	0.25
3rd MTH	–3.60 (50.54)	–16.81 (59.80)	0.51
4th MTH	–23.52 (71.60)	–15.34 (40.37)	0.11
5th MTH	0.00 (72.86)	0.00 (34.41)	0.95
Midfoot	–29.37 (62.37)	–8.97 (57.36)	0.22
Medial heel	0.00 (57.91)	13.65 (36.09)	0.53
Lateral heel	–1.76 (54.24)	7.82 (55.41)	0.81

Mann–Whitney test results; a negative value indicates higher pressure at the left foot; standard deviation is given in brackets; MTH, metatarsal head; significant results are marked in bold.

Plantar pressure measurements are very useful for foot function assessment, but generalised assumptions based only on levels of PPP cannot be made. Plantar pressures vary widely among individuals and there is no single plantar pressure value that can be used as an indicator for the onset of a foot injury (Wafai *et al.*, 2015). Our study data indicated that statistically significant PPP differences between cases and control groups exist at the hallux and heel regions, which correspond to heel-contact and toe-off gait cycle phases. It has been reported that for a healthy foot, larger motion in the foot joints during walking was associated with lower plantar pressure in almost all regions (Giacomozzi *et al.*, 2014). It is recommended to investigate gait pattern as well as foot and ankle motion to establish a possible association with lower extremity injury.

Scoring of foot type with the FPI-6 was not significantly associated with a history of previous lower extremity overuse injury. Despite that, cases appeared to have a non-neutral foot position more frequently when compared with controls. This finding is consistent with a previous study, where lower extremity overuse injury was linked with a non-neutral foot position (Yates and White, 2004).

Our findings showed asymmetry in both FPI and PPP among cases and controls. Foot posture and function can be affected by injuries. The site of injury is often reflected not only in the plantar pressure distribution but also in the measures of asymmetry between the feet (Wafai *et al.*, 2013). SI was used for plantar pressure symmetry assessment. The normal range of asymmetry determined among healthy individuals is approximately 10–18% (Wafai *et al.*, 2015), which is similar to SI values found in our control group (SI values from 0% to 16%). Larger and statistically significant PPP asymmetry between cases and controls was found at the 1st MTH. The presence of asymmetry between feet means unequal lower limb loading and imbalance during walking, which requires the attention of physiotherapists. However, lower limb motion during the gait cycle has been considered as globally symmetrical (Sadeghi, 2003). Lower limb dominance is task-dependent and it can impact the roles the lower limbs play during the gait cycle and contribute to a local asymmetry. Improving the abnormal biomechanical parameters of the lower extremity during military training can prevent stress fracture of the lower limbs (Zhao *et al.*, 2020).

Infantry soldier's feet are regularly exposed to large forces and are constantly adapting to various environments. Footwear should be comfortable to reduce pressure, shear, and shock forces from the foot. Consequently, it is important to analyse foot function as well as military footwear comfort and proper fit. Footwear sizes in the Latvian Army have been self-selected by the soldier and an improper size may have been used. It is known that a large proportion of the common population wear incorrectly sized footwear, which is associated with foot pain and foot disorder (Schwarzkopf *et al.*, 2011; Buldt and Menz, 2018). Our study identified that cases used bigger shoe sizes than controls ($p = 0.04$), but the difference between groups was not statistically significant. Such a difference might appear due to different foot width or lack of footwear comfort among injured subjects and these factors were not included in data analysis.

Our study findings should be considered in context with limitations of the study. The retrospective case-control study design was a limitation due to the relatively small study population, inability to establish causal sequences, and recall bias of history of injury. The study grouping also depended on medical-record quality. It has been reported that approximately half of MSKI among infantry populations are not reported to medical personnel (Smith *et al.*, 2016). The used plantar pressure system is able to measure the force that is perpendicular to the pressure sensor and it is not possible to measure other forces, for example, shear forces. The masking process was performed automatically by the software, which could shift plantar pressure values. It has been reported that automated masking reduces overall pressure values (Deschamps *et al.*, 2009). Gait kinematic and EMG data were not collected and therefore conclusions about overall lower limb biomechanics and their influence on injury risk could not be made.

CONCLUSIONS

To the authors' knowledge, this is the first study of peak plantar pressure and symmetry index among infantry soldiers in Latvia with and without a history of lower extremity overuse injury. The study results demonstrate elevated peak plantar pressures among cases with prior lower extremity injury. Significantly high results were found at forefoot (hallux, $\chi^2(1) = 6.8$; $p = 0.01$) and rearfoot (medial heel ($\chi^2(1) = 5.18$; $p = 0.02$; lateral heel ($\chi^2(1) = 12.12$; $p < 0.01$)). Cases demonstrated asymmetrical peak plantar pressures and foot posture. The results showed that plantar pressure assessments could be a useful screening tool for early lower extremity overuse injury detection or in planning implementation of an injury prevention programme.

ACKNOWLEDGEMENTS

The author would like to thank soldiers who participated in the study and Latvian National Armed Forces LC Military medical support centre for the support.

REFERENCES

Barell, V., Aharonson-Daniel, L., Fingerhut, L. A., Mackenzie, E. J., Ziv, A., Boyko, V., Abargel, A., Avitzour, M., Heruti, R. (2002). An introduction to the Barell body region by nature of injury diagnosis matrix. *Injury Prev.*, **8** (2), 91–96.

Bonanno, D. R., Ledchumanasarma, K., Landorf, K. B., Munteanu, S. E., Murley, G. S., Menz, H. B. (2019). Effects of a contoured foot orthosis and flat insole on plantar pressure and tibial acceleration while walking in defence boots. *Sci. Rep.* **9** (1), 1–10.

Bonanno, D. R., Murley, G. S., Munteanu, S. E., Landorf, K. B., Menz, H. B. (2018). Effectiveness of foot orthoses for the prevention of lower limb overuse injuries in naval recruits: a randomised controlled trial. *Brit. J. Sports Med.*, **52** (5), 298–302.

Buldt, A. K., Menz, H. B. (2018). Incorrectly fitted footwear, foot pain and foot disorders: A systematic search and narrative review of the literature. *J. Foot Ankle Res.*, **11**, 43.

Cavanagh, P. R., Rodgers, M. M. (1987). The arch index: A useful measure from footprints. *J. Biomech.*, **20** (5), 547–551.

Chatzistergos, P. E., Gatt, A., Formosa, C., Farrugia, K., Chockalingam, N. (2020). Optimised cushioning in diabetic footwear can significantly enhance their capacity to reduce plantar pressure. *Gait Posture*, **79**, 255–250.

Cheron, C., Scanff, C., Le Leboeuf-Yde, C. (2016). Association between sports type and overuse injuries of extremities in children and adolescents: A systematic review. *Chiropractic Manual Ther.*, **24**, 41

Cornwall, M. W., McPoil, T. G., Lebec, M., Vicenzino, B., Wilson, J. (2008). Reliability of the modified foot posture index. *J. Amer. Podiatric Med. Assoc.*, **98** (1), 7–13.

Deschamps, K., Birch, I., Mc Innes, J., Desloovere, K., Matricali, G. A. (2009). Inter- and intra-observer reliability of masking in plantar pressure measurement analysis. *Gait Posture*, **30** (3), 379–382.

Dixon, S., Nunns, M., House, C., Rice, H., Mostazir, M., Stiles, V., Davey, T., Fallowfield, J., Allsopp, A. (2019). Prospective study of biomechanical risk factors for second and third metatarsal stress fractures in military recruits. *J. Sci. Med. Sport*, **22** (2), 135–139.

Franklyn-Miller, A., Bilzon, J., Wilson, C., McCrory, P. (2014). Can RSScan footscan® D3D™ software predict injury in a military population following plantar pressure assessment? A prospective cohort study. *Foot*, **24** (1), 6–10.

Fulton, J., Wright, K., Kelly, M., Zebrosky, B., Zanis, M., Drvol, C., Butler, R. (2014). Injury risk is altered by previous injury: A systematic review of the literature and presentation of causative neuromuscular factors. *Int. J. Sports Phys. Ther.*, **9** (5), 583–595.

Geary, K. G., Irvine, D., Croft, A. M. (2002). Does military service damage females? An analysis of medical discharge data in the British armed forces. *Occup. Med.*, **52** (2), 85– 90.

Giacomozzi, C., Leardini, A., Caravaggi, P. (2014). Correlates between kinematics and baropodometric measurements for an integrated *in-vivo* assessment of the segmental foot function in gait. *J. Biomech.*, **47** (11), 2654–2659.

Grier, T., Dinkeloo, E., Reynolds, M., Jones, B. H. (2020). Sleep duration and musculoskeletal injury incidence in physically active men and women: A study of U.S. Army Special Operation Forces soldiers. *Sleep Health*, **6** (3), 344–349.

Hauschild, V. D., Schuh-Renner, A., Lee, T., Richardson, M. D., Hauret, K., Jones, B. H. (2019). Using causal energy categories to report the distribution of injuries in an active population: An approach used by the U.S. Army. *J. Sci. Med. Sport*, **22** (9), 997–1003.

Hernandez, A. J., Kimura, L. K., Laraya, M. H. F., Fįvaro, E. (2007). Calculation of staheli's plantar arch index and prevalence of flat feet: A study with 100 children aged 5–9 years. *Acta Ortopedica Brasileira*, **15** (2). Available from: https://doi.org/10.1590/S1413-78522007000200001 (accessed 3 February 2021).

Hoffman, J. R., Church, D. D., Hoffman, M. W. (2015). Overuse injuries in military personnel. In: *The Mechanobiology and Mechanophysiology of Military-Related Injuries.* Springer, pp. 141–161.

Jones, B. H., Canham-Chervak, M., Sleet, D. A. (2010). An evidence-based public health approach to injury priorities and prevention: Recommendations for the U.S. Military. *Amer. J. Prevent. Med.*, **38** (1 Suppl.), S1–S10.

Kaufman, K. R., Brodine, S., Shaffer, R. (2000). Military training-related injuries: Surveillance, research, and prevention. *Amer. J. Prevent.Med.*,**18** (3 Suppl.), 54–63.

Knapik, J. J., Hauret, K. G., Arnold, S., Canham-Chervak, M., Mansfield, A. J., Hoedebecke, E. L., McMillian, D. (2003). Injury and fitness outcomes during implementation of physical readiness training. *Int. J. Sports Med.*, **24** (5), 372–381.

Landorf, K. B., Keenan, A. M. (2000). Efficacy of foot orthoses. What does the literature tell us? *J. Amer. Podiatric Med. Assoc.*, **90** (3), 149–158.

Lovalekar, M., Johnson, C. D., Eagle, S., Wohleber, M. F., Keenan, K. A., Beals, K., Nindl, B. C., Connaboy, C. (2018). Epidemiology of musculoskeletal injuries among US Air Force Special Tactics Operators: An economic cost perspective. *BMJ Open Sport Exerc. Med.,* **4** (1), 1–7.

Morrison, S. C., Ferrari, J. (2009). Inter-rater reliability of the Foot Posture Index (FPI-6) in the assessment of the paediatric foot. *J. Foot Ankle Res.,* **2**, 26.

Nesterovica, D. (2018). Musculoskeletal overuse injury prevalence and comfort perception of military boots. In: *Proceedings of the 60th International Scientific Conference of Daugavpils University*, pp. 123–128. Available from: https://www.researchgate.net/publication/325966715_Musculoskeletal_overuse_injury_prevalence_and_comfort_perception_of_military_boots (accessed 3 February 2021).

Redmond, A. C., Crosbie, J., Ouvrier, R. A. (2006). Development and validation of a novel rating system for scoring standing foot posture: The Foot Posture Index. *Clin. Biomech.,* **21** (1), 89–98.

Rice, H., Nunns, M., House, C., Fallowfield, J., Allsopp, A., Dixon, S. (2013). High medial plantar pressures during barefoot running are associated with increased risk of ankle inversion injury in Royal Marine recruits. *Gait Posture*, **38** (4), 614–618.

Robinson, R. O., Herzog, W., Nigg, B. M. (1987). Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. *J. Manipulat. Physiol. Ther.,* **10** (4), 172–176.

Ruscio, B. A., Jones, B. H., Bullock, S. H., Burnham, B. R., Canham-Chervak, M., Rennix, C. P., Wells, T. S., Smith, J. W. (2010). A process to identify military injury prevention priorities based on injury type and limited duty days. *Amer. J. Prevent. Med.,* **38** (1 Suppl), S19–S33.

Sadeghi, H. (2003). Local or global asymmetry in gait of people without impairments. *Gait Posture,* **17** (3), 197–204.

Schwarzkopf, R., Perretta, D. J., Russell, T. A., Sheskier, S. C. (2011). Foot and shoe size mismatch in three different New York city populations. *J. Foot Ankle Surgery*, **50** (4), 391–394.

Sharma, J., Greeves, J. P., Byers, M., Bennett, A. N., Spears, I. R. (2015). Musculoskeletal injuries in British Army recruits: A prospective study of diagnosis-specific incidence and rehabilitation times Epidemiology of musculoskeletal disorders. *BMC Musculoskel. Disord.,* **16**, 106.

Smith, L., Westrick, R., Sauers, S., Cooper, A., Scofield, D., Claro, P., Warr, B. (2016). Underreporting of musculoskeletal injuries in the US Army: Findings from an Infantry Brigade Combat Team survey study. *Sports Health,* **8** (6), 507–513.

Snyder, R. A., DeAngelis, J. P., Koester, M. C., Spindler, K. P., Dunn, W. R. (2009). Does shoe insole modification prevent stress fractures? A systematic review. *HSS J. (Musculoskeletal Journal of Hospital for Special Surgery),* **5** (2), 92–98.

Taanila, H., Suni, J. H., Kannus, P., Pihlajamäki, H., Ruohola, J.-P., Viskari, J., Parkkari, J. (2015). Risk factors of acute and overuse musculoskeletal injuries among young conscripts: A population-based cohort study. *BMC Musculoskel. Disord.,* **16**, 104.

Wafai, L., Zayegh, A., Begg, R., Woulfe, J. (2013). Asymmetry detection during pathological gait using a plantar pressure sensing system. In: *Proceedings of the 7th IEEE GCC Conference and Exhibition, GCC 2013*, 17–20 November 2013. IEEE, Doha, pp. 182–187.

Wafai, L., Zayegh, A., Woulfe, J., Mahfuzul, S., Begg, R. (2015). Identification of foot pathologies based on plantar pressure asymmetry. *Sensors,* **15** (8), 20392–203408.

Wardle, S. L., Greeves, J. P. (2017). Mitigating the risk of musculoskeletal injury: A systematic review of the most effective injury prevention strategies for military personnel. *J. Sci. Med. Sport*, **20**, S3–S10.

Yates, B., White, S. (2004). The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. *Amer. J. Sports Med.,* **32** (3), 772–780.

Zhao, Y., Zhang, Z., Luo, D., Li, M., Wang, J., Fang, J., Jiang, W., Feng, Y., Peng, J., Xu, W., Wang, Y., Wang, A., Zhang, M. (2020). Risk factors for stress fracture of lower limbs and future research direction. *Chinese J. Tissue Eng. Res.,* **24** (9), 1422–1429.

Received 21 July 2020
Accepted in the final form 13 November 2020

MAKSIMĀLAIS PLANTĀRAIS SPIEDIENS KĀ APAKŠĒJO EKSTREMITĀŠU PĀRSLODZES TRAUMU RISKA FAKTORS KĀJNIEKU VIDŪ

Karavīru populācijā liels īpatsvars no novērotām muskuloskeletālām traumām ir kumulatīva rakstura pārslodzes traumas, kas skar apakšējās ekstremitātes. Pēdas plantāro spiedienu jeb uz pēdām izdarītā spēka sadalījuma izmeklēšana ir vienkārša apakšējo ekstremitāšu biomehānikas analīzes metode. Šis pētījums analizē saistību starp maksimālo plantāro spiedienu (MPS) un apakšējo ekstremitāšu pārslodzes traumām. Gadījumu–kontroles pētījumā piedalījās sešdesmit seši aktīvā dienesta kājnieki, vidējais vecums 29,7 gadi (vecuma diapazons 22–40 gadi); vidējais izdienas ilgums 5,2 gadi (no 1 līdz 15 gadiem). MPS pēdas priekšējā daļā tika reģistrēts I pirksta rajonā (gadījumi: 50,82 n/cm^2, SD = 38,84; kontroles: 34,39 n/cm^2, SD = 28,03) un pie III pleznas kaula (gadījumi: 54,40 n/cm^2, SD = 33,83; kontroles: 49,16 n/cm^2, SD = 28,87). Paaugstināti MPS tika novēroti gadījumu grupā. Statistiski ticamas atšķirības atrastas pie I pirksta (χ^2 (1) = 6,8; p = 0,01), papēža rajonā mediāli (χ^2 (1)= 5,18; p = 0,02) un laterāli χ^2 (1) = 12,12; p < 0,01). Pētījuma rezultāti rāda, ka pēdu plantārā spiediena izmeklēšana ir noderīga skrīninga metode agrīnai apakšējo ekstremitāšu pārslodzes traumu diagnostikai.

Nesterovica *et al.*
BMC Musculoskeletal Disorders (2021) 22:952
https://doi.org/10.1186/s12891-021-04839-9

BMC Musculoskeletal Disorders

RESEARCH ARTICLE

Open Access

Relationship of footwear comfort, selected size, and lower leg overuse injuries among infantry soldiers

Darja Nesterovica[1*], Normunds Vaivads[2] and Ainars Stepens[1]

Abstract

Background: High rates of musculoskeletal injuries such as plantar fasciitis and stress fractures have been observed among physically active military personnel. During service time, infantry soldiers use issued boots daily that should fit well and provide comfort to prevent injuries and decrease lower extremity pain effectively. The association of military boot comfort with overuse injuries remains unclear. This study investigates the relationship between the chosen military boot size, perceived boot comfort and lower leg overuse injury.

Methods: During the cross-sectional study, 227 (males, n = 213; females, n = 14) active-duty infantry soldiers at a mean age of 29.5 years old, and with an average service time of 7.2 years were assessed for a history of overuse injury, footprint length, appropriate shoe size, and footwear comfort. Males with a history of overuse injury (n = 32) and non-injured age-matched controls (n = 34) were selected for detailed testing and establishing the possible relationship between footwear comfort and lower leg overuse injury.

Results: No relationship was found between footwear comfort and a history of lower leg overuse injury. *N* = 38 (57.6%) of study subjects were wearing an inappropriate shoe size daily. Inappropriate shoe size usage affected footwear comfort ratings significantly.

Conclusions: Study results showed that improper boot size was significantly related to comfort ratings but was not associated with a history of lower leg overuse injury.

Keywords: Military personnel, Footwear comfort, Overuse injuries, Military boot

Background

Most military personnel require high physical demands during service time. It has been reported that 41–67% of sustained injuries in the military affect the lower extremities [1–3]. Typical injuries associated with physical training and prolonged load carriage are cumulative micro-traumatic lower extremity overuse injuries [4]. Injuries such as stress fractures, shin splints, patellofemoral pain, plantar fasciitis, and Achilles tendinopathy reduce military readiness and could even be a reason for medical discharge [5, 6]. This study explores military boot comfort and its relationship with musculoskeletal overuse injury in detail.

During training or actual combat scenarios, military personnel use military boots that protect the shank and foot from environmental hazards such as irregular and uneven terrain. Foot health and footwear comfort are crucial for the military readiness of infantry soldiers. Shock absorbance and stability on uneven terrain are also very important military footwear features. Footwear shock-absorbance study results among Israeli infantry recruits showed that soldiers who used basketball shoes during basic training had a lower incidence of overuse

*Correspondence: darja.nesterovica@rsu.lv
[1] Military Medicine Research and Study Centre, Rīga Stradiņš University, 14 Baložu Street, Riga LV-1048, Latvia
Full list of author information is available at the end of the article

injuries of the foot (18%) than those who wore infantry boots (34%). The authors of the study concluded that the basketball shoes' shock attenuation reduced foot overuse injuries, but not injuries at other lower extremity locations [7]. Other studies showed that military footwear specifically made for prolonged standing and marching, adverse weather conditions, and with a proper fit may effectively prevent injuries and decrease lower extremity pain [8, 9].

Footwear comfort is a complex combination of several factors including good fitting, internal temperature, humidity environment, plantar pressure distribution, and ground impact force [10–12]. As reported by a recent systematic review, a large proportion of the population wears ill-fitting shoes that contribute to foot pain and foot disorders [13]. Research evaluating shoe sizing on the subjective fit and comfort of shoes is encouraged [14]. Pressure-induced skin lesions and toenail problems are clinical effects of poor-fitting or uncomfortable footwear observed in the general population, especially those with chronic foot disorders [15, 16]. Footwear comfort has been proposed as an important factor for all movement-related lower extremity injuries [17, 18]. Associations of chronic foot disorders (e.g., pes planus, hallux valgus) and acute injuries (ankle fracture or sprain) with boot usage among military populations, as well as military boot functional needs were established previously [19, 20]. This study compares the used infantry boot size (subjective fit) with correct fit according to bare footprint length among infantry soldiers with and without a history of lower extremity overuse injury.

Methods

We carried out a study designed in two stages: stage I - cross-sectional study and stage II case-control study. Flow chart of the study design is seen in Fig. 1.

In 12 consecutive interview sessions total, 228 (16%) of all active-duty infantry soldiers of Latvian Land Forces (males, $n=214$; females, $n=14$) were invited to participate in our study during the annual medical check-up at the Latvian National Army Logistic Command Military Medical Support Centre. Participation was voluntary, and the study results did not change the annual medical check-up results. Before entering the study, written informed consent was provided for each potential study participant; one person did not sign the informed

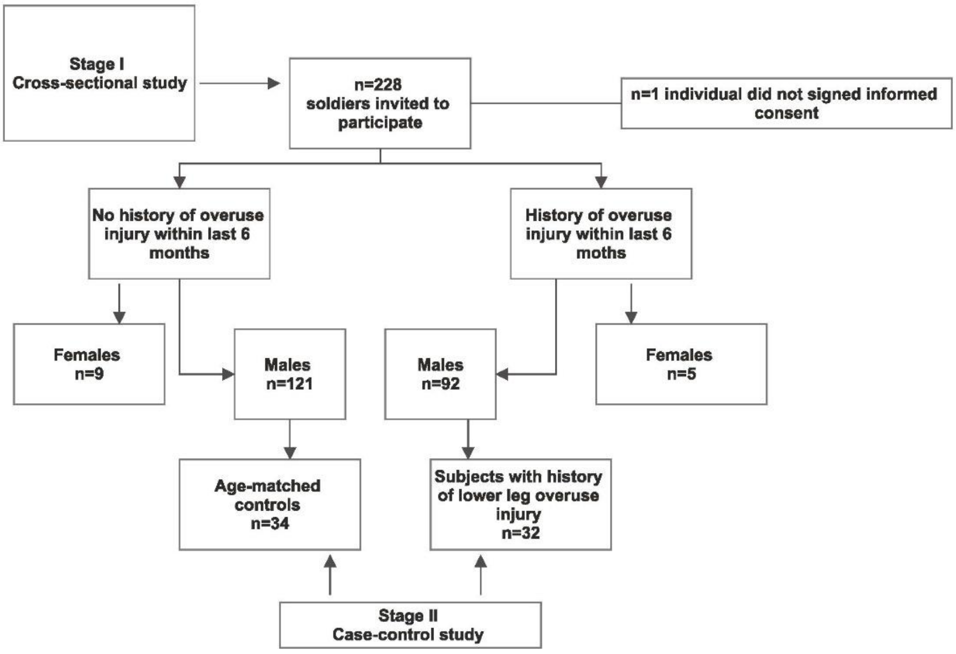

Fig. 1 Flowchart of the study design

consent, and according to the protocol, 227 infantry soldiers were selected for further activities. Their mean age was 29.5 ± 7.1 years old (range 20–49 years), service time 7.2 ± 6.4 years (range 0.5–25 years). Study population characteristics are shown in Table 1.

The musculoskeletal injury was considered if soldier either reported or had a medical record of injury, which did not allow participation in at least one activity during the last 6 months of service. Musculoskeletal injuries were classified into two groups: acute and overuse injuries and the coding was performed by the interviewer (DN). The acute injury was defined as an injury due to blunt, crushing, penetrating trauma. Acute injuries are strains, sprains, ligament ruptures, fractures [excluding stress fractures] and were classified by ICD-10 (International Classification of Diseases, Tenth Revision) codes S00-T32 [21]. Overuse injuries were defined as injuries caused by repetitive or forceful tasks resulting from repeated overstretching or overloading [22]. Injuries such as anterior or posterior tibial syndrome (ICD-10 code M76.8), plantar fasciitis (M72.2), Achilles tendonitis (or bursitis, M76.6), peroneal tendinitis (M76.7), and stress fractures (M84.3) were classified as overuse injuries. For both types of injury, body regions were classified in the same manner as in the Barell injury matrix [23].

For this study, we have prepared a military comfort assessment tool according to the previously used methodology [24]. A visual analogue scale with a ten-centimetre length was used to rate the footwear comfort for six dimensions: overall comfort, forefoot cushioning, arch cushioning, heel cushioning, arch support, heel support, according to a previously used method. The left end was labelled as 'not comfortable' (0) and the right end was labelled as 'best comfort' (10). Example is shown in Additional file 1.

For the second stage of our study, we have invited all 32 (14%) subjects with a history of the lower leg, ankle, and foot overuse injury and 34 (15%) age-matched non-injured subjects for more detailed testing. Visual inspection of the skin and nails of the foot and bare footprint length were additionally assessed. The presence of blisters, corns, or calluses, as well as ingrown toenails and subungual haematoma, were documented according to the classification by Carr&Cropley [25]. Characteristics of the case-control study population are shown in Table 2.

For footprint length assessment, participants were asked to stand in a relaxed manner on a pressure platform (2 m × 0.4 m × 0.02 m, RSscan International, Belgium). Platform calibration was performed before each measurement. Plantar pressure analysis software (Footscan® v.7.11, RSscan International) was used to detect the precise footprint length in millimetres. Footscan® pressure plate has shown good repeatability and is commonly

Table 1 Cross-sectional study population characteristics

	Total (*n* = 227)	Males (n = 213)	Females (*n* = 14)
Age, years (SD)[a]	29.5 (7.2)	29.4 (7.0)	32.1 (8.3)
Service time, years (SD)	7.2 (6.4)	7.1 (6.4)	8.3 (6.5)
History of total lower extremity overuse injury, % (n)	42.7 (*n* = 97)	43.2 (*n* = 92)	35.7 (*n* = 5)
History of lower leg and foot overuse injury, % (n)	15.0 (n = 34)	15.0 (n = 32)	14.3 (n = 2)
Foot blisters after long marching, % (n)	46.3 (*n* = 105)	46.5 (*n* = 99)	42.9 (n = 6)
Usage of foot orthotics, % (n)	4.9 (*n* = 11)	4.7 (n = 10)	7.1 (n = 1)

[a] Standard deviation (SD) is given in brackets

Table 2 Case-control study population characteristics

	Total (n = 66)	Subjects with prior OI[a] (n = 32)	Non-injured subjects (n = 34)	*P* value[b]
Age, years	29.7 (5.5)	29.0 (5.7)	30.5 (5.3)	0.12
Height, m (SD[c])	1.81 (0.13)	1.81 (0.13)	1.81 (0.13)	0.96
Weight, kg (SD)	81.3 (12.9)	81.3 (13.3)	81.2 (12.6)	0.96
Foot length, mm (SD)	274 (13)	275 (13)	273 (13)	0.19
Usage of foot orthotics, % (n)	(*n* = 4)	12.5 (n = 4)	0	**0.04**
Foot blisters after long marching, % (n)	57.6 (n = 38)	53.1 (*n* = 17)	61.8 (n = 21)	0.16
Foot skin lesions, % (n)	(n = 14)	(n = 6)	(*n* = 8)	0.58
Toenail problems, % (n)	(n = 18)	(n = 14)	(*n* = 4)	**0.01**

[a] OI – overuse injury. [b]One-way ANOVA test results; significant results are marked in bold. [c]Standard deviation (SD) is given in brackets

used in foot pressure and foot area data assessment [26, 27]. To detect the correct shoe size, bare footprint length was converted to shoe size using the metric footwear sizing — Mondopoint system [28]. In the case of footprint length difference, the longer foot was chosen to analyse footwear sizing. A comparison of the used self-selected shoe size with a correct shoe size was made according to the bare footprint length. The correct fit was defined if the self-selected footwear size matched the Mondopoint sizing.

The size of issued military boots was self-selected based on soldier's previous shoe fitting experience; each size has only one width and half-sizes have not been provided. The footprint width was not analysed. Given that Latvia's average annual air temperature is +5.9 °C [29], and for most of the year soldiers use boots for hot weather conditions, we assessed the footwear comfort rating for this type of issued infantry boot only.

Statistical analysis was performed using the SPSS 22.0 software package (Statistical Package for the Social Sciences). Data were explored for distribution; normality was investigated using the Kolmogorov-Smirnov test. If data did not meet normal distribution assumptions, non-parametric tests were applied. Quantitative variables are presented as means with standard deviation; categorical variables are presented as frequencies if not stated otherwise. The study sample was defined as an "availability sample". Sample size calculations were based on one-year musculoskeletal lower extremity injury among Latvian Land Forces (12.4%) and performed using the open-source calculator (OpenEpi, Open Source Statistics for Public Health) [30, 31]. The significance level was set to $p<0.05$ (two-tailed), and statistical power was set to 0.9.

Results

Footwear comfort rating

Footwear comfort rating was assessed for all study participants ($n=227$). Differences in footwear comfort rating between gender groups were independent of the previous history of overuse injury. The highest overall footwear comfort rating was 6.7 in the non-injured males group. The lowest rating of 5.2 was observed for the heel cushioning among the non-injured females group. Mean footwear comfort ratings among females were lower across all dimensions, but the difference with the male group was not statistically significant (see Table 3).

Footwear sizing analysis

In total, $n=66$ male subjects were additionally tested to assess the relationship between footwear comfort and lower leg overuse injury. For the additionally tested group, self-selected military footwear sizes were converted to mm (millimetres) using the Mondopoint system and then compared with the footprint length measurement from the Footscan® software. As a result, 57.6% ($n=38$) of all study subjects daily were wearing an inappropriate shoe size: 30.3% among subjects with a history of overuse injury ($n=20$) and 27.3% among subjects without a history of overuse injury ($n=18$). Only six subjects wore bigger shoe sizes, and others ($n=31$) used a smaller shoe size than would be recommended according to their foot measurement. Self-selected shoe sizes were statistically significantly different among groups ($p=0.04$). The median footprint length difference between the left and right sides was 1 mm (range 0–5 mm). See Table 4 for details.

Lower extremity overuse injury and comfort rating

Subjects who wore the wrong shoe size in both (injured and non-injured) groups showed lower military footwear perceived comfort ratings across all dimensions, independent of previous lower extremity overuse injury. For most of the comfort dimensions, the difference between injured and non-injured groups was statistically significant. Detailed results are shown in Table 5.

Table 3 Mean military footwear comfort ratings

	Males (n = 213)		Females (*n* = 14)		*P*-value[c]
	With prior OI[a] (n = 92)	Non-injured (*n* = 121)	With prior OI[a] (n = 5)	Non-injured (n = 9)	
Overall comfort	6.3 (1.8) [b]	6.7 (1.7)	5.6 (2.1)	6.1 (2.2)	0.16
Forefoot cushioning	6.0 (1.9)	6.4 (1.8)	5.6 (1.7)	5.7 (2.0)	0.12
Arch cushioning	6.1 (1.8)	6.2 (2.0)	5.6 (1.8)	6.1 (1.7)	0.67
Heel cushioning	6.2 (1.8)	6.2 (2.0)	5.6 (1.3)	5.2 (2.0)	0.84
Arch support	6.0 (1.9)	6.4 (1.9)	6.0 (1.7)	5.7 (1.9)	0.19
Heel support	6.2 (1.9)	6.7 (1.8)	5.8 (1.6)	6.0 (2.4)	0.05

[a] OI – overuse injury; [b] Standard deviations are given in brackets; [c] One-way ANOVA test results comparing injured and non-injured groups

Table 4 Military footwear sizing preferences

	Total (n = 66)	Subjects with prior OI[a] (n = 32)	Non-injured subjects (n = 34)	P value[b]
Self-selected EU[d] shoe size, (SD[c])	43 (1.5)	43.5 (1.6)	43 (1.4)	**0.04**
Measured EU shoe size, (SD)	43.6 (1.6)	43.9 (1.6)	43.4 (1.5)	**< 0.01**
Suitable shoe size usage, % (n)	42.4 (n = 28)	37.5 (n = 12)	47.1 (n = 16)	0.16
Inappropriate shoe size usage, % (n)	57.6 (n = 38)	62.5 (n = 20)	52.9 (n = 18)	

[a] OI – overuse injury. [b]Chi-square test results; significant results are marked in bold. [c]Standard deviation (SD) is given in brackets

[d] EU – European shoe size

Table 5 Military footwear comfort rating comparison among study subjects

	Subjects wearing inappropriate shoe sizes (*n* = 38)		Subjects wearing suitable shoe sizes (*n* = 28)		$\chi^2(1)$	P value[†]
	With prior OI (*n* = 20)	Non-injured (*n* = 18)	With prior OI (*n* = 12)	Non-injured (*n* = 16)		
Overall comfort	6.69 (1.22)	6.91 (1.11)	7.29 (1.04)	7.28 (1.33)	5.23	**0.02**
Forefoot cushioning	6.24 (1.57)	6.18 (1.78)	7.00 (0.98)	6.59 (1.72)	4.17	**0.04**
Arch cushioning	6.24 (1.57)	6.15 (1.79)	6.88 (1.36)	6.53 (2.00)	3.61	**0.06**
Heel cushioning	6.29 (1.38)	6.26 (1.52)	6.92 (1.38)	6.66 (1.66)	5.06	**0.03**
Arch support	5.90 (1.79)	6.15 (1.74)	6.75 (1.59)	6.63 (1.88)	4.38	**0.04**
Heel support	6.38 (1.61)	6.47 (1.58)	7.58 (1.02)	7.19 (1.18)	11.07	**< 0.01**

OI – overuse injury. [†]Kruskal Wallis test results; standard deviation is given in brackets. Significant results are marked in bold

Discussion

To the author's knowledge, this is the first attempt to systematically evaluate perceived footwear comfort for different boot dimensions in a relationship with previous foot overuse injury among infantry soldiers. The present study assessed military boot comfort ratings and footwear fit among infantry soldiers with and without a history of lower extremity overuse injury. However, the overuse injury definition used widely is not uniform, we used the definition that emphasises a mechanism of gradual onset and underlying pathogenesis of repetitive microtrauma as was recommended by Roos et al. [32] Previous military footwear research performed in 1976 focused on different lower extremity disorders, both acute (ankle fractures) and overuse injuries (heel contusions, toe paresthesia, and retrocalcaneal bursitis), and military boot comfort data for different boot dimensions remained unknown [19, 20]. According to Dijksma et al. findings of previous footwear research among military populations may no longer apply due to the design of military boots evolving [33]. Current military boot design should contribute to better perceived comfort and a standardised military footwear comfort evaluation tool is needed.

Footwear comfort measures are difficult to compare with other studies due to methodological differences. Perceived comfort perception in our study was measured using a visual analogue scale, not only for overall comfort but also for cushioning and supporting different parts of the foot [24]. Muniz et al. only reported overall footwear comfort among Brazilian army recruits that varied from 5.5 to 7.7 points, with higher comfort provided by softer midsole and lower boot weight [34]. Paisis et al. investigated perceived comfort among the Greek army, and study results showed that participants also preferred walking with the lightest weight boot. It has been reported that reduced weight, increased stiffness, and the construction of military boots could be beneficial for higher footwear comfort [35]. Types of military footwear materials, shock-absorbing possibilities, microclimate features, footwear width, and footwear weight, as well as gait kinematics, were not assessed in our study.

Footwear sizes in the Latvian Land Forces are self-selected by the soldier. Footwear sizes vary among producers, and the soldier's choice of footwear size is based on previous experience, which can be wrong. Study findings conducted among infantry of Canadian Land Forces showed that personnel footwear was not appropriately fitted according to foot length and width [36].

We compared self-selected footwear sizes with recommended footwear sizes (based on footprint length). We used a universal Mondopoint footwear size measurement system for size conversion, which is performed on a statistically constructed human foot and uses foot length in millimetres. Our study findings showed that 56% of study participants wore inappropriate shoe sizes, and these results are consistent with the previously mentioned study [36]. Wearing incorrectly sized footwear is a common problem, and it has been associated with foot pain and foot disorder [13]. The shoe's fit has been associated with skin disorders of the foot such as corns and calluses. In our study, foot skin disorders were not prevalent among both study groups, and recently it has been proposed that corns and calluses could indicate the asymmetrical behaviour of the lower limbs during gait [37]. Toenail disorders, which could result from the tight toe box of footwear [25], were more prevalent among subjects with prior overuse injury who used an inappropriate shoe size. Highly rated footwear comfort is possible if the proper fit is provided, and our study results show moderately low comfort ratings.

Study subjects who used inappropriate shoe sizes showed statistically significantly lower military footwear perceived comfort ratings across all dimensions, and these results are partly consistent with previous findings. It has been reported that inappropriate shoe fit could lead to discomfort and contribute to lower extremity overuse injury due to gait adaptations [38]. However, the complexity of what makes the appropriately fitted shoe more comfortable, and the impact of shoe comfort on gait and pathology is not yet well understood [39].

Our study results found no relationship between footwear comfort ratings and lower extremity injury history. Grier et al. have identified that better cushioned footwear did not lower injury incidence, although poor footwear fit and cushioning were associated with foot pain and discomfort. Our study results showed that subjects wearing the wrong shoe size reported lower footwear comfort ratings. To potentially increase footwear cushioning and comfort shock-absorbing insoles have been recommended [8, 40]. Prefabricated foot orthoses were found to be effective in preventing lower limb overuse injuries [41].

Current study findings should be considered in the context of study limitations. The cross-sectional study design is a limitation due to the inability to establish causal sequences and recall bias of injury history. Although the study population is relatively small, it is representative ($n=227$) and considerably larger than calculated sample size ($n=150$). Grouping of the case-control study also depends on participant honesty, and it has been reported that approximately half of the injuries among military populations are not usually reported to medical personnel [42]. We believe that answers to the interviewer were honest because soldiers were informed that the study results would not affect the medical annual check-up status. Also, comfort ratings could influence the fact that only one type of infantry boot (for hot weather conditions) was assessed. Additionally, including foot width could provide more detailed comfort ratings, but since it did not impact boot size measurements, it was not included in the analysis. We did not check if the same boot pair was used for the last 6 months; however, all soldiers of the Land Forces of Latvia use the same boot model, and in any case, comfort ratings were provided for the same boot model. Given that perceived footwear comfort rating could change during physical activity due to fatigue [43], our study participants rated footwear comfort during a day-off to avoid the possible skewing of comfort data. The use of Footscan® software for foot length measurement was selected as reliable since digital footprint measurement for foot length assessment was found to be similar to a 3D (three-dimensional) foot scan [44]. Despite these limitations, the strength of this research is that it comes from a relatively homogeneous population and helps to gain a deeper understanding of military footwear fit and comfort by comparing previously injured and non-injured infantry soldiers groups.

According to our study, proper fit is an essential factor that leads to more comfortable military footwear usage. It is recommended to issue adequate military footwear size according to foot dimension measurement using a Brannock device or 3D foot scan to provide better footwear comfort. The findings of this study can also provide valuable information on footwear comfort to other users of work boots.

Conclusions

To the authors' knowledge, this is the first study of subjective infantry boot fit and comfort among infantry soldiers considering a history of lower extremity overuse injury. Study results showed that inappropriate infantry boot size significantly affects footwear comfort ratings. History of previous lower extremity overuse injury was not related to either shoe size selection or footwear comfort ratings. Based on our study results, we recommend footprint length assessment for proper footwear size selection.

Abbreviations

ICD-10: International Classification of Diseases; : Tenth Revision; SPSS: Statistical Package for the Social Sciences; mm: millimetres; 3D: three-dimensional.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12891-021-04839-9.

Additional file 1. "Military_boot_comfort_tool.pdf", example of visual analogue scale used for footwear comfort assessment.

Acknowledgments
The authors would like to thank the soldiers who participated in the study and the Latvian National Army Logistic Command Military Medical Support Centre for the support.

Authors' contributions
DN contributed to the whole study (research design, literature review, data collection and analysis, writing the manuscript). NV contributed to research design and data collection. AS contributed to data analysis and manuscript writing. All the authors read and approved the final manuscript.

Funding
This research was financially supported by a Rīga Stradiņš University doctoral research grant.

Availability of data and materials
Datasets analysed in this study are not publicly available because the Latvian National Army Logistic Command Military Medical Support Centre did not permit data sharing. Request to access the datasets should be directed to the corresponding author.

Declarations

Ethics approval and consent to participate
Participation was voluntary. All study participants provided written informed consent. Ethical approval was obtained from the Ethics Committee of Riga Stradiņš University (No. 40/26.10.2017).

Consent for publication
Not applicable.

Competing interests
The authors have no competing interests to declare.

Author details
[1]Military Medicine Research and Study Centre, Rīga Stradiņš University, 14 Baložu Street, Riga LV-1048, Latvia. [2]Latvian National Armed Forces Joint Headquarters Medical Service, Kadaga 2103, Latvia.

Received: 20 June 2021 Accepted: 4 November 2021
Published online: 15 November 2021

References

1. Taanila H, Suni JH, Kannus P, Pihlajamäki H, Ruohola J-P, Viskari J, et al. Risk factors of acute and overuse musculoskeletal injuries among young conscripts: a population-based cohort study. BMC Musculoskelet Disord. 2015;16:104. https://doi.org/10.1186/s12891-015-0557-7.
2. Lovalekar M, Johnson CD, Eagle S, Wohleber MF, Keenan KA, Beals K, et al. Epidemiology of musculoskeletal injuries among US air force special tactics operators: an economic cost perspective. BMJ Open Sport Exerc Med. 2018;4:e000471. https://doi.org/10.1136/bmjsem-2018-000471.
3. Jamal A, Ali MK, Mirza TM, Raza M, Access O, Related S, et al. Patterns of stress related injuries of lower limbs in military setup on skeletal scintigraphy. Pak Armed Forces Med J. 2016;66:742–6.
4. Hauschild VD, Schuh-Renner A, Lee T, Richardson MD, Hauret K, Jones BH. Using causal energy categories to report the distribution of injuries in an active population: an approach used by the U.S. Army. J Sci Med Sport. 2019;22:997–1003.
5. Fredette MA, Roy J-S, Esculier J-F, ois, Perreault K. Most military runners report recent changes in running parameters before lower limb injury onset. Mil Med. 2020. https://doi.org/10.1093/milmed/usaa524.
6. Lovalekar M, Hauret K, Roy T, Taylor K, Blacker SD, Newman P, et al. Musculoskeletal injuries in military personnel—descriptive epidemiology, risk factor identification, and prevention. J Sci Med Sport. 2021;24:963–9. https://doi.org/10.1016/j.jsams.2021.03.016.
7. Milgrom C, Finestone A, Shlamkovitch N, Wosk J, Laor A, Voloshin A, et al. Prevention of overuse injuries of the foot by improved shoe shock attenuation. A randomized prospective study. Clin Orthop Relat Res. 1992:189–92.
8. Grier TL, Knapik JJ, Swedler D, Jones BH. Footwear in the United States Army band: injury incidence and risk factors associated with foot pain. Foot. 2011;21:60–5. https://doi.org/10.1016/j.foot.2010.12.002.
9. Milgrom C, Sorkin A, Gam A, Singer J, Nir I, Kogan B, et al. The search for the best infantry boot. Disaster Mil Med. 2016;2:14. https://doi.org/10.1186/s40696-016-0024-5.
10. Miller JE, Nigg BM, Liu W, Stefanyshyn DJ, Nurse MA. Influence of foot, leg and shoe characteristics on subjective comfort. Foot Ankle Int. 2000;21:759–67.
11. West AM, Schönfisch D, Picard A, Tarrier J, Hodder S, Havenith G. Shoe microclimate: an objective characterisation and subjective evaluation. Appl Ergon. 2019;78:1–12.
12. Jordan C, Bartlett R. Relationship between plantar and dorsal pressure distribution and perception of comfort in casual footwear. Gait Posture. 1994;2:251.
13. Buldt AK, Menz HB. Incorrectly fitted footwear, foot pain and foot disorders: a systematic search and narrative review of the literature. J Foot Ankle Res. 2018;11:43.
14. Luximon A, Jiang L, Luximon Y. Sizing and grading methods with consideration of footwear styles. Int J Ind Ergon. 2020;78:102960.
15. Mayeaux EJ, Carter C, Murphy TE. Ingrown toenail management. Am Fam Physician. 2019;100:158–64.
16. Ganesan B, Prasad P, Akter S, Tong RKY. Common orthopedic problems in the foot and their implications for footwear design. In: Handbook of Footwear Design and Manufacture Elsevier; 2021. p. 413–438.
17. Nigg B, Baltich J, Hoerzer S, Enders H. Running shoes and running injuries: mythbusting and a proposal for two new paradigms: 'preferred movement path' and 'comfort filter.' Br J Sports Med 2015;49:1290–1294. doi:https://doi.org/10.1136/bjsports-2015-095054.
18. Willems TM, De Ridder R, Roosen P. Is consumer behaviour towards footwear predisposing for lower extremity injuries in runners and walkers? A prospective study. J Foot Ankle Res. 2019;12:43.
19. Bensel C. The effects of tropical and leather combat boots on lower extremity disorders among US Marine Corps Recruits 1976;:63. https://apps.dtic.mil/sti/citations/ADA025938. Accessed 03 Mar 2021.
20. Bensel C, Kish R. Lower extremity disorders among men and women in Army basic training and effects of two types of Boots. 1983:99. https://apps.dtic.mil/sti/citations/ADA133002. Accessed 03 Mar 2021.
21. World Health Organization. International statistical classification of diseases and related health problems, 10th revision (ICD-10). World Heal Organ. 2016.
22. Kernan M, Raja B, Matuszak J. The collegiate/professional male athlete. In: Heidelbaugh JJBT-CMH, editor. Clinical Men's health. Philadelphia: Elsevier; 2008. p. 485–522. https://doi.org/10.1016/B978-141603000-3.10026-7.
23. Barell V. An introduction to the Barell body region by nature of injury diagnosis matrix. Inj Prev. 2002;8:91–6. https://doi.org/10.1136/ip.8.2.91.
24. Mills K, Blanch P, Vicenzino B. Identifying clinically meaningful tools for measuring comfort perception of footwear. Med Sci Sport Exerc. 2010;42:1966–71. https://doi.org/10.1249/MSS.0b013e3181dbacc8.
25. Carr PC, Cropley TG. Sports dermatology: skin disease in athletes. Clin Sports Med. 2019;38:597–618. https://doi.org/10.1016/j.csm.2019.06.001.
26. Xu C, Wen X-X, Huang L-Y, Shang L, Cheng X-X, Yan Y-B, et al. Normal foot loading parameters and repeatability of the Footscan® platform system. J Foot Ankle Res. 2017;10:30. https://doi.org/10.1186/s13047-017-0209-2.
27. Takata Y, Kawamura R, Matsuoka S, Hashida H, Asano G, Kimura K, et al. Comparison of flatfeet and normal feet using data of the gait cycle, contact area, and foot pressure. Data Br. 2021;36:106990. https://doi.org/10.1016/j.dib.2021.106990.
28. Celko J. Chapter 20 - Shoe Sizes. In: Celko J, editor. Joe Celko's data, measurements and standards in SQL. Boston: Morgan Kaufmann; 2010. p. 167–168. doi:https://doi.org/https://doi.org/10.1016/B978-0-12-374722-8.00020-7.
29. Latvian Environment, Geology and meteorology Centre. Climate of Latvia https://www.meteo.lv/en/lapas/environment/climate-change/climate-of-latvia/climat-latvia?id=1471&nid=660. Accessed 15 Oct 2017.
30. Ņesteroviča D, Stepens A, Vaivads N. Peak plantar pressure as a risk factor for lower extremity overuse injury among infantry soldiers. Proc Latv

Acad Sci Sect B Nat Exact, Appl Sci. 2021;75:52–7. https://doi.org/10.2478/prolas-2021-0009.
31. Kelsey L, Fleiss K FP. Methods in observational Epidemiology 2nd Edition, Statistical Methods for Rates and Proportion, formulas 3.18 and 19. Methods in observational epidemiology 2nd edition, statistical methods for rates and proportion, formulas 3.18 and 19. 2010.
32. Roos KG, Marshall SW. Definition and usage of the term "overuse injury" in the US high school and collegiate sport epidemiology literature: a systematic review. Sport Med. 2014;44:405–21. https://doi.org/10.1007/s40279-013-0124-z.
33. Dijksma I, Arslan IG, van Etten-Jamaludin FS, Elbers RG, Lucas C, Stuiver MM. Exercise programs to reduce the risk of musculoskeletal injuries in military personnel: a systematic review and Meta-analysis. PM R. 2020;12:1028–37.
34. Muniz AMS, Bini RR. Shock attenuation characteristics of three different military boots during gait. Gait Posture. 2017;58 July:59–65. doi:https://doi.org/10.1016/j.gaitpost.2017.07.037.
35. Paisis P, Hanley B, Havenetidis K, Bissas A. Cypriot and greek army military boot cushioning: ground reaction forces and subjective responses. Mil Med. 2013;178:e493–7.
36. Dyck W. A study of the relationship between foot size and combat boot size in the Canadian forces. Defence and Civil Institute of Environmental Medicine, Defence R&D Canada, DCIEM TR 2000-137, 2000; p. 1–31.
37. Grouios G. Footedness as a potential factor that contributes to the causation of corn and callus formation in lower extremities of physically active individuals. Foot. 2005;15:154–62. https://doi.org/10.1016/j.foot.2005.05.003.
38. Finestone A, Shlamkovitch N, Eldad A, Karp A, Milgrom C. A prospective study of the effect of the appropriateness of foot-shoe fit and training shoe type on the incidence of overuse injuries among infantry recruits. Mil Med. 1992;157:489–90. https://doi.org/10.1093/milmed/157.9.489.
39. Branthwaite H, Chockalingam N. Everyday footwear: an overview of what we know and what we should know on ill-fitting footwear and associated pain and pathology. Foot. 2019;39:11–4.
40. Lullini G, Giangrande A, Caravaggi P, Leardini A, Berti L. Functional evaluation of a shock absorbing insole during military training in a Group of Soldiers: a pilot study. Mil Med. 2020;185:e643–8. https://doi.org/10.1093/milmed/usaa032.
41. Bonanno DR, Murley GS, Munteanu SE, Landorf KB, Menz HB. Effectiveness of foot orthoses for the prevention of lower limb overuse injuries in naval recruits: a randomised controlled trial. Br J Sports Med. 2018;52:298–302.
42. Smith L, Westrick R, Sauers S, Cooper A, Scofield D, Claro P, et al. Underreporting of musculoskeletal injuries in the US Army. Sport Heal A Multidiscip Approach. 2016;8:507–13. https://doi.org/10.1177/1941738116670873.
43. Hintzy F, Cavagna J, Horvais N. Evolution of perceived footwear comfort over a prolonged running session. Foot. 2015;25:220–3. https://doi.org/10.1016/j.foot.2015.08.003.
44. Lee Y-C, Lin G, Wang M-JJ. Comparing 3D foot scanning with conventional measurement methods. J Foot Ankle Res 2014;7:44. doi:https://doi.org/10.1186/s13047-014-0044-7.

Publisher's Note

International Journal of
Environmental Research and Public Health

MDPI

Communication

Increased Barefoot Stride Variability Might Be Predictor Rather than Risk Factor for Overuse Injury in the Military

Darja Nesterovica-Petrikova [1,*], Normunds Vaivads [2] and Ainārs Stepens [1]

[1] Military Medicine Research and Study Center, Rīga Stradiņš University, LV-1048 Riga, Latvia; ainars.stepens@rsu.lv
[2] Joint Headquarters of the Latvian National Armed Forces Medical Service, LV-1006 Riga, Latvia
* Correspondence: darja.nesterovica-petrikova@rsu.lv

Abstract: Footwear usage could be a promising focus in reducing musculoskeletal injury risk in lower extremities commonly observed among the military. The goal of this research was to find potential gait-related risk factors for lower leg overuse injuries. Cases (n = 32) were active-duty infantry soldiers who had suffered an overuse injury in the previous six months of service before enrolling in the study. The control group (n = 32) included infantry soldiers of the same age and gender who did not have a history of lower leg overuse injury. In the gait laboratory, individuals were asked to walk on a 5-m walkway. Rearfoot eversion, ankle plantar/dorsiflexion and stride parameters were evaluated for barefoot and shod conditions. Barefoot walking was associated with higher stride time variability among cases. According to the conditional regression analysis, stride time variability greater than 1.95% (AUC = 0.77, 95% CI (0.648 to 0.883), $p < 0.001$) during barefoot gait could predict lower leg overuse injury. Increased barefoot gait variability should be considered as a possible predictive factor for lower leg overuse injury in the military, and gait with military boots masked stride-related differences between soldiers with and without lower leg overuse injury.

Keywords: musculoskeletal injuries; military personnel; gait analysis; stride variability; infantry boot

check for updates

Citation: Nesterovica-Petrikova, D.; Vaivads, N.; Stepens, A. Increased Barefoot Stride Variability Might Be Predictor Rather than Risk Factor for Overuse Injury in the Military. *Int. J. Environ. Res. Public Health* **2023**, *20*, 6449. https://doi.org/10.3390/ijerph20156449

Academic Editors: Domiziano Tarantino and Bruno Corrado

Received: 22 June 2023
Revised: 24 July 2023
Accepted: 25 July 2023
Published: 26 July 2023

1. Introduction

Military service is physically challenging and requires high volumes of marching and running activities. Non-combat musculoskeletal overuse injuries of the lower extremities have military readiness and socioeconomic impacts [1–4]. Despite years of musculoskeletal injury research and the injury risk prevention strategies implemented in the military, the prevalence of lower leg overuse injuries remains high. The reported prevalence of lower leg overuse injuries vary from 8% in the foot, to 22% in the knee region, and 34% in the calf and ankle [5]. Reduction in physical activity volume, bracing for high-risk activities, high level of pre-accession physical fitness, and awareness of injury prevention strategies are reported to reduce injury rates in military populations [6]. According to a recent meta-analysis, the evidence base of musculoskeletal injury preventive strategies remains insufficient to provide strong recommendations for practice [7].

Several risk factors for lower extremity overuse injury have been previously identified, including age, gender and peak plantar pressure [8,9]. Jacobsson et al. discovered an elevated risk of sustaining a subsequent injury in athletes with inadequate primary injury recovery [10]. In the military and athletic populations, previous injury increased the risk of subsequent lower limb injuries, and altered gait biomechanics [9,11–13].

Gait is a functional rhythmical movement, and complex fluctuations of unknown origin appear in the normal pattern among healthy individuals [14,15]. Although significant variation of gait is most often observed in movement disorders [16], few studies have looked at changes in the coefficient of variation of gait parameters (variability) as a risk factor or as a result of an injury [17]. Psoriatic arthritis patients showed higher stride variability [18], while patients with traumatic brain injury had increased step width variability [19]. Adults with a history of musculoskeletal injury had higher running gait variability than injury-free individuals [20,21].

Footwear usage impacts physical task performance and acutely affects gait stability and variability [22–24]. During service time, military personnel use military boots and running shoes, and shoe usage differs between countries and services [9]. The role of military footwear in protecting military personnel against musculoskeletal injuries of the lower extremities remains debatable. Considering the impact of footwear on gait biomechanics, the goal of this study was to identify a gait-related predictor for lower leg overuse injury in previously injured and non-injured infantry soldiers while walking barefoot and in military boots.

2. Materials and Methods

2.1. Study Population

Case-control study subjects were active-duty infantry male soldiers from the Latvian Land Forces. Subjects were selected after a cross-sectional study regarding the status of musculoskeletal injury. Injuries that occurred due to repetitive or forceful tasks and resulted from repeated overstretching or overloading were defined as overuse musculoskeletal injuries [3,25]. Common lower leg overuse injuries in the military are anterior or posterior tibial syndrome (ICD-10 code M76.8) [26], plantar fasciitis (M72.2), Achilles tendonitis (or bursitis, M76.6), peroneal tendinitis (M76.7), and stress fractures (M84.3) [9,27]. A detailed selection process was presented in a previous article [28]. Cases (n = 32) were subjects with a history of overuse injury in the lower leg, ankle, or foot during the last 6 months of service before entering the study. The injury was considered if a soldier had a medical record or reported an injury that restricted at least one activity. The recovery time from a musculoskeletal overuse injury ranged between 3 and 12 weeks [29,30], and the study started from 4 to 6 months after the injury occurred. The cases experienced complete recovery from injury before the research period, did not have functional limitations, and could participate in all kinds of physical activities. Controls were age and gender-matched infantry soldiers (n = 32) with no history of lower leg overuse injury. The characteristics of the study population are shown in Table 1. Participation was voluntary, and all study subjects provided written informed consent before entering the study. The study protocol was approved by the Ethics Committee of Rīga Stradiņš University (No. 40/26.10.2017).

Table 1. Characteristics of study subjects (Mean ± SD).

	Case (n = 32)	Control (n = 32)	p-Value
Age, years [1]	29.13 ± 5.77	30.78 ± 5.13	0.087
Height, m	1.81 ± 0.08	1.77 ±0.07	0.103
Weight, kg	81.09 ± 13.54	81.75 ±12.53	0.731
BMI	24.74 ± 2.90	25.94 ± 2.85	0.100
Foot sole length, mm	275 ± 12	272 ± 12	0.488

[1] SD—standard deviation, BMI—body mass index, mm—millimeters.

2.2. Gait Assessment

Subjects in shorts were advised to walk comfortably barefoot on a straight 5-m walkway (active area). Shod walking trials were used to evaluate the effects of military boots on gait. During the shod gait analysis, a standardized infantry boot model for hot weather conditions with a 25 cm height was used; the worn boots had no visible attrition signs. Two gait trials were used for familiarization [31] with each gait condition (barefoot, shod) and were not investigated for reliable gait parameter measurement. Walking trials continued until full n = 50 gait cycles were recorded, and only straight walking patterns were included in the research to access gait variability; spatiotemporal stride parameters before/after turns were not evaluated [32,33].

All study subjects were fitted with spherical retroreflective markers ($n = 12$) using double-sided tape for motion tracking and gait cycle analysis. A single examiner placed markers bilaterally on the subject's anatomical landmarks of the foot and shank. Markers were attached to the middle shank, the lateral and medial femoral epicondyles, the lateral and medial malleoli, the heads of the first, second, and fifth metatarsals, and the posterior calcaneus. During the shod condition, markers were placed after palpation of the anatomical landmark through the shoe. The marker set used in this study is similar to the conventional lower-limb gait model marker set ($n = 8$) and showed good test–retest reliability (ICC > 0.80) [34]. The markers were placed in the same locations as in previous studies for barefoot and shod conditions [35,36].

The study was carried out in the Riga Stradiņš University gait laboratory, which was equipped with two high-speed camera motion capture systems (100 samples/s) for video recording of gait. Data from marker tracking and Quintic v31 Biomechanics software (Quintic Consultancy Ltd., United Kingdom) were used to analyze 2D kinematics and spatiotemporal gait parameters [37,38]. Rearfoot eversion and ankle plantar/dorsiflexion angles were measured throughout the gait cycle's stance phase. Heel contact was defined as the initial contact [39]. The foot contact angle was defined as the angle created between the foot and the ground during a heel strike. The anteroposterior distance between the left and right heel markers at each initial contact was used to calculate the step length. The definitions of spatiotemporal gait parameters presented in this study were the same as in a previous study that investigated lower-limb overuse injuries among military recruits [40]. The stride time variability was calculated as 100 × (stride time SD/mean stride time), the stride length variability was calculated as 100 × (stride length SD/mean stride length), and the step length asymmetry was calculated as 100 × ln (right step length/left step length).

2.3. Data Processing and Statistical Analysis

Sample size was calculated using the open-source calculator (OpenEpi, Open Source Statistics for Public Health) [41], estimate based on one-year musculoskeletal lower extremity injury among Latvian Land Forces (12.4%) [8].

Statistical analysis was performed using the SPSS 22.0 software package (Statistical Package for the Social Sciences). Data distribution was investigated using the Kolmogorov–Smirnov test. Data are presented as mean with standard deviations (SD) if not stated otherwise.

Continuous variables were log-transformed if needed to obtain a normal distribution; when the log transformation did not give an approximately normal distribution, nonparametric tests were used. The paired *t*-test or Wilcoxon signed-rank test was used to compare differences in gait parameters between matched cases and controls [42].

An index of effect size point biserial correlation, r, is reported for statistically significant differences among groups and between shod and barefoot conditions [43]; effect sizes were defined as 0.1—small, 0.3 medium and 0.5 large [44]. The p-value < 0.05 was considered statistically significant. A strong correlation between data of left and right side was found. Data from both sides were used for stride time, stride length and step asymmetry calculations; from right side only loading response, foot contact angle, rearfoot angle and angular velocities were used for statistical analysis. Conditional logistic regression analysis was performed using the COXREG function in SPSS to determine the effect of the statistically significant gait parameters on the risk of lower leg overuse injury. Furthermore, for the statistically significant gait parameters receiver operating characteristic (ROC) analysis was used to examine the area under the curve (AUC), and the specificity, sensitivity, and cut-off value were based on the Youden index [45].

3. Results

3.1. Gait Parameters

Both groups' barefoot and shod conditions showed statistically different gait stride characteristics ($p < 0.001$). The barefoot walking showed shorter stride length ($r = 0.64$) but increased stride time ($r = 0.52$) and increased stride length variability ($r = 0.74$) compared to the shod condition in both study groups. Barefoot stride time ($p = 0.053$) and stride time variability ($p = 0.030$) were statistically different between the cases and control group, effect sizes r = 0.31 and r = 0.85, respectively. During the shod walk the stride time was statistically different between the study groups ($p = 0.048$, r = 0.36). Table 2 presents the gait characteristics for barefoot and shod conditions.

Table 2. Gait characteristics of case and control groups (Mean ± SD).

	Case	**Control**	***p***
	Barefoot		
Stride time, SD	**1.11 ± 0.09**	**1.04 ± 0.12**	**0.053 ***
Stride variability, %	**1.98 ± 0.79**	**1.27 ± 0.66**	**0.030**
Loading response, %	12.11 ± 2.26	12.12 ± 2.04	0.962
Step length asymmetry index	0.56 ± 5.55	0.42 ± 3.74	0.893
Stride length, m	1.14 ± 0.32	1.08 ± 0.33	0.176
Stride length variability, %	1.88 ± 1.72	1.97 ± 1.88	0.165
	Shod		
Stride time, SD	**1.24 ± 0.01**	**1.19 ± 0.09**	**0.048 ***
Stride variability, %	1.24 ± 0.85	1.21 ± 0.73	0.629
Loading response, %	11.83 ± 2.45	10.69 ± 1.53	0.132
Step length asymmetry index	0.53 ± 4.56	0.12 ± 1.03	0.332
Stride length	1.34 ± 0.26	1.32 ± 0.30	0.571
Stride length variability, %	0.81 ± 0.73	0.72 ± 0.63	0.630

* Significant results marked in bold; SD—standard deviation.

3.2. Foot and Ankle Joint Kinematics

Foot and ankle motion analysis during shod and barefoot walking differed in both groups and showed no dissimilarities between cases and control subjects. Foot contact angle increased during the shod walking, but rearfoot eversion angle and angular velocities decreased. See Table 3 for details.

Table 3. Foot and ankle complex movements with standard deviations during barefoot and shod gait.

Barefoot	**Group**		
	Case	Control	*p*
Foot contact angle (°)	16.41 ± 5.86	17.04 ± 5.18	0.487
Rearfoot eversion (°)	5.64 ±1.96	4.97 ± 1.65	0.692
Peak angular velocity, PF [1] (°/s	242.17 ± 36.71	256.4 ± 30.17	0.138
Peak angular velocity, DF [1] (°/s)	157.38 ± 28.62	149.52 ± 14.04	0.201
Shod	Case	Control	*p*
Foot contact angle (°)	25.31 ±4.77	25.38 ± 4.63	0.896
Rearfoot eversion (°)	3.28 ±1.10	2.88 ± 1.11	0.147
Peak angular velocity, PF (°/s)	157.47 ± 23.99	162.32 ± 26.79	0.475
Peak angular velocity, DF (°/s)	119.14 ± 36.36	120.07 ± 30.69	0.915

[1] PF—plantarflexion, DF—dorsiflexion, s—seconds.

3.3. Regression Analysis

In univariate and multivariate analysis, only stride time variability during barefoot gait could significantly predict the risk of lower leg overuse injury. See details in Table 4. Univariate ROC analysis showed an AUC of 0.77 ($p < 0.001$; 95% CI 0.648–0.883), a sensitivity of 56%, and a specificity of 88%, with an optimal cutoff value for barefoot stride time variability of 1.95%.

Table 4. Summary of conditional logistic regression analysis.

	Barefoot		Shod	
Variable	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted OR (95% CI)	Adjusted OR [1] (95% CI)
Stride time variability	**2.59** (1.30–5.18)	**2.71** (1.31–5.60)	1.01 (0.99 –1.01)	1.00 (0.97–1.04)
p	**0.009 ***	**0.007 ***	0.928	0.131

[1] OR—odds ratio; CI—confidence interval; * significant results marked in bold.

4. Discussion

According to our findings, infantry boots have significant effects on gait parameters, with gait with boots becoming faster, less variable, and more symmetric. Shod gait results support prior research that found military boots design features contributed to body balance [46,47]. The study's findings on increased stride time and stride length when walking in boots are consistent with earlier research. [24,48]. Furthermore, shod gait analysis shows that military boots decrease ankle joint motion, stabilize the rearfoot and slow the ankle movement during walking, which is consistent with earlier research that investigated barefoot and shod gait during running and walking [24,48–50]. Our findings on the maximum angular velocities during ankle dorsiflexion and plantar flexion, as well as range of rearfoot eversion, are comparable with the previously reported data observed in healthy populations [51,52]. Infantry boots usage significantly alters gait parameters, and the evaluation of shod gait can mask the musculoskeletal injury risk of a lower leg. Therefore, barefoot gait assessment protocols can be recommended for the evaluation of military personnel.

The main result of this study is that barefoot stride time variability is significantly related to previous lower leg overuse injuries. The normal range of stride variability in healthy individuals varies from 0.6–2.0% [53], and based on our study results stride variability value among previously injured infantry soldiers is 1.98 ± 0.79. Based on our study findings, a more restricted reference range of stride time variability could be considered in specific physically active populations, such as the armed forces. Furthermore, regression analysis showed that stride time variability is greater than 1.95%, and lower leg overuse injuries can be predicted with 88% specificity and 56% sensitivity. Our prediction should have both high sensitivity (true cases—those who will experience an event) and high specificity (correctly identify true non-cases). However, in practice, there is a trade-off between sensitivity and specificity, and high specificity is more important when screening recruits for a low prevalence outcome. Nevertheless, our finding regarding increased barefoot stride variability is consistent with previous prospective study reporting an association of stride time variability with the musculoskeletal injury risk among Israeli Defense Forces soldiers [40], but the possible cutoff value for the stride time variability has not been set previously. Prospective studies on healthy individuals are needed to evaluate stride time variability cutoff value as a potential lower leg overuse injury risk factor. For possible musculoskeletal injury mitigation, stride variability could be corrected through knee extension and hip abduction strength training or during gait retraining [54,55].

Our study results are limited due to several factors. This study was a case-control study and it could be discussed whether change in barefoot stride time variability is a result of an overuse injury or a protective mechanism. We did not find significant differences in body height or foot sole length between the research groups, so we did not modify the gait data for these characteristics that might shift the results, even though stride duration differences may emerge due to anthropometric factors [56,57]. Gait variability may have been influenced by a history of musculoskeletal overuse injury. Although recovery from injury can vary widely among individuals [58,59], all study subjects were free of any injury, felt healthy, and did not report any symptoms or functional limitations that could influence walking patterns throughout the gait testing. We also tested our study subjects in a gait laboratory, and stride data measured under certain conditions cannot be easily transferred to other conditions [24]. Nevertheless, soldiers during the walking trials used the same infantry boots they use daily and not an experimental pair, which could lead to a more natural gait pattern. Additionally, our study results cannot be generalized to all types of shoes worn in the military, because soldiers also use running shoes during service time. Only one infantry boot type was used and we did not investigate different military boot features that could impact the result. For example, Helton et al. found that running shoes with mild to moderate lateral-torsional stiffness were effective in reducing the lower extremity injury risk among military cadets [60].

Additionally, we did not analyze shoe attrition, but Chen et al. recently postulated that running shoe attrition impacts the kinematics and kinetics of lower extremity joints [36], and we do not know if it is the same for the infantry boot. Footwear in the Latvian Land Forces is changed regularly if visible shoe attrition persists, and no visual damage (e.g., asymmetrical shoe heel abrasion) of the infantry boots was found before marker placement during the study period.

Moreover, the rearfoot and ankle joint motion tracking with markers during barefoot gait analysis can be a source of error due to soft tissue artifacts (STA); however, the STA in the heel is likely to be small [61,62], but STA could influence ankle joint motion results. The marker set for the foot motion analysis, as well as marker placement errors, might shift the results. However, during the study, all markers were placed by one examiner following the standardized scheme of marker placement. The rearfoot motion findings are also consistent with previous study results with a similar marker set (11 markers, without a second metatarsal head marker) [63].

For shod analysis, we have used shoe-mounted markers that do not fully represent foot motion [64]. Other study findings obtained from shoes with holes in the heel have reported differences from the findings of shoes with an intact heel, but high accuracy of the placement of the shoe marker was reported for the hindfoot and forefoot [61,65]. Additionally, infantry boots with holes could not be used by soldiers afterward and would need to be replaced, which would have increased the study expenses and caused inconvenience for the study participants.

Despite these limitations, this study adds knowledge to gait-related parameters in military personnel in terms of lower leg overuse injuries. To the author's knowledge, this is the first case-control study to evaluate gait parameters as possible risk factors for lower leg overuse injuries in infantry soldiers. The findings of our study emphasize the importance of gait variability as a possible lower leg overuse injury risk factor among infantry soldiers, and gait analysis can be considered for screening and training purposes.

5. Conclusions

Overuse injury risk is independent of stride-related characteristics during walking in infantry boots. Shod gait analysis may underestimate the risk of a lower leg overuse injury because military boots modify gait parameters. A stride time variability of more than 1.95% during barefoot walking is the strongest predictor of lower leg overuse injury in infantry soldiers. In the military, increased gait variability should be considered as a possible predictive factor for lower extremity overuse injury.

Author Contributions: D.N.-P.: methodology and conceptualization, literature review, data collection and analysis, original draft preparation and editing; N.V.: research design and conceptualization, data collection, writing—review and editing; A.S.: conceptualization, data analysis, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was financially supported by a Rīga Stradiņš University doctoral research grant.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the This study has been approved by the ethics committee of Rīga Stradiņš University (No. 40/26.10.2017). Participation was voluntary and written informed consent was provided.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The Latvian National Army Logistics Command Military Medical Support Centre did not allow data sharing, and the analyzed data sets are not publicly available. Requests to access the data sets should be directed to the corresponding author.

Acknowledgments: The authors would like to thank Aivars Vētra the Head of Rīga Stradiņš University Rehabilitation Research Laboratory for his helpful advice.

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

References

1. Grimm, P.D.; Mauntel, T.C.; Potter, B.K. Combat and Noncombat Musculoskeletal Injuries in the US Military. *Sports Med. Arthrosc.* **2019**, *27*, 84–91. [CrossRef] [PubMed]
2. Fredette, M.A.; Roy, J.-S.; Esculier, J.-F.O.; Perreault, K. Most Military Runners Report Recent Changes in Running Parameters Before Lower Limb Injury Onset. *Mil. Med.* **2021**, *186*, e1140–e1148. [CrossRef] [PubMed]
3. Lovalekar, M.; Hauret, K.; Roy, T.; Taylor, K.; Blacker, S.D.; Newman, P.; Yanovich, R.; Fleischmann, C.; Nindl, B.C.; Jones, B.; et al. Musculoskeletal Injuries in Military Personnel—Descriptive Epidemiology, Risk Factor Identification, and Prevention. *J. Sci. Med. Sport* **2021**, *24*, 963–969. [CrossRef] [PubMed]
4. Dijksma, C.I.; Bekkers, M.; Spek, B.; Lucas, C.; Stuiver, M. Epidemiology and Financial Burden of Musculoskeletal Injuries as the Leading Health Problem in the Military. *Mil. Med.* **2020**, *185*, e480–e486. [CrossRef] [PubMed]
5. Schwartz, O.; Malka, I.; Olsen, C.H.; Dudkiewicz, I.; Bader, T. Overuse Injuries in the IDF's Combat Training Units: Rates, Types, and Mechanisms of Injury. *Mil. Med.* **2018**, *183*, E196–E200. [CrossRef]
6. Wardle, S.L.; Greeves, J.P. Mitigating the Risk of Musculoskeletal Injury: A Systematic Review of the Most Effective Injury Prevention Strategies for Military Personnel. *J. Sci. Med. Sport* **2017**, *20*, S3–S10. [CrossRef]
7. Arslan, I.G.; Dijksma, I.; van Etten-Jamaludin, F.S.; Lucas, C.; Stuiver, M.M. Nonexercise Interventions for Prevention of Musculoskeletal Injuries in Armed Forces: A Systematic Review and Meta-Analysis. *Am. J. Prev. Med.* **2021**, *60*, e73–e84. [CrossRef]
8. Ņesteroviča, D.; Stepens, A.; Vaivads, N. Peak Plantar Pressure as a Risk Factor for Lower Extremity Overuse Injury Among Infantry Soldiers. *Proc. Latv. Acad. Sci. Sect. B. Nat. Exact. Appl. Sci.* **2021**, *75*, 52–57. [CrossRef]
9. Andersen, K.A.; Grimshaw, P.N.; Kelso, R.M.; Bentley, D.J. Musculoskeletal Lower Limb Injury Risk in Army Populations. *Sport. Med. Open* **2016**, *2*, 22. [CrossRef]
10. Jacobsson, J.; Timpka, T.; Kowalski, J.; Ekberg, J.; Nilsson, S.; Dahlström, Ö.; Renström, P. Subsequent injury during injury recovery in elite athletics: Cohort study in swedish male and female athletes. *Br. J. Sports Med.* **2014**, *48*, 610–611. [CrossRef]
11. Baida, S.R.; Gore, S.J.; Franklyn-Miller, A.D.; Moran, K.A. Does the Amount of Lower Extremity Movement Variability Differ between Injured and Uninjured Populations? A Systematic Review. *Scand. J. Med. Sci. Sports* **2018**, *28*, 1320–1338. [CrossRef]
12. Hamill, J.; Palmer, C.; Van Emmerik, R.E.A. Coordinative Variability and Overuse Injury. *Sport. Med. Arthrosc. Rehabil. Ther. Technol.* **2012**, *4*, 45. [CrossRef] [PubMed]
13. Toohey, L.A.; Drew, M.K.; Cook, J.L.; Finch, C.F.; Gaida, J.E. Is Subsequent Lower Limb Injury Associated with Previous Injury? A Systematic Review and Meta-Analysis. *Br. J. Sports Med.* **2017**, *51*, 1670–1678. [CrossRef]
14. Hausdorff, J.M.; Peng, C.K.; Ladin, Z.; Wei, J.Y.; Goldberger, A.L. Is Walking a Random Walk? Evidence for Long-Range Correlations in Stride Interval of Human Gait. *J. Appl. Physiol.* **1995**, *78*, 349–358. [CrossRef] [PubMed]
15. Winter, D.A. Kinematic and Kinetic Patterns in Human Gait: Variability and Compensating Effects. *Hum. Mov. Sci.* **1984**, *3*, 51–76. [CrossRef]
16. Ahsan, M.; Abualait, T.; Al-Subaiei, M.; Al Muslem, W.; Aldokhayyil, M.; Nuhmani, S.; Alzahrani, A. Determining the Characteristics of Gait Variability with a Preferred Walking Speed in Hypertensive and Normotensive Participants. *Clin. Epidemiol. Glob. Health* **2023**, *23*, 101344. [CrossRef]
17. Strongman, C.; Morrison, A. A Scoping Review of Non-Linear Analysis Approaches Measuring Variability in Gait Due to Lower Body Injury or Dysfunction. *Hum. Mov. Sci.* **2020**, *69*, 102562. [CrossRef]
18. Walha, R.; Gaudreault, N.; Dagenais, P.; Boissy, P. Spatiotemporal Parameters and Gait Variability in People with Psoriatic Arthritis (PsA): A Cross-Sectional Study. *J. Foot Ankle Res.* **2022**, *15*, 19. [CrossRef]
19. Niechwiej-Szwedo, E.; Inness, E.L.; Howe, J.A.; Jaglal, S.; McIlroy, W.E.; Verrier, M.C. Changes in Gait Variability during Different Challenges to Mobility in Patients with Traumatic Brain Injury. *Gait Posture* **2007**, *25*, 70–77. [CrossRef]
20. Nakayama, Y.; Kudo, K.; Ohtsuki, T. Variability and Fluctuation in Running Gait Cycle of Trained Runners and Non-Runners. *Gait Posture* **2010**, *31*, 331–335. [CrossRef]
21. Blyton, S.J.; Snodgrass, S.J.; Pizzari, T.; Birse, S.M.; Likens, A.D.; Edwards, S. The Impact of Previous Musculoskeletal Injury on Running Gait Variability: A Systematic Review. *Gait Posture* **2023**, *101*, 124–133. [CrossRef]
22. Orr, R.; Maupin, D.; Palmer, R.; Canetti, E.F.D.; Simas, V.; Schram, B. The Impact of Footwear on Occupational Task Performance and Musculoskeletal Injury Risk: A Scoping Review to Inform Tactical Footwear. *Int. J. Environ. Res. Public Health* **2022**, *19*, 10703. [CrossRef]

Data Availability Statement: The Latvian National Army Logistics Command Military Medical Support Centre did not allow data sharing, and the analyzed data sets are not publicly available. Requests to access the data sets should be directed to the corresponding author.

Acknowledgments: The authors would like to thank Aivars Vētra the Head of Rīga Stradiņš University Rehabilitation Research Laboratory for his helpful advice.

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

References

1. Grimm, P.D.; Mauntel, T.C.; Potter, B.K. Combat and Noncombat Musculoskeletal Injuries in the US Military. *Sports Med. Arthrosc.* **2019**, *27*, 84–91. [CrossRef] [PubMed]
2. Fredette, M.A.; Roy, J.-S.; Esculier, J.-F.O.; Perreault, K. Most Military Runners Report Recent Changes in Running Parameters Before Lower Limb Injury Onset. *Mil. Med.* **2021**, *186*, e1140–e1148. [CrossRef] [PubMed]
3. Lovalekar, M.; Hauret, K.; Roy, T.; Taylor, K.; Blacker, S.D.; Newman, P.; Yanovich, R.; Fleischmann, C.; Nindl, B.C.; Jones, B.; et al. Musculoskeletal Injuries in Military Personnel—Descriptive Epidemiology, Risk Factor Identification, and Prevention. *J. Sci. Med. Sport* **2021**, *24*, 963–969. [CrossRef] [PubMed]
4. Dijksma, C.I.; Bekkers, M.; Spek, B.; Lucas, C.; Stuiver, M. Epidemiology and Financial Burden of Musculoskeletal Injuries as the Leading Health Problem in the Military. *Mil. Med.* **2020**, *185*, e480–e486. [CrossRef] [PubMed]
5. Schwartz, O.; Malka, I.; Olsen, C.H.; Dudkiewicz, I.; Bader, T. Overuse Injuries in the IDF's Combat Training Units: Rates, Types, and Mechanisms of Injury. *Mil. Med.* **2018**, *183*, E196–E200. [CrossRef]
6. Wardle, S.L.; Greeves, J.P. Mitigating the Risk of Musculoskeletal Injury: A Systematic Review of the Most Effective Injury Prevention Strategies for Military Personnel. *J. Sci. Med. Sport* **2017**, *20*, S3–S10. [CrossRef]
7. Arslan, I.G.; Dijksma, I.; van Etten-Jamaludin, F.S.; Lucas, C.; Stuiver, M.M. Nonexercise Interventions for Prevention of Musculoskeletal Injuries in Armed Forces: A Systematic Review and Meta-Analysis. *Am. J. Prev. Med.* **2021**, *60*, e73–e84. [CrossRef]
8. Ņesteroviča, D.; Stepens, A.; Vaivads, N. Peak Plantar Pressure as a Risk Factor for Lower Extremity Overuse Injury Among Infantry Soldiers. *Proc. Latv. Acad. Sci. Sect. B. Nat. Exact. Appl. Sci.* **2021**, *75*, 52–57. [CrossRef]
9. Andersen, K.A.; Grimshaw, P.N.; Kelso, R.M.; Bentley, D.J. Musculoskeletal Lower Limb Injury Risk in Army Populations. *Sport. Med. Open* **2016**, *2*, 22. [CrossRef]
10. Jacobsson, J.; Timpka, T.; Kowalski, J.; Ekberg, J.; Nilsson, S.; Dahlström, Ö.; Renström, P. Subsequent injury during injury recovery in elite athletics: Cohort study in swedish male and female athletes. *Br. J. Sports Med.* **2014**, *48*, 610–611. [CrossRef]
11. Baida, S.R.; Gore, S.J.; Franklyn-Miller, A.D.; Moran, K.A. Does the Amount of Lower Extremity Movement Variability Differ between Injured and Uninjured Populations? A Systematic Review. *Scand. J. Med. Sci. Sports* **2018**, *28*, 1320–1338. [CrossRef]
12. Hamill, J.; Palmer, C.; Van Emmerik, R.E.A. Coordinative Variability and Overuse Injury. *Sport. Med. Arthrosc. Rehabil. Ther. Technol.* **2012**, *4*, 45. [CrossRef] [PubMed]
13. Toohey, L.A.; Drew, M.K.; Cook, J.L.; Finch, C.F.; Gaida, J.E. Is Subsequent Lower Limb Injury Associated with Previous Injury? A Systematic Review and Meta-Analysis. *Br. J. Sports Med.* **2017**, *51*, 1670–1678. [CrossRef]
14. Hausdorff, J.M.; Peng, C.K.; Ladin, Z.; Wei, J.Y.; Goldberger, A.L. Is Walking a Random Walk? Evidence for Long-Range Correlations in Stride Interval of Human Gait. *J. Appl. Physiol.* **1995**, *78*, 349–358. [CrossRef] [PubMed]
15. Winter, D.A. Kinematic and Kinetic Patterns in Human Gait: Variability and Compensating Effects. *Hum. Mov. Sci.* **1984**, *3*, 51–76. [CrossRef]
16. Ahsan, M.; Abualait, T.; Al-Subaiei, M.; Al Muslem, W.; Aldokhayyil, M.; Nuhmani, S.; Alzahrani, A. Determining the Characteristics of Gait Variability with a Preferred Walking Speed in Hypertensive and Normotensive Participants. *Clin. Epidemiol. Glob. Health* **2023**, *23*, 101344. [CrossRef]
17. Strongman, C.; Morrison, A. A Scoping Review of Non-Linear Analysis Approaches Measuring Variability in Gait Due to Lower Body Injury or Dysfunction. *Hum. Mov. Sci.* **2020**, *69*, 102562. [CrossRef]
18. Walha, R.; Gaudreault, N.; Dagenais, P.; Boissy, P. Spatiotemporal Parameters and Gait Variability in People with Psoriatic Arthritis (PsA): A Cross-Sectional Study. *J. Foot Ankle Res.* **2022**, *15*, 19. [CrossRef]
19. Niechwiej-Szwedo, E.; Inness, E.L.; Howe, J.A.; Jaglal, S.; McIlroy, W.E.; Verrier, M.C. Changes in Gait Variability during Different Challenges to Mobility in Patients with Traumatic Brain Injury. *Gait Posture* **2007**, *25*, 70–77. [CrossRef]
20. Nakayama, Y.; Kudo, K.; Ohtsuki, T. Variability and Fluctuation in Running Gait Cycle of Trained Runners and Non-Runners. *Gait Posture* **2010**, *31*, 331–335. [CrossRef]
21. Blyton, S.J.; Snodgrass, S.J.; Pizzari, T.; Birse, S.M.; Likens, A.D.; Edwards, S. The Impact of Previous Musculoskeletal Injury on Running Gait Variability: A Systematic Review. *Gait Posture* **2023**, *101*, 124–133. [CrossRef]
22. Orr, R.; Maupin, D.; Palmer, R.; Canetti, E.F.D.; Simas, V.; Schram, B. The Impact of Footwear on Occupational Task Performance and Musculoskeletal Injury Risk: A Scoping Review to Inform Tactical Footwear. *Int. J. Environ. Res. Public Health* **2022**, *19*, 10703. [CrossRef]

23. Baumfeld, D.; Raduan, F.C.; Macedo, B.; Silva, T.A.A.; Baumfeld, T.; Favato, D.F.; de Andrade, M.A.P.; Nery, C. Shoe Heel Abrasion and Its Possible Biomechanical Cause: A Transversal Study with Infantry Recruits. *J. Orthop. Surg. Res.* **2015**, *10*, 179. [CrossRef] [PubMed]
24. Hollander, K.; Petersen, E.; Zech, A.; Hamacher, D. Effects of Barefoot vs. Shod Walking during Indoor and Outdoor Conditions in Younger and Older Adults. *Gait Posture* **2022**, *95*, 284–291. [CrossRef] [PubMed]
25. Kernan, M.; Raja, B.; Matuszak, J. The Collegiate/Professional Male Athlete. In *Clinical Men's Health*; Heidelbaugh, J.J., Jauniaux, E., Landon, M.B., Eds.; Elsevier: Philadelphia, PA, USA, 2008; pp. 485–522. ISBN 978-1-4160-3000-3.
26. WHO. *World Health Organization International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10)*; World Health Organization: Geneva, Switzerland, 2016.
27. Almeida, S.A.; Williams, K.M.; Shaffer, R.A.; Brodine, S.K. Epidemiological Patterns of Musculoskeletal Injuries and Physical Training. *Med. Sci. Sports Exerc.* **1999**, *31*, 1176–1182. [CrossRef]
28. Nesterovica, D.; Vaivads, N.; Stepens, A. Relationship of Footwear Comfort, Selected Size, and Lower Leg Overuse Injuries among Infantry Soldiers. *BMC Musculoskelet. Disord.* **2021**, *22*, 1–8. [CrossRef]
29. Khan, K.; Cook, J. The Painful Nonruptured Tendon: Clinical Aspects. *Clin. Sports Med.* **2003**, *22*, 711–725. [CrossRef] [PubMed]
30. Brumitt, J.; Cuddeford, T. Current concepts of muscle and tendon adaptation to strength and conditioning. *Int. J. Sports Phys. Ther.* **2015**, *10*, 748–759.
31. Hamacher, D.; Hamacher, D.; Krowicki, M.; Schega, L. Between-Day Test–Retest Reliability of Gait Variability in Older Individuals Improves with a Familiarization Trial. *Aging Clin. Exp. Res.* **2017**, *29*, 327–329. [CrossRef] [PubMed]
32. König, N.; Singh, N.B.; von Beckerath, J.; Janke, L.; Taylor, W.R. Is Gait Variability Reliable? An Assessment of Spatio-Temporal Parameters of Gait Variability during Continuous Overground Walking. *Gait Posture* **2014**, *39*, 615–617. [CrossRef]
33. Kroneberg, D.; Elshehabi, M.; Meyer, A.C.; Otte, K.; Doss, S.; Paul, F.; Nussbaum, S.; Berg, D.; Kühn, A.A.; Maetzler, W.; et al. Less Is More—Estimation of the Number of Strides Required to Assess Gait Variability in Spatially Confined Settings. *Front. Aging Neurosci.* **2019**, *11*, 435. [CrossRef]
34. Molina-Rueda, F.; Fernández-González, P.; Cuesta-Gómez, A.; Koutsou, A.; Carratalá-Tejada, M.; Miangolarra-Page, J.C. Test-Retest Reliability of a Conventional Gait Model for Registering Joint Angles during Initial Contact and Toe-Off in Healthy Subjects. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1343. [CrossRef] [PubMed]
35. Peng, Y.; Wong, D.W.C.; Wang, Y.; Chen, T.L.W.; Tan, Q.; Chen, Z.; Jin, Z.; Zhang, M. Immediate Effects of Medially Posted Insoles on Lower Limb Joint Contact Forces in Adult Acquired Flatfoot: A Pilot Study. *Int. J. Environ. Res. Public Health* **2020**, *17*, 2226. [CrossRef] [PubMed]
36. Chen, S.F.; Wang, Y.; Peng, Y.; Zhang, M. Effects of Attrition Shoes on Kinematics and Kinetics of Lower Limb Joints During Walking. *Front. Bioeng. Biotechnol.* **2022**, *10*, 824297. [CrossRef]
37. Zult, T.; Allsop, J.; Tabernero, J.; Pardhan, S. A Low-Cost 2-D Video System Can Accurately and Reliably Assess Adaptive Gait Kinematics in Healthy and Low Vision Subjects. *Sci. Rep.* **2019**, *9*, 18385. [CrossRef]
38. Maykut, J.N.; Taylor-Haas, J.A.; Paterno, M.V.; DiCesare, C.A.; Ford, K.R. Concurrent Validity and Reliability of 2d Kinematic Analysis of Frontal Plane Motion during Running. *Int. J. Sports Phys. Ther.* **2015**, *10*, 136–146.
39. Pipkin, A.; Kotecki, K.; Hetzel, S.; Heiderscheit, B. Reliability of a Qualitative Video Analysis for Running. *J. Orthop. Sports Phys. Ther.* **2016**, *46*, 556–561. [CrossRef]
40. Springer, S.; Gottlieb, U.; Lozin, M. Spatiotemporal Gait Parameters as Predictors of Lower-Limb Overuse Injuries in Military Training. *Sci. World J.* **2016**, *2016*, 1–5. [CrossRef]
41. Kelsey, L.; Fleiss, K. Methods in Observational Epidemiology 2nd Edition, Statistical Methods for Rates and Proportion, Formulas 3.18 and 19. Available online: http://www.openepi.com/SampleSize/SSCohort.htm (accessed on 10 February 2019).
42. Breslow, N.E.; Day, N.E. *Statistical Methods in Cancer Research*; IARC Scientific Publications: Lyon, France, 1980; Volume I, pp. 248–279.
43. Nakagawa, S.; Cuthill, I.C. Effect Size, Confidence Interval and Statistical Significance: A Practical Guide for Biologists. *Biol. Rev.* **2007**, *82*, 591–605. [CrossRef]
44. Cohen, J. A Power Primer. In *Methodological Issues and Strategies in Clinical Research*, 4th ed.; American Psychological Association: Washington, DC, USA, 2016; pp. 279–284.
45. Fluss, R.; Faraggi, D.; Reiser, B. Estimation of the Youden Index and Its Associated Cutoff Point. *Biom. J.* **2005**, *47*, 458–472. [CrossRef]
46. Hill, C.M.; DeBusk, H.; Knight, A.C.; Chander, H. Military-Type Workload and Footwear Alter Lower Extremity Muscle Activity during Unilateral Static Balance: Implications for Tactical Athletic Footwear Design. *Sports* **2020**, *8*, 58. [CrossRef] [PubMed]
47. DeBusk, H.; Hill, C.M.; Chander, H.; Knight, A.C.; Babski-Reeves, K. Influence of Military Workload and Footwear on Static and Dynamic Balance Performance. *Int. J. Ind. Ergon.* **2018**, *64*, 51–58. [CrossRef]
48. Franklin, S.; Grey, M.J.; Heneghan, N.; Bowen, L.; Li, F.X. Barefoot vs Common Footwear: A Systematic Review of the Kinematic, Kinetic and Muscle Activity Differences during Walking. *Gait Posture* **2015**, *42*, 230–239. [CrossRef] [PubMed]
49. Willems, T.M.; Witvrouw, E.; De Cock, A.; De Clercq, D. Gait-Related Risk Factors for Exercise-Related Lower-Leg Pain during Shod Running. *Med. Sci. Sports Exerc.* **2007**, *39*, 330–339. [CrossRef]
50. Majumdar, D.; Banerjee, P.K.; Majumdar, D.; Pal, M.; Kumar, R.; Selvamurthy, W. Temporal Spatial Parameters of Gait with Barefoot, Bathroom Slippers and Military Boots. *Indian J. Physiol. Pharmacol.* **2006**, *50*, 33–40. [PubMed]

51. Mentiplay, B.F.; Banky, M.; Clark, R.A.; Kahn, M.B.; Williams, G. Lower Limb Angular Velocity during Walking at Various Speeds. *Gait Posture* **2018**, *65*, 190–196. [CrossRef]
52. Campbell, K.J.; Wilson, K.J.; LaPrade, R.F.; Clanton, T.O. Normative Rearfoot Motion during Barefoot and Shod Walking Using Biplane Fluoroscopy. *Knee Surg. Sport. Traumatol. Arthrosc.* **2016**, *24*, 1402–1408. [CrossRef]
53. Tan, A.M.; Weizman, Y.; Van Netten, J.J.; Fuss, F.K. Comparing the Applicability of Temporal Gait Symmetry, Variability and Laterality in Bilateral Gait Conditions: A Feasibility Study of Healthy Individuals and People with Diabetic Neuropathy. *Clin. Biomech.* **2022**, *91*, 105530. [CrossRef] [PubMed]
54. Zimmermann, W.; Linschoten, C.; Beutler, A. Gait Retraining as Part of the Treatment Programme for Soldiers with Exercise-Related Leg Pain: Preliminary Clinical Experiences and Retention. *South African J. Sport. Med.* **2017**, *29*, 1–6. [CrossRef]
55. Bogen, B.; Moe-Nilssen, R.; Aaslund, M.K.; Ranhoff, A.H. Muscle Strength as a Predictor of Gait Variability after Two Years in Community-Living Older Adults. *J. Frailty Aging* **2020**, *9*, 23–29. [CrossRef]
56. Hof, A.L. Scaling Gait Data to Body Size. *Gait Posture* **1996**, *4*, 222–223. [CrossRef]
57. Sekiya, N. The Invariant Relationship between Step Length and Step Rate during Free Walking. *J. Hum. Mov. Stud.* **1996**, *30*, 241–257.
58. Lentz, T.A.; Paterno, M.V.; Riboh, J.C. So You Think You Can Return to Sport? *Br. J. Sports Med.* **2018**, *52*, 1482–1483. [CrossRef]
59. Hsu, C.-J.; Meierbachtol, A.; George, S.Z.; Chmielewski, T.L. Fear of Reinjury in Athletes. *Sport. Health A Multidiscip. Approach* **2017**, *9*, 162–167. [CrossRef]
60. Helton, G.L.; Cameron, K.L.; Zifchock, R.A.; Miller, E.; Goss, D.L.; Song, J.; Neary, M.T. Association Between Running Shoe Characteristics and Lower Extremity Injuries in United States Military Academy Cadets. *Am. J. Sports Med.* **2019**, *47*, 2853–2862. [CrossRef] [PubMed]
61. Alcantara, R.S.; Trudeau, M.B.; Rohr, E.S. Calcaneus Range of Motion Underestimated by Markers on Running Shoe Heel. *Gait Posture* **2018**, *63*, 68–72. [CrossRef]
62. Benoit, D.L.; Ramsey, D.K.; Lamontagne, M.; Xu, L.; Wretenberg, P.; Renström, P. Effect of Skin Movement Artifact on Knee Kinematics during Gait and Cutting Motions Measured in Vivo. *Gait Posture* **2006**, *24*, 152–164. [CrossRef]
63. Chuter, V.H. Relationships between Foot Type and Dynamic Rearfoot Frontal Plane Motion. *J. Foot Ankle Res.* **2010**, *3*, 9. [CrossRef] [PubMed]
64. Sinclair, J.; Greenhalgh, A.; Taylor, P.J.; Edmundson, C.J.; Brooks, D.; Hobbs, S.J. Differences in Tibiocalcaneal Kinematics Measured with Skin- and Shoe-Mounted Markers. *Hum. Mov.* **2013**, *14*, 64–69. [CrossRef]
65. Bishop, C.; Paul, G.; Uden, H.; Thewlis, D. The Development of a Multi-Segment Kinematic Model of Footwear. *Footwear Sci.* **2011**, *3*, S13–S15. [CrossRef]

Veidlapa Nr. E-9 (2)

RSU ĒTIKAS KOMITEJAS LĒMUMS NR. 40 / 26.10.2017.

Rīga, Dzirciema iela 16, LV-1007
Tel. 67061596

	Komitejas sastāvs	Kvalifikācija	Nodarbošanās
1.	Profesors Olafs Brūvers	Dr.theo.	teologs
2.	Profesore Vija Sīle	Dr.phil.	filozofs
3.	Asoc.prof. Santa Purviņa	Dr.med.	farmakologs
4.	Asoc.prof. Voldemārs Arnis	Dr.biol.	rehabilitologs
5.	Profesore Regīna Kleina	Dr.med.	patalogs
6.	Profesors Guntars Pupelis	Dr.med.	ķirurgs
7.	Asoc.prof. Viesturs Liguts	Dr.med.	toksikologs
8.	Docente Iveta Jankovska	Dr.med.	
9.	Docents Kristaps Circenis	Dr.med.	

Pieteikuma iesniedzējs: **Darja Ņesteroviča, doktorante**
Medicīnas fakultāte, doktorantūra

Pētījuma nosaukums: "Militāro apavu valkāšanas biomehāniskie aspekti un to saistība ar apakšējo ekstremitāšu pārslodzes traumām."

Iesniegšanas datums: 25.10.2017.

Pētījuma protokols: Izskatot augstāk minētā pētījuma pieteikuma materiālus (protokolu) ir redzams, ka pētījuma mērķis tiek sasniegts veicot ar dalībniekiem dažāda veida pēdu pozīcijas klīniskās novērtēšanas testus un tiem atbilstošus mērījumus, iegūto datu apstrādi un analīzi, kā arī izsakot priekšlikumus. Personu (dalībnieku) datu aizsardzība, informēta brīvprātīga piedalīšanās un konfidencialitāte ir ievērota un nodrošināta. Līdz ar to pieteikums atbilst pētījuma ētikas prasībām.

Izskaidrošanas formulārs: **ir**

Piekrišana piedalīties pētījumā: **ir**

Komitejas lēmums: **piekrist** pētījumam

Komitejas priekšsēdētājs Olafs Brūvers Tituls: Dr. miss., prof.

Paraksts

Ētikas komitejas sēdes datums: 26.10.2017.

Annex 6

Saņemts e-pasts
Anda Šerpa
Rektora biroja administratore
13. 07. 2017

Nacionālie bruņotie spēki

NACIONĀLO BRUŅOTO SPĒKU KOMANDIERIS
Krustabaznīcas iela 9, Rīga, LV-1006, tālr. 67213718, fakss 67071102, e-pasts nafhqcws@mil.lv, www.mil.lv

Rīgā

2017.gada 13. jūlijā Nr. 2/VN/1050

Uz 28.06.2017. Nr. 51-7/119/2017

Rīgas Stradiņa universitātei

Par promocijas darba īstenošanu

Atbildot uz Jūsu 28.06.2017. Nr. 51-7/119/2017 vēstuli "Par promocijas darba īstenošanu", informēju, ka Nacionālie bruņotie spēki akceptē šāda darba izstrādi un atļauj aptaujāt un izmeklēt profesionālā dienesta karavīrus un zemessargus. Kontaktpersona no NBS turpmākai saziņai ir pulkvežleitnants Normunds Vaivads, NBS apvienotā štāba Nodrošinājuma departamenta Medicīnas pārvaldes vadītājs. E-pasts: normunds.vaivads@mil.lv. Tel. Nr. 67071940.

Cieņā,

Ģenerālmajors L.Kalniņš

R.Mūrniece
67071093

SAŅEMTS
Rīgas Stradiņa universitātē
13 -07- 2017
Nr. 51-6/323/2017

INFORMĀCIJA PAR PĒTĪJUMU UN PACIENTA PIEKRIŠANAS VEIDLAPA
Militāro apavu valkāšanas biomehāniskie aspekti un to saistība ar apakšējo ekstremitāšu pārslodzes traumām

Apakšējo ekstremitāšu traumas ir bieži sastopamas karavīru vidū visā pasaulē un arī Latvijā. Smagumu nešana, fiziskās sagatavotības treniņi un ar sportu saistītās aktivitātes ir cēlonis 90 % kustību-balsta sistēmas traumām karavīru populācijā, no kurām ap 80 % ir apakšējo ekstremitāšu biomehāniskās pārslodzes rakstura traumas. Biomehāniskās pārslodzes rakstura traumas tiek definētas kā kumulatīvās mikrotraumas nepareizas slodzes sadalījuma dēļ. Biežāk sastopamās šāda veida apakšējo ekstremitāšu traumas ir: patelofemorāls sāpju sindroms, lielā liela kaula stresa sindroms, pēdas kaulu stresa lūzumi, plantārais fascīts.

Lai nodrošinātu adekvātu kaujas gatavību, kā arī samazinātu veselības aprūpes izmaksas, ir nepieciešamas noteiktas stratēģijas pārslodzes izraisītā apakšējo ekstremitāšu traumatisma kontrolē. Kaut arī militārā pārslodzes traumatisma cēloņfaktoriem ir veltīts plašs pētījumu klāsts, Latvijas karavīru populācijā līdz šim nav pieejamas informācijas par pārslodzes traumu biežumu, kā arī par apakšējo ekstremitāšu traumu saistību ar noteiktu apavu veidu un to valkāšanas paradumiem.

Šī pētījuma mērķis izpētīt apakšējo ekstremitāšu pārslodzes traumu biežumu Nacionālo bruņoto spēku karavīriem un noskaidrot to sakarības ar militāro apavu izmantošanas paradumiem un pēdu uzbūves īpatnībām. Tas ļaus novērtēt apakšējo ekstremitāšu pārslodzes traumu sakarības ar militāro apavu izmantošanu un izstrādāt vadlīnijas attiecībā uz karavīru pēdu skrīningu un nepieciešamajām militāro apavu modifikācijām, atkarībā no pēdu tipa.

Šis pētījums tiek realizēts sadarbojoties Nacionāliem bruņotiem spēkiem, Rīgas Stradiņa universitātei un SIA Veselības centra 4 filiālei Pēdu centrs.
Pētījums norisinās Rīgas Stradiņa universitātes Doktora studiju programmas "Medicīna un NATO STO realizētā projekta HFM-283 "Reducing Musculo-Skeletal Injuries" ietvaros.
Kā priekšnoteikums līdzdalībai pētījumā kalpo piekrišana piedalīties zemāk aprakstītajos izmeklējumos un atbildēt uz aptauju anketās uzdotajiem jautājumiem:

1. Jums tiks lūgts aizpildīt aptaujas anketu par kustību-balsta sistēmas pārslodzes traumām un apavu valkāšanas paradumiem. Aptauja satur jautājumus par pārslodzes traumām, kas radušās dienesta un treniņu laikā, par apavu valkāšanas paradumiem un komfortu, par sāpēm pēdās, par sporta aktivitāšu intensitāti, par veselības aprūpes iestādes apmeklējumiem saistībā ar pārslodzes traumām.
2. Klīniskā stāvokļa novērtēšana notiks balstoties uz aptaujas datiem, iepriekš norunātā dienā Veselības centra 4 filiālē "Pēdu centrs". Izmeklējumu veikšanai būs nepieciešamas aptuveni 20 minūtes.
3. Jūsu klīnisko novērtēšanu veiks pamatojoties uz kritērijiem, kas aprakstīti unificētajā Pēdas pozīcijas indeksā (*Foot Posture Index*). Jums tiks lūgts veikt dažus uzdevumus (stāvēt un staigāt). Izmeklēšanai nepieciešamie uzdevumi būtiski neatšķirsies no tiem, kādus Jums lūdz veikt parastā ambulatorā vizītē pie tehniskā ortopēda.
4. Jums tiks veikta dinamiskā podometrija, kas ilgs aptuveni 10 minūtes. Tas ir vienkāršs un drošs izmeklējums, kas tiek veikts pacientiem klīniskajā praksē, lai apstiprinātu pēdu patoloģijas.
5. Papildus tiks izmeklēta gaita un skriešana. Jums ejot pa celiņu, veiks gaitas analīzi, izmeklējuma precizitātei tiks izmantoti speciālie gaismas marķieri. Kāju kustības gaitas laikā tiks ierakstītas uz videokameru. Skriešanas analīzi nodrošinās zeķes no viedā tekstila ar spiediena sensoriem, kuras Jums tiks piedāvāts uzvilkt pirms viena izturības treniņa.

Dalība šajā pētījumā ir brīvprātīga. Jums nav nepieciešams apstiprināt līdzdalību pētījumā pirms Jūs par to neesat ieguvis pietiekamu informāciju. Jebkurā laikā Jums ir tiesības atteikties no dalības pētījumā. Atteikums piedalīties neietekmēs Jūsu turpmāko dienēšanu.

Jūsu parakstītā Pacienta piekrišanas veidlapa ir slepena. Jūsu personīgie dati būs anonīmi visu pētījuma laiku. Informācija par Jums būs konfidenciāla un Jūsu datus apzīmēs tikai ar identifikācijas kodu. Jūsu sniegtās informācijas apstrāde un uzglabāšana notiks saskaņā ar "Fizisko personu datu aizsardzības likumu".

Ar savu parakstu apliecinu savu piekrišanu dalībai pētījumā.

………………………………………………………………………………………
/Pacienta vārds, uzvārds/ /Paraksts/ /Datums/

………………………………………………………………………………………
/Pētnieka vārds, uzvārds/ /Paraksts/ /Datums/

Paldies par sadarbību! Ja Jums ir nepieciešama papildus informācija, tā ir pieejama, kontaktējoties ar personu, kura veic pētniecību;
Darja Ņesteroviča, tālruņa numurs +371 26851975, e-pasts: darja.nesterovica@rsu.lv.