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Rīga Stradiņš University

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

Summary of the Doctoral Thesis for obtaining the scientific degree "Doctor of Science (*PhD*)"

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

Riga, 2024

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The Doctoral Thesis was developed at the Rīga Stradiņš University and the Latvian National Army Logistic Command Military Medical Support Centre

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Abbreviations used in the Thesis

3D	Three dimensional
AI	Arch index
AUC	Area under curve
CI	Confidence interval
cm	Centimetres
DF	Dorsiflexion
EU	European Union
FPI	Foot posture 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
U.S.	United States
VAS	Visual analogue scale

Introduction

Non-combat musculoskeletal injuries (MSKI) are a primary reason for medical discharges within the military, leading to increased financial pressure on military healthcare and a decline in army readiness (Dijksma et al., 2020; Fredette et al., 2021; Grimm et al., 2019; Lovalekar et al., 2021). Multiple injury risk factors have been previously identified, such as load carriage, overweight, low physical fitness, female sex, and previous injury (Sammito et al., 2021). Despite years of military injury research and the implementation of injury prevention programmes, the reported rates of musculoskeletal system injuries (which encompass bones, muscles, ligaments, nerves, and tendons) remain persistently high. The incidence of MSKI is reported to be 47 % among Swedish soldiers, 49 % in the British army and 53 % among US military personnel, demonstrating variations in injury rates between these groups (Grier et al., 2020; Halvarsson et al., 2018; Sharma et al., 2015).

The monitoring of musculoskeletal injury (MSKI) within the Latvian National Armed Forces (LNAF) is carried out by the National Army Medical Centre, relying on monthly medical reports furnished by regional military medical centres. In 2018, the one-year MSKI incidence, according to the medical reports, was 12.4 % within the LNAF. In particular, the areas most frequently affected were the lower legs (2.5 %), foot and the toes (1.7 %), with only three documented stress fracture cases (LNAF Joint Headquarters Medical Service, 2018). On the contrary, a three-year analysis of injury data (2017–2020) from a specific Latvian regional medical centre revealed that MSKI in the extremities was prevalent in 74 % of soldiers, a pattern consistent with findings in other military populations. However, this particular analysis did not provide a detailed breakdown of the types of injury (acute or overuse) or specific locations within the extremities (upper or lower) (Barovska, 2020).

The most prevalent MSKI in military personnel, with reported incidences ranging from 70 % to 80 %, are cumulative microtraumatic injuries, commonly referred to as overuse injuries (Hauret et al., 2010; Molloy et al., 2020; Schwartz et al., 2018; Wilkinson et al., 2011). These injuries typically affect the lower part of the body, including areas such as the lower back, knee, calf, ankle, and foot (Fredette et al., 2021; Lovalekar et al., 2021). The injury rates in the LNAF, as documented in medical records, appear to be considerably lower compared to those observed in other military groups. It remains unclear whether the injuries were intentionally hidden from medical personnel or if there were inaccuracies in the reporting process, possibly only severe cases being recorded. However, it is crucial to emphasise that systematic assessment of MSKI incidence and continuous monitoring of trends in acute and overuse injuries are vital components of an effective injury prevention strategy (Wardle & Greeves, 2017).

Appropriate footwear that offers protection to the foot (Mawusi, 2019), provides pain-free mobility during locomotion (Menz & Bonanno, 2021) and relieves the load on the lower extremities (Zhang et al., 2013), presents a promising path to reduce the incidence of lower leg MSKI. Although the use of military footwear varies between countries and military branches (Andersen et al., 2016), it remains imperative that military footwear provides comfort, assists gait symmetry, facilitates mediolateral foot motion control, and ensures stability on uneven terrain (Hamill J, 1996). However, even if a soldier may not prioritise military footwear comfort and fit, addressing these aspects remains crucial for achieving optimal gait stability, physiological well-being, and job performance within the military (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 in the general population (Ellis et al., 2022), but regular assessment of military footwear stability, fit, and comfort, along with evaluation of foot posture, is not routinely performed. Multiple studies have linked MSKI of the lower extremities with military boots (Andersen et al., 2016; Knapik et al., 2015; Orr et al., 2022). However, a recent systematic review did not identify military boots as a potential risk factor for musculoskeletal injuries (Sammito et al., 2021). The exact role of military footwear in the development of overuse MSKI remains uncertain. Further research is proposed to investigate the connection between military footwear and MSKI overuse (Baumfeld et al., 2015).

Footwear significantly impacts gait kinetics, kinematics, and variability (Braunstein et al., 2010; Dixon et al., 2003; Franklin et al., 2015; Hollander et al., 2022). Reduced shock absorption and altered gait kinematics are recognised risk factors for MSKI of the lower leg and foot overuse (Dowling et al., 2014; Willwacher et al., 2022). Prior military-related lower extremity MSKI has also been associated with subsequent injuries 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 variations in gait parameters are commonly observed in movement disorders (Ahsan et al., 2023) limited research has explored changes in gait variability as a risk factor or consequence of injury in the military (Strongman & Morrison, 2020). More research is essential to develop evidence-based strategies to reduce MSKI in the military and establish guidelines for medical gait and foot screening.

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 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. In addition, military footwear comfort, a critical element in soldier 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.

Tasks of the Thesis

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.

Hypotheses 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 focusses on a detailed analysis of 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 Latvian Land Forces, as well as for other armies of Baltic states, are currently unavailable. This thesis investigates foot posture and the biomechanical aspects of military footwear usage. Additionally, this thesis explores the potential use of military footwear and the non-neutral relationship of foot posture with lower extremity overuse injuries among infantry soldiers.

This thesis combines exploration of nonmodifiable (history of injury, foot posture) and modifiable (military footwear, plantar pressure) lower leg overuse injury 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 of tactical boots. The thesis contributes to a more comprehensive 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 injury among infantry soldiers.

1 Materials and methods

1.1 Study population

Research was carried out in two stages: stage I – cross-sectional study and stage II – case-control study (Figure 1.1).

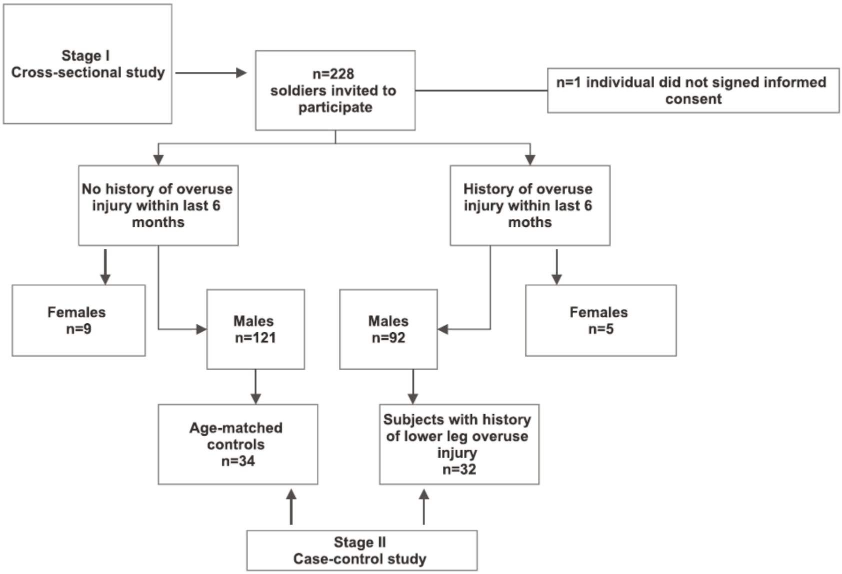

Figure 1.1 **Flow-chart of the research process**

Stage I was carried out during the annual medical check-up of the Latvian Land Forces at the Latvian National Army Logistic Command Military Medical Support Centre from 2018 to 2020. To mitigate potential variations in fitness levels and physical activity routines, only active duty infantry soldiers were eligible for participation. All available active-duty infantry soldiers were invited to participate in the research during their annual medical check-up. In total of 12 consecutive interview sessions, n = 228 or 16 % of all active duty infantry soldiers (males, n = 214; females, n = 14) were invited to participate. Before conducting interviews, written informed consent was obtained from each study participant. For subsequent activities, a total of 227 infantry soldiers were chosen, with only one individual declining participation and not providing his consent by refusing to sign. During stage II, functional evaluation of cases and control groups was carried out in the Rehabilitation Research Laboratory of Rīga Stradiņš University.

Before beginning the study, approvals were obtained from both the Rīga Stradinš University Ethics Committee (approval No. 40/26.10.2017) and the LNAF. Participation in the study was entirely voluntary and the study findings had no impact on the results of the medical check-up of the soldiers.

1.2 Cross-sectional study

Soldiers were asked to recall all injuries they had experienced in the last six months of their service. The interviewer completed the injury matrix. Additionally, information from medical records, including injury history, participant age, and length of service, was extracted and documented. An injury was identified if a soldier had a documented medical record or reported MSKI (such as injuries to bones, muscles, or tendons) that had hindered his participation in at least one activity during the preceding six months.

MSKIs were classified according to the Barell injury matrix by type, acute or overuse, and by body regions (Barell et al., 2002). Overuse injuries were defined as MSKI resulting from repetitive or forceful tasks, arising from repeated overstretching or overloading, and typically occurring without a single identifiable event (Hoffman et al., 2015; Kernan et al., 2008). The injury coding and classification was performed by the thesis author using the ICD-10 classification (World Health Organisation, 2019). For example, an ankle sprain was classified as an acute injury with the ICD-10 code S93.4, while posterior tibial syndrome was designated as an overuse injury with the ICD-10 code

M76.8. It should be noted that the aetiology and pathophysiology of medial tibial stress syndrome or shin splints (ICD-10 code S86.9) have not been definitively established (Jamal et al., 2016; Milgrom et al., 2021; Zimmermann et al., 2017), although running-related biomechanical factors have been confirmed as contributing factors (Willwacher et al., 2022). Therefore, in this study, medial tibial stress syndrome was classified as overuse injury, but participants with this diagnosis were not included in the case-control study.

1.2.1 Military footwear comfort assessment

During stage I, all participants in the study evaluated the comfort of military boots intended for hot weather conditions. All participants were infantry soldiers equipped with the same standard footwear, both for hot and cold weather conditions, provided to them throughout their service. This ensured that, regardless of lower extremity injuries, infantry soldiers consistently used the same military boot models. Given that an average annual air temperature in Latvia is around +5.9°C (*Latvian Environment, Geology and Meteorology Centre*), soldiers commonly rely on this particular type of military boot (Figure 1.2).

The military boot comfort assessment tool was created based on the methodology used previously (MILLS et al., 2010). It used a ten-centimetre VAS to rate overall boot comfort, forefoot comfort, arch and heel cushioning, as well as arch and heel support. The scale ranged from "not comfortable" (0) on the left to "best comfort" (10) on the right (Figure 1.3).

Figure 1.2 **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 1.3 **Footwear comfort tool example**

Source: author's diagram adapted from Mills, K., Blanch, P., & Vicenzino, B. (2010).

1.3 Case-control study

In stage II of the research, cases and controls were selected from the cross-sectional study population based on their injury status. Specifically, participants (n = 32, 14 %) with a history of lower leg, ankle, and foot overuse injuries were invited for a more detailed evaluation. Individuals diagnosed with medial tibial stress syndrome (S86.9) were excluded. Controls (n = 34, 15 %) were selected as individuals of the same age without injuries from the same population. The matching process for cases and controls was carried out using MedCalc Software Ltd (v.18.5, Belgium). During the detailed testing, various measurements were collected, including height, weight, and footwear size. Additionally, assessments were made for foot posture, foot arch, and length of the bare footprint. Further examinations involved plantar pressure assessments, as well as barefoot and shod gait analysis. Two individuals in the control group did not participate in gait analysis.

1.3.1 Foot posture

Before the assessment of foot posture, an examination of plantar skin and toenails was performed to check the presence of blisters, calluses, corns, ingrown toenails, and subungual haematoma. The findings were documented in accordance with the classification system described previously (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 1.1). The neutral FPI range is from 0 to +5, the pronated foot from +6 to +9, highly pronated +10, the supinated FPI range from −1 to −4, the highly supinated foot from −5 to −12. For the recording of the FPI assessment, the datasheet adapted from Redmond et al. was used. The adaptation of the FPI to Latvian was performed using forward-backward translation according to the recommendations of Beaton et al. (Beaton et al., 2007) with the permission (professor Anthony Redmond) for translation. During FPI measurements, study participants were instructed to maintain a relaxed double-limb support stance while looking straight ahead (Redmond et al., 2006).

Table 1.1

Foot posture 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

1.3.2 Footprint length and footwear fit

A digital bare footprint image was obtained for length assessment using a pressure platform (RSscan International, Belgium, 2 m × 0.4 m × 0.02 m). Participants were instructed to stand barefoot in a relaxed position on the platform, with calibration performed prior to each measurement. Footscan® v.7.11 software (RSscan International) was used to determine foot arch length and footprint length in millimetres. Foot arches were classified according to the arch index (AI): high-arch ($AI \le 0.21$), normal arch ($0.22 < AI \le 0.26$), and 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 (*International Organisation for Standardisation*). In the Mondopoint system, the size of the shoes is determined by the length of the footprint in millimetres. If there was a difference between the lengths of the left and right footprints, the longer foot was used for the analysis of footwear size. A comparison was made between the self-selected military boot size and the appropriate boot size according to the length of the footprint. A military boot was considered to have an appropriate fit if the boot size used matched the Mondopoint sizing, and analysis of toe clearance was not performed.

1.3.3 Dynamic plantar pressure assessment

The plantar pressure platform (the same as mentioned above) was placed in the centre of a 5-meter walkway within the Rehabilitation Research Laboratory of Rīga Stradiņš University. Weight calibration was performed prior to each assessment. Participants were instructed to walk barefoot at their own comfortable pace and not look at the ground. To minimise the impact of walking speed on plantar pressure measurements, a two-step initiation protocol was employed, placing participants two steps away from the platform's edge. Several walking trials were used to allow participants to acclimate, and average data from three successful trials were used to analyse plantar pressure in each foot.

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

$$SI = \frac{|X_r - X_l|}{0.5 * (X_r + X_l)} \times 100 \ \% \quad (1.3)$$

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

1.3.4 Gait analysis

Gait analysis took place in the same laboratory as previously mentioned. The gait assessment involved participants walking barefoot and in military boots on the walkway at a comfortable pace until a total of n = 50 gait cycles were captured with two high-speed camera motion capture systems (100 samples/s) (König et al., 2014; Kroneberg et al., 2019). Two familiarisation gait trials (Hamacher et al., 2017) were conducted for both barefoot and shod gait conditions, but were excluded from the analysis. All participants wore shorts and the same military boot model designed for hot weather conditions with a height of 25 cm (as shown in Figure 1.2). The boots were eligible for gait evaluation unless visible signs of attrition were observed.

During the gait cycle and the analysis of lower extremity movement, all study participants were fitted with retroreflective spherical markers (n = 12) using double-sided tape. A single examiner marked the subject's anatomical landmarks of the bare foot and shank bilaterally according to the previously used marker set: the middle shank, lateral and medial femoral epicondyles, lateral and medial malleoli, first, second and fifth metatarsal heads, and posterior calcaneus (Chen et al., 2022; Peng et al., 2020). After palpation of the anatomical landmarks through the military boot, markers were attached for shod gait assessment. The set of markers in this study (n = 8) is identical to the set of conventional lower limb gait model markers and has shown strong test-retest reliability ($ICC > 0.80$)(Molina-Rueda et al., 2021). For two dimensional kinematics and spatio-temporal 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.

Gait spatiotemporal and variability characteristics of straight walking patterns were statistically analysed. The definitions and calculations of the gait parameters (Table 1.2) were the same as in a previous study among military recruits (Springer et al., 2016).

Table 1.2

Calculations of selected spatiotemporal 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.

1.4 Statistical analysis

1.4.1 Sample size

The sample size calculations were based on the one-year incidence (12.4 %) of MSKI of the lower extremity among the Latvian Land Forces (2017, *Latvian National Army Logistic Command Military Medical Support Centre*), considering the population size of the Latvian Land Forces in the same year ($n = 1418$). Representative sample size calculations were performed using the OpenEpi open source calculator (Kelsey L, Fleiss K, 2010) with a statistical power of 0.9. Significance was established at $p < 0.05$ (two-tailed). To ensure adequate statistical power, a total of 150 participants were required for the cross-sectional study, while the case-control study required n = 60 participants (n = 30 in each group). Statistical analysis was carried out using IBM® SPSS® Statistics for Windows (Statistical Package for the Social Sciences), software version 2.0.

1.4.2 Data analysis

Categorical variables in the tables are presented as frequencies, while quantitative variables are expressed as means ± standard deviation, unless otherwise specified.

To assess the distribution of all variables, the Kolmogorov-Smirnov test was used for the cross-sectional study, while the Shapiro-Wilk test was used for the case-control study. The choice of normality test was determined based on the sample size at different stages of the study (Mishra et al., 2019). If the data did not conform to the assumptions of a normal distribution, nonparametric tests (Mann-Whitney test, Kruskal-Wallis test) were applied.

Injury incidence was determined by dividing the number of injuries by the population at risk of an injury within a one-year time frame, and the results were represented as the number of injuries per 1,000 person-years.

For the case-control study, logarithmic transformation was applied to continuous gait-related variables when necessary to achieve a normal distribution. If log-transformation did not result in an approximately normal distribution, nonparametric tests were used. Differences in gait within the same group were evaluated using paired t tests or Wilcoxon signed rank tests (Breslow & Day, 1980). Data collected from both the right and left sides were used in the statistical analysis of plantar pressure, stride time, stride length and step asymmetry, but data from the right side only were used for the analysis of foot contact angle, rearfoot angle, and angular velocities. To assess the differences in gait-related parameters between the study groups and under both barefoot and shod conditions, the point biserial correlation r was used (Nakagawa & Cuthill, 2007). The effects sizes were classified into three levels: 0.1 indicated a small effect, 0.3 indicated a medium effect, and 0.5 represented a large effect (Cohen, 2016).

Conditional logistic regression analysis was performed using the COXREG function in SPSS to explore the impact of statistically significant gait-related factors on the probability of lower limb overuse injury. Furthermore, for statistically significant gait parameters, receiver operating characteristic (ROC) analysis was used to assess the area under the curve (AUC). Specificity, sensitivity, and cut-off value were based on the Youden index (Fluss et al., 2005).

2 Results

2.1 Cross-sectional study results

N = 227 active duty infantry soldiers participated in Stage I, 94 % of study participants were male (Table 2.1).

Table 2.1

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)

*Continuous variables are presented as mean ± standard deviation, categorical variables are presented as % (n).

2.1.1 Self-reported injury incidence

Active-duty infantry soldiers reported 197 musculoskeletal injuries and the overall incidence rate of injuries in 2017 was 867.8 injuries per 1,000 person-years (95 % CI 824.8–913.0). The incidence rate of acute injury was 436.1 injuries per 1,000 person-years (95 % CI 376.1–505.6); overuse injury was 431.7 injuries per 1,000 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).

Acute injuries predominantly affected the lower leg, ankle, knee, wrist, and shoulder. Among these injuries, the most common types were sprains (n = 29), followed by superficial contusion injuries (n = 24), fractures (n = 21), and joint dislocations (n = 21). The Barell injury matrix with the absolute numbers of acute and overuse injuries listed is presented in Table 2.2.

Table 2.2

Barell injury matrix for acute and overuse injuries

Body region of injury			**Fracture**	**Dis-location**	**Sprains and strains**	**Open wound**	**Contu-sion or super-ficial**	**Burns**	**Nerves**	**Total, by body region**	
										AI* (n)	**OI* (n)**
Torso		Chest (thorax)	1	–	–	–	–	–	–	1	1
		Pelvis and urogenital	–	–	–	–	1	–	–	1	-
		Back and buttocks	–	–	1	–	2	–	–	3	42
Extremities	Upper	Shoulder and upper arm	3	4	2	–	1	–	–	10	4
		Forearm and elbow	–	–	2	–	4	–	–	6	6
		Wrist, hand, and fingers	3	1	1	2	2	1	–	10	1
	Lower	Hip	–	–	–	–	1	–	–	1	–
		Upper leg and thigh	–	–	1	–	4	–	1	6	–
		Knee	–	2	5	–	5	–	–	12	15
		Lower leg and ankle	11	14	16	–	–	–	–	41	17
		Foot and toes	3	–	1	–	4	–	–	8	12
Total by injury type			21	21	29	2	24	1	1	99	98

*AI – acute injuries, OI – overuse injuries.

2.1.2 Military footwear comfort rating

Differences in military boot comfort rating between male and female groups were independent of the history of overuse injury (Table 2.3). The mean comfort ratings of military boots among male group were higher in all dimensions, but the difference from the female group was not statistically significant.

Table 2.3

Military footwear comfort ratings among infantry soldiers

Comfort dimension	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 ± standard deviation; one-way ANOVA test compared the injured and non-injured groups.

2.2 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. The foot arches of the study participants were predominantly classified as normal (AI = 0.26). There were no significant differences in FPI values between feet or groups ($\chi^2(1) = 0.15$, p = 0.70) (Table 2.4).

Table 2.4

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

Table 2.4 continued

	Cases (n = 32)	Controls (n = 34)	P*
Position of the left foot			0.70
Supinated foot	n = 6	n = 2	–
Neutral foot	n = 19	n = 25	
Pronated foot	n = 7	n = 7	
AI	0.26 ± 0.06	0.26 ± 0.08	0.60
Position of the right foot			0.70
Supinated foot	n = 4	n = 1	–
Neutral foot	n = 25	n = 27	
Pronated foot	n = 3	n = 6	
AI	0.26 ± 0.07	0.26 ± 0.7	0.60

*P values based on the Mann-Whitney test, foot posture determined using Foot Posture Index, AI – arch index.

2.2.1 Footwear sizing analysis

The footwear sizing analysis showed that 57.6 % (n = 38) of all study participants used an inappropriate military boot size: 30.3 % between cases (n = 20) and 27.3 % in the control group (n = 18) (Table 2.5).

Table 2.5

Military footwear size preferences among infantry soldiers

	Total (n = 66)	Cases (n = 32)	Controls (n = 34)	P*
Self-selected shoe size, EU ± SD	43 ± 1.5	43.5 ± 1.6	43 ± 1.4	0.04
Measured shoe size, EU± SD	43.6 ± 1.6	43.9 ± 1.6	43.4 ± 1.5	< 0.01
Inappropriate shoe size usage, % (n)	57.6 (38)	62.5 (20)	52.9 (18)	0.16

*European footwear sizes (EU) compared using the Chi-square test; SD – standard deviation.

2.2.2 Military footwear comfort and overuse injury history

Independent of the history of lower limb overuse injuries, the study participants who wore the incorrect military boot size in cases and controls showed lower perceived comfort ratings of military footwear (Table 2.6).

Table 2.6

Comparison of military shoe comfort rating among study participants

	Subjects wearing inappropriate shoe sizes (n = 38)		**Subjects wearing suitable shoe sizes (n = 28)**		**$\chi^2(1)$**	**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, standard deviation is given in brackets, and significant results are marked in bold.

2.2.3 Plantar pressure assessment

Differences in peak plantar pressure values (Figure 2.2) were evident in the forefoot and rearfoot regions between the case and control groups, with higher values observed in the case group (Table 2.7) Statistically significant differences were observed between the groups only for the hallux ($\chi^2(1) = 6.8$; $p = 0.01$), medial ($\chi^2(1) = 5.18$; $p = 0.02$), and lateral ($\chi^2(1) = 12.12$; $p < 0.01$) rearfoot regions.

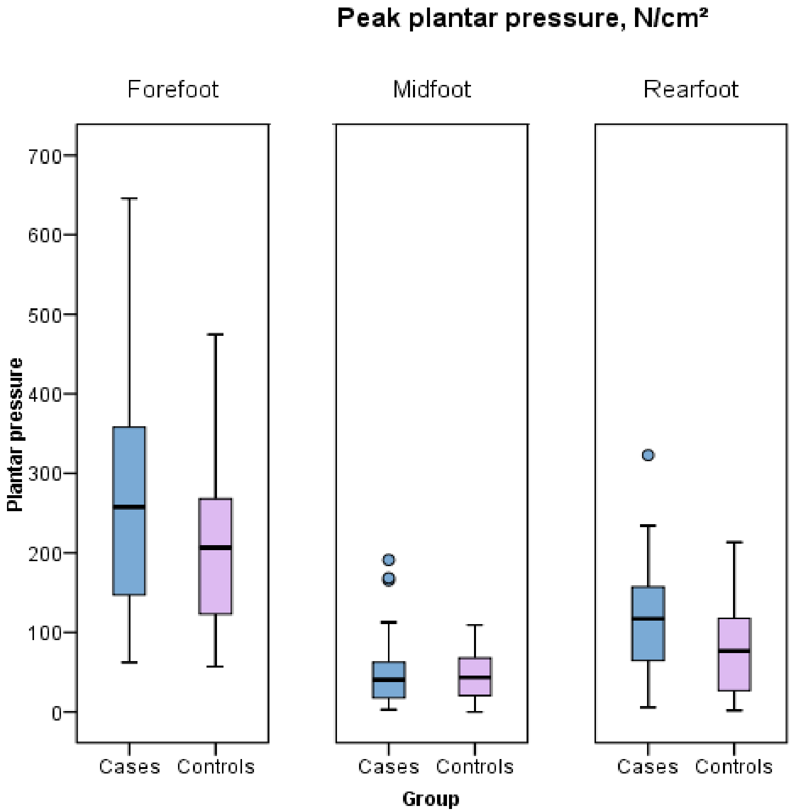

Figure 2.2 **Peak plantar pressure distribution during barefoot walking among cases and control groups for different foot regions**

Table 2.7

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

		Cases		Controls		$\chi^2(1)$	P
		Foot					
		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

*MTH – metatarsal head; all pressure values are in N/cm^2; Kruskal-Wallis test results with standard deviation in brackets.

In the case group, the median range of the degree of peak plantar pressure asymmetry (SI) varied from 1 % to 45 % in different foot regions, with the exception of the medial heel, where perfect symmetry was observed. On the contrary, the control group showed a lower range of SI values, approximately between 7 % and 16 %. Both groups showed perfect symmetry in the peak plantar pressure under the fifth metatarsal head (5th MTH). Furthermore, perfect symmetry was observed under the lesser toes and third MTH in the control group (Table 2.8.).

Table 2.8

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
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

*MTH – metatarsal head; Mann-Whitney test results with standard deviation in brackets, negative value indicates greater pressure on the left foot.

2.2.4 Gait analysis results

Significant differences were observed in the characteristics of barefoot and shod gait between the case and control groups ($p < 0.001$) (Table 2.9). When comparing shod gait with barefoot gait, the case and control groups showed prolonged stride length ($r = 0.64$), reduced step asymmetry index, and less variable stride time ($r = 0.52$). In the barefoot walk, statistical differences were found in stride time ($p = 0.053$; $r = 0.31$) and stride time variability ($p = 0.030$; $r = 0.85$) between the study groups. During the shod walk, the only difference between the case and control groups was in stride time ($p = 0.048$, $r = 0.36$).

Analysis of foot and ankle motion while walking in military boots and barefoot revealed variations in both groups, although there were no differences between cases and controls. The rearfoot eversion angle and angular velocities decreased as the foot contact angle increased during shod walking (Table 2.10).

Table 2.9

Spatiotemporal gait parameters for case and control groups

	Cases	Controls	P*
Walking barefoot			
Stride time, s	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
Shod walking			
Stride time, s	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, m	1.34 ± 0.26	1.32 ± 0.30	0.57
Stride length variability, %	0.81 ± 0.73	0.72 ± 0.63	0.63

*Paired t-test results, s – seconds, m – metres.

Table 2.10

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.

2.2.5 Regression analysis

Univariate and multivariate conditional logistic regression analyses revealed that only stride time variability during barefoot gait is a statistically significant predictor of the risk of lower leg overuse injury (Table 2.11).

Table 2.11

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	0.009	0.007	0.928	0.131

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

The ROC analysis of barefoot stride time variability resulted in an AUC of 0.77 (p = 0.001; 95 % CI 0.648–0.883). According to the Youden index, the optimal cutoff value for stride time variability was 1.95 %, which could predict lower leg overuse injury with sensitivity 56 % and specificity 88 % (Figure 2.3).

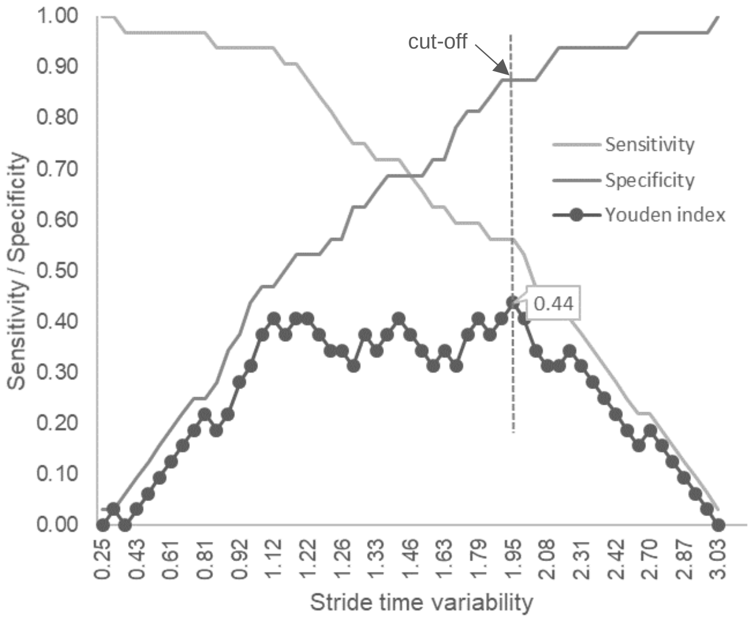

Figure 2.3 **Sensitivity, specificity, Youden index and cut-off value for stride variability**

3 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 analyse their probable association with military footwear use 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 military footwear use. Furthermore, after a thorough examination of military footwear comfort, it was discovered that improper footwear sizing had an adverse effect on footwear comfort regardless of the history of injury. Additionally, barefoot stride time variability was found to be significantly associated with lower leg overuse injury in the military. Based on these results, the restriction of the reference range of stride time variability could be considered among military and other physically active populations. Therefore, future prospective studies among healthy individuals are needed for the evaluation of stride time variability as a risk factor for overuse injury.

This 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). This thesis also provides an overview of the most common acute and overuse MSKI types and their specific anatomical locations among infantry soldiers. 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. In addition, it offers valuable data on foot function, comfort and fit of shoes, and gait variability by comparing groups of previously injured and uninjured infantry soldiers.

The studies included in the thesis have few limitations, mainly related to the design of the studies conducted. 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 the 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). The grouping of the case-control study could shift the results due to the recall bias of the injury history, so an analysis of medical records was also performed to confirm the injury status. Furthermore, the author believes that the interview responses were true, since the study participants were assured that the study results would not affect their annual medical check-up status and were given a day off during the research period.

Calculating the incidence rate of injuries 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 systematically classified self-reported incidence statistics of acute and overuse MSKI sites among Latvian Land Forces infantry personnel using a Barell injury matrix. Previous research found that self-reported injury data were more accurate than medical record data, which supports 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. The numbers 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 comprehensive picture of the incidence of MSKI. Furthermore, systematic injury monitoring should continue, as it allows to implement and assess 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 plantar pressure system utilised (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, the 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 of the limitations, plantar pressure is a simple gait kinetic measurement that allows evaluating symmetry of lower extremity loading during walking. Although wide variations in plantar pressure data have been observed among Latvian infantry soldiers, the single plantar pressure value that could indicate the onset of foot MSKI remains unknown (Wafai et al., 2015). More research is needed to investigate how plantar pressures could be related to MSKI.

Plantar pressure assessment showed a significant degree of asymmetry in previously injured infantry soldiers. This suggests that there is an uneven distribution of lower extremity loads and an imbalance during the gait cycle, despite the assessment being conducted in a controlled gait laboratory environment without external load, and all study participants have recovered from their injuries. Foot skin inspection should be performed regularly since foot skin disorders could be an indicator of asymmetric motion of the lower extremities during gait (Grouios, 2005). Furthermore, plantar pressure measurement and Footscan® software provided reliable digital footprint length measurement that is admitted to be similar to 3D foot scan measurement (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 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 military 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. Foot dimension measures with the Brannock device or 3D foot scan are needed to provide comfortable use of military or other occupational footwear.

Gait kinematics assessment with motion tracking markers limits the precision of results. Due to soft tissue artefacts (STA), markers can be a source of error in the kinematic data of the ankle and foot joint. 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 (thesis author) 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 at 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 the shod gait, 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, tactical boots with holes could not be worn by soldiers afterward 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 biomechanics 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. Nonneutral 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 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.

List of publications, reports and patents on the topic 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).
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).
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).
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).

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 and oral presentation in 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 online at 18th World Congress of the International Society for Prosthetics and Orthotics.
6. Nesterovica, D. (2020). *Definition of the lower extremity overuse: A review*. Abstract 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 in 10th International Baltic Sports Medicine Congress, European Journal of Sports Medicine, vol.5. (Suppl.2), 32, https://www.eujsm.eu/index.php/EUJSM/article/view/171/81
8. Nesterovica, D., Vaivads, N., Stepens, A. (2018). *Musculoskeletal overuse injury prevalence and comfort perception of military boots*. Abstract in I. Kokina (Ed.), Proceedings of the International Scientific Conference of Daugavpils University, part A: Natural Sciences, 123–128, (EBSCOhost).

References

1. 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

2. 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

3. 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

4. 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

5. 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

6. Barovska, S. (2020). *Karavīru biežāk gūto traumu analīze nacionālo bruņoto spēku veselības aprūpes iestādē laika posmā no 2017. līdz 2020. gadam: bakalaura darbs*. Latvijas Universitāte.

7. 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

8. 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*.

9. 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

10. 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].

11. 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].

12. 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

13. 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

14. 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.

15. 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

16. 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

17. 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

18. 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

19. 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

20. 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

21. 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

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

23. 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

24. 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

25. 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

26. 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

27. 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

28. 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

29. 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

30. 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

31. 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

32. 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

33. 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

34. 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

35. 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

36. 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.*

37. 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

38. 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

39. 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

40. 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

41. 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

42. *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]

43. 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.

44. 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. Retrieved from http://www.openepi.com/SampleSize/SSCohort.htm [accessed 10.02.2019]

45. 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

46. Knapik, J. 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

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

48. 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

49. 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

50. *Latvian Environment, Geology and Meteorology Centre*. 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]

51. 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.

52. 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

53. 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

54. 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

55. 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.

56. 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

57. 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

58. 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

59. 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

60. 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

61. 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

62. 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

63. 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

64. 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

65. 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

66. 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.

67. 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

68. 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

69. 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

70. 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

71. 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

72. 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

73. 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

74. 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

75. 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

76. 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

77. 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

78. 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

79. 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

80. 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

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

82. 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

83. 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

84. 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

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