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ORIGINAL RESEARCH

Static and dynamic plantar foot shape following long-term use of military boots

Vahid Sobhani[1], Hossein Nabavinik[2], Shirin Aali[3], Georgian Badicu[4,*], Luca Paolo Ardigò[5]

[1] Exercise Physiology Research Center, Lifestyle Research Institute, Baqiyatallah University of Medical Sciences, 009821 Tehran, Iran
[2] Department of Sport Sciences, Faculty of Literature and Human Sciences, Lorestan University, P.O. Box 44316-68151, 009866, Iran
[3] Department of Physical Education, Farhangian University, P.O. Box 14665-889, 009821, Iran
[4] Department of Physical Education and Special Motricity, Faculty of Physical Education and Mountain Sports, Transilvania University of Braşov, 500068 Braşov, Romania
[5] Department of Teacher Education, NLA University College, 0166 Oslo, Norway

***Correspondence**
georgian.badicu@unitbv.ro
(Georgian Badicu)

Abstract

Foot structure can be influenced by various factors, such as footwear, body weight and physical activity. A change in foot structure can alter shock absorption and force transition. The main objective of this study is to investigate the effect of the long-term use of military boots on foot shape parameters. Thirty military and thirty non-military subjects participated in this case-control study. All participants had been regularly wearing military boots for the past 12 years. After introducing the experiment, static and dynamic footprints were recorded via paper and ink while standing and walking. The footprints were analysed using ImageJ software to extract foot width indices, area indices, truncated arch index, footprint index and arch angle index. The findings indicated no significant difference in comparison static and dynamic variables in the military and non-military groups ($p \geq 0.05$). However, there was a significant difference between the two groups in both static (midfoot area, arch index (AI), truncated arch index, footprint index and arch angle index) and dynamic (midfoot width, Staheli Index (SAI), truncated arch index and arch angle index) conditions, when static and dynamic variable were compared ($p < 0.05$). Findings revealed the military personnel have low arch, making them susceptible to musculoskeletal disorders. To mitigate this risk, it is recommended that military boots be reassessed or that insoles be used. Furthermore, it is suggested that military boots be limited to specific activities and fewer hours of usage to avoid potential health issues.

Keywords

Military personnel; Military boot; Foot biomechanics; Foot deformities; Gait

1. Introduction

Foot is the complex structure comprised of 26 bones, more than 30 joints, numerous ligaments, tendons and intra- and extra-articular muscles [1]. This structure's function during walking and other tasks is influenced by footwear [2], the walking or running surface [3], and anatomical factors [4]. Any change in these factors can affect the foot and ankle joint's primary functions of shock absorption and propulsion [5]. Footwear, in particular, plays a significant role in altering foot shape and anatomy [6].

Previous studies have examined foot dimensions and volume to investigate disease, swelling, and short-term effects of activities like running [7]. Military boots, used during marching and running, can impact foot function [8]. Additionally, carrying loads, typical military settings, can exacerbate these effects, leading to changes in foot dimensions. Changes in foot dimensions may be temporary, occurring with weight-bearing activities [9]. However, athletes and individuals with long-term weight-bearing activities, such as football players and those with obesity, often experience permanent changes in foot structure [10–13].

Military boots can increase ground reaction forces (GRFs) [14], potentially contributing to musculoskeletal disorders [14]. While foot dimensions might not significantly change [6], alterations in GRFs and plantar pressure distribution can lead to inadequate foot performance [15], possibly resulting in deformities and musculoskeletal issues. Despite meeting certain specifications, military boots may not fit well due to individual variations in foot geometry, causing further problems. Discrepancy between the foot and the shoe can impact foot performance [16].

Military boots' characteristics, such as stiffness and curvature, affect activities like standing, weight-bearing and military carrying [14, 17], potentially leading to musculoskeletal disorders [18], changes in GRFs [14] and pressure distribution patterns [19]. Previous studies have compared different types of military boots and their effects on foot structure, finding mixed results regarding their impact. Studies have also examined the use of insoles [20], compared different types of military boots to each other [21], and compared them to other kinds of shoes [22], yielding varied results.

While previous research has investigated various factors affecting foot anatomy in cross-sectional studies, the impact of prolonged boot use on foot anatomy remains to be determined. Understanding this issue is crucial because military boots can significantly impact foot function and, over time, may lead to musculoskeletal health issues and injuries. This study investigates the static and dynamic plantar foot shape in individuals who have regularly worn military boots for at least 12 years. The research explores the characteristics of foot shape in static and dynamic states following the long-term use of military boots, providing insights into the potential long-term effects on foot health and overall musculoskeletal function.

2. Methods

2.1 Subjects

Sixty male participants, 30 military personnel and 30 non-military, with no history of conditions affecting balance or walking, eye problems, trauma or systemic diseases, were included in the study. Additionally, the military group consisted of individuals who engaged in regular physical activity similar to the general population. The sample size was determined using G*Power software (Version 3.1, Kiel, SH, Germany). An effect size of 0.6, with an alpha error level of 0.05 and a power of 0.8, resulted in approximately 22 participants per group. As previously mentioned, each group in this study comprised a total of 30 participants. However, due to the quality of the footprints obtained, the number of participants available for analysis in the static condition was 28 in the military group and 26 in the non-military group. In the dynamic condition, the number of footprints suitable for analysis was 22 participants in both the military and non-military groups (Fig. 1). A general practitioner verified their medical history. Military personnel had been wearing military boots for 12 years, six days a week for approximately 8 hours. The specifications of their military boots included Polyurethane sole (PU) and leather upper, they were manufactured in Iran.

2.2 Tool

Using gouache ink which was safe for the subjects' health, 80-gram writing sheets measuring 70 × 200 cm were used to capture both static and dynamic footprint. This document was used as a walkway. The subject's footprint was captured as it passed over the gouache-stained stamp at one end of the paper before moving on to the other. Previous studies have validated the use of ink footprints as a reliable measure for both static and dynamic foot shape [23–27]. The gouache ink provides a clear and precise imprint, ensuring accurate measurement and analysis.

2.3 Procedure

Participants underwent both static and dynamic assessments to evaluate their footprints. Initially, they were instructed to stand comfortably while facing forward on a gouache-painted stump for the static footprints. The body weight was evenly distributed on both legs, and participants were asked to stand and gaze at a sign fixed at head height on the wall. This exercise was repeated several times to ensure consistent results, with the optimal foot posture chosen after confirming regular and proper standing in three trials.

For the dynamic assessment, participants were instructed to walk naturally without looking at their feet, while maintaining their heads on the Frankfort plane. A gouache-painted stamp was positioned along the walkway. As participants reached the stamp, their footprints were recorded on the paper. The process was repeated for three walks, with the optimal footprint selected after participants thoroughly understood the procedure and had completed several repetitions of the task.

For both static and dynamic assessments, the optimal footprints were chosen based on a systematic approach. The key criteria for selecting the optimal footprints included:

Consistency: Repetition of the trials (three times for each condition) ensured consistency in the footprints.

Stability: In the static assessment, stability and even weight distribution were confirmed by repeating the exercise and choosing the most stable footprint.

Normal Gait: In the dynamic assessment, footprints were selected after ensuring that participants walked naturally and maintained the correct posture, as indicated by several repetitions.

2.4 Data processing

Lastly, a scanner (Scanjet G2710, HP, Palo Alto, CA, USA) with a resolution of 200 dpi was used to scan the footprint and it was stored in JPG format. Then, Footprint parameters were extracted using the 32-bit Windows version of Image software. The right foot of each subject was analyzed to extract variables which are as follows:

Foot width indices: The intersection of the line with the side of the heel (most medial point of the heel area) and the metatarsal region (most medial point of the metatarsal area) was identified using the line on the medial side of the foot which was called long axis (Fig. 2). The widest line was then drawn in the forefoot (A) and rear of the foot from these regions (C) as forefoot and rearfoot width respectively. Minimal width of the foot in the arch area was considered as midfoot width (B) [23]. The SAI is the ratio of midfoot width (B) to rearfoot width (C) midfoot width [23]. Chippaux-Smirak index (CSI) defined as the ratio of the midfoot width (B) to forefoot width (A) [23, 28] (Fig. 2).

Area foot indices: The first, the foot axis (line from center of heel to second toe) was determined. Without including the toes, the foot axis is divided into three equal sections [23, 28]. The horizontal lines are perpendicular to the foot axis, and then the forefoot, midfoot and rearfoot area is calculated. The area in Fig. 2 are labeled A, B and C, accordingly. The total contact area index (CAI) is equal to the area of the entire foot excluding the toe (A + B + C) [23, 28]. Finally, AI is calculated as the ratio of the midfoot area to CAI.

Truncated arch index: The truncated arch index was defined as the ratio of non-contact area to truncated footprint area. The index is determined by drawing the long axis and two perpendicular lines intersecting the contact area of the long axis with the metatarsal and heel areas of the foot [28] (Fig. 2).

Footprint index: The ratio of the non-contact area to CAI, is known as the footprint index (Fig. 2). The distance between the long axis and the medial edge of the footprint is known as

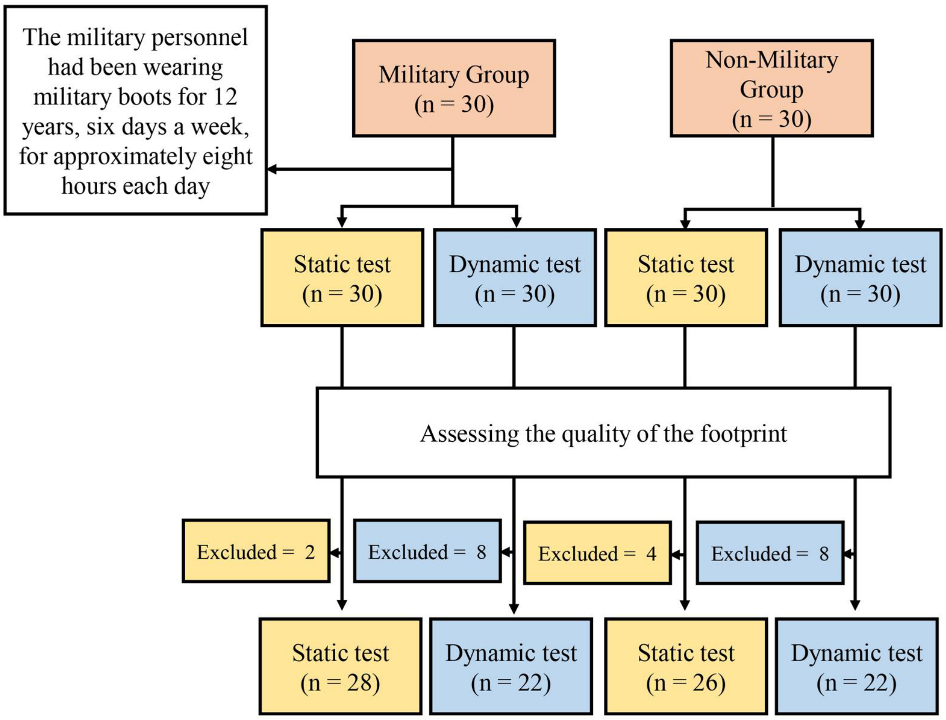

FIGURE 1. Flowchart of participant recruitment in the case-control study. This flowchart details the step-by-step process of participant recruitment, from initial population screening and eligibility assessment, to informed consent, and the final selection of case and control groups for the study.

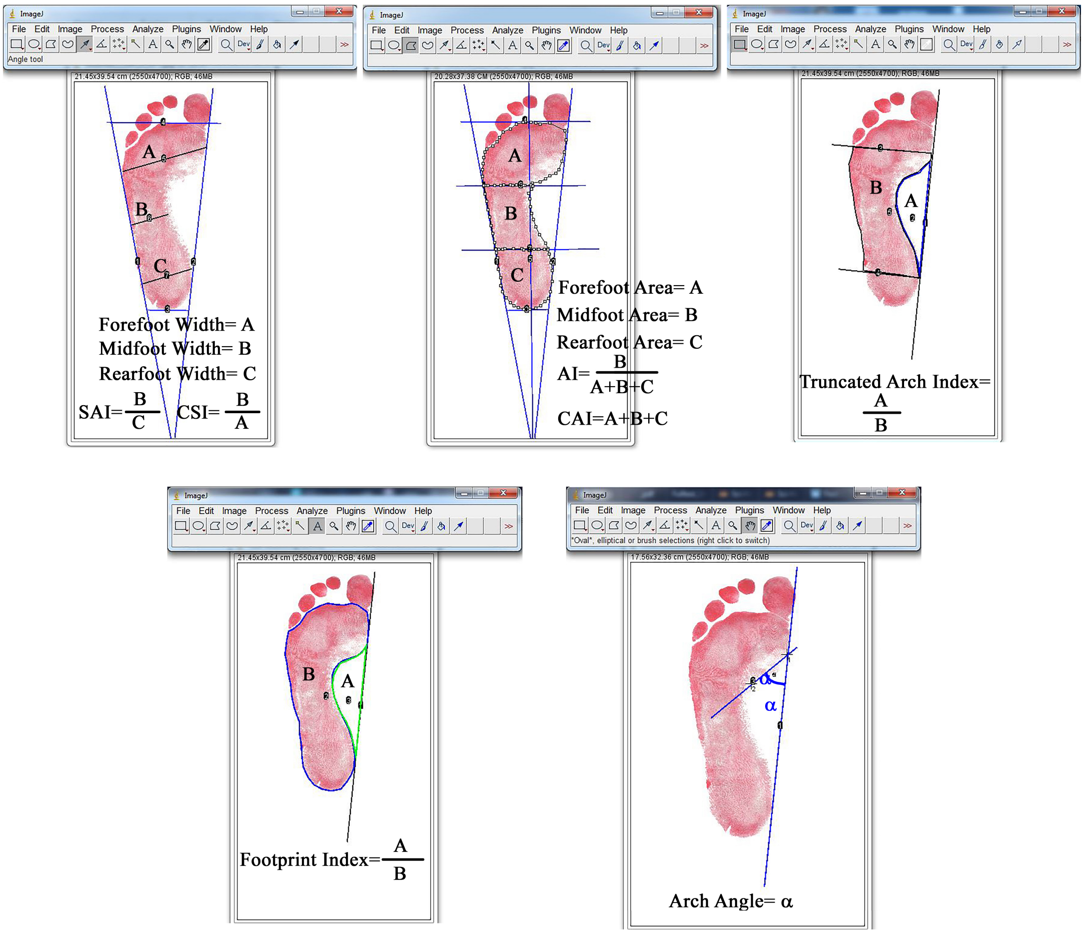

FIGURE 2. Measurement of footprint variables using ImageJ software.

the non-contact surface [23, 28].

Arch angle index: The arch angle index was obtained by measuring the angle of a long axis that connects the medial edges of the first metatarsal head and the heel, and the second line that connects the first metatarsal head and the highest point of the medial longitudinal arch concavity [29] (Fig. 2).

2.5 Statistical analysis

Data were analyzed using SPSS software, version 27 (IBM SPSS Software, Chicago, IL, USA). The Kolmogorov-Smirnov test was used to assess the normality of data distribution. To compare the footprint parameters in static and dynamic conditions within each group, and to account for confounding factors such as weight and height, generalized linear models (GLMs) were employed. Weight and height were included as covariates in the GLMs to adjust for their impact on the footprint parameters. Statistical significance was set at a level of 0.05.

3. Results

Based on demographic data, the military group had a mean height of 174.02 ± 5.84 cm, weight of 83.02 ± 11.19 kg and age of 35.05 ± 7.09. Similarly, the non-military group had a mean height of 171.24 ± 15.62 cm, weight of 77.73 ± 16.47 kg and age of 34.67 ± 8.06.

In the intra-group comparison between static and dynamic positions within both military and non-military groups, no significant differences were observed in any of the Foot Width Indices, Area Foot Indices, Truncated Arch Index, Footprint Index and Arch Angle Index, as shown in Table 1 ($p > 0.05$).

The analysis compared static footprint parameters between military and non-military groups, as shown in Table 1. A significant difference was found between the two groups in terms of footprint parameters. The military group had a significantly larger midfoot area (Mean (M) = 32.29, standard deviation (SD) = 6.82, $p = 0.04$) than the non-military group (M = 27.01, SD = 4.71) and higher AI (M = 0.28, SD = 0.08, $p = 0.04$) compared to the non-military (M = 0.25, SD = 0.02). On the other hand, the truncated arch index was significantly lower in military group (M = 0.36, SD = 0.12, $p = 0.04$) than in the non-military group (M = 0.46, SD = 0.12) and the footprint index was also significantly lower in the military group (M = 0.24, SD = 0.07, $p = 0.03$) than in non-military group (M = 0.30, SD = 0.07). Finally, the military group had a significantly smaller arch angle (M = 36.48, SD = 7.59, $p < 0.001$) than the non-military group (M = 44.76, SD = 7.46).

The analysis compared dynamic footprint parameters between military and non-military groups, as illustrated in Table 1. Specifically, the midfoot width was significantly greater in the military group (M = 3.95, SD = 0.59, $p = 0.04$) compared to the non-military group (M = 3.51, SD = 0.55). Additionally, the military group exhibited a significantly higher value for the SAI (M = 0.74, SD = 0.11, $p < 0.001$) than the non-military group (M = 0.67, SD = 0.10). Furthermore, the non-military group demonstrated a significantly higher value for the truncated arch index non-military (M = 0.43, SD = 0.08, $p = 0.01$) than the military group (M = 0.34, SD = 0.11). Finally, the non-military group had a significantly higher value in the arch angle (M = 42.00, SD = 6.00, $p = 0.04$) than the military group (M = 36.11, SD = 7.19).

4. Discussion

This study investigated the static and dynamic plantar foot shape after the long-term use of military boots. The findings support that wearing boots daily for 12 years can alter the anatomical structure of the foot. Although there is no research on the long-term effects of military boots, existing studies in the field of weight-bearing and athletic activities can help draw conclusions. As previously reported, structural changes in the foot could be temporary, like weight-bearing, or permanent, like sports' effects on joint support structures. Houston *et al.* [30] demonstrated a general 71% change in foot parameters occurred during full weight-bearing. However, these changes begin after tolerating 25% of body weight [30]. Other studies on weight-bearing have shown similar results [31, 32]. Sports activities can also result in permanent changes, rather than the temporary changes associated with weight-bearing alone.

Aydog *et al.* [33] found that gymnasts and wrestlers exhibit significantly different static AI index scores compared to non-athletes, while handball players and gymnasts also show significant differences. Similarly, Berdejo-del-Fresno reported that hockey can lead to decreased foot arches. At the same time, futsal is associated with an increase in the CAI Index and a decrease in Hernández Corvo [34]. These results of our research support these findings. One potential reason for this could be the extended stress or load that an individual undergoes, similar to engaging to sports activities [11, 35]. Some studies have also discussed the impact of footwear structure on foot anatomy. For example, research comparing running shoes, therapeutic footwear and minimal footwear has shown that the thinner the sole and the greater the range of motion allowed by the shoe upper, similar to barefoot conditions, the stronger the muscles and the more robust the longitudinal arch of the foot. This concept is particularly relevant to military boots, which impose significant restrictions on both the sole and the upper part of the boot. These restrictions likely profoundly impact on the foot structure of military personnel [36, 37].

Numerous studies have examined military boots' impact on musculoskeletal disorders [18], weight-bearing [38], and foot soles [20]. Findings have confirmed musculoskeletal disorders such as stress fractures, increased force on the foot and GRFs. The present study provides insights into the causes of common injuries reported in earlier studies. This is because the feet of the subjects are evaluated base on value of the AI, SAI, CSI and arch angle indices in both static and dynamic as a low arch [39]. The factor that can impact usage long-term are the type of footwear and weight-bearing. Although military boot differs in design (shaft), weight (heavier) and sole flexibility (harder) compared to sports shoes, there are difference in GRFs within a specific type of running shoe and military boot [14]. According to Muniz, thicker SBR (styrene-butadiene rubber) soles reduce heel-strike impact forces, in contrast, PU (polyurethane) soles are lighter and more comfortable [21]. These studies highlight the crucial role of shoe soles in controlling forces, and their findings suggest the need for further research on the final

TABLE 1. Comparison of intra- and inter-group static and dynamic footprint variable in military and non-military groups.

Variable	Group	Static	Dynamic	Within group (static-dynamic)
		Mean ± SD (95% CI)	Mean ± SD (95% CI)	
Forefoot Width (cm)				
	Military	9.55 ± 0.62 ([9.31–9.80]), n = 28	9.34 ± 0.58 ([9.07–9.59]), n = 22	0.17
	Non-Military	9.57 ± 0.49 ([9.37–9.76]), n = 26	9.34 ± 0.46 ([9.13–9.54]), n = 22	0.10
Midfoot Width (cm)				
	Military	3.85 ± 0.55 ([3.63–4.06]), n = 28	3.95 ± 0.59[‡] ([3.69–4.22]), n = 22	0.67
	Non-Military	3.52 ± 0.60 ([3.28–3.76]), n = 26	3.51 ± 0.55[‡] ([3.26–3.75]), n = 22	0.93
Rearfoot Width (cm)				
	Military	5.22 ± 0.38 ([5.07–5.36]), n = 28	5.32 ± 0.31 ([5.19–5.46]), n = 22	0.40
	Non-Military	5.26 ± 0.44 ([5.08–5.44]), n = 26	5.26 ± 0.53 ([5.02–5.49]), n = 22	0.62
SAI				
	Military	0.74 ± 0.11 ([0.69–0.78]), n = 28	0.74 ± 0.11[‡] ([0.69–0.79]), n = 22	0.97
	Non-Military	0.66 ± 0.09 ([0.63–0.70]), n = 26	0.67 ± 0.10[‡] ([0.63–0.71]), n = 22	0.81
CSI				
	Military	0.40 ± 0.06 ([0.37–0.42]), n = 28	0.42 ± 0.07 ([0.39–0.46]), n = 22	0.39
	Non-Military	0.37 ± 0.06 ([0.34–0.39]), n = 26	0.37 ± 0.05 ([0.35–0.40]), n = 22	0.60
Forefoot Area (cm^2)				
	Military	50.77 ± 10.47 ([46.71–54.83]), n = 28	50.72 ± 12.07 ([45.36–56.07]), n = 22	0.93
	Non-Military	50.36 ± 5.06 ([48.32–52.41]), n = 26	50.43 ± 4.54 ([48.41–52.44]), n = 22	0.94
Midfoot Area (cm^2)				
	Military	32.16 ±7.11[†] ([29.40–34.92]), n = 28	31.88 ± 5.87 ([29.28–34.49]), n = 22	0.47
	Non-Military	27.96 ± 6.37[†] ([25.39–30.53]), n = 26	28.08 ± 4.50 ([26.09–30.07]), n = 22	0.96
Rearfoot Area (cm^2)				
	Military	30.94 ± 2.74 ([29.87–32.00]), n = 28	32.37 ± 4.46 ([30.39–34.35]), n = 22	0.56
	Non-Military	31.71 ± 4.25 ([29.99–33.43]), n = 26	31.85 ± 4.26 ([29.96–33.74]), n = 22	0.68
AI				
	Military	0.28 ± 0.08[†] ([0.25–0.31]), n = 28	0.28 ± 0.08 ([0.24–0.32]), n = 22	0.73
	Non-Military	0.25 ± 0.03[†] ([0.24–0.26]), n = 26	0.25 ± 0.02 ([0.24–0.26]), n = 22	0.99

TABLE 1. Continued.

Variable	Group	Static	Dynamic	Within group (static-dynamic)
		Mean ± SD (95% CI)	Mean ± SD (95% CI)	
CAI Index (cm^2)				
	Military	113.87 ± 10.99 ([109.61–118.14]), n = 28	114.97 ± 14.41 ([108.58–121.36]), n = 22	0.81
	Non-Military	110.82 ± 14.45 ([109.43–115.88]), n = 26	110.37 ± 11.69 ([105.18–115.54]), n = 22	0.87
Truncated Arch				
	Military	0.36 ± 0.12† ([0.32–0.41]), n = 28	0.34 ± 0.11‡ ([0.29–0.39]), n = 22	0.84
	Non-Military	0.46 ± 0.12† ([0.41–0.51]), n = 26	0.43 ± 0.08‡ ([0.40–0.47]), n = 22	0.55
Footprint Index				
	Military	0.24 ± 0.07† ([0.21–0.27]), n = 28	0.24 ± 0.08 ([0.20–0.27]), n = 22	0.86
	Non-Military	0.30 ± 0.07† ([0.26–0.33]), n = 26	0.28 ± 0.05 ([0.25–0.30]), n = 22	0.60
Arch Angle (degree)				
	Military	36.48 ± 7.59† ([33.54–39.43]), n = 28	36.11 ± 7.19‡ ([32.92–39.30]), n = 22	0.86
	Non-Military	44.76 ± 7.46† ([41.74–47.77]), n = 26	42.00 ± 6.00‡ ([39.33–44.65]), n = 22	0.19

†*indicates significantly different static footprint between military and non-military group* ($p < 0.05$); ‡*indicates significantly different dynamic footprint between military and non-military* ($p < 0.05$); *Abbreviation: SAI, Staheli index; CSI, Chippaux-Smirak index; AI, arch index; CAI, contact area index; SD, standard deviation; CI, confidence interval.*

material composition and thickness of soles. Hinz *et al.* [40] examined pressure distribution patterns at the metatarsal level using various insoles in German soldiers' boot to prevent march fractures. It has been found that flexible insoles provide a more evenly distributed pressure compared to regular insoles.

On the other hand, shock-absorbing insoles improve the distribution of forces in military boots when compared to regular insoles [41]. The study shows load transfer to the metatarsal heads during long-distance military marching based on the pressure distribution pattern, which can cause an increase in pressure on the medial longitudinal arch [6]. To mitigate injury risks from prolonged military boot use, it is essential to consider insole design and materials. Flexible insoles conform to the foot's shape, providing better support and comfort by allowing natural foot movement. In contrast, regular insoles are stiffer and can increase pressure points and discomfort. Shock-absorbing insoles, made from materials like gel or foam, reduce impact forces on the feet during activities. This is crucial in preventing injuries from the stiff, less adaptive military boots.

These findings indicate that the shape of the foot changes from a normal to a low arch under static and dynamic conditions due to prolonged use of standard military boots, commonly worn during various activities, including military marching, long-term standing, and military exercises. This extended use of boots can lead to stretching of ligaments and aponeurosis, resulting in discomfort [42] and alteration of foot structure in a static state. Moreover, it appears that the muscles cannot support the foot structure in both static and dynamic states, as supported by the low arch of the military group which can likely confirm this deformation. Additionally, long-term use of these boots can potentially cause damage, as even if the structure remains unchanged, it can alter the weight distribution on the foot [43] and is associated with musculoskeletal injuries [5]. However, it has been demonstrated that the medial longitudinal arch, one of the most crucial structures in the foot, is related to force transmission and absorption [44].

Although the footprint method has been validated in research, a foot scanner can provide more accurate results. Furthermore, analyzing foot pressure distribution can offer better insight into the long-term effects of military boot usage. Another limitation of the study is the lack of control over physical activity levels, as physical activity can also be a factor affecting foot shape. Additionally, the absence of female participants and control over the type of footwear in the non-military group are notable limitations that may have influenced the results.

5. Conclusions

The results of this study demonstrate that the feet of military personnel undergo prolonged deformation, as evidenced by differences between the two groups in indices such as AI, Arch angle index and Midfoot area under static and dynamic conditions. Therefore, it is suggested that insoles be utilized to mitigate the impact of military boots on the feet. Additionally, considering that some countries limit the use of boots to specific events or short periods, this practice is a potential solution to alleviate the effects of prolonged boot usage. Furthermore, future research should investigate the relationship between military injuries and the characteristics of military boots. Moreover, it is essential to recognize that everyday boots may increase the risk of musculoskeletal disorders.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the authors.

AUTHOR CONTRIBUTIONS

VS and HN—Conceptualization. SA—methodology. VS—software, formal analysis, data curation, project administration. HN, SA and VS—validation. HN—investigation, writing–original draft preparation. GB and LPA—resources. VS, HN, SA, GB and LPA—writing–review and editing. GB—visualization. LPA—supervision, funding acquisition. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved on Clinical Research Ethics Committees of Baqiyatallah University of Medical Sciences (IR.BMSU.REC.1397.268). Informed consent was obtained from all subjects involved in the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. Georgian Badicu is serving as one of the Editorial Board members of this journal. We declare that Georgian Badicu had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to DS.

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