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Artigo Original

Changes in Plantar Pressure Levels Generated Using Military Backpack During Standing Position: An Experimental Study

Alterações nos níveis de pressão plantar gerados pelo uso de mochila militar durante a posição em pé: um estudo experimental

Fabio Alves Machado[§1,2] MSc; Klinger Alex Fernandes[1] Esp; Marco Túlio Baptista[1] MSc; Trent Ray Nessler[4] PhD; Eduardo Camilo Martinez[1,2] PhD; Runer Augusto Marson[1] PhD

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Abstract

Introduction: The feet are one the main anatomical site affected by injuries arising from load carriage tasks and can negatively affect the soldier mobility reducing the operational capability of an entire military troops.

Objective: Identify the changes in the plantar pressure distribution during standing position carrying a military backpack with 15 kg, 20 kg, 25 kg, and no-load (NL) always comparing with control group; and examining if the combat boots contribute to decreasing the plantar pressure.

Methods: Twenty-four active-duty male military (26.4±5.6 years; 171.5±3.6 cm; 75.2±6.0 kg) were evaluated in standing posture using an insole baropodometry system wearing a military backpack. The Kruskal-Wallis test was used to check for differences and the Dunnett post hoc test to determine which groups were different from the control ($p \leq 0.05$).

Results: Data showed a significant decrease in plantar pressure in the forefoot no loaded when we compare barefoot (control = 54.02±19.56 kPa) versus wearing combat boots (35.30±13.00 kPa). With loads there was a significative increase in the plantar pressure only in the rearfoot (control = 74.18±3.80 kPa *vs* 15 Kg = 89.19±15.49 kPa, 20 Kg = 102.81±15.01 kPa, 25 Kg = 94.20±26.60 kPa).

Conclusion: Rearfoot is most affected by the load and boot promoted a significant decrease of plantar pressure in the forefoot in the NL group. Midfoot does not change the plantar pressure. This information can help to minimize the soldier's discomfort.

Key Points

- Backpack loads over 20kg probably stimulate changes in foot posture leading to repositioning the center of gravity and thus redistributing pressure on the soles of the feet.

- Plantar pressure in the rearfoot is load-dependent and in the forefoot and midfoot, it is shoe-dependent.

- The boot distributed by the Brazilian Army help to minimize the soldier's discomfort during military activities.

Keywords: biomechanical phenomena, plantar print, weight-bearing, military personnel, standing position.

[§]Corresponding Author: Fabio Alves Machado - e-mail: machado.fa@gmail.com
Affiliations: [1] Brazilian Army Research Institute of Physical Fitness - Rio de Janeiro – Brazil; [2]University of Trás-os-Montes and Alto Douro – Vila Real – Portugal; [3] Brazilian Army Center of Physical Fitness - Rio de Janeiro – Brazil; [4]Rebound Vitality – Milwaukee - EUA.

Resumo

Introdução: Os pés são um dos principais sítios anatômicos acometidos por lesões decorrentes de tarefas com transporte de carga, podendo afetar negativamente a mobilidade do soldado e reduzir a capacidade operacional de uma tropa militar.

Objetivos: Identificar as alterações na pressão plantar durante a postura estática usando mochila militar com 15 kg, 20 kg, 25 kg e sem carga (NL) comparando com um grupo controle; e verificar se coturno fornecido pelo Exército Brasileiro contribui para a redução da pressão plantar.

Métodos: Vinte e quatro militares do sexo masculino (26.4±5.6 anos; 171.5±3.6 cm; 75.2±6.0 kg) foram avaliados em posição ortostática usando um sistema de baropodometria de palmilhas. O teste de Kruskal-Wallis verificou as diferenças entre os grupos e o teste post hoc de Dunnett determinou quais grupos são diferentes do controle ($p \leq 0.05$).

Resultados: Os dados mostraram uma diminuição significativa da pressão plantar no antepé ao comparar a condição controle (54.02±19.56 kPa) com a condição sem carga (35.30±13.00 kPa). Com as cargas houve aumento significativo da pressão plantar apenas no retropé (controle = 74.18±3.80 kPa *vs* 15 kg = 89.19±15.49 kPa, 20 kg = 102.81±15.01 kPa, 25 kg = 94.20±26.60 kPa). Retropé é a região mais afetada pela carga.

Conclusão: O coturno promove uma diminuição significativa da pressão plantar no antepé em NL. O mediopé não altera a distribuição da pressão plantar. Essas informações podem auxiliar a minimizar o desconforto do soldado.

Pontos Chave

- Cargas da mochila acima de 20kg, provavelmente, estimulam mudanças na postura do pé, levando ao reposicionamento do centro de gravidade redistribuindo a pressão na planta dos pés.

- A pressão plantar no retropé é dependente da carga e no antepé e mediopé, é dependente do calçado.

- Os coturnos distribuídas pelo Exército Brasileiro ajudam a minimizar o desconforto do soldado durante as atividades militares.

Palavras-chave: fenômenos biomecânicos, impressão plantar, sustentação de peso, militares, posição em pé.

Changes in Plantar Pressure Levels Generated Using Military Backpack During Standing Position: An Experimental Study

Introduction

Humans spend a substantial proportion of their lifetimes in the standing position(1). In the human body the foot is a functional unit with a fundamental role for locomotion(2–4), attenuation of impact forces(5) and stability(6) as well providing sensorial information regarding the contact with the ground, which is important for balance and gait(3,6,7). Active and passive anatomy structures of the foot such as plantar arches, muscles, joint capsules and peripheral nervous system provide to the central nervous system information needed to control postural balance during standing position(8).

Workers of distinct professions need to hold the standing position for long time periods(9) and those situations have been associated with lower limbs discomfort and fatigue(10,11). Plantar pressure causes compression of soft and hard foot tissues and there is evidence suggesting that high plantar pressure plays a critical role for discomfort and foot pain development during prolonged standing position(12).

During their routine, for military personnel who are required to remain in standing position for long time periods, and often carrying heavy loads(13). Load carriage is a typical military activity and may become critical in situations during military operations(14). Therefore, to keep postural stability on support basis provided by the feet is one of the most important tasks for a soldier(15). Feet are the main anatomical site affected by injuries arising from load carriage tasks (16) and can negatively affect the soldier mobility and thus reduce the operational capability of an entire military team(17).

Plantar pressure measurements during both static and dynamic activities can provide detailed information for the evaluation of the human foot mechanical behavior, as well as, in its pathomechanics with the objective to track disease progression(18). Thus, to examine soldiers' footwear to improve the comfort in the standing position is important to better understand the mechanisms that cause discomfort.

Proper biomechanics of the foot exerts a significant role for the maintenance of body posture and symmetrical distribution of plantar pressure(19) as well as on postural control in the standing position and gait(20). High pressures in the plantar region caused by load carriage can lead to deformities and injuries that affect the feet such as stress fractures, callosities, pain, and neuropathic ulcerations(14,16,21,22). Therefore, the analysis of these pressures is important to provide information for the elaboration of a proposal with the objective of preventing diseases, pain, and postural disorders, especially in the feet(23). No study was identified analyzing the plantar pressure distribution during standing position with load carriage dressing military backpack, or the combat boots provided by the supply chain in the Brazilian Army.

Our hypothesis is that wearing combat boots will decrease plantar pressure levels in the forefoot (FF), rearfoot (RF) and midfoot (MF) and that the addition of load in the military backpack will increase those pressures.

The aim of this study was to identify the changes in the plantar pressure distribution during standing position carrying a military backpack with 15 kg, 20 kg, 25 kg comparing with control group with no load (NL) examining if the use of combat boots provided by Brazilian Army to troops contribute to decrease plantar pressure.

Methods

Study design and sample

This was a cross-sectional experimental study, with a convenience sample, in which 24 healthy active-duty military male volunteers participated (age: 26.4±5.6 years, height: 171.5±3.6 cm, body mass: 75.2±6.0 kg). Inclusion criteria for this study was to be in the active duty in parachute troops readiness unit. Exclusion criteria were the presence of recent back problems, lower extremity muscular, joint or bone disorders(13) or receiving any medication that could interfere with their neuromuscular responses on walking pattern.

Ethical aspects

All the principles of scientific research involving human beings were observed. Participants signed an Informed Consent, and this study was approved by the Brazilian National Research Ethics Committee (Nr 471.614) of Health Ministry.

Study variables

Outcome variables were plantar pressure at FF, RF and MF. The exposure variables were the loads: NL, 15 kg, 20 kg, and 25 kg. Anthropometric measures were covariables used to describe the sample.

Data Collection

Each trial took 60 seconds and during this time the plantar pressure was recorded in three anatomical regions of the foot (FF, RF and MF). Next, each insole was divided in those three areas corresponding anatomical regions of the foot: FF with 36 sensors, MF with 34 sensors and RF with 28 sensors. For each foot region of the foot, the mean plantar pressure was obtained by summing the values of each sensor divided by the total number of sensors in the region and reported in kilopascals (kPa). The mean plantar pressure analysis in each region of the foot was carried out comparing control group with NL, 15 kg, 20 kg, and 25 kg.

Instrumentation

Plantar pressures were measured using baropodometry insoles electronic system

(EMG System of Brazil Ltda, Biomec model 4000P), signal acquisition module (EMG System of Brazil Ltda, Brazil) with sampling frequency of 20 Hz, pressure range of 0.035 kg/mm2, linearity (Error) of ± 3%, response time < 5 μsec, maximum force of 10 Kgf. The insoles with 98 resistive sensors (1cm2) were connected to a computer with the analysis software Measure X 2.0 (EMG System do Brasil, Version 3.4.0).

The combat boots and operational military backpack used in all trials were the standard models provided by the Brazilian Army and are the same equipment worn by all troops in military training and operations.

Experimental protocol

Initially, subjects were submitted to anthropometric analysis and have received verbal guidance about study objectives and procedures. The assessment was carried out early in the morning at the laboratory in a controlled environment. Plantar pressure measurements were obtained during standing position on a flat surface with relaxed arms along the body, jaw relaxed, eyes focused on a fixed reference point 3 meters away and 1.80 meters tall. The lower limbs were fixed in 30° external rotation. Each subject acted as their own control and took part in five different trial conditions (Control, NL, 15 kg, 20 kg, and 25 kg) with each repeated three times. Each trial took 60 seconds with 60 seconds rest intervals between each evaluation. In all trials the participants were dressed in their combat clothes.

The insoles were placed under barefeet and inside the combat boots, to carry out the quantification of the levels of average plantar pressure (kPa). The protocol was divided into two different days.

Day One: Were obtained anthropometric data of the sample and then the plantar pressure value in two conditions, control, and no load.

- Reference trial (Control): Plantar pressure was measured in bare feet and dressed in combat uniform. This trial was considered the reference condition (Control).

- No load trial (NL): plantar pressure was measured with wearing combat boots and no additional load.

Day Two: Were carried out trial with load as 15 kg, 20 kg, and 25 kg. Plantar pressure was measured wearing combat boots and carrying each additional load of 15 kg, 20 kg and 25 kg always distributed in the same way inside the backpack. The loads on the backpacks were prepared with the necessary material to carry out a combat mission such as warm clothes, woolen blanket, rainwear, hygiene material, and others. The assessment sequence of the backpack load was set randomly to reduce neuromuscular adaptation to increasing loads.

Statistical analysis

Elements of descriptive statistics were used to characterize the sample and the distribution of plantar pressure in percentage terms. Shapiro-Wilk test was used to verify if the data had Gaussian distribution. To compare all conditions with a control, the Kruskal-Wallis test was used to check for differences between groups and the Dunnett post hoc test was used to determine which groups are different to the control. All tests were performed using the Data Analysis Software System, Statistica 12 (StatSoft Inc. 2014). The statistical significance level of $p \leq 0.05$ was considered to reject the hypothesis of equality.

Results

In the present study, we evaluated the average plantar pressure in 3 distinct regions of the human foot (Figure 1).

The normality test was conducted, and it was found that the data obtained has no Gaussian distribution. The following tables highlight the pressure variation in each foot region expressed in kPa and the percentage of pressure distribution in each foot region with regards to the whole foot. Table 1 shows the average plantar pressure in kPa for each foot region for 60 seconds period under the five trial conditions and Table 2 shows the percentage distribution of pressure in each region of the foot.

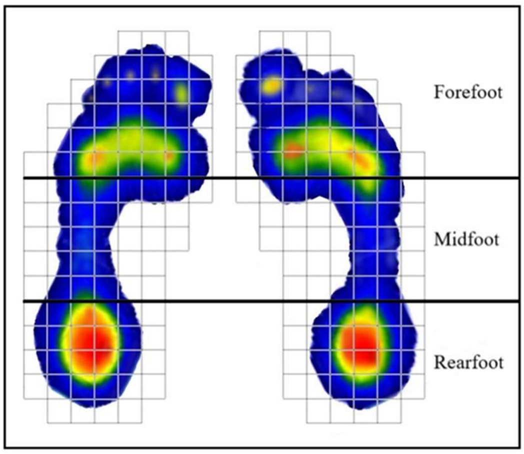

Figure 1 – Insole sensor matrix used to record the plantar pressure on the rearfoot, midfoot and forefoot.

Discussion

This was the first study to evaluate the relationship between load carriage in the backpack and levels of plantar foot pressure that commonly occur during standing in the Brazilian Army military personnel.

Average and peak pressures are important parameters that can identify the pressure distribution as well as injury potential. Average pressure is a more stable measure and gives a better overall picture of interface pressure than using peak pressure. Further, the average and peak pressure has a high average correlation coefficient(24). Plantar pressure distribution of both feet was recorded simultaneously, and each foot was divided into the anatomical regions, FF, MF, and RF. In line with the findings of Syed et al.(7), we observed that the average pressures of left and right feet are found to be similar in all regions of the feet. Due to this finding, during data analysis, the values of both feet were considered as one.

There are factors that affect the plantar pressure value such as postural changes(25) gender(26–28), age(26,28,29), the anatomical structure of the foot(7,28,30–32) and external loads(33). Therefore, there are many ways to analyze the result obtained. Although the subjects were instructed to stand still as much as possible, the plantar pressure load on the human foot resting on the surface of the ground or on the sole of the shoe is not constant. This statement becomes explicit in the high standard deviation values obtained in all regions of the feet and in all experiments. The exception was in barefoot and unloaded RF where the standard deviation was low (Table 1). We believe that this can be

Table 1 – Plantar pressure values and variation in each foot region according weight load

	Forefoot **Average±SD** ***P*/CV (%)**	**Midfoot** **Average±SD** ***P*/CV (%)**	**Rearfoot** **Average±SD** ***P*/CV (%)**
Control	54.02 ± 19.56 -- / 36.0	32.19 ± 4.15 -- / 13.0	74.18 ± 3.80 -- / 5.0
NL	***35.30 ± 13.00** **0.00 / 37.0**	30.73 ± 7.74 0.98 / 25.0	76.07 ± 10.14 0.98 / 13.0
15kg	47.62 ± 16.53 0.46 / 35.0	33.58 ± 13.83 0.98 / 41.0	***89.19 ± 15.49** **0.01 / 17.0**
20kg	54.24 ± 19.45 1.00 / 36.0	39.42 ± 16.94 0.09 / 43.0	***102.81 ± 15.01** **0.00 / 15.0**
25kg	51.07 ± 11.95 0.93 / 23.0	37.92 ± 8.77 0.24 / 23.0	***94.20 ± 26.60** **0.00 / 28.0**

SD: standard deviation; **Control:** barefoot and no additional load, **NL:** wearing military combat boots and no additional load; **15kg:** 15kg additional load, **20kg:** 20kg additional load, **25kg:** 25kg additional load. *Statistical significance $\alpha \leq 0.05$. ***P***: *p*-value. **CV:** Coefficient of variation.

Table 2 – Plantar pressure (%) distribution by foot region

	Whole foot (kPa)	Forefoot (%)	Midfoot (%)	Rearfoot (%)
Control	160.39	33.7	20.1	46.2
NL	142.10	24.8	21.6	53.5
15kg	170.39	27.9	19.7	52.3
20kg	196.47	27.6	20.1	55.3
25kg	183.19	27.9	20.7	51.4

Control: barefoot and no load, **NL:** wearing military combat boots with no load; **15kg:** 15kg additional load, **20kg:** 20kg additional load, **25kg:** 25kg additional load.

explained by the anatomical relationship of the ankle with RF. Talus, one of the tarsal bones in the RF is a component of the ankle joint. At this anatomical site, the talus supports the body weight axially deposited over the RF without the stress caused by the posterior torque that is generated by the external loads wrapped in the backpack during the loading trials. Whereas MF and FF regions receive the load transfer from RF as a shear force and due to this are subject to greater variation in plantar pressure values.

Based on previous studies(13,29), a significant increase in plantar pressure levels was expected in the three regions evaluated as the load on the backpack also increased, however, this only occurred in RF. According to our data, the static plantar pressure in the RF was overloaded and is associated with load in the backpack. The possible bias caused by the manner of distribution of the loads inside the backpack that could have interfered in the results was minimized by backpack load standardized arrangement which was like that used in operations. Regardless of what condition the soldiers were submitted to, i.e., Control, NL, 15 kg, 20 kg or 25 kg. After applying loads occurred a significant increase in the plantar pressure in the RF, suggesting that the RF is quite sensitive to the three loads studied. The data also suggest that loads from 20 kg may be the threshold to trigger adjustments to a new foot posture during quiet posture, as well as trigger the use of postural control strategies that were in latent condition so that vertical forces redistributed to the base of support. All these adjustments of the foot are carried out through motor responses guided by the sensory system and is influenced by extrinsic factors as: load carried; body's capacity to absorb and mitigate forces through the lower extremity; and influence of the heel fat pad that acts to protect the heel bone from excessive pressure and ground reaction force and intrinsic factors as absorptive properties of the sole in combat boots. Therefore, this sensory information provided by the plantar surface interacting with the ground through the combat boot sole is important components of motor control during military activities with load carriage. Additional studies with varying load carriage and the larger sample size are needed to assess additional structural foot disorders.

Wiggermann and Keyserling(12) showed that in the standing position, harder surfaces are associated with increased peak pressure and softer surfaces probably reduce discomfort contributing to redistribution plantar pressure over a larger contact area. Our data pointed to the same direction, demonstrating that when soldiers wear combat boots without a backpack occur a significant decrease in plantar pressure in the FF suggesting that FF is more sensitive to changing the foot support surface. On the other hand, RF seems not to be responsive to surface changes but the inclusion of load in the backpack. According to the authors(12) the redistribution of pressure that occurs in softer surfaces increases the load deposited in the MF with peak pressures ranged from 17 to 41 kPa. However, our data indicated that the plantar pressure in MF has discrete clinical alterations with no statistical significance ranged from 32 to 39 kPa in all trials studied, i.e., with and without load and on hard and soft surface.

In the FF discrete and no significant increase in pressure was noted from 20 kg while in the MF it started to increase from 15 kg. The data suggest that loads of 15 kg, 20 kg, and 25 kg have no significant impact on the distribution of the plantar pressure in the FF and MF in soldiers wearing the combat boots. We believe these results are beneficial to Brazilian soldiers. Reinforcing our affirmative, Wiggermann and Keyserling(12) found that reducing peak plantar pressures and limiting the pressure on the MF can delay the onset of pain and reduce discomfort during prolonged standing position. Considering the reduction in plantar pressures shown in our study the combat footwear provided by the Brazilian Army could act as an effective strategy in the reduction of plantar pressure during standing position, potentially reducing the risk of soldiers sustaining such lower limb musculoskeletal injuries as plantar fasciitis. Additionally, Torres et al.(34), showed a significant decrease in impact forces during gait utilizing the same combat boot and this further supports their use.

Periyasamy et al.(35) found significant differences in the maximum and average plantar pressure in the MF comparing men and women in the standing position. This fact emphasizes the importance of considering the MF as an isolated region. Our results suggest that MF is a key area of plantar pressure with an average of 20% of the pressure. However, MF seems to have as its main function the load transfer between RF and FF and not the load support proper. Our speculation about MF function is supported by our results showing that MF does not undergo significant changes in plantar pressure even after progressive loads are added to the backpack. Our results indicated that from the moment the load is added to the backpack the MP responds with adaptive adjustment in the plantar arches. Syed et al.(7) also affirm that minor changes in plantar pressure values are associated with postural changes of the plantar arches. Such adjustments may result in better distribution of vertical forces through the base of support and lead to compensatory adjustments evoked through external perturbation like a backpack. Additionally, applying the 25 kg load result in pressure decreasing in RF. This is the result of the mechanical stress generated by the increase in load, which would trigger new anatomical foot adjustments to better support, improving load transfer between RF and FF. Our data showed plantar pressure in FF represents 72% of RF pressure in soldiers.

Taking into consideration that the neuromechanical capacity to distribute the pressure on the plantar surface is a response of the interaction of the foot with the sole of the combat boots, we believe it is important to provide the combat boots suitable for the soldier. In this sense, the structural architecture and mechanical properties of the Brazilian combat boot must be considered as a potential influential factor in the magnitude of average and peak plantar pressures. For example, boots may have greater shock absorbing properties in the heel area or higher arch supports. Further, the loads that soldiers must carry during operational tasks should be kept as low as possible. This will allow the soldier to enjoy maximal comfort through an optimal distribution of the vertical forces on the plantar surface of the feet without compromising functionality and operational ability. This strategy can reduce the risk of musculoskeletal disorders and maximize a soldier's operational efficiency. Supporting our affirmatives Wiggermann & Keyserling(12), showed that during standing position the pain onset and peak pressure has the same place (metatarsal heads and heel) in 58% of cases. In this sense, significant decreases occurred only in the FF (Control = 54.02 kPa; NL = 35.30 kPa) suggesting that the combat boots provided by the Brazilian Army contribute to a decreased stress to the FF. This idea is supported also by the fact that loads of 20 kg (54.24 kPa) and 25 kg (51.07 kPa) the FF plantar pressure was similar to Control (54.02 kPa). These results confirm our hypothesis that wearing combat boots results in a decrease in plantar pressure levels in the foot.

According to Schulze et al.(36), increasing load affects trunk muscles. In accordance with the findings reported by Schulze et al.(36), visually one can observe anterior body inclination (not quantified) in the sagittal plane that probably occurred due to posterior torque progressive generated by backpack. We believe that this posterior torque was kinetically represented by the increased RF plantar pressure during load addition in our trials. This was an expected result for us, but we also expect that plantar pressure in RF increases with the load until the feet perform a new postural readjustment. This torque was offset by compensatory motor responses through the ventral muscle to allow maintaining the body in a stable position. However, the body anterior inclination in the sagittal plane was maintained. Lindner et al.(37) support that hypothesis, who demonstrated that the backpack with 15 kg, caused a mean 75% increase in knee extensor muscle activity in comparison with the reference trial. In our study, it was not possible to quantify the slope of the trunk forward.

Strong points and limitations of the study

The strong point of the study was appropriate and well-defined methodology, stringent data collection procedure, and a heterogeneous study population with respect to anthropometry and age, and insole suitable calibration. The precision of the equipment is associated with the technology employed to manufacture the sensor, the spatial resolution of the array, the range of pressure variation, the sampling rate, calibration procedures and post-processing of raw data(38). According Rosário(39), to improve the technique quality of the and display evidence of its clinical and scientific value the baropodometry, it is required system standardization and suitable calibration. In this sense, we performed the insoles calibration, and the accuracy of the system was assessed by a simple test during which a static measurement was made with a subject standing on the insole on one leg. Additionally, to confirm system accuracy, there was established a pattern to the force obtained: the individual's body weight could not vary more than 5%(40). Finally, the objective of the study was to obtain relative values and not absolute values. Thus, many of those limitations and biases were minimized and, in some cases, were even disregarded.

In literature, scientific work is scarce regarding static plantar pressure in healthy individuals and even less about load carriage in military backpacks. Miscellaneous studies, however, characterize dysfunctions and injuries in the feet and associate them with abnormal conditions of load distribution in the feet in static or dynamic situations. Our study reveals that healthy military personnel show significant load-dependent differences in RF and shoes-dependent in FF in standing position. These preliminary findings may help guide future work to evaluate plantar static pressure distribution sharing of healthy military personnel during load carriage with the backpack. On the other hand, are needed studies with Brazilian soldiers during dynamic conditions. Limitations of this study that need to be considered, relates to the reduced sample size and the precision of the baropodometry equipment.

Conclusion

The aim of this study was to identify the changes in the plantar pressure distribution during standing position carrying a military backpack with 15 kg, 20 kg, 25 kg, no load (NL) comparing with control group examining if the use of combat boots provided by Brazilian Army to troops contribute to decrease plantar pressure. The RF was the region most affected by the load carried in military backpacks. The boot promoted significant decrease of plantar pressure in the FF in the absence of load in the backpack. The MF region does not change the distribution of plantar pressure under the conditions in which the subject is wearing the boot without backpack and carrying the three loads studied. In the sample studied data suggest that in loads above 20kg the feet adopt a new posture and the body's center of gravity is repositioned in order to redistribute and reduce plantar pressure levels. This information may help to inform military on important matters such as maximize the comfort of the soldier while carrying load in military backpacks.

Conflict of interests

There is no conflict of interest in relation to this study.

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References

1. Ang CK, Solihin MI, Chan W, Ong Y. *Study of plantar pressure distribution*. In: MATEC Web of Conferences. [Internet] 2018. p. 01016. Available from: https://doi.org/10.1051/matecconf/201823701016
2. Bosch K, Rosenbaum D. Gait symmetry improves in childhood - A 4-year follow-up of foot loading data. *Gait and Posture*. [Internet] 2010;32(4):464–8. Available from: https://doi.org/10.1016/j.gaitpost.2010.07.002
3. Zhang S, Li L. The differential effects of foot sole sensory on plantar pressure distribution between balance and gait. *Gait and Posture*. [Internet] 2013;37(4):532–5. Available from: https://doi.org/10.1016/j.gaitpost.2012.09.012
4. Arnold JB, Mackintosh S, Jones S, Thewlis D. Differences in foot kinematics between young and older adults during walking. *Gait and Posture*. [Internet] 2014;39(2):689–94. Available from: https://doi.org/10.1016/j.gaitpost.2013.09.021
5. Whittle MW. Generation and attenuation of transient impulsive forces beneath the foot: a review. *Gait and Posture*. [Internet] 1999;10(3):264–75. Available from: https://doi.org/10.1016/s0966-6362(99)00041-7
6. Humphrey LR, Hemami H. A computational human model for exploring the role of the feet in balance. Journal of *Biomechanics*. [Internet] 2010;43(16):3199–206. Available from: https://doi.org/10.1016/j.jbiomech.2010.07.021
7. Syed N, Karvannan H, Maiya AG, Binukumar B, Prem V, Chakravarty RD. Plantar pressure distribution among asymptomatic individuals: a cross-sectional study. *Foot and Ankle Specialists*. [Internet] 2012;5(2):102–6. Available from: https://doi.org/10.1177/1938640011434503
8. Wright WG, Ivanenko YP, Gurfinkel VS. Foot anatomy specialization for postural sensation and control. *Journal of Neurophysiology*. [Internet] 2012;107(5):1513–21. Available from: https://doi.org/10.1152/jn.00256.2011
9. Tissot F, Messing K, Stock S. Standing, sitting and associated working conditions in the Quebec population in 1998. *Ergonomics*. [Internet] 2005;48(3):249–69. Available from: https://doi.org/10.1080/00140130512331326799
10. Cham R, Redfern M. Effect of flooring on standing comfort and fatigue. *Human Factors*. [Internet] 2001;43:381–91. Available from: https://doi.org/10.1518/001872001775898205
11. Madeleine P, Voigt M, Arendt-Nielsen L. Subjective, physiological and biomechanical responses to prolonged manual work performed standing on hard and soft surfaces. *European Journal of Applied Physiology*. [Internet] 1998;77(1–2):1–9. Available from: https://doi.org/10.1007/s004210050292
12. Wiggermann N, Keyserling WM. Time to onset of pain: effects of magnitude and location for static pressures applied to the plantar foot. Applied *Ergonomics*. [Internet] 2015;46 Pt A:84–90. Available from:

https://doi.org/10.1016/j.apergo.2014.07.008

13. Goffar SL, Reber RJ, Christiansen BC, Miller RB, Naylor JA, Rodriguez BM, et al. Changes in dynamic plantar pressure during loaded gait. *Physical Therapy*. [Internet] 2013;93(9):1175–84. Available from: https://doi.org/10.2522/ptj.20120103
14. Knapik JJ, Reynolds KL, Harman E. Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Military Medicine*. [Internet] 2004;169(1):45–56. Available from: https://doi.org/10.7205/milmed.169.1.45
15. Loth EA, Albuquerque CE, Ciena AP, Rossi ÂG. Evaluation of the postural control in young adults by use of foam-laser dynamic posturography and power plataform. *Revista Brasileira de Medicina do Esporte*. [Internet] 2011;17(3):171–4. Available from: https://doi.org/10.1590/S1517-86922011000300004
16. Knapik JJ, Reynolds K, Staab J, Vogel JA, Jones B. Injuries associated with strenuous road marching. *Military Medicine*. [Internet] 1992;157(2):64–7. Available from: https://doi.org/10.1093/milmed/157.2.64
17. Reynolds KL, White JS, Knapik JJ, Witt CE, Amoroso PJ. Injuries and risk factors in a 100-mile (161-km) infantry road march. *Preventive Medicine*. [Internet] 1999;28(2):167–73. Available from: https://doi.org/10.1006/pmed.1998.0396
18. Ramirez-Bautista JA, Hernández-Zavala A, Chaparro-Cárdenas SL, Huerta-Ruelas JA. Review on plantar data analysis for disease diagnosis. *Biocybernetics and Biomedical Engineering*. [Internet] 2018;38(2):342–61. Available from: https://doi.org/10.1016/j.bbe.2018.02.004
19. Vianna DL, Greve JMD. Relação entre a mobilidade do tornozelo e pé e a magnitude da força vertical de reação do solo. Brazilian *Journal of Physical Therapy*. [Internet] 2006;10:339–45. Available from: https://doi.org/10.1590/S1413-35552006000300014
20. Lafond D, Corriveau H, Prince F. Postural control mechanisms during quiet standing in patients with diabetic sensory neuropathy. *Diabetes Care*. [Internet] 2004;27(1):173–8. Available from: https://doi.org/10.2337/diacare.27.1.173
21. Orr RM, Pope R, Johnston V, Coyle J. Soldier occupational load carriage: a narrative review of associated injuries. *International Journal of Injury Control and Safety Promotion*. [Internet] 2014;21(4):388–96. Available from: https://doi.org/10.1080/17457300.2013.833944
22. Orr R, Pope R, Lopes TJA, Leyk D, Blacker S, Bustillo-Aguirre BS, et al. Soldier load carriage, injuries, rehabilitation and physical conditioning: an international approach. *International Journal of Environmental Research and Public Health*. [Internet] 2021;18(8):4010. Available from: https://doi.org/10.3390/ijerph18084010
23. Zammit GV, Menz HB, Munteanu SE. Reliability of the TekScan MatScan® system for the measurement of plantar forces and pressures during barefoot level walking in healthy adults. *Journal of Foot and Ankle Research*. [Internet] 2010;3:11. Available from: https://doi.org/10.1186/1757-1146-3-11
24. Naemi R, Healy A, Dunning D, Ashford RL, Chatzistergos P, Chockalingam N. Peak and average pressure correlations and their ratio at different plantar regions of the foot. *Footwear Science*. [Internet] 2013;5(sup1):S96–8. Available from: https://doi.org/10.1080/19424280.2013.799579
25. Catan L, Cerbu S, Amaricai E, Suciu O, Horhat DI, Popoiu CM, et al.

Assessment of static plantar pressure, stabilometry, vitamin D and bone mineral density in female adolescents with moderate idiopathic scoliosis. *International Journal of Environmental Research and Public Health*. [Internet] 2020;17(6):E2167. Available from: https://doi.org/10.3390/ijerph17062167

26. Demirbüken İ, Özgül B, Timurtaş E, Yurdalan SU, Çekin MD, Polat MG. Gender and age impact on plantar pressure distribution in early adolescence. *Acta Orthopaedica et Traumatologica Turcica*. [Internet] 2019;53(3):215–20. Available from: https://doi.org/10.1016/j.aott.2019.01.006
27. Gimunová M, Zvonař M, Mikeska O. The effect of aging and gender on plantar pressure distribution during the gait in elderly. *Acta of Bioengineering and Biomechanics*. 2018;20(4):139–44.
28. Song J, Choe K, Neary M, Zifchock RA, Cameron KL, Trepa M, et al. Comprehensive biomechanical characterization of feet in USMA cadets: comparison across race, gender, arch flexibility, and foot types. *Gait and Posture*. [Internet] 2018;60:175–80. Available from: https://doi.org/10.1016/j.gaitpost.2017.12.001
29. Pomarino D, Pomarino A. Plantar static pressure distribution in healthy individuals: percentiles for the evaluation of forefoot loading. *Foot and Ankle Specialists*. [Internet] 2014;7(4):293–7. Available from: https://doi.org/10.1177/1938640014528973
30. Gravante G, Pomara F, Russo G, Amato G, Cappello F, Ridola C. Plantar pressure distribution analysis in normal weight young women and men with normal and claw feet: a cross-sectional study. *Clinical Anatomy.* [Internet] 2005;18(4):245–50. Available from: https://doi.org/10.1002/ca.20081
31. Martínez-Nova A, Sánchez-Rodríguez R, Pérez-Soriano P, Llana-Belloch S, Leal-Muro A, Pedrera-Zamorano JD. Plantar pressures determinants in mild hallux valgus. *Gait and Posture*. [Internet] 2010;32(3):425–7. Available from: https://doi.org/10.1016/j.gaitpost.2010.06.015
32. Buldt AK, Forghany S, Landorf KB, Levinger P, Murley GS, Menz HB. Foot posture is associated with plantar pressure during gait: a comparison of normal, planus and cavus feet. *Gait and Posture*. [Internet] 2018;62:235–40. Available from: https://doi.org/10.1016/j.gaitpost.2018.03.005
33. Ahmad HN, Barbosa TM. The effects of backpack carriage on gait kinematics and kinetics of schoolchildren. *Scientific Reports*. [Internet] 2019;9(1):3364. Available from: https://doi.org/10.1038/s41598-019-40076-w
34. Torres AS, Ferrari DM, Cirolini VX, Valente AM dos S, Muniz AM de S. Análise do impacto do tênis e coturno fornecidos pelo Exército Brasileiro durante a marcha. *Revista Brasileira de Educação Física e Esporte*. [Internet] 2014;28(3):377–85. Available from: https://doi.org/10.1590/1807-55092014000300377
35. Periyasamy R, Mishra A, Anand S, Ammini AC. Preliminary investigation of foot pressure distribution variation in men and women adults while standing. *Foot* (Edinburgh, Scotland). [Internet] 2011;21(3):142–8. Available from: https://doi.org/10.1016/j.foot.2011.03.001
36. Schulze C, Lindner T, Woitge S, Finze S, Mittelmeier W, Bader R. Effects of wearing different personal equipment on force distribution at the plantar surface of the foot. *Scientific World Journal*. [Internet] 2013;2013. Available from: https://doi.org/10.1155/2013/827671
37. Lindner T, Schulze C, Woitge S, Finze S, Mittelmeier W, Bader R. The effect of the weight of equipment on muscle

activity of the lower extremity in soldiers. *Scientific World Journal.* [Internet] 2012;2012:976513. Available from: https://doi.org/10.1100/2012/976513

38. Giacomozzi C. Hardware performance assessment recommendations and tools for baropodometric sensor systems. *Annali dell'Istituto Superiore di Sanità*. [Internet] 2010;46:158–67. Available from: https://doi.org/10.4415/ANN_10_02_09

39. Rosário JLP. A review of the utilization of baropodometry in postural assessment. *Journal of Bodywork and Movement Therapies.* 2014 Apr 1;18(2):215–9.

40. Putti AB, Arnold GP, Cochrane LA, Abboud RJ. Normal pressure values and repeatability of the Emed ST4 system. *Gait and Posture*. [Internet] 2008;27(3):501–5. Available from: https://doi.org/10.1016/j.gaitpost.2007.06.009