Functional Evaluation of a Shock Absorbing Insole During Military Training in a Group of Soldiers: A Pilot Study

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ABSTRACT

Objective

Soldiers' lower limbs and feet are frequently affected by overload- and overuse-related injuries. In order to prevent or limit the incidence of these injuries, the use of foot orthoses is often recommended. The aim of this study is to assess the effects of shock-absorbing insoles on in-shoe plantar pressure magnitude and distribution in a group of professional infantry soldiers wearing military boots during standard indoor military training.

Methods

Twenty male professional soldiers of the Italian Army (age 35.1 ± 6.1 years; BMI 25.2 ± 2.3 kg/m^2) were recruited for this study. Each subject underwent clinical examination to assess possible overuse-related diseases of the lower limb and trunk. Subjects with altered foot morphology according to the Foot Posture Index (FPI) were excluded from this study. Twelve subjects were considered eligible and therefore underwent an indoor training routine comprised of marching, running, jumping inside parallel bars and jumping from different heights. Soldiers repeated the training session twice wearing standard military boots along with two types of insoles: the standard prefabricated insole within the boots (STI), and a special shock-absorbing insole (SAI) featuring an elastic medial arch support. A 99-capacitive sensor insole system was used to record plantar pressure distribution in both feet. Analysis of in-shoe pressure parameters at rearfoot, midfoot and forefoot and in the total foot was performed via a custom-software application developed in MATLAB. Perceived foot comfort (VAS 0–15) was also assessed.

Results

Pressure parameters recorded during walking and running were considered suitable for statistical analysis. In the whole foot region, pressure parameters were 18–22% lower in military boots fitted with the SAI during walking and 14–18% lower during running. SAI resulted in better comfort (+25%) with respect to the prefabricated boot orthotics (median comfort: SAI = 15/15; STI = 12/15; $p = 0.0039$) both during walking and running.

Conclusions

Shock-absorbing insoles can be an effective solution when fitted inside military boots. The present functional evaluation shows that wearing a prefabricated shock-absorbing insole can provide a significant amelioration of perceived foot comfort and plantar pressure parameters. Further studies are now needed with a larger population and more demanding exercises.

INTRODUCTION

Excessive workloads, by intensity and/or duration, predispose to overuse disorders. Military population and athletes are the two professional categories most frequently affected by these pathologies.[1] In frequent runners and ultra-marathoners as well as in military recruits, the most common chronic lower limb pain syndromes related to excessive workload (overtraining and running) include stress fractures, medial tibial stress syndrome, anterior knee pain and patellofemoral pain syndrome, plantar fasciitis or plantar heel pain, and Achilles Tendon tendinopathy.[1–3] The main recognized factors influencing overuse injuries are the type and frequency of the activity, the nature and the intensity of the exercise, the footwear, Body Mass Index (BMI), smoking habit, lower limb anatomy, and psychological stressors.[4–6] Above all, altered gait biomechanics is recognized as a major risk factor.[7–9] The most frequently affected anatomical sites by overuse injuries are the calf and ankle joints (34%), during running (45%), and long-distance walking activities (29%).[10] Metatarsal stress or "march fractures" have a wide range of incidence in military recruit population[11] and were reported to rise dramatically in elite infantry units (31%).[12] Moreover, although tibial and femoral fractures decrease in elite infantry training after a period of bone adaptation to high intensity workout, the incidence of metatarsal stress fractures continues to increase with overtraining.[13] Stress fractures caused by repetitive compressive forces are considered low-risk trauma and are treated with training adaptations and correction of all modifiable risk factors.[14] Although intrinsic risk factors (ie, anatomy, high foot arches, gender, age, and history of stress fracture) cannot be modified, the extrinsic ones (ie, training program intensity,

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potential dietary deficiency, and equipment inadequacy) should be monitored and adjusted as needed.

Modern infantry boots design should satisfy specific requirements such as comfort, lightness, durability, foot protection, and breathability.[15] However, design constraints result in increased stiffness and reduced shock absorption capacity which make these boots not suitable to support correct foot biomechanics.[16] Moreover, these critical features have been shown to reduce comfort and to increase fatigue, injury risk and energy cost, and may also result in higher incidence of dermatological disease and cutaneous lesions.[17,18] A way to reduce the incidence of overuse injuries of the foot is fitting footwear with plantar orthoses. Properly designed orthoses made with appropriate materials to provide pressure relief in critical plantar regions can be used to decrease the stress transmitted from the ground to the bones during repetitive tasks such as marching and running and while carrying heavy weights as in military training sessions. The reduction of impact forces associated with running has been claimed to be achieved by using foot insoles inside boots.[19,20] In military boots, shoe insoles can reduce peak pressure and can reduce excessive impact loads on the plantar aspect of the foot, without the need to alter boots design.[7,21,22] Shock absorbing orthotic inserts can also help to reduce foot pain.[23] When used in a group of male military recruits, foot orthoses improved comfort and reduced pain in the posterior heel, plantar heel, plantar fascia, and metatarsals. Recently, the efficacy of prefabricated foot orthoses in preventing stress fractures and soft tissue injuries in naval recruits undertaking initial defense training was shown, and their contribution in preventing overuse injuries was investigated.[24] In a systematic review from the same authors,[25] prefabricated orthoses were shown to be as effective as custom-made ones in reducing injuries, albeit at lower costs.

In order to assess plantar pressures abnormalities, a detailed analysis of forces developed during military load carriage should be performed. In the literature, both vertical and antero-posterior components of the ground reaction force increase proportionally when a load is added.[26] This may lead to instability potentially resulting also in injuries, with severity proportional to the carried loads. Plantar pressures are related to the overall reaction force and are a reliable and objective measure to evaluate foot orthoses effectiveness. Studies with different plantar pressure measurement systems, ie, Parotec[20] or Pedar systems,[27,28] showed that foot orthoses can significantly reduce plantar pressure. However, further evidence in real training conditions would be necessary to support these preliminary findings in a soldier population. Moreover, to the best of author's knowledge, no studies were conducted on a selected military population (ie, without foot morphological abnormalities) to test a specific and performing shock absorbing insole. The present pilot study aimed at assessing the effectiveness of a shock-absorbing foot orthosis in redistributing pressure over the plantar aspect of the foot, thus reducing peaks of pressure and improving general foot comfort in a group of soldiers of the Italian Army Special Forces. The use of this orthosis may contribute to reduce overuse injuries in this professional category.

MATERIALS AND METHODS

The present pilot study was conducted in accordance with the Declaration of Helsinki and Good Clinical Practice Guidelines. Informed consent was obtained from each subject enrolled in the study.

Twenty male soldiers from the Italian Army Special Forces (mean age 36 ± 6 years; BMI 25.5 ± 2.8) were recruited for this pilot study. Each subject underwent clinical examination to assess possible overuse-related diseases of the lower limb and trunk. Subjects with altered foot posture, ie, with Foot Posture Index (FPI) [29] lower than 1 and higher than 7 according to established normative values,[30] were excluded from the study. According to this criterion, 12 soldiers (12 males; age 35.1 ± 6.1 years; BMI 25.2 ± 2.3 kg/m^2; 43 ± 1 shoe Euro-size; FPI = 3.4 ± 1.3) were considered eligible to further analyses.

Two insoles were tested: the prefabricated insole present in the military boots (STI) and a novel off-the-shelf shock-absorbing insole (SAI) (Podartis, Treviso, Italy) (Fig. 1). The military boots were 24 cm high (based on a 45 Euro shoe size) and included a latex insole with leather cover and holes for aeration (Fig. 1). The SAI was composed of a shock-absorbing heel pad (Podiane, PVC, 4 mm), a metatarsal support, an ortho-shell with wedge for lateral stabilization, and an elastic arch support. This insole was designed and studied in order to guarantee a better impact absorption and to increase comfort, thanks to the combination of specific materials in specific location of the insole itself, ie, heel pad made out of PVC, an arch support made out of elastic material, a lateral wedge for lateral stabilization.

In-shoe plantar pressure was collected in some motor tasks typical of routine military training. Level walking and running (Fig. 1) were performed over 30 and 50 m long walkway, respectively, at self-selected speed. Overtaking in sequence two parallel bars, about 150 cm high and 50 cm distant, and jumping off a 80 cm and a 110 cm high platforms were also performed. Each soldier underwent these exercises twice, one wearing the STI and one wearing the SAI. The order in which the two insoles were worn was randomized for each subject, and the test was blinded both to the examiner and to the trainee. At the end of each training session, participants rated the perceived comfort via a 0–15 Visual Analogue Comfort Scale, where 0 indicates minimum comfort, and 15 maximum comfort.[31]

Capacitive sensor insoles (Pedar, Novel GmbH, Munich, Germany) were used to record in-shoe plantar pressure. Analysis of the in-shoe pressure data was performed using a custom-software (inIORshoe ver. 1.0) developed in MATLAB (The MathWorks, Inc., Massachusetts, USA). The software was previously validated by assessing the accuracy of the

FIGURE 1. Left: Picture taken during the military training. The Pedar-x belt attached to the subject's back and Pedar-x box attached to the sensored insoles. The subject is wearing tested military boots. Right: The standard Insole and the shock-absorbing insole. Arrows point out differences among insoles (a: shock-absorbing heel pad; b: metatarsal support; c: elastic arch support).

in-shoe pressure parameters against the Pedar-x (Novel, Munich GmbH) calculated values.[32] inIORshoe imports the Pedar-x exported raw pressure data (ASCII format) from the 99 sensor cells within each insole and allows for automatic identification of motor tasks events via a graphical user interface in MS windows. The software allows calculation of the main plantar pressure parameters (contact time, contact area, mean and peak pressure, pressure-time integral, mean and maximum force, and force-time integral) in standard (rearfoot, midfoot, and forefoot) and custom foot regions, with a tenfold reduction in processing time with respect to the Pedar-x analysis. The software can export the calculated pressure parameters either in numerical (ASCII, MS Excel and MATLAB formats) and in graphical format using color maps.

Cadence (steps/min), mean and peak pressure (kPa), and pressure-time integral (kPa∗s) samples were calculated as average across 10 steps for each soldier during walking and running in each of the following regions of interest: rearfoot (0–30% of the insole length), midfoot (31–60%), and forefoot (61–100%).

Data distribution was assessed via Anderson-Darling test. Since data were not normally distributed, paired Wilcoxon signed rank test with Bonferroni correction was used to assess the effect of insole type on cadence and pressure parameters in each foot region ($\alpha = 0.05$).

RESULTS

The clinical examination revealed a high incidence of foot overuse injuries in the army population recruited in the pilot study (67%): this may be either the consequence of acute direct traumas or subsequent to cumulative micro-traumatic forces associated to repetitive movements and stresses from intense physical activities. The following pathologies, that can be correlated to chronic overuse, were observed: plantar fasciitis (25%), knee pain (33%), and backache (58%).

The median comfort rating was 12.0 [9.5–13.8] point using the STI, and 15.0 [14.8–15.0] using the SAI ($p = 0.0039$). The percentage improvement in perceived comfort while wearing the SAI was +25%. Soldiers reported more stability and best cushioning at rear-foot while wearing the military boots fitted with SAI.

No significant differences in stance time, walking cadence (steps/min, STI = 119.7 [117.1 122.8]; SAI = 118.8 [113.9 123.2]; $p > 0.05$), and running cadence (steps/min, STI = 196.0 [169.6 211.4]; SAI = 184.7 [172.7 219.6]; $p > 0.05$) were found between the two insole conditions.

In terms of the maximum force recorded, the only difference between the two insole conditions was observed at forefoot during running (% of Body Weight, STI = 230.1 [209.1 247.0]; SAI = 218.9 [191.7 239.1]; $p < 0.005$). These data confirm that soldiers were subjected to the same dynamic conditions while testing both insoles.

The average pressure, across all steps of all soldiers, recorded by each sensor in the sensor-insole during stance phase of walking and running is reported in Figure 2. Analysis of the median peak pressure (kPa) recorded by each pressure-area of the Pedar® sensor insole across all steps and all soldiers, revealed that the SAI resulted in better distribution of the peak pressures across the central metatarsal region and at rearfoot in both walking and running (Fig. 2). Pressure parameters were significantly lower in SAI at several foot regions, both in walking and running (Figs 2 and 3, Table I). In the whole foot region, as average over all walking steps of all soldiers, pressure parameters were 18–22% lower in SAI during walking and 14–18% lower during running. Peak pressure during walking was 16–24% lower in SAI across all foot regions (Table I, Fig. 3). Pressure-time integral was significantly lower during walking in all foot regions and in running with except of the midfoot area. Because of the large variability and the small sample size of jumping and overtaking parallel bars data, the results of these two motor tasks were not deemed robust

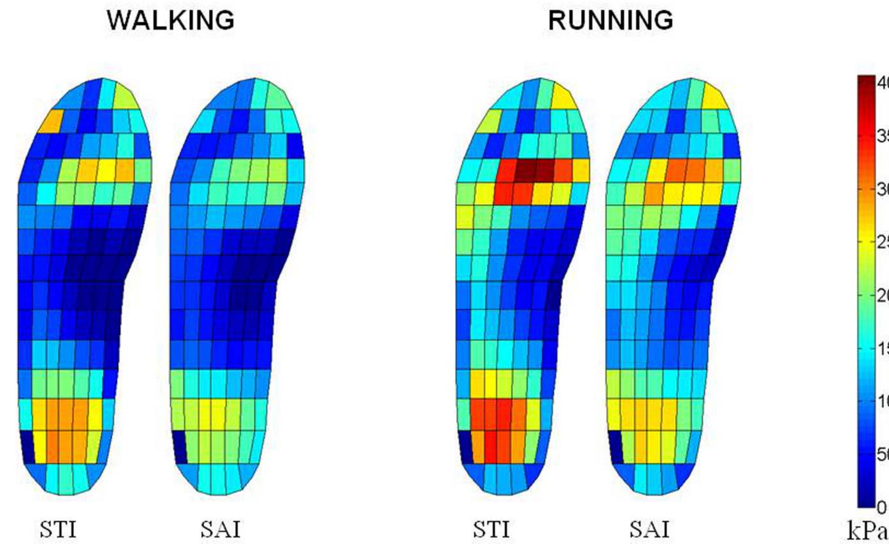

FIGURE 2. Color maps of the median peak pressure (kPa) in each sensor across all walking steps (left) and running steps (right) of all soldiers, in STI and SAI.

TABLE I. Median Pressure Parameters in Different Foot Regions During Walking and Running

	Pressure Parameters					
	Walking					
	Peak Pressure (kPa)		Mean Pressure (kPa)		Pressure-Time Integral (kPa*s)	
	STI	SAI	STI	SAI	STI	SAI
Rearfoot	325 [282 370]	265 [230 302]*	120 [105 139]	114 [99 141]	72 [64 83]	60 [54 69]*
Midfoot	141 [109 174]	100 [86 125]*	68 [56 79]	59 [52 69]*	39 [30 48]	35 [29 41]*
Forefoot	389 [322 511]	294 [245 362]*	133 [120 154]	102 [93 116]*	82 [73 104]	68 [61 79]*
Total Foot	407 [347 520]	307 [270 382]*	196 [173 222]	158 [144 173]*	137 [124 156]	111 [100 121]*
	Running					
Rearfoot	381 [224 519]	326 [220 444]*	92 [65 121]	98 [67 132]	27 [21 36]	23 [16 31]*
Midfoot	211 [157 266]	182 [150 231]*	86 [72 104]	79 [68 92]*	22 [17 27]	22 [17 28]
Forefoot	539 [461 637]	436 [354 566]*	181 [158 199]	136 [116 152]*	69 [55 81]	60 [47 70]*
Total foot	599 [480 637]	471 [394 622]*	185 [160 203]	148 [127 172]*	82 [68 97]	68 [58 79]*

enough for statistical analysis and therefore could not be reported.

DISCUSSION

The literature generally concurs that shock absorbing orthotics can reduce peak plantar pressure and can ameliorate pressure distribution, and thus can prevent overuse pathologies in lower limbs. In the US Army, the most frequent site of injury is the lower back (40.3%) followed by the lower extremities (39.0%).[33] Plantar fasciitis and patella-femoral syndrome are the main musculoskeletal injuries reported in running,[3] because of overloading of the lower limb musculoskeletal structures. Notably, the anatomical structures below the knee are those most involved in running related injuries. The present pilot study aimed at investigating the performance of a novel SAI in a group of soldiers by measuring foot comfort and plantar pressure distribution during walking and running. FPI scores showed that the subjects included in the pilot study were consistent for foot morphology and presented no major foot deformities that could have moreover limited their capability to accomplish the demanding tasks of the training.

No differences in cadence, stance time, and total force at the whole foot were observed between insoles both during walking and running, thus showing good repeatability of the protocol and resulting in consistent boundary dynamic conditions for the insoles comparison. Therefore, the differences detected in pressure parameters should only be accounted for differences in design features and insole materials. The present plantar pressure analysis showed that pressure parameters were reduced in most foot regions when fitting the

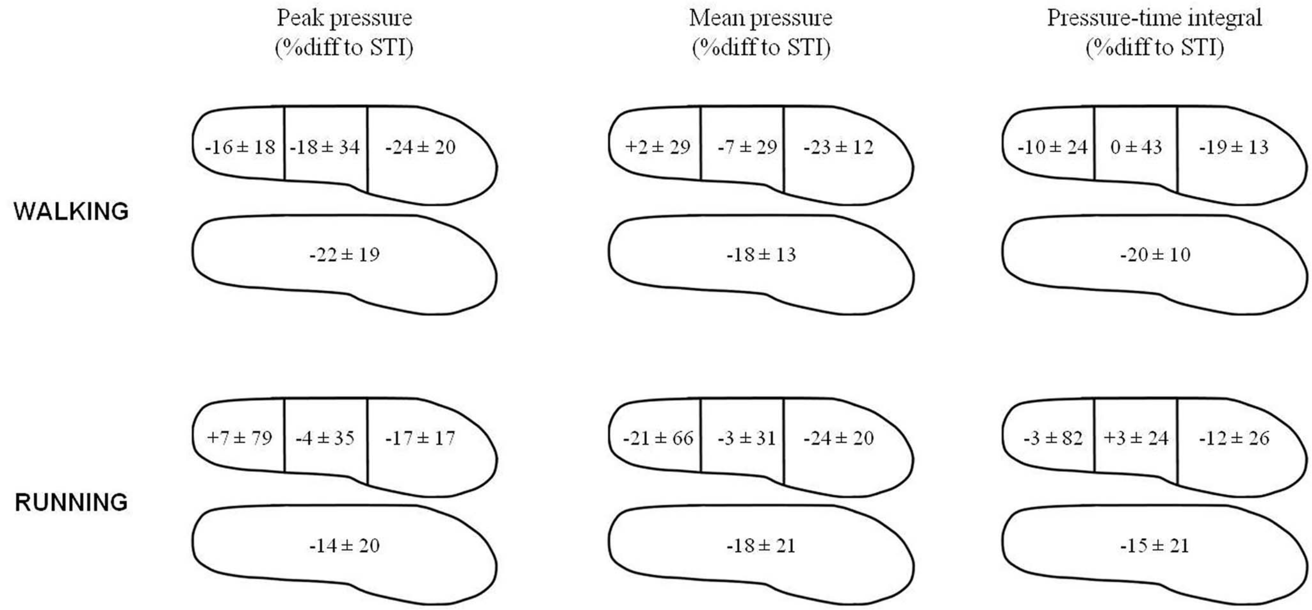

FIGURE 3. Percentage difference in mean and peak pressure and pressure-time integral between the two insoles in each of the three foot regions during walking (top) and running (bottom). Negative values represent lower parameters in SAI. *represents statistically significant differences compared to STI values ($p < 0.005$).

military boots with the SAI both during walking and running. Wearing the SAI resulted in lower peak pressure and pressure-time integral in all foot regions during walking. Peak pressure was lower in all foot regions also during running. Peak pressure represents the local maximum stress perpendicular to a specific region in the plantar aspect of the foot. Analysis of the median peak pressure showed that the SAI resulted in better distribution of the peak pressures across the central metatarsal region and at rearfoot in both walking and running. These observations are in accordance with typical patterns of load distribution, ie, higher at the three central metatarsals heads, both in static and dynamic conditions.[34] Mean pressure, which represents the average loading per unit area during the roll over progression, was significantly reduced by the SAI at midfoot and forefoot and in the whole foot region. Reduced pressure at this foot region is consistent with lower dynamic overload in subjects involved in very intense physical activities, such as athletes and soldiers. Previous studies showed that SAI can prevent common overuse injuries,[27,35] thus wearing these can be a valid option in order to decrease the incidence of metatarsal fractures and injuries especially at the second metatarsal head.[1]

Pressure-time integral represents the cumulative effect of pressure over time in a specific area of the foot. This parameter represents the total load exposure of specific foot areas during one step[36] and may provide a qualitative estimation of local bone and soft tissue damage.[37] Since the SAI resulted in reduced pressure-time integral in all foot regions, both during walking and running, its use may be effective in limiting or preventing overuse injuries of the most loaded foot areas.

Although most of the pressure parameters showed large statistical difference between the two insole conditions, the results of the pilot study should be interpreted in view of its limitations. First, the relatively small sample size was partly related to the number of soldiers who agreed to participate to the pilot study, and further reduced by the number of participants having feet without major deformations. Secondly, any medium or long-term evaluation of the SAI, in terms of foot adaptation and comfort, was not performed and possible correlations with incidence of overuse pathologies and lower limb injuries were not investigated. In addition, only male participants were included in the cohort. The presence of female soldiers is rather uncommon in the Italian special armed forces, and these were not available at the venue and at the time of the data acquisition. Finally, because of the large variability and the small sample size of jumping and overtaking parallel bars data, the results of these two motor tasks were not deemed robust to be included in the manuscript and for statistical analysis. Further studies with longer follow-ups and on larger cohort of participants need be conducted to increase the statistical power of the present results.

CONCLUSIONS

Even though further studies should be performed to assess possible correlations between plantar pressure parameters and foot overuse injuries, the present pilot study shows that fitting military boots used by the Italian Army Special Forces with a relatively inexpensive insole, such as a prefabricated SAI, can be an effective solution to improve perceived comfort and plantar pressure parameters. However, these results would certainly benefit from further validation using more demanding exercises and on a larger population.

CONFLICT OF INTEREST

The authors declare that they do not have any conflict of interest.

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