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Effect of Shod Walking on Plantar Pressure with Varying Insole

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ABSTRACT

Walking and running are very critical factors in human being's everyday life. A human being takes more than 2,000 steps to walk 1.6 km. The human being wear a boot with insole to protect feet when walking, playing and doing various activities. The boot with insole provides significant impact on the feet during these events and transmitted through the feet due to intense force and pressure. Measurements of plantar pressure are important for diagnosing lower limb disorders, designing footwear, injury prevention and applications in sports biomechanics. The objective of this study is to investigate the plantar pressure exerted on the feet during shod walking (wearing boot with three types of insoles); to identify effective insole for reducing plantar pressure during walking (wearing same boot with three insoles). Eighteen fits, healthy male adults volunteered for this study with mean and SD (mean±SD) age (36±9) years, height (169±4) cm, and weight (71±8) kg. During experiments, each volunteer underwent 5 min of treadmill walking (4.5 km/hr speed) with wearing of boot with varying types of insoles (Low-density polyurethane (LDPU) insole 1; High-density polyurethane (HDPU), insole 2; and Silicone rubber (SR), insole 3). Plantar pressures were measured by using a foot pressure measuring device. A paired t-test was conducted to observe significant changes in plantar pressures of different foot region ($P<0.05$). Observations of the present study revealed that plantar pressures (N/cm^2*s) were minimum during the use of LDPU insole than HDPU and SR insoles. It was also noticed that during the using of LDPU insole, less plantar pressure observed in the heel (3.84 ±1.16 in right foot) followed by forefoot (right 3.92±0.88), lateral (right 3.56±0.85), and medial foot (right 3.60±0.69). Hence, the present study suggested that using LDPU insole reducing the transfer of impact forces to the body/foot in comparison to HDPU and SR insoles during walking and minimizing the risk of foot-related injuries in long term use.

Keywords: Military shod walking; Plantar pressure; Insoles types; Injury prevention

1. INTRODUCTION

Interactive ground reaction forces are transferred between the human body and ground during walking. Measurement of these interactive forces in a unit of foot area termed as plantar pressure and used to quantify the magnitude of external load or impact absorbed by lower extremity, especially the foot, during various activities like running, jumping, jogging. Measurements of plantar pressure are important for diagnosing lower limb disorders, designing footwear, injury prevention and applications in sports biomechanics[1]. Walking and running are very critical factors in human being's everyday life. A human being takes more than 2,000 steps to walk 1.6 km. The human being wear a boot with insole to protect feet when walking, playing and doing various activities. The boot with insole provides significant impact on the feet during these events and transmitted through the feet due to intense force and pressure. Earlier studies[2,3] reported that foot pain and foot disorders are considered as serious burdens for older individuals, especially those with rheumatic diseases, in the US foot pain is considered to be a very common musculoskeletal complaint in the adult population, relatively little is known of the prevalence or cause of foot pain in older Americans in a population-based sample[4]. Examining the association between footwear and foot pain may lead to a greater understanding of this relationship, which is important when considering strategies to prevent sequelae due to foot pain in older adults[2,3]. Qiu[5], *et al.* studied the effect of different types of insole on somatosensory information and postural stability. Their observations stated, during more challenging balance tasks, textured insole surfaces minimised postural sway, providing an important intervention in falls prevention, especially in older people. Turpin[6], *et al.* experimented on knee osteoarthritis patients to find out the effectiveness of shock-absorbing insoles for reducing knee joint load, pain, and dysfunction. They found that significant reductions in self-reported knee joint pain, physical dysfunction and no consistent changes observed in knee joint load due to wearing of shock-absorbing insoles. Ferreira[7], *et al*. conducted experiments to find out the efficacy of custom insoles for redistributing plantar pressure, decreasing musculoskeletal pain and reducing postural changes in obese people. The study revealed that the use of proprioceptive insoles contributed to reducing plantar pressure (peak), musculoskeletal pain and

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lateral postural deviations. The use of proprioceptive insoles may be an important strategy to encourage obese people to exercise and, consequently, reduce weight. Overuse of lower limb injury is common in incidence, and different kinds of overuse injuries were observed in the athletic population[8,9]. Earlier studies of reported that overuse injuries and foot problems are very common in high-intensity sports activities like long-distance runners, marathon runners, trekkers, joggers and military personnel[10-13]. Previously numerous studies, have been conducted to develop preventive strategies to reduce risks of lower limb or foot disorders, e.g., overuse injuries, foot blisters, plantar fasciitis, stress fracture and pain syndrome in civilian and military population to reduced/redistribution of plantar pressure) through using orthotic footwear, orthoses and insoles[13-16]. However, in most of the earlier studies, plantar pressure measured on patient's population, data were collected for very short duration varied from few seconds to one minute even two steps only[17-22].

Till date, plantar pressure data on continuous steady-state shod walking among healthy individuals are very scanty in global and not available in the Indian population. Hence, the present study was undertaken to investigate the plantar pressure exerted on the feet during shod walking (wearing same boot with three types of insoles); and to identify effective insole for reducing plantar pressure during walking.

2. MATERIALS AND METHODS

2.1 Participants

Eighteen trained, physically fit, non-smoking healthy male adults from Indian soldiers with normal gait patterns volunteered for the study. The mean and SD age, height and weight were (36±9) years (169±4) cm and (71±8) kg. They had no history of cardiovascular or musculoskeletal disorders, fractures, disorders of the locomotors or vestibular systems. All the volunteers have given informed consent to take part in this investigation.

2.2 Ethical Clearance

The present study was conducted at the Ergonomics Lab, Defence Institute of Physiology and Allied sciences, Delhi. The study protocol was approved by the Institutional Ethical Committee and the experiment conforms to the standards outlined in the Helsinki Protocol Declaration[23].

2.3 Experiment Details

A week before the experiments, the volunteers were briefed on the purpose of the study and provided boot (details properties of boot in Table 1) for accustomed to walking during normal activities on the ground for habituation; after that, accustomed to walking on the motorised treadmill (Taeha, Intertrack 6025, Korea) to minimise the chances of slip and fall during the experiments. Before the experiment and data collection, the participant was fitted with the foot scan insole (M/s Medilogic, Germany) as per their foot dimension just beneath the skin of their plantar surface of feet, after that wear studded boots; and the cables from insole were connected to the data logger modem which was tightly fitted at the waist region using a waist belt.

2.4 Data Capture

During the experiment, each volunteer underwent on treadmill walking at 4.5 km /hr medium paced walking speed at 0 % gradient (level walking) for 5 min wearing same boot with different insole. Plantar pressure data collected continuously throughout the walking trials by using foot scan insole and data collected at 50 Hz cutoff frequency (M/s Medilogic 5.8, Germany). All the experiments have been conducted in a controlled laboratory environment of 23-25 °C, 50-55% relative humidity. The pictorial diagram of data collection is shown in Fig. 1. The pressure data were extracted through the foot scanning gait software is shown in Fig. 2.

3. DATA ANALYSIS

All the statistical analysis was conducted using version 17 of Minitab. Firstly, Kolmogorov-Smirnov test was used for check the normality of data and it was observed that data was normally distributed. Afterwards, pairwise t-test was used and $p < 0.05$ considered as the level of significance.

4. RESULT

The effect of different insoles on studied plantar pressure at various anatomical foot regions (Forefoot, midfoot, heel, lateral and medial foot) during steady-state treadmill walking is presented in Table 2 and Fig. 3). It was observed that plantar pressure at all studied anatomical foot regions was significantly higher ($p<0.05$) during the use of insole 2 and insole 3 in comparison with insole 1. It was also noticed that the rate of increase in plantar pressure is higher in insole 3 than insole 1 and insole 2 at all anatomical foot regions. During using of insole 1, maximum reduction of plantar pressure observed in heel followed by lateral, medial, forefoot and midfoot in comparison to insole 2, whereas maximum reduction observed in heel followed by lateral forefoot, medial and midfoot in comparison to insole 3.

Table 1. Detail Properties of Boot and Insoles

	Weight (gm)	Density of insole material (g/mm^3)	Thickness (mm)	Material
Boot	899.39	-	Midsole and out-sole were 23.5 mm at the heel part and 7.2 mm at the forefoot.	Outsole pre-molded rubber, Midsole phylon, Upper consist of chromed tanned leather and nylon fabric
Insole 1	40.79	~0.129	5	Low-Density Polyurethane (LDPU)
Insole 2	81.58	~0.258	5	High-Density Polyurethane (HDPU)
Insole 3	173.35	~0.550	5	Silicon Rubber (SR)

(a) (b) (c)

Figure 1. (a) Foot scan insole (M/s Medilogic, Germany), (b) Embedded foot scan insole into the boot, and (c) Treadmill walking, and data capturing (4.5 km/h at 0% gradient).

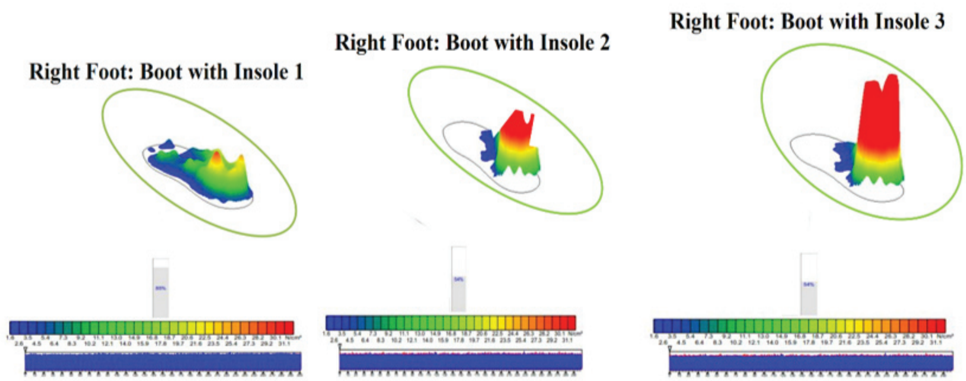

Figure 2. Collecting right foot plantar pressure data using foot scan insole software (walking; boot with insole 1, insole 2 and insole 3.

5. DISCUSSION

The objective of this study is to investigate the plantar pressure exerted on the feet during shod walking and to identify effective insole combination for reducing plantar pressure during walking (wearing same boot with three insoles). The recommended range of device plantar pressure (N/cm²*s) for right foot at anatomical region (forefoot, midfoot, heel, lateral and medial are 2.5 N/cm²*s, 1.1 N/cm²*s, 4.1 N/cm²*s, 2.8 N/cm²*s and 2.7 N/cm²*s, respectively). From Table 2 clears that the maximum amount of cross limit in term of plantar pressure in boot with insole 2 and boot with insole 3 at all anatomical region expect in midfoot (in case of boot with insole3). The findings of the present stated that the lowest plantar pressures (N/cm²*s) were observed at the forefoot (3.92±0.88), heel (3.84±1.16), lateral (3.56±0.85) and medial (3.60±0.69) in a boot with low-density polyurethane (insole 1, LPDU), in comparison with high-density polyurethane (insole 2, HDPU) and boot with Silicon Rubber (insole 3, SR) as per Table 2 and Fig. 3. In the present study, plantar pressures were significantly higher (11.73 % in the forefoot, 20.83 % in heel, 15.44 % in the lateral foot and 13.05 % in a medial foot) in a boot with high-density polyurethane (insole 2, HDPU) in comparison with the boot with low-density polyurethane (insole 1, LPDU). Plantar pressures were significantly higher in all anatomical foot regions (forefoot 19.13 %, heel 28.64%, lateral foot 21.91 % and medial foot 16.66%)

Table 2. Effect of boot with a different insole on plantar pressure (N/cm²*s, Mean±SD) at different anatomical foot region during steady-state shod walking (n=18)

Anatomical foot region	Boot with different insole			% of change (increase)			p-value		
	1	2	3	1 vs. 2 (%)	1 vs. 3 (%)	2 vs. 3 (%)	1 vs. 2	1 vs. 3	2 vs. 3
Forefoot	3.92±0.88	4.38±0.84	4.67±0.77	11.73**	19.13***	6.62**	0.017	0.001	0.011
Mid-foot	3.04±1.35	3.15±1.20	2.89±1.31	3.61	4.93	8.25	0.707	0.623	0.172
Heel	3.84±1.16	4.64±1.33	4.94±1.02	20.83*	28.64***	6.46	0.024	0.001	0.278
Lateral	3.56±0.85	4.11±1.05	4.34±0.62	15.44*	21.91***	5.59	0.047	0.001	0.194
Medial	3.60±0.69	4.07±0.53	4.20±0.79	13.05**	16.66****	3.19	0.013	0.000	0.472

1: Boot with insole 1, 2: Boot with insole 2, 3: Boot with insole 3; $p < 0.05$

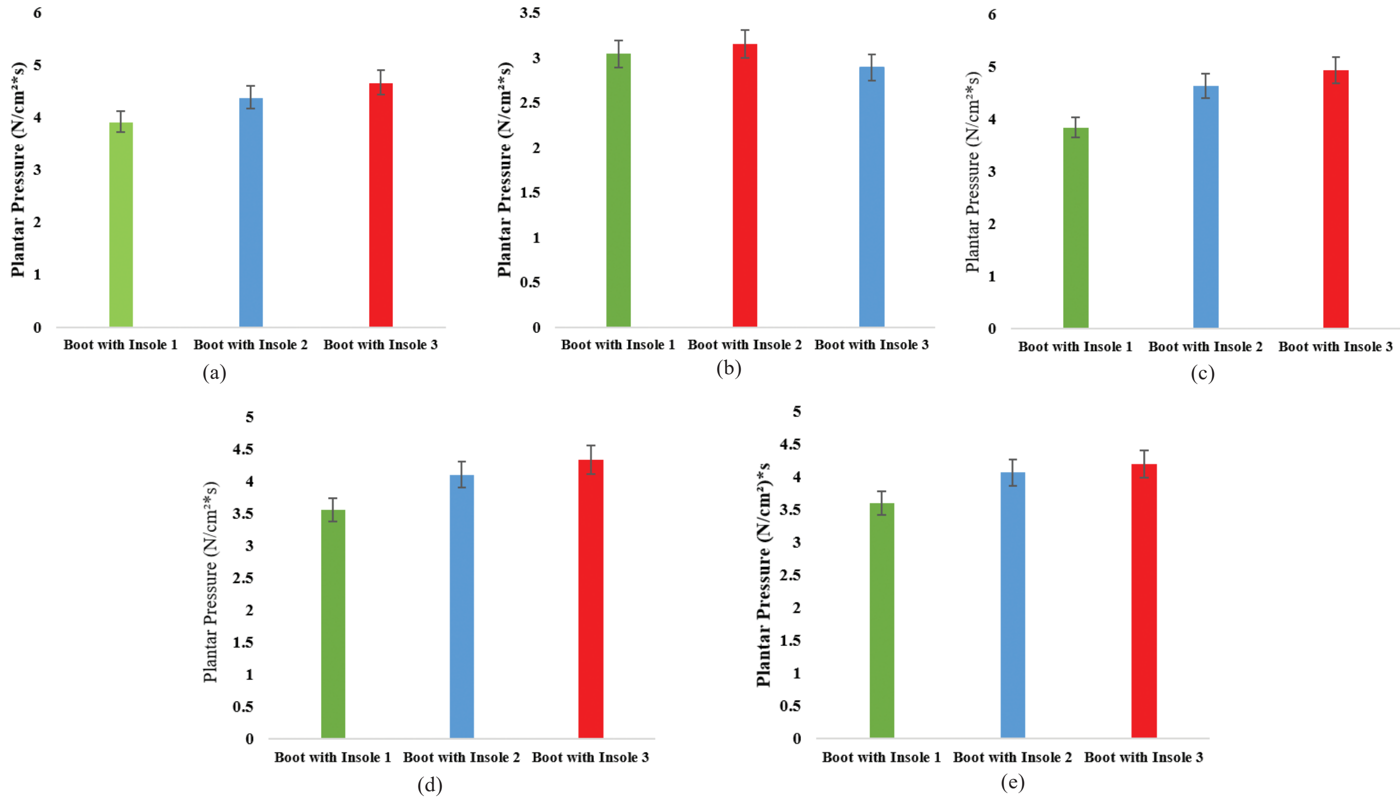

Figure 3. Graphical representation of the effect of boot with a different insole on plantar pressure (N/cm²*s, Mean±SD) at different anatomical foot region during steady-state shod walking (n=18), (a= forefoot foot, b= mid-foot, c= heel, d = lateral foot, e = medial foot).

during the use of silicon rubber insole in comparison with the insole of LPDU. Findings of the present study extended the observations of earlier work[24-30]. Healy[20], *et al.* experimented on a patient population and stated that the use of low-density Polyurethane insole reduced plantar pressure as compared to medium and high-density polyurethane insole by increasing the contact area. They recommended low-density Polyurethane insole to patients for long run use to minimise or avoid pain due to the use of medium and high-density Polyurethane insole. Similar, observations were reported by Shuib[25], *et al.*, they stated that low-density Polyurethane insoles are more effective because of better shock-absorber properties able to reduction or migrate the worst effects on the foot.

Shuib[25], *et al.* conduct the experiments for evaluating the best insole among the healthy individual (n= 4) during quiet standing and investigate the overall peak pressure with condition barefoot and insoles without boots. They observed that higher plantar pressure during the barefoot condition and due to the higher value of plantar pressure under the foot and in the long run, it can lead to musculoskeletal disorder. Therefore, the insole is believed to have the capacity to reduce the plantar pressure under the foot by redistributing the pressure. Alirezaei[26], *et al.* conducted experiments on healthy male college athletes (n=15) and found that material with higher density reduced shock-absorption capacity during jumping\ landing activity. They also stated that the knee flexion angle during contact time was greater in medium-density insoles as compare to the low-density insole. Hence, they suggested that the use of low-density insole material recommended for exercise time, running time because it may help to reduce injury risk. Niazi[27], *et al.* conducted six months follow up study on one hundred plantar fasciitis patients (mean age of the patients was 44.25±12.75 years) to find out the effectiveness of silicon heel pad to the management of pain. Pain relief was measured by pain intensity difference percentage scales and stated that the Silicone heel pad reported a better outcome measure associated with the patient's heel pain as 74 (84.09%) patients resolved their condition or reached a tolerance level and showed a preferable reduction in heel pain. Conservative intervention with silicone heel pad showed relief from heel pain, and it allowed the patient to manage the condition more effectively with no complications but for the short term. It was less effective in the long term. However, in earlier studies, most of the experiments conducted on patient's population, pressure were measured for very short duration walking with limited steps, static conditions, and limited anatomical foot regions.

The present study, unique in few points like continuous steady-state shod walking (5 min) among eighteen healthy military personnel, whole 5 min data was considered for analysis, plantar pressure measured at five anatomical foot regions (forefoot, heel, midfoot, lateral and medial foot) and speed was controlled at 4.5 km/hr, and the first attempt was made to collect plantar pressure data on Indian soldiers population. The observations of present study may be useful for identifying suitable insole for prevention of foot related injuries. It is important as the distribution and magnitude of plantar pressure depends on material properties of the insole and boot in addition to so many intrinsic (age, sex, presence or absence of health complications, level of fitness) and extrinsic (load carriage, working surface or terrain, type of task and personal protective equipment (PPE) that includes occupational footwear) factors.

Van[12], *et al.* reported that overuse injuries and foot problems are very common in high-intensity sports activities like long-distance runners, marathon runners, trekkers and military personnel. Lysholm & Wiklander[10] reported that the injury rate per 1,000 h of training was 2.5 in long-distance/marathon runners and 5.6 to 5.8 in sprinters and middle-distance runners. The injury pattern varied among the three groups of runners: hamstring strain and tendinitis were most common in sprinters, backache and hip problems were most common in middle-distance runners, and foot problems were most common in marathon runners. Marti[11], *et al.* conducted studies on 4,358 male joggers to identify incidence, site, and nature of jogging injuries and reported that 45.8 % had sustained jogging injuries during the 1 year study period, 14.2 % had required medical care, and 2.3 % had missed work because of jogging injuries. Injuries were not significantly related to race running speed, training surface, characteristics of running shoes, or relative weight. Miller[13], *et al.* reported that injury is normal in initial military training with incidences from 25 % to 65 % of recruits. Injuries risk factors includes extrinsic factors such as the rapid start of high volume training, but intrinsic factors such as lower limb biomechanics and foot type. Plantar pressure interpretation of footfall has been shown to reflect intrinsic biomechanical abnormality and no quantifiable method of risk stratification exists.

The present study clearly stated that the use of low-density polyurethane insole with boot (made up of outsole pre-molded rubber, midsole phylon, Upper consist of chromed tanned leather and nylon fabric) minimizing the transfer of impact forces to the lower extremity during walking. This reduction of plantar pressures may be due to improved cushioning, increased foot contact area, changing the positioning of the feet on the insoles, aligning the joints and reducing the stress on tendons and ligaments, finally, redistribution of pressure in different regions of foot (forefoot, midfoot, lateral and medial foot) and significantly decreased plantar pressure within the plantar surface of foot as Table 2. As a result, using this combination of boot and insole may reduce the risk of overuse injuries, musculoskeletal disorders in lower extremities, osteoarthritis, foot-related injuries of different occupational activities like military, trekkers, sport spersons, industrial workers and beneficial for rehabilitation application also.

6. CONCLUSION

The observation of the present study indicated that, the use of boot with insole 1 (Low-density polyurethane) minimise the plantar pressure (N/cm^2*s, A pressure time integral is the representative of magnitude of pressure as well as the rate at which pressure is transferred in foot) than using insole 2 (High-density polyurethane) and 3 (Silicon rubber) during walking. The present study was restricted on level walking, one speed and the right foot only.

Therefore, future studies may be directed to inclusion of different gradients (uphill and downhill), slow /fast walking speed, sex and age variation, effect of dominancy of leg, different footwear, foot anthropometry and different rough terrains.

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In the current study, he was involved in conceptualisation of study, finalised study protocol, interpretation of findings and overall supervision of the study.