

Effect of military footwear on balance and stability: A pilot study

Suranjana Sen¹, Subhojit Chatterjee¹, Tammanna R Sahrawat², Shashi Bala Singh³,
Madhusudan Pal⁴

¹Defence Institute of Physiology and Allied Sciences, Lucknow Road, Delhi -110054, India,

²Centre for Systems Biology and Bioinformatics, UIEAST, Panjab University, Chandigarh -160014, India

³Director, NIPER, Hyderabad, Telangana-500037, India.

⁴Scientist- F & Addl. Director , Human Physiology, Ergonomics Defence Institute of Physiology and Allied Sciences, Lucknow Road, Timarpur, Delhi-110054, India.

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ABSTRACT: : To perform daily activity under both static and dynamic conditions maintenance of balance and stability plays an important role to prevent slip and falls. Maintenance of balance is essential in an occupational workplace and industrial setting during performing tasks. The effect of footwear on balance is poorly understood in military setting. Proper military footwear helps improve balance and postural stability, minimizing the risk injuries. This study was aimed to observe the influence of military footwear on balance and postural sway during quiet standing. Twenty one (n=21) physically fit Indian infantry soldiers volunteered for the study. Two types of footwear, namely footwear 1 & 2 (without & with proper foot bed respectively) were investigated for suitability or fitness during standing. Participants stood on force platform for 40 seconds in each condition. Bioware was used to collect and process the data. Results suggest that in footwear 2, sway area is more concentrated than footwear 1 and a shifting of the center of pressure (COP) to midline was also observed in footwear 2. All the parameters were decreased in Footwear 2 compared to footwear 1. The use of footwear with proper foot bed for absorbing impact force (footwear 2) improves balance and stability during quiet standing.

Key Words: Balance and stability, COP, Military footwear

Introduction

To perform daily activity under both static and dynamic conditions, maintenance of balance and stability plays an important role to prevent slip and falls. Maintenance of balance is essential in occupational workplace and industrial setting to prevent falls and fall related injuries when/while performing distracting and de-stabilizing tasks where maintaining static and dynamic body positions is required/needed [1]. The Bureau of Labor Statistics (BLS) reported 208,470 cases of work related falls in 2010 of which 646 were fatal [2]. Balance is maintained by visual, vestibular and somatosensory senses coupled with an intact musculoskeletal system along with a higher level of cognitive neural function [3]. Degradation in one system increases the chance of lowering balance performance with resultant possibility of a fall [4]. Maki *et al*, [1] reported that loss of balance is the primary cause of falls in occupational environments. This decrement in balance may be attributed to prolonged standing and walking with inappropriate footwear. The type of footwear plays an important role for maintaining balance and stability as it serves as the medium between foot and surface and contributes to somatosensory feedback mechanisms. Design features of footwear such as mid sole hardness, heel elevation play an important role on postural control strategies and balance [5-6].

Incorrect footwear without a good grip may be detrimental in terms of fall or injury [7]. Proper balance and stability of one's body, whether in standing or in walking posture is solely dependent upon the feet and the lower limb joints. Standing postural control depends upon numerous inputs interacting with several temporal-spatial scales [8]. Thus, balance is achieved when the individual's centre of gravity (COG) remains within the base of support, but to evaluate static postural control the centre of pressure (COP) movement on a stable surface is commonly used [9]. COP is the point of location of the vertical ground reaction force vector [10]. During quiet standing, humans invariably sway in medio-lateral (m-l) as well as in antero-posterior (a-p) directions to maintain balance [9]. COP excursion and the static postural sway generated by the body have been commonly studied on the force platform [10]. The stabilometric parameters such as velocity of COP trajectory, the deviation of COP displacement, the sum of maximal deviation time [11] support the study of postural control and explain footwear on this basis [12].

Therefore, the relationship of the development of different footwear and postural stability have been studied in different diseased conditions [13], in different sports [14] as well as in the older population [7, 8] with little focus on occupational footwear especially in military population [15]. Therefore, the present

study was designed to investigate/examine the differences in balance and postural sway with two different types of military footwear while standing quietly. It was hypothesized that differences in postural sway would be observed between the military footwear during quiet standing.

Material and Methods

Participants- Twenty one (n= 21) physically fit Indian infantry soldiers without any previous history of musculoskeletal disorders, fractures, disorders of the locomotors or vestibular systems etc. volunteered for the study. Their mean (\pm standard deviation) age, height and weight were 30 (\pm 3.9) years, 170 (\pm 4.97) cm and 72 (\pm 6.3) kg respectively. Before commencing with the experiments/studies, the participants were acquainted with the experimental design and their informed written consent taken.

Footwear- Two types of footwear (FW) were used. Details of the dimensions and modifications of footwear were given in table 1.

Table 1: Dimensions of footwear used in study

Parameters (cm)	Footwear 1 (FW- 1)	Footwear 2 (FW-2)	
Shoe length	29.1	Same as Footwear 1	
Upper Height (from back)	16.5		
Upper Height (from side)	17		
Front (Toe box)	6.5		
Metatarsal width	9.5		
Heel width	7		
Heel height	4		
Shaft height (side/Back)	13.2		
Arch height	3		
Ankle circumference	35		
Upper circumference	28		
Shock absorbing insoles	No		Yes , 5 mm

Ethical clearance-The Institutional ethics committee of DIPAS approved the experimental protocol prior to the study following Helsinki protocol [16].

Experimental protocol- Subjects were briefed regarding the study protocol and their written consent taken before commencement of the experiments. A week prior to undertaking the experiments, the subjects routinely wore their shoes (FW-1 & FW-2) for habituation. They were also made to habituate for 5 minutes while standing in an upright position on the force platform. To reduce biasness, 11 subjects (n=11) wore FW 1 first followed by FW- 2 while the remaining 10 subjects were allowed to wear footwear 2 first and then footwear 1. Five times/instances kinetic data of each subject was collected in quiet standing condition. The subjects stood for 40 seconds during each condition with about 10 min interval between two experimental conditions to overcome any effect of fatigue or experimental biasness. Two piezoelectric sensor-based force platforms (M/s Kistler Instrumente AG, Switzerland, Model 9286AA) were installed by Pit installation method at the centre of the 10-m walkway and area of 3 m x 1.5 m area at the centre within the walkway where the force plates were placed [17]. Bioware software (version 3.24; M/s Kistler Instrumente AG, Switzerland) was used to collect and process the data. Data were collected at a sampling rate of 50 Hz [18]. Stabilometry software was used for data processing [11].

Data collection- For each volunteer, data was recorded for 40 seconds during each of the experimental conditions on the force plates. Data of first and last 5 seconds were excluded from each trial and remainder considered for analysis. For each subject, 2 trials in total were recorded for each condition. The mean values of the trials were tabulated for each parameter and considered as individual value for further statistical analysis.

Parameters studied- Postural sway or antero-posterior (A-P) and medio-lateral (M-L) components of center of pressure (COP) (mm), Standard deviation of COP trajectories in x (M-L) and y (A-P) direction Planar deviation or PD (mm), Mean displacement velocity or V (mm/sec), Critical time or CT (sec), Area of COP or A (mmsq) and mean squared critical displacement or MSCD (mm) were acquired as per Raymakers et al. [11].
Data analyses – Mean and standard deviation (SD) of the raw data of different stabilometric parameters were calculated. Students' t test was used to determine significance between the measured parameters after wearing footwear 1 and 2, for the chosen level of significance ($p < 0.05$). Postural sway of the subjects was measured by plotting a scatter plot with the average excel values of medio-lateral and antero-posterior area

of COP movements (Ax & Ay). This method permits/allows only a visual illustration of sway area.

Results

Sdx and Sdy are the measurement of movement of length of COP trajectories in medio-lateral and antero-posterior directions respectively. ‘Planar deviation’ (PD) is obtained from the formula $\sqrt{(\sigma^2x + \sigma^2y)}$; where σ^2x and σ^2y = squared estimated standard deviation of x and y. ‘Mean Velocity’ (V) is defined as $\sum Vd/n$ where Vd is displacement velocity of COP molecules in every point (n). ‘Critical time’ (CT) is the Interval at which the slope of the regression of the mean squared distance between random pairs (Sdx, Sdy) on the time interval of different random points. The time co-ordinate of the intersection point was termed by the original authors ‘critical time interval’ and the corresponding squared distance was taken as the ‘mean squared critical displacement’(MSCD)[19]. Area (A) is the Surface contained within the closed curve including all recorded COP’s. All the above COP related parameters were computed using Raymaker’s DOS based software. All these parameters describe some aspect of the intricate movement pattern termed body sway and thereby of stability. Specifically, analysis is based on the movements of COP trajectories in one-dimensional and two-dimensional plane. Barring some differences, several of the displacement parameters contain similar information.

Table 2: Stabilometric responses of military footwear during quite standing position

Stabilometry Parameters	Sdx (mm)	Sdy (mm)	PD (mm)	Velocity (mm/sec)	CT (sec)	MSCD (mm)	Area (mmsq)
Footwear 1	0.043 (±0.010)	0.039 (±0.011)	0.058 (±0.014)	3.356 (±0.830)	2.060 (±0.571)	8526.219 (±1815.704)	486.477 (±196.20)
Footwear 2	0.041 (±0.010)	0.039 (±0.011)	0.057 (±0.014)	3.257 (±0.797)	1.426 (±0.508)	7039.019 (±1657.48)	443.526 (±152.922)
P value	0.27 NS	0.98 NS	0.48 NS	0.47 NS	0.001 **	0.001 **	0.15 NS
% change	4	0.1	2	3	31	17	9

Data presented as mean (±SD); NS- not significant; * = P<0.005; Sdx- standard deviation of COP in x direction Sdy- standard deviation of COP in y direction PD- Planar deviation, CT- Critical time, MSCD- Mean squared critical displacement

It has been observed from table 1 that all of the studied COP parameters decreased in footwear 2 in comparison to footwear 1. Sdx, Sdy, PD, Velocity, and area decreased, though not significantly, by 4%, 0.1%, 2%, 3%, and 9% respectively in comparison to footwear 1. In other hand, Mean squared critical displacement (MSCD) and Critical time (CT) was significantly decreased upto 17% and 31 %.

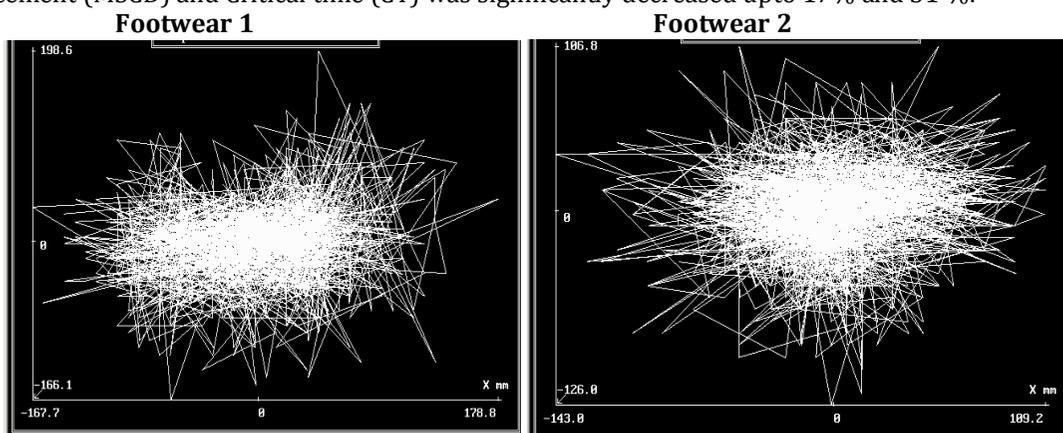


Fig 1: Example of stabilogram of one individual whilst wearing footwear 1 & 2

It was observed from figure1 that changes of COP patterns differed in Footwear 1 and Footwear 2 and sway area are more dispersed in footwear 1 than footwear 2. Figure 2 represents the pattern of changes in stabilometric responses with Footwear 1 and 2.

Discussion

Standing stationary is a highly complex task involving multiple body segments, joints and sensory systems in order to regulate balance while attempting to stay upright in a static position without moving. In

the first phase of the experiment, therefore, quiet standing with footwear 1 and 2 was evaluated to assess the postural stability of the subjects. The balance responses were evaluated in terms of movement of COP trajectory in both existing and customized shoes to improve balancing capabilities in different military activities. It is established that by measuring the displacement of COP an individual's balance can be evaluated [20]. An assessment of the stabilometry parameters, Sdx, Sdy, PD, velocity, area, MSCD and CT showed a decrement in footwear 2 when compared to footwear 1. The percentage change is 4%, 0.1%, 2%, 3%, and 9%, 17% and 31 % respectively. As per Collins and De Luca [18], COP trajectories can be modeled as fractional Brownian motion that operate whilst standing quietly for either short or long-term duration (n=25). These trajectories, generated due to the particular motion theory of a COP point that are considered as a molecule in our case, are the main component of Raymaker software from which the values of stabilometry parameters were calculated. The results obtained in this study support the hypothesis that wearing of footwear 2 increases postural control performance, established by a decrease in most of the representative COP displacement parameters [20]. Hyun et al. [21] observed that both COPx and COPy showed less displacement with 9 cm high-heeled shoe than with 0 cm (flat) shoe in normal female adults (n=13) and demonstrated that in the high heeled shoes the velocity of COP is controlled by delaying in propulsive phase whereas in 0 cm shoes the COP velocity cannot be controlled due to quick touch down and take off (propulsion phase). Bennell et al. [22] demonstrated that a scattered plot indicating reduction of the COP area (COP shift towards midline) after wearing of the orthopedic shoes having ankle support (taping and brace) which provide cushioning and revealed that sufficient but stress contributes to increased efficiency and effectiveness of postural control system as it supports the decreasing chance of ankle injury (n=24). In a study by Menz et al.[7] most subjects (n = 18) reported that they would consider wearing the prototype footwear to reduce their risk of falling. In another study on soccer players, the three shoe models led to greater stability than when the subjects (n= 24) were barefoot [14]. These studies support our findings that a proper grip, neither too high nor too low, offers ideal stability lowering the risk of fall injuries. Correct distribution of weight on feet gives the body optimal postural alignment and proper foundation for walking, marching and in combat situations as fatiguing foot muscles during exercise decreases foot muscle strength that in turn alters postural sway whilst standing (n=18) [23].

In the present study, the subjects consist of Indian soldiers who work for prolonged time in standing posture. A worker is considered to be exposed to prolonged standing if he spends over 50 % of the total working hours during a full work shift in standing position [24]. It has been established that persons spending at least 50% of the working time in a standing position are at risk of developing neuro-musculoskeletal impairments and venous insufficiency [25]. Prolonged standing has been linked to the onset of work-related musculoskeletal disorders (WMSDs) associated with lower back pain among industrial workers (n=12) [26]. Reduced blood circulation in the lower legs and localized muscle fatigue might contribute to WMSD and whole body fatigue associated with prolonged standing conditions. Duration of standing has also been identified as a significant contributor to WMSD [27]. According to Hansen et al,[28] pain in the feet is commonly reported during standing position compared to sedentary or walking tasks (n=8). The static contraction of lower back and legs results in diminished function of the calf muscle, muscle fatigue, discomfort and even low back pain. Discomfort or fatigue can be linked to psychological fatigue and has been recognized as a factor in the decline of alertness, concentration, and motivation [29]. In this context there is another study which substantiated that the leg and back muscle pain is influenced by disturbance in postural sway parameters generated due to shoe design [30]. Use of specially designed shock absorbing in-soles in the footwear is one of the commonly selected ergonomic interventional methods to reduce pain and discomfort associated with prolonged standing [31]. This solution enables the body to sway naturally and imperceptibly. Our observations with respect to footwear 2 having advanced sole bed were indicative of improved balance and stability through proper distribution of body weight on the foot during quiet standing position.

Conclusion

Findings of the present study indicated that wearing of footwear with advanced/proper foot bed (footwear 2) had contributed to a reorganization of postural control that increased balance and stability performance (Sdx, Sdy, PD, Velocity, MSCD and area) during upright standing. Footwear with advanced sole may facilitate balance and stability under long duty hours where a combination of standing and walking activities are the norm, such as prevalent in military, other industrial workers, health staffs. The outcome of the present study will be utilized for designing and development of different occupational footwear and orthopedic footwear used by patients with the diabetes and flat feet. Finally it can be treated as first attempt

to create a database of individuals' balance and stability among Indian population as there is no normal standardized value of measuring stability of an individual. A large scale study with larger sampling size following similar protocol walking condition will be beneficial for its translation to real life/field conditions.

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