https://ijpp.com

Indian Journal of Physiology and Pharmacology

Article in Press

Original Article

Effect of wearing high heel and flat footwear on balance and stability dynamics: A kinetic study

Sugata Das Kumar[1], Kamalpreet Sandhu[2], Madhusudan Pal[3]

[1]Department of Physiology, City College, Affiliated to University of Calcutta, 102/1, Raja Ram Mohan Sarani Road, Kolkata, West Bengal, [2]Product and Industrial Design, Lovely Professional University (LPU) Phagwara, Punjab, [3]Director CoEs, Footwear Design and Development Institute (FDDI), Ministry of Commerce and Industry, Govt of India, A-10/A Sector 24, Noida-201301, Gautam Budh Nagar, Uttar Pradesh, India.

***Corresponding author:**
Madhusudan Pal,
Director CoEs, Footwear Design and Development Institute (FDDI), Ministry of Commerce & Industry,Govt of India, A-10/A Sector 24, Noida-201301, Gautam Budh Nagar, Uttar Pradesh, India.

madhusudanpal@rediffmail.com

Received: 18 November 2023
Accepted: 05 May 2024
EPub Ahead of Print: 06 June 2024
Published:

DOI
10.25259/IJPP_578_2023

Quick Response Code:

ABSTRACT

Objectives: Maintaining balance and stability is essential for performing everyday activities and complex tasks that require coordination between muscles, tendons, bones, eyes, ears and the brain. However, slip, trip or fall incidents may occur if balance is compromised. Footwear (FW) design features have been identified as factors that affect balance. To investigate the impact of high-heeled and flat FW on balance stability during stationary standing, this study was conducted.

Materials and Methods: Seven ($n = 7$) physically fit female subjects volunteered for the study. A repeated method was used to conduct this study. A high heel and flat FW were investigated for detailed kinetic parameters during standing. Participants stood on a force platform for 40 seconds in each condition. Bioware software was used to collect and process the data. Student's *t*-test was applied to determine the significant effects ($P < 0.05$) of the selected FW on dependent variables.

Results: Ground reaction force (GRF) (Fx, $P = 0.001$), (Fy, $P = 0.002$), (Fz, $P = 0.000$), Centre of Pressure (CoP) Trajectories (Ax, $P = 0.02$), (Ay, $P = 0.011$), displacement (sx, $P = 0.002$), (sy, $P = 0.001$) and (sz, $P = 0.002$) and Absolute Coefficient of Friction (Cofxy) ($P = 0.0012$) values of high heel FW reflect poor balance and stability patterns compared to flat FW.

Conclusion: Recent studies have shown that wearing high-heeled FW for extended periods can be detrimental to one's health. This is due to the significantly elevated GRF, a more dispersed body sway area in terms of Centre of Pressure (CoP) movement, a curved displacement path and a lower coefficient of friction value. As a result, there is an increase in postural load and effort, which can lead to an increased risk of injury.

Keywords: Balance, Stability, High heel footwear, Flat footwear, Centre of pressure, Ground reaction force

INTRODUCTION

Balance is the capacity of the body and mind to retain flexibility and stability in the absence of external influences. It is essential for every action that the human body makes. Stability takes it even further by enabling the body and mind to maintain equilibrium regardless of external pressures, as long as they do not cause one to slip, trip or fall. Maintaining both balance and stability is crucial for carrying out simple tasks and complicated ones that require coordination from muscles, tendons, bones, eyes, ears and the brain. Achieving and maintaining balance requires a complex network of sensorimotor control systems, including the integration of sensory input from vision (sight), proprioception (touch), the vestibular system (motion, equilibrium and spatial orientation), and motor output to the eye and body muscles.[1] Sensory impairments are a growing issue in many Western countries, as noted by Palmer *et al.* in 2015.[2] About 3.3% of the working population suffers from balance disorders. Falls are a major public health concern worldwide. They are responsible for 684,000 deaths annually and are the second leading cause of unintentional injuries. Falls also result in high medical expenses. According to the World Health Organization, the average healthcare costs per fall injury for individuals aged 65 or above in Australia and the Republic of Finland are US$ 1049 and US$ 3611, respectively.[3]

Footwear (FW) is an essential item in a person's wardrobe. Research has found that over 50% of falls are linked to the type of FW being worn at the time of the accident. Despite this, both high heels and slippers pose a risk of collapsing and causing falls.[4] Up to 45% of falls have been linked to inappropriate FW.[5,6] According to recent research, 75% of individuals who experienced hip fractures due to falls had been wearing inappropriate FW at the time of the injury. Several factors related to FW design have been linked to issues with balance, including the outer sole's slide resistance, high heel and midsole geometry, heel height, heel-collar height and sole hardness. However, only a few of these factors have been studied during the design and development of specific types of FW regarding their impact on balance.[7]

The centre of pressure (COP) is a crucial concept in the study of human movement and balance. It refers to the point at which the ground reaction force (GRF) acting on an individual's foot or feet is focused. Maintaining stability and preventing falls is a vital component of the COP. By keeping the centre of mass (COM) within the base of support, the COP is believed to indicate the motor systems involved in preserving balance while standing. The displacement of the COP at the boundaries of stability is linked to falls, highlighting the importance of examining dynamic balance to assess the risk of falling.[8] During quiet standing, humans tend to sway both in the mediolateral (M-L) and anterior-posterior (A-P) directions to maintain balance.[9] COP excursion and static postural sway have been commonly studied using force platforms.[10] The study of postural control can be supported by examining stabilometric parameters such as the velocity and deviation of COP displacement trajectory. This can provide insight into the effects of flat and high-heel FW.[11] Determining the coefficient of performance (COP) is crucial for analysing the balance control, postural stability and identification and management of balance, leading to the prevention of falls in different types of FW.

Nonetheless, a number of studies have examined the relationship between the development of various FW and postural stability in various medical conditions [12] in various sports[13] and in older individuals.[14] However, there are very few detailed kinetic studies on balance and stability dynamics among particular types of FW.[15] Therefore, the present study was designed to determine the detailed kinetics of flat and high heel FW on balance stability during standing quiet.

MATERIALS AND METHODS

Subjects

Seven physically fit female subjects with no previous history of musculoskeletal disorders or fractures on the lower extremity and vestibular system volunteered for the study. Their mean age, height and weight were 30.5 ± 3.9 years, 170.7 ± 4.8 cm and 73.8 ± 6.03 kg, respectively. Each subject was tested 3 times for each condition, resulting in six trials per subject: Standing quietly while wearing high-heel FW and flat FW.

Before the study began, participants were given all the necessary information to understand the experimental procedure and completed an informed consent form. Subjects had the right to withdraw from the experiment at any time.

Ethical clearance

The study was conducted at the Ergonomics Lab, Defence Institute of Physiology and Allied Sciences, Delhi. The Institutional Ethical Committee approved the study protocol on human use as an experimental subject, and the experiment followed the principles outlined by the Declaration of Helsinki Protocol in 1964.[16] The Institutional approved IEC Reference number: IEC/DIPAS/A-6/2. dated 03.12.2015.

Details of Footwear (FW)

Two types of FW, high heel and flat, were used for the experiment. Details of the physical dimensions of FW are given in Table 1.

Table 1: Physical dimensions of FW used in the study.

S. No	Parameters	High heel footwear (size 8)	Flat FW (size-8)
1.	High heel height	10.2 cm	2 cm
2.	Toe width	7 cm	8.5 cm
3.	Ball width	5.7 cm	7.3 cm
4.	FW length	23.0 cm	24.5 cm
5.	Number of layers	3	3
6.	Weight	500 g	260 g
7.	Sole design	Little grooves	Little grooves
8.	Shock absorbing insole	No	No

FW: Footwear

Experimental design

Before the study began, the participants were given information about the study process and their agreement was obtained in writing. To get accustomed, the participants were asked to wear the selected FW (high heels and flats) regularly for a week prior to the study. They were also made to stand still on the force platform for 5 min. The kinetic data of each subject were recorded 3 times while they were standing still. To avoid any fatigue or experiment-related bias, the subjects stood for 40 s for each condition with a 10-minute break between two experimental conditions. Two piezoelectric sensor-based force platforms (M/s Kistler Instrumente AG, Switzerland, Model 9286AA) were installed using the Pit installation method. The force plates were placed at the centre of the 10-m walkway and in the 3 × 1.5-m area within the walkway.[17,18] 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.[19]

Data collection

Data were collected for 40 seconds for each participant under each experimental setting on the force plates. The initial 5 s of data were excluded from each trial, and the remaining data were analysed. Each individual completed three trials of each condition, resulting in a total of 42 trials for seven subjects. The final value was determined by calculating the mean of the three trials for each condition during data processing. Six trials were eliminated due to their diversity, and 36 trials were ultimately chosen for each condition in the final experiment.

Parameters studied

GRF at M-L Fx, A-P Fy and vertical Fz direction, postural sway at A-P y and M-L x components of force application point of the centre of pressure (COP), displacement at M-L x, A-P y and vertical z direction and absolute coefficient of friction μ (Cofxy) were acquired from Bioware software.

Statistical analysis

The mean and standard deviation of the raw data of different stabilometric parameters were calculated by using Minitab 20.4 statistical software. Student's t-test was used to determine the significance between the measured parameters after wearing high heels and flat FW for the

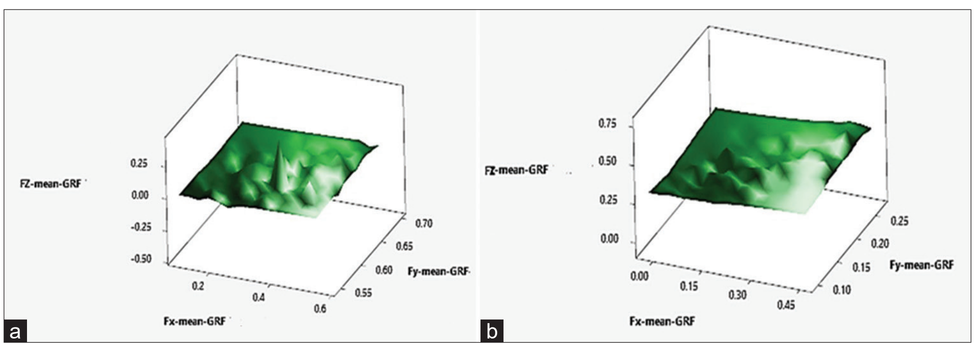

Figure 1: (a) Three dimensional graphical representation of Ground Reaction Force (GRF) during standing while wearing High-Heel Footwear. (b) Three dimensional graphical representation of Ground Reaction Force (GRF) during standing while wearing Flat Footwear.

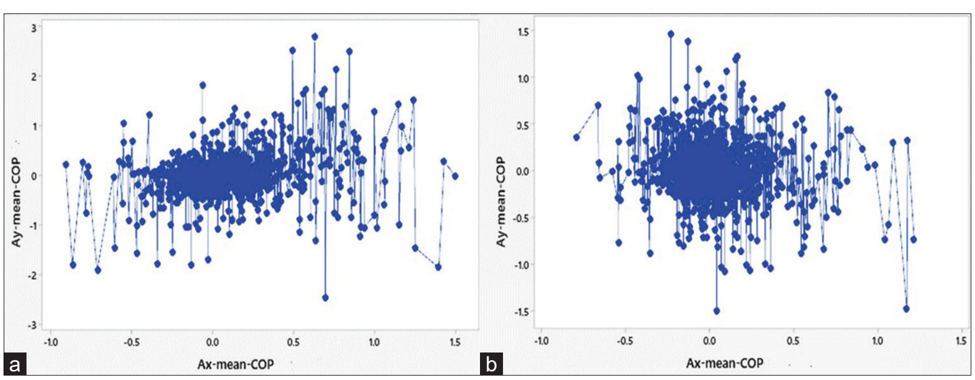

Figure 2: (a) Graphical Representation of movement of Centre of Pressure (CoP) trajectories during stationary standing while wearing High-Heel Footwear. (b) Graphical Representation of movement of Centre of Pressure (CoP) trajectories during stationary standing while wearing Flat Footwear.

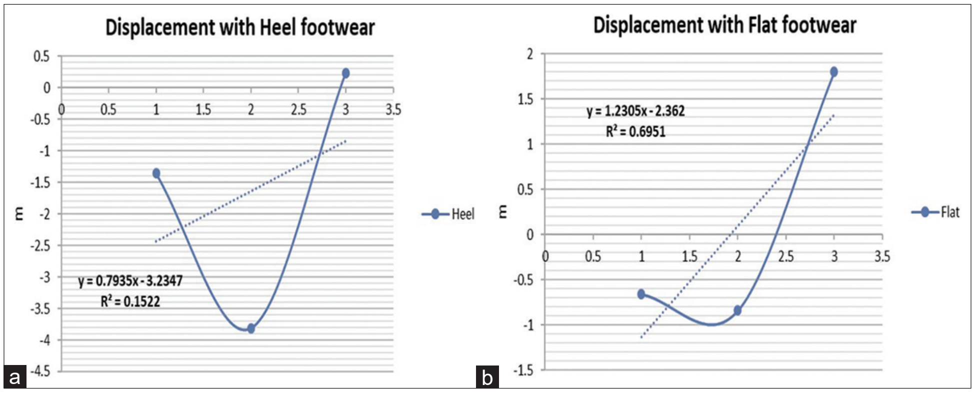

Figure 3: (a) Two dimensional graphical representation of Displacement occurrence during stationary standing while wearing High-Heel Footwear. (b) Two dimensional graphical representation of Displacement occurrence during stationary standing while wearing Flat Footwear

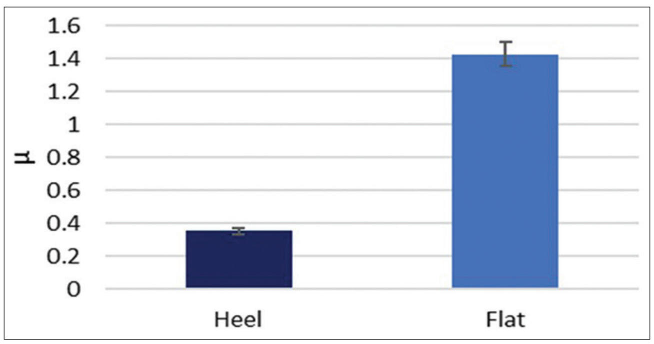

Figure 4: Graphical representation of absolute coefficient of friction (Cofxy) during stationary standing after wearing high heels and flat footwear (Data represent as mean ± standard deviation).

chosen level of significance ($P < 0.05$). GRF, postural sway and displacement of the subjects were measured by plotting a scatter plot with the average values of Fx, Fy and Fz, COP movements at Ax and Ay and line plot of sx, sy and sz direction. This method allows only a visual illustration of the movement area.

RESULTS

The figures illustrate the kinetic dynamics of balance stability determinants. These determinants include the GRF, force application point, COP trajectory, displacement and absolute coefficient of friction between high-heeled and flat FW. All of these parameters describe aspects of body sway and stability. The analysis is based on COP trajectory movements, the forces exerted on the force plate, and the frictional forces in two/three-dimensional planes. The importance of FW selection during long periods of standing, such as in industrial work, is also highlighted. The student t-test values showed significant differences in the kinetic dynamics between high-heeled and flat FW. GRF (Fx, $P = 0.001$), (Fy, $P = 0.002$), (Fz, $P = 0.000$), COP trajectory (Ax, $P = 0.02$), (Ay, $P = 0.011$), displacement (sx, $P = 0.002$), (sy, $P = 0.001$) and (sz, $P = 0.002$) and absolute coefficient of friction (Cofxy) ($P = 0.0012$) values of high heel FW reflects poor balance and stability pattern compare to flat FW.

DISCUSSION

Wearing the right FW can greatly improve a person's well-being. Therefore, when developing a management programme, it is crucial to take into account the features of the FW. Previous research has demonstrated a correlation between FW and diseases, making it important to consider the FW a person wears carefully.[20] When wearing shoes, the foot receives sensory information and regulates posture using proprioceptive and tactile senses.[21] The plantar surface of the foot contains cutaneous mechanoreceptors which sense tactile stimulation and provide information to the central nervous system about plantar pressure distribution.[22] Maintaining balance while standing still requires the coordination of many bodily parts, joints and sensory systems. The objective is to remain upright and still in a static position. To reduce the risk of injury during any activity, it is essential to maintain both static and dynamic balance. The type of FW worn can affect the feet's sensory feedback.[23] FW is frequently made to provide stability and support, which may have an impact on the foot's ability to balance and perform its purpose.[24] This study aimed to investigate the impact of wearing high heels for prolonged periods during standing activities, as well as the specific effects of flat and high heel FW on balance stability when standing still.

The study found that wearing high heels during long-standing activities is a significant concern, as it leads to a considerable increase in GRF, a larger area of body sway in terms of centre of pressure movement, a curved displacement path and a lower coefficient of friction value [Figures 1-4].

For centuries, women all around the world have worn high-heeled footwear (HHF) extensively. HHF has a high heel that is taller than the forepart and is characterised by a sturdy high-heel cap, a curved plantar region and a narrow toe section.[25] According to prior studies, 37–69% of women wear HHF every day, and 59% wear them for 1–2 hours each day.[26] Wearing HHF has been linked to various types of injuries, discomfort in the muscles and skeleton and even hallux valgus. In fact, between 2002 and 2012, the prevalence of first-party injuries nearly doubled from 7.1% to 14.1%. To maintain foot health and take preventative measures, it is crucial to understand the risk factors associated with the frequency of these injuries.

Several investigations have proven that the benefits of wearing HHF are not limited to the foot-ankle complex. There is a chain reaction of kinematic consequences that travel up the lower extremities, changing spatiotemporal results, kinematics, kinetics, muscle activation and energy expenditure in the process. Based on the current research available, walking in HHF may require a different kind of neurological control than walking barefoot. HHF causes the body's alignment to change, which negatively impacts postural stability and gait biomechanics, impairs static and dynamic balance and raises the risk of falls for those who wear HHF.[27]

When it comes to FW, high-heeled shoes tend to shift the COM forward compared to flat ones. This shift in posture results in an increase in the vertical ground response force applied on the forefoot while standing. This, in turn, causes a rise in the vertical GRF component when walking in high heels.[28] The diagram shows how the force in the vertical direction changes when standing still in flat shoes compared to high heels. The difference in height of 8.2 cm creates a 42.10% increase in vertical reaction forces (with a significant level of $P = 0.001$). This increased force could potentially cause long-term damage to the lower extremities of the person wearing the high heels. As the height of the heel increases, the base of the shoe becomes smaller, which means that the force is distributed over a smaller area, resulting in greater pressure on the foot compared to flat shoes. A study has shown that wearing high heels can result in decreased postural stability both when standing still and when moving. This is due to the increased sideways and forward/backward movement of the centre of pressure under the foot. It is believed that one of the main reasons for this is the changes to the sensory input from the foot caused by the raised position of the heel.[29] Weight distribution on feet provides a solid foundation for posture, walking and standing. However, if it reduces foot muscular strength, it modifies postural sway during standing.[30] A study has found that wearing high-heel shoes can negatively affect balance due to their poor characteristics, such as less shock absorption, pointed and less contact area, counter stiffness and poor motion control. The researchers found that these characteristics lead to increased postural sway and reduced stability when tested with HHF compared to flat shoes.[31]

Wearing high heels while standing causes a shift in weight forward, as it changes the centre of gravity (CG) and plantar pressure. Initially, the calcaneus bone elevates, which alters the centre of gravity's forward displacement, leading to postural imbalance. To restore balance, the body adapts by making postural corrections. The postural system is flexible and can meet the demands of excessive or reduced postural muscular actions against gravity. Compared to flat FW, the high heel displacement area of the foot is more curved to maintain balance and stability when standing. However, prolonged exposure to this situation can lead to forefoot abnormalities, muscle shortening and joint discomfort.[32]

When two surfaces are in contact, and a force is applied both laterally (frictional force) and vertically (pressing force), the two surfaces establish a connection that provides frictional resistance. This connection is characterised by a value known as the coefficient of friction (Cof). The Cof is a crucial factor in any activity because a higher Cof leads to greater friction, whereas a lower Cof leads to less friction.[33] The proper selection of FW and floor coverings is crucial in preventing slip and fall accidents. A recent study conducted a graphic to illustrate the the Absolute Coefficient of Friction (Cofxy) of two pairs of shoes and found that high heels have a significantly lower Cof than flats. This is because high heels have smaller contact areas, which results in less frictional force and increases the risk of slipping, falling and tripping.

Efforts are being made to mitigate the negative effects of wearing high-heeled shoes in everyday activities. However, certain factors such as heel height, heel base size and insert insoles must be considered while designing and developing HHF. These factors can significantly affect lower extremity biomechanics and provide comfort. This study presents new findings from an analysis of the results, shedding light on the impact of high heels and flat FW on balance and stability in different directions of movement. The values of pressure trajectory, GRF, displacement and coefficient of friction for both types of FW indicate an increased risk of injury with prolonged use of high heels. Based on available data, it can be concluded that: (i) The optimal high heel height range is 3.76–4.47 cm; (ii) larger high heel bases effectively improve gait stability, lower the risk of ankle injury and increase comfort rating when walking in high heels and (iii) using a total contact insert significantly reduces plantar pressure and impact forces on the foot, leading to a higher perceived comfort level.[34]

Limitation

The present study was limited in scope by a small sample size, only examining two types of FW in standing and laboratory conditions. To improve the translation of these findings to real-world scenarios, a larger sample size should be used, with similar protocols for walking conditions. For future studies, additional data on physiological factors, barefoot conditions, other FW types and different standing and walking conditions should be included.

CONCLUSION

Based on a recent study, standing still while wearing high heels can result in increased reactive force, leading to greater postural load and effort and painful lower extremities. The lack of shock-absorbing material and inadequate outsole grooves cause much higher applied forces (~42.10%) as compared to flat FW. The increased static postural load can cause pain and an increased risk of injury. HHF also results in a diminished sense of stability and balance, which can be seen by the noticeable dispersed postural sway in terms of COP (Centre of Pressure) trajectory, as compared to flat FW. It was discovered that high heel users' COP position in relation to the base of support (BOS) was more medial, indicating lower functional limitations of dynamic stability. More dispersed medial postural sway leads to an increased risk of injury. By integrating shock-absorbing material in both types of FW, an improved balance and stability can be achieved.

A shoe with a high heel design has a less contact surface, resulting in unequal weight distribution that causes the CG to slip forward. When standing still, the COM of the body continuously shifts, creating a curved displacement area for HHF, compared to flat FW, which can more evenly distribute pressure by regulating CoM momentum through a larger contact surface. FW with an improved sole, an ideal high heel and increased traction can improve stability and balance during prolonged standing activities such as industry-specific occupations. However, a high coefficient of variation for HHF indicates a greater risk of slippage and falls. The results of a study suggest that wearing high heels can have a negative impact on health during long periods of stationary-standing activity-related occupations. High heels can increase the postural load and effort, leading to an increased risk of slips, trips, falls and decreased balance and stability compared to flat FW. These results will be used to develop databases for future HHF design, as there is currently no standard method for determining an individual's stability.

Acknowledgment and author contribution

Participant contributions are appreciated; the authors would like to thank them for their efforts in this study. MSP was involved in conceptualisation, experiment design, and overall technical and administrative guidance and supervision. SDK was involved in manuscript writing, data analysis, interpretation, and statistical analysis. KS was involved in data collection, manuscript writing, and interpretation. All authors read and approved the final manuscript.

Ethical approval

The study protocol was approved by the Institutional Ethical Committee, Defence Institute of Physiology and Allied Sciences, Delhi.The Institutional approved IEC Reference number: IEC/DIPAS/A-6/2. dated 03.12.2015.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

Financial support and sponsorship

Government of India.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

REFERENCES

1. Meyer G, Ayalon M. Biomechanical aspects of dynamic stability. Eur Rev Aging Phys Act 2006;3:29-33.
2. Palmer KT, D'Angelo S, Harris EC, Linaker C, Coggon D. Sensory impairments, problems of balance and accidental injury at work: A case-control study. Occup Environ Med 2015;72:195-9.
3. Harwood RH. The world falls guideline. Age Ageing 2022;51:afac229.
4. Alghadir AH, Zafar H, Anwer S. Effect of footwear on standing balance in healthy young adult males. J Musculoskelet Neuronal Interact 2018;18:71-5.
5. Gabell A, Simons MA, Nayak US. Falls in the healthy elderly: Predisposing causes. Ergonomics 1985;28:965-75.
6. Sherrington C, Menz HB. An evaluation of footwear worn at the time of fall-related hip fracture. Age Ageing 2003;32:310-4.
7. Menant JC, Steele JR, Menz HB, Munro BJ, Lord SR. Effects of footwear features on balance and stepping in older people. Gerontology 2008;54:18-23.
8. Morasso P. Centre of pressure versus centre of mass stabilization strategies: The tightrope balancing case. R Soc Open Sci 2020;7:200111.
9. Nejc S, Jernej R, Loefler S, Kern H. Sensitivity of body sway parameters during quiet standing to manipulation of support surface size. J Sports Sci Med 2010;9:431-8.
10. Palmieri RM, Ingersoll CD, Stone MB, Krause BA. Center-of-pressure parameters used in the assessment of postural control. J Sport Rehabil 2002;11:51-66.

11. Duarte M, Harvey W, Zatsiorsky VM. Stabilographic analysis of unconstrained standing. Ergonomics 2000;43:1824-39.
12. MacRae CS, Critchley D, Morrissey M, Shortland A, Lewis JS. Do rocker-sole shoes influence postural stability in chronic low back pain? A randomised trial. BMJ Open Sport Exerc Med 2016;2:e000170.
13. Notarnicola A, Maccagnano G, Pesce V, Tafuri S, Mercadante M, Fiore A, *et al*. Effect of different types of shoes on balance among soccer players. Muscles Ligaments Tendons J 2015;5:208-13.
14. Menz HB, Auhl M, Munteanu SE. Preliminary evaluation of prototype footwear and insoles to optimise balance and gait in older people. BMC Geriatr 2017;17:212.
15. Zhou J, Habtemariam D, Iloputaife I, Lipsitz LA, Manor B. The complexity of standing postural sway associates with future falls in community-dwelling older adults: The MOBILIZE Boston Study. Sci Rep 2017;7:2924.
16. World Medical Association. World Medical Association declaration of Helsinki: Ethical principles for medical research involving human subjects. JAMA 2013;310:2191-4.
17. Majumdar D, Pal MS, Pramanik A, Majumdar D. Kinetic changes in gait during low magnitude military load carriage. Ergonomics 2013;56:1917-27.
18. Sen S, Chatterjee S, Sahrawat TR, Singh SB, Pal M. Effect of military footwear on balance and stability: A pilot study. IJRAR 2019;6:464-9.
19. Barbier F, Allard P, Guelton K, Colobert B, Godillon-Maquinghen AP. Estimation of the 3-D center of mass excursion from force-plate data during standing. IEEE Trans Neural Syst Rehabil Eng 2003;11:31-7.
20. Barton CJ, Bonanno D, Menz HB. Development and evaluation of a tool for the assessment of footwear characteristics. J Foot Ankle Res 2009;2:10.
21. Hijmans JM, Geertzen JH, Dijkstra PU, Postema K. A systematic review of the effects of shoes and other ankle or foot appliances on balance in older people and people with peripheral nervous system disorders. Gait Posture 2007;25:316-23.
22. Perry SD, Radtke A, Goodwin CR. Influence of footwear midsole material hardness on dynamic balance control during unexpected gait termination. Gait Posture 2007;25:94-8.
23. Arnadottir SA, Mercer VS. Effects of footwear on measurements of balance and gait in women between the ages of 65 and 93 years. Phys Ther 2000;80:17-27.
24. Alghadir AH, Zafar H, Anwer S. Effect of footwear on standing balance in healthy young adult males. J Musculoskelet Neuronal Interact 2018;18:71.
25. Cronin NJ. The effects of high heeled shoes on female gait: A review. J Electromyogr Kinesiol 2014;24:258-63.
26. Hapsari VD, Xiong S. Effects of high heeled shoes wearing experience and heel height on human standing balance and functional mobility. Ergonomics 2016;59:249-264.
27. Zeng Z, Liu Y, Hu X, Li P, Wang L. Effects of high-heeled shoes on lower extremity biomechanics and balance in females: A systematic review and meta-analysis. BMC Public Health 2023;23:726.
28. Ebbeling CJ, Hamill J, Crussemeyer JA. Lower extremity mechanics and energy cost of walking in high-heeled shoes. J Orthop Sports Phys Ther 1994;19:190-6.
29. Masani K, Popovic MR, Nakazawa K, Kouzaki M, Nozaki D. Importance of body sway velocity information in controlling ankle extensor activities during quiet stance. J Neurophysiol 2003;90:3774-82.
30. Koyama K, Yamauchi J. Altered postural sway following fatiguing foot muscle exercises. PLoS One 2017;12:e0189184.
31. Brenton-Rule A, D'Almeida S, Bassett S, Carroll M, Dalbeth N, Rome K. The effects of sandals on postural stability in patients with rheumatoid arthritis: An exploratory study. Clin Biomech (Bristol, Avon) 2014;29:350-3.
32. Bae YH, Ko M, Park YS, Lee SM. Effect of revised high-heeled shoes on foot pressure and static balance during standing. J Phys Ther Sci 2015;27:1129-31.
33. Jones C, Manning DP, Bruce M. Detecting and eliminating slippery footwear. Ergonomics 1995;38:242-9.
34. Wang M, Jiang C, Fekete G, Teo EC, Gu Y. Health view to decrease negative effect of high heels wearing: A systemic review. Appl Bionics Biomech 2021;2021:6618581.

How to cite this article: Das Kumar S, Sandhu K, Pal M. Effect of wearing high heel and flat footwear on balance and stability dynamics: A kinetic study. Indian J Physiol Pharmacol. doi: 10.25259/IJPP_578_2023