

Shod landing provides enhanced energy dissipation at the knee joint relative to barefoot landing from different heights

C.H. Yeow^{a,b}, P.V.S. Lee^{c,d}, J.C.H. Goh^{a,b,*}

^a Department of Orthopaedic Surgery, National University of Singapore, Singapore

^b Division of Bioengineering, National University of Singapore, Singapore

^c Department of Mechanical Engineering, University of Melbourne, Australia

^d Biomechanics Lab, Defence Medical and Environmental Research Institute, Singapore

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ABSTRACT

Athletic shoes can directly provide shock absorption at the foot due to its cushioning properties, however it remains unclear how these shoes may affect the level of energy dissipation contributed by the knee joint. This study sought to investigate biomechanical differences, in terms of knee kinematics, kinetics and energetics, between barefoot and shod landing from different heights. Twelve healthy male recreational athletes were recruited and instructed to perform double-leg landing from 0.3-m and 0.6-m heights in barefoot and shod conditions. The shoe model tested was Brooks Maximus II. Markers were placed on the subjects based on the Plug-in Gait Marker Set. Force-plates and motion-capture system were used to capture ground reaction force (GRF) and kinematics data respectively. 2×2 -ANOVA (barefoot/shod condition $\times$ landing height) was performed to examine differences in knee kinematics, kinetics and energetics between barefoot and shod conditions from different landing heights. Peak GRF was not significantly different ($p = 0.732$ – 0.824) between barefoot and shod conditions for both landing heights. Knee range-of-motion, flexion angular velocity, external knee flexion moment, and joint power and work were higher during shod landing ($p < 0.001$ to $p = 0.007$), compared to barefoot landing for both landing heights. No significant interactions ($p = 0.073$ – 0.933) were found between landing height and barefoot/shod condition for the tested parameters. While the increase in landing height can elevate knee energetics independent of barefoot/shod conditions, we have also shown that the shod condition was able to augment the level of energy dissipation contributed by the knee joint, via the knee extensors, regardless of the tested landing heights.

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1. Introduction

The ability of shoes in enhancing athletic performance has been suggested to be partly attributed to the elastic energy storage and recovery in its cushioning system [1,2]. The athletic shoe wear is usually composed of soft compressible support surface interfaces designed to protect against injuries occurring in sports due to large ground reaction forces (GRF); however, the impact remains high with the use of shoe wear as the athletes actively seek to transform the soft interface into a thinner-stiff form associated with improved stability [3]. Chiu and Shiang [4] further demonstrated that insoles play an important role in the cushioning properties of sport shoes by absorbing up to 32% of impact energy under low impact energy condition. These studies collectively indicated that athletic shoes can contribute to shock absorption and attenuate injury risk during sports through its cushioning system.

A previous epidemiological study by Hootman et al. [5] reported that barefoot sports such as gymnastics displayed a high incidence rate of knee injuries, like anterior cruciate ligament (ACL) injuries, as compared to shod sports including volleyball and basketball. Moreover, Baitch [6] documented that barefoot dancers sustained a higher injury rate (65%), relative to that of dancers wearing shoes (49%). In addition, although beach volleyball involves barefoot landing on soft sand surfaces, there is a notable risk of acute and overuse knee injuries, which is comparable to that of indoor volleyball [7,8]. In view of the injury risk implicated with barefoot landing during sporting activities, it is important to understand how the kinematics, kinetics and energetics of barefoot landing differ from that of shod landing.

Most previous studies examined the biomechanical differences, in terms of kinematics and kinetics, between barefoot and shod running. For instance, Divert et al. [9] reported that barefoot running delivered lower contact and flight time, and lower peak GRF than shod running, which could be attributed to a neural-mechanical adaptation mechanism to reduce the high impact stress sustained during repetitive steps. A more recent study by Squadrone and Hallozzi [10] demonstrated that athletes landed in more ankle plantar flexion during barefoot running than shod running, which resulted in

* Corresponding author. Department of Orthopaedic Surgery, NUS Tissue Engineering Programme, Office of Life Sciences, National University of Singapore, 27 Medical Drive, Singapore 117510, Singapore. Tel.: +65 6516 5259; fax: +65 6776 5322.

E-mail address: dosgohj@nus.edu.sg (J.C.H. Goh).

reduced impact forces and changes in stride kinematics. With relevance to landing, Webster et al. [11] found that barefoot landing can significantly reduce peak knee flexion angles and moments, especially for the limb that underwent ACL reconstruction.

Apart from kinematics and kinetics, prior studies have reported on energetics parameters, particularly joint power and work, in order to describe the energy dissipation at the lower extremities during landing [12–14]. Landing results in the application of forces and moments to the lower extremities, which accelerate joint flexion motions and lead to a tendency of the extremities to collapse. A stable landing would require counter extensor moments at the lower extremity joints in order to resist collapse and reduce body velocity to zero without injury. These joint extensor muscles provide eccentric work by absorbing kinetic energy from the skeletal system and stabilizing the landing [13]. An energetics study by Zhang et al. [14] demonstrated that the knee extensors were the major energy dissipaters for different landing heights (0.32-m, 0.62-m and 1.03-m) and different landing techniques (soft, normal and stiff). Moreover, Decker et al. [12] further reported that the knee was the primary shock absorber, among the lower extremity joints, for both genders during landing.

While there are preceding investigations of the shod condition on joint kinematics and kinetics, it is still unclear how the shod condition may affect the level of energy dissipation contributed by the knee joint during landing, which may be vital for understanding how athletic shoes can indirectly influence shock absorption at the knee joint during impact maneuvers. The objective of our study was to investigate the biomechanical differences, in terms of knee kinematics, kinetics and energetics, between barefoot and shod landing from different heights. The use of different heights was necessary to understand whether a difference in landing height would influence the effect of the shod condition on the level of energy dissipation contributed by the knee joint during landing. We hypothesized that shod landing can promote the level of energy dissipation contributed by the knee joint, through greater knee flexion range-of-motion (ROM), flexion angular velocity, external flexion moment, and joint power and work, as compared to barefoot landing from the tested landing heights.

2. Methods

2.1. Subjects and shoe model

Twelve healthy male recreational athletes (age: 23.1 ± 0.8 years, mass: 63.7 ± 6.3 kg, and height: 1.73 ± 0.05 m) were recruited from the local university. Subject exclusion criterion was a history of lower extremity injuries/diseases that might affect landing biomechanics. All subjects signed informed consent forms prior to their participation in accordance with the university's Institutional Review Board. Anthropometric data, such as height, weight, knee width, ankle width, leg length and inter-anterior superior iliac spine distance were acquired from all subjects. The subjects wore the same shoe model (Maximus II, Brooks Sports Inc., WA) and were fitted according to their foot size. The Brooks Maximus II shoe is a cross trainer, which features forefoot and rearfoot hydroflow cushioning for comfort and protection of the heel and forefoot from shock.

2.2. Instrumentation setup

The study was conducted at the Motion Analysis Laboratory, Department of Orthopaedic Surgery, National University Hospital, Singapore. Two force-plates (Kistler, Winterthur, Switzerland), embedded into the floor, were used to obtain GRF data while a motion-capture system (Vicon MX, Oxford Metrics, UK) with six infrared cameras was used to obtain kinematics data. GRF and kinematics data were collected at sampling rates of 1000 Hz and 250 Hz respectively. Prior to the start of landing trials, the force-plates

and the motion-capture system were calibrated based on the manufacturers' recommendations and then synchronized via MX UltraNet HD using a GigaBit Ethernet connection. For the barefoot condition, fifteen retroreflective markers (25-mm diameter) were attached to the subject's lower body, according to the Plug-in-Gait Marker Set, specifically on the sacrum and bilaterally on the anterior superior iliac spine, lateral thigh, lateral femoral epicondyle, lateral shank, lateral malleolus, second metatarsal head and calcaneus (Fig. 1). The same marker placement was adopted for the shod condition, except that the calcaneus and second metatarsal head markers were placed on the shoe, rather than on the foot.

2.3. Landing protocol

The subjects were instructed to perform a double-leg drop landing maneuver by stepping off a height-adjustable platform with the dominant limb (preferred limb for kicking a ball) and landing with each foot/shoe on each force-plate. They were asked to utilize their natural landing style. The double-leg landing maneuvers were executed from 0.3-m and 0.6-m heights. These heights were similar to landing heights that were commonly adopted in previous reports [12–15]. At each height, the subjects were given 3 min of practice and 5 min of rest before conducting the actual landing trials, and another 5 min of rest prior to the trials for the next landing height. For all subjects, the barefoot and shod landing trials were performed in random sequence. A trial is taken as successful when the subject steps off the platform (without an upward and/or forward jump action) and adopts a stable landing posture. The motion of upward and/or forward jump action was determined from the plot of the average z-coordinate (vertical axis) and x-coordinate (anterior-posterior axis) of the three pelvic markers (left and right anterior superior iliac spine markers, and sacrum marker) against time. We defined an increase in z-coordinate, during step-off, by more than 10 mm with respect to an initial standing position as an upward jump action. Upon landing, if the x-coordinate exceeds 450 mm (75% of the 600-mm distance between the far-edge of the force-plate and edge of the platform) with respect to the initial standing position, we would assume a forward jump action during step-off. For each subject, average data from five successful drop landing trials at each landing height and barefoot/shod condition, were used for analysis.

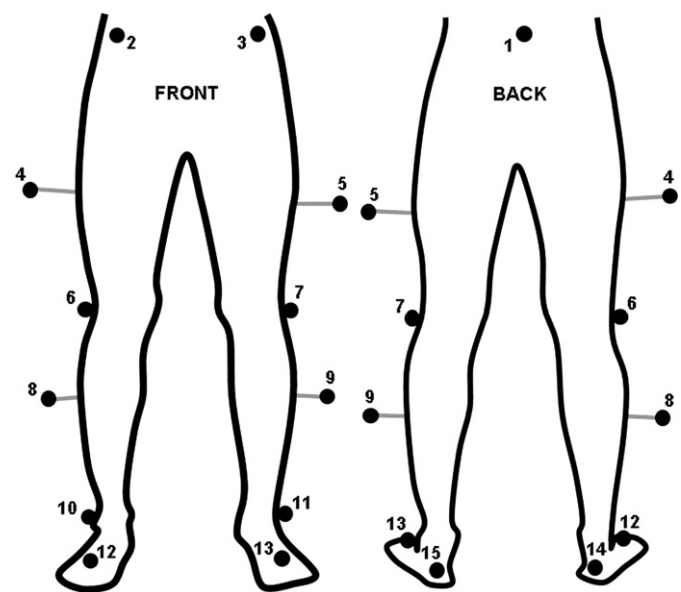


Fig. 1. Plug-in-Gait Marker Set. [1 – sacrum; 2, 3 – anterior superior iliac spine; 4, 5 – lateral thigh; 6, 7 – lateral femoral epicondyle; 8, 9 – lateral shank; 10, 11 – lateral malleolus, 12, 13 – second metatarsal head; 14, 15 – calcaneus].

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