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Effect of Minimalist Shoe Heel Height on Foot Strike Pattern in Running

¹ Hyun Joon Kwon, ¹ Kyung Koh, ^{1,2} Hiroaki Hobara, ¹ Edward Chu and ^{1*} Jae Kun Shim

¹ Department of Kinesiology, University of Maryland, College Park, MD, USA

² Research Fellow of the Japan Society for the Promotion of Science, Tokyo, Japan

*Corresponding Author; jkshim@umd.edu

SUMMARY

The purpose of this study was to investigate the mechanism of foot strike pattern (FSP) adaptations to a minimalist shoe among the different heel height in running. We found that the strike index (SI) and foot strike angle (FSA) were systematically affected by changes in heel height. We also observed a linear correlation between FSA and SI. However, no changes in initial foot angle (IFA) were found during running despite the differences among shoe heel heights.

INTRODUCTION

There has been interest in methods to modify pattern of human locomotion associated with kinetics and/or kinematics during running [1]. The foot of habitually shod runners typically lands with an initial heel strike, while the foot of a barefoot runner typically lands with a midfoot or forefoot strike [2,3]. The changes in footstrike pattern induce different kinetic and kinematics. A previous study has shown that barefoot runner is known to have lower incidences of injury when compared to shod runners [4].

Recent studies have focused on the effects of less rigid, minimalist, or unstable interventions to minimize injury risk with respect to mimetic barefoot condition [5,6]. Minimalist shoes have been known to be the most appropriate form of footwear for mimicking the barefoot running style [7]. Although, there is currently no clear definition of minimalist shoes, minimalist shoes have been designed to essentially serve as a safer alternative to barefoot running by imitating the barefoot condition, while also maintaining the biomechanical performance feature of running shoes [8]. However, previous investigations have not determined the influence of minimalist shoe design on running mechanics.

Heel height or lift is believed to be a critical factor in the design and construction of running shoes. Hamill found that midsole thickness has no effect on foot strike pattern (FSP), vertical impact force (VIP), time to VIP, and vertical loading rate [9]. Reinschmidt reported that a higher heel leads to higher initial dorsiflexion moment [10]. However, kinematic and kinetic differences in minimalist shoe category have not been clearly examined.

The purpose of this study was to investigate the effect of heel height construction on the running mechanics. We

focused on changes in strike index (SI), foot strike angle (FSA), and the kinematic measure of initial foot angle (IFA).

METHODS

Nine female volunteers between 18 to 28 years of age (average age = 21.5±3.1 years; average height = 161.8±5.9 cm; average mass = 58.25±4.6 kg; shoe size = 23.5 cm) participated in the study. All subjects were healthy habitually shod rearfoot strikers (RFS) without any history of neuromuscular disorders or functional limitations in their legs. Participants were recreational runners who ran for a minimum total 16 km at least twice in a week.

The subjects were asked to run around a 60 m track at a controlled speed of 2.6 m/s (± 5%) for 15 minutes in each shoe for all four shoes. Four different height heel minimalist shoes (insole, 1.5 mm; outsole, 3 mm; midsole, 3 mm, 6 mm, 9 mm, 12 mm) and corresponding heel lift (0°, 1°, 2°, 3°), were specially customized for this study. Eight tracking markers were placed on the shoe (Figure 1). Running speed was monitored using 6 photoelectric sensors which were located every 10 m along the track and running speed was calculated with a customized LabVIEW™ (National Instruments, Austin, TX) program. Data was collected throughout the whole 15 minutes, but the first 10 minutes were allotted for subjects to get used to the shoe, while the last 5 minutes of data were used for analysis.

Ground reaction force (GRF) data were collected by 10 force plates (Kistler Instrument Corp., NY, USA) at 1,000 Hz. Retro-reflective markers for tracking kinematic data were placed on the pelvis, shank, knee, leg, ankle which similar to the Helen Hayes marker system of lower limb. Kinematic data were recorded using a MX giganet with 10 Vicon cameras (Vicon motion systems, Oxford, UK) at 200 Hz sampling rate.

Marker data and force data were filtered with a second order Butterworth filter at 20Hz. Both cutoff frequencies were decided by residual analysis. A threshold of 15 N was used to determine foot strike (FS) and toe off. The center of pressure (COP) was calculated for all trials using only clean force plate strike. The COP location was referenced to the anatomic coordinate system of the foot. The SI calculated by kinetics data as the location of the COP at initial contact as a

percentage of the total foot length [11]. The foot strike angle (FSA) was defined as the angle between the distal heel marker (A) and the marker on the dorsum of the second metatarsal (B) on figure 1. The FSA in resting stance was subtracted from all values such that 0° corresponds with a standing [2]. The heel lift (HL) was defined as the angle between the ground and line from mid heel to mid forefoot in the insole [10]. In order to quantify an anatomical foot angle, IFA was produced by subtracting the HL from FSA.

A one-way analysis of variance for repeated measures was conducted to examine the effect of the different heel height shoes. Our dependent variables included kinematic and kinetic variables. Significance for all statistical tests was set at $p < 0.05$. When a significant effect was present, a post hoc pairwise comparison test was performed to determine where these differences lay. Further, we calculated regression coefficient between SI and FSA in each heel heights. Statistical analysis was executed using SPSS (SPSS Inc., Chicago, IL).

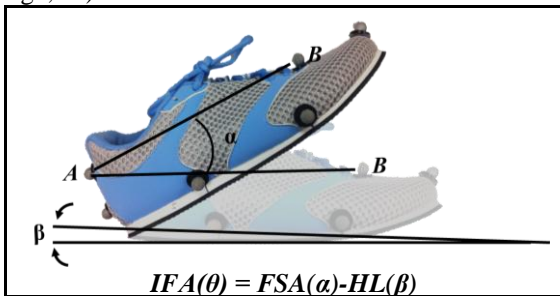


Figure 1: Retro-reflective marker placement and schematic illustration of FSA (α) and HL (β) measurement. IFA (θ) was represented by subtracting HL (β) from FSA (α).

RESULTS AND DISCUSSION

Statistical analyses revealed that there significantly main effect of heel height on SI (Figure 2). For every 3 mm increase in the heel height, the SI decreased 14% from the previous height. The SI in 12 mm heel height was significantly smaller than in 3 mm ($p < 0.01$). As heel height and lift decreased, SI moved closer to anterior direction even close to boundary of midfoot SI. In addition, some of participants changed their FSP from rearfoot to midfoot strike at 3 mm and 6 mm heel heights. These results suggest that changes in heel height and lift of minimalist shoes would be a possible factor to induce FSP change.

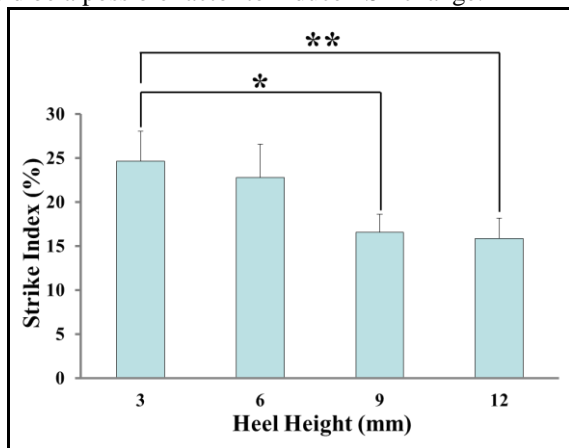


Figure 2: Mean and standard errors in strike index (SI) compared between heel heights.

Similarly, FSA increased as heel heights increased (Figure 3). The FSA were significantly greater for the 12 mm as compared to the 3 mm ($p < 0.01$) and 6 mm ($p = 0.02$) heel height. FSA was correlated with SI, $R = 0.89-0.98$ ($p < 0.01$) according to heel height. Regression coefficients among heel heights were not different ($p = 0.3$). This result is consistent with a previous finding which demonstrated that the FSA was significantly correlated with SI ($R = 0.92$ ($p < 0.01$)) from fixed FSP [2].

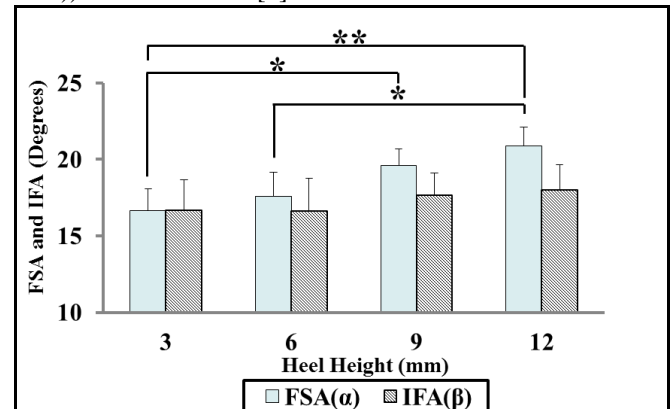


Figure 3: Mean FSA and IFA compared between heel heights; every 3 mm heel height changes 1° of HL.

Previous studies have shown that mid and forefoot strike patterns indicates more plantarflexed ankle position than heel foot strikes at contact [7,9]. When heel height decreased (SI move closer to AP direction), more plantarflexed ankle positions may take place. However, in this study, IFA was not affected by SI (Figure 3). This may indicate 1) strike patterns are mediated by different adaptations, 2) kinematic adaptation may take place at some lower extremity other than the foot, or 3) there may be no kinematic adaptations affected by changes in heel height and lift.

CONCLUSION

The results of present study suggest that changes in heel height and lift of minimalist shoes affects SI and FSA while IFA remained constant. Additional work is necessary to justify lower extremity kinematics and kinetics to pinpoint what factors influence IFA during running with different shoe heel heights.

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