Effect of Barefoot and Shod Conditions on Temporal Parameter and Plantar Fascia Strain During Running on Different Surfaces

N. A. A. Abdul Yamin, K. S. Basaruddin*, A. F. Salleh, W. M. R. Rusli and N. Abdul Razak
School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
*Corresponding author
Email: khsalleh@unimap.edu.my

Abstract-- Running shoes have been continuously considered as a risk or solution to injury. Plantar fascia strain is always associated with common foot injury of runners. The aim of this study to evaluate the influence of barefoot and shod condition to temporal parameter and plantar fascia strain. This study analyzes temporal parameter, plantar fascia strain (PFS) and medial longitudinal arch (MLA) angle during the stance phase of 9 male subjects that running with barefoot (BF) or two shod conditions (cushioned heeled (HS) and minimally running shoes (MS)). Differences of the running conditions were analyzed using visual 3D software. The result showed there is no correlation between stance time and running condition. However, BF running revealed the highest PFS and peak medial longitudinal arch (MLA) angle during running on each surface. Thus, it seems that BF running has the highest possibility of injury compared to HS and MS with respect to plantar fascia.

Index Term-- Running surfaces, shod conditions, plantar fascia strain, stance time.

INTRODUCTION

Recreational running always implicated in numerous clinical benefits1. However, injuries are fairly common in runners since the late 1970s2 with an occurrence 70% per year3. Unfortunately, injuries that associated with running and walking4 activities attributed to incorrect shoe choice, training errors and excessive shoe wear or other biomechanical factors associated with ground reaction forces5. However, running shoes also have been frequently linked as a solution to running injuries. Previously, a few published studies have explored the effect of shod condition in running which connected with foot injury specifically. One of favourite running footwear among runners is cushioned heeled running shoe (HS). Divert et al.8 stated that the functions of shoes should be to provide protection to the foot and leg structure with damping and low stiffness materials which referring to HS. In addition, Rome et al.7 pointed out that shock absorbing insoles which commonly in HS may reduce the occurrence of stress fractures. Besides, thick ethylene-vinyl acetate (EVA) in HS requires a large impact force in order to transform the interface into more durable surface6. Thick midsole of HS also causes too much inversion that may lead to ankle sprain7. Therefore, the use of minimally shoe (MS) that was designed to mimic or imitate barefoot (BF) running, was considered. Although BF running is exposed to some environmental dangers, it allows runners to naturally undergo shock attenuation and energy return capabilities naturally. MS is defined by the footwear industry as a shoe with a thin, flexible midsole and outsole and a light, basic upper with little or no heel counter2. A classic study believed that, shoe should maintain the foot function and structure instead to protect it against injuries and coldness. Reduction of midsole thickness can improve balance which can limit injuries occurrence. MS also can reduce foot related injuries by simply shift the injury location, however, the total number of injuries were not decreased2. Each shod condition during running can be considered either beneficial or harmful to runners. However, although injury risk that vulnerable to runner with respect to effect of shod condition is frequently studied, there are limited studies that tested the different shod condition on different surface types or hardness. Thus, the purpose of this paper to assess the influence of barefoot and shod conditions on temporal parameter and plantar fascia strain to further understand the occurrence of injury in foot during running on different surface hardness.

MATERIALS AND METHODS

Subjects
Nine healthy participants were volunteers from university population that had age between 23 to 26 years old. These participants were included in the normal body mass index (BMI) category with body mass and height in the range of 59 to 76 kg and 168 to 175 cm respectively. Participants with previously musculoskeletal injury or orthopaedic abnormality were excluded from this study in order to prevent any dissimilarity in the movement and difficulty potential to perform the task. Each participant that filled the survey was voluntarily agreed to participate and signed the consent form prior to the experiment.

Equipment
Three dimensional (3D) foot segment kinematics data were collected using five Oqus camera Motion Captured System at a frequency of 200 Hz and two Bertex force plates as presented in Figure 1. The foot kinematics were analysed using marker placement by Leardini et al.9 as reference. Twelve reflective markers were placed on the right foot of each subject where multi segment foot model was applied. The anatomical landmark comprised three segments; metatarsus, mid-foot and calcaneus. The following anatomical landmark were included; base of the first metatarsal (FMB), head of the first metatarsal (FMH), base of second metatarsal (SMB), head of second metatarsal (SMH), base of fifth metatarsal (VMB) and head of fifth metatarsal (VMH) for Metatarsus (Met) segment. For Mid-foot (Mid) segment landmark involved is most medial apex
Fig. 1. Experimental set up

Fig. 2. Markers placement for each condition: (a) barefoot, (b) heeled shoe, (c) minimally shoe.

Experimental Protocol

After the markers were installed in the anatomical landmark using double-sided adhesive tape, subjects were first ran on the runway prior data collection to familiarize to each condition of the experiment. Subjects then were requested to run over 10 m indoor in barefoot (BF) condition followed by minimally running shoe (MS) and heeled running shoe (HS) condition at their comfortable speed on rubber, artificial grass and concrete runway. The running surface selected was prepared on the basis of surface hardness. The marker was re attached during each running condition. A reference static trial was also recorded by the subject stand up-right in the double-leg support posture in order to determine the neutral position of the joint. Data collection of subject running in each condition were then took place. Trials were accepted when all markers placed were well visible and right foot contact with the force plate was achieved without obvious alterations to running stride.

Data Analysis

The three-dimensional foot segment kinematic position and orientation was processed and analysed using Visual 3D software. The parameters measured and analysed included 1) stance time: duration for participant completing one cycle of stance phase, 3) plantar fascia strain (PFS): the change in length during the stance phase divided by the original length of the relative position distance between the of calcaneus and first metatarsal markers\(^{(10)}\) 4) medial longitudinal arch (MLA) angle: the angle subtended by two lines, one from the marker on the FMH to the TN and the other from the ST to the TN marker\(^{(11)}\).

RESULTS

The average of stance time, plantar fascia strain (PFS), peak medial longitudinal arch (MLA) angle and relative of MLA to range of motion (ROM) of each shod condition were analysed in order to find the influence of barefoot and shod running during on different surfaces. Analysis on the effect of barefoot and shod condition in the present study only involving heel-striker participants in order to eliminate the potential influence of foot strike pattern.

Temporal parameter

Temporal parameter calculated in this experiment is stance time. The stance time is measured starting from foot strike until toe off during running in each shod condition on each surface. As shown in Figure 3, compared to BF and MS, the HS elicited a higher stance time during running on concrete surface. The MS led to a greater stance time during running on rubber, whereas having almost similar stance time to BF during running on artificial grass and concrete surface. The BF shows the lowest in stance time for each running surface. Overall, duration of the stance phase is in the range from 240 ms to 280 ms. The highest stance time is showed by HS on concrete and MS on rubber with value of 278.3 ms and the lowest stance time is during BF running on concrete at 243.3 ms.
Plantar fascia strain (PFS)
The results of PFS for each shod condition are shown in Figure 4. It is apparent that on each surface, the highest value of PFS is during running in BF followed by MS and HS. Among BF condition, the highest PFS is during running on artificial grass with value of $132.12 \times 10^{-3}$ and the lowest PFS in HS is during running on concrete with a value of $70.63 \times 10^{-3}$.

Medial Longitudinal Arch (MLA)
Figure 5 presents the experimental data of peak MLA. Interestingly, the highest value of peak MLA is in BF condition followed by MS and HS condition on each surface. The peak MLA of each running condition is in small value which ranges from $1^\circ$ to $10^\circ$. From the chart, it can be observed that peak MLA of each running condition is in correlation with surface hardness. The highest peak MLA is the hardest surface, i.e. concrete. However, in relation to range of motion (ROM) where the angular displacement from foot strike to peak angle was evaluated, there is no correlation of MLA with the surface hardness for each running condition as showed in Figure 6. On rubber and concrete surface, the MLA relative to ROM is the highest during MS for both surfaces and the lowest during BF and HS condition respectively. But on artificial grass, the highest value is in HS condition followed by BF and MS condition.

DISCUSSION
The present study investigated the influence of running in different condition (i.e. shod (BF, MS, and HS), surface (rubber, artificial grass and concrete)) on temporal parameter, plantar fascia strain and medial longitudinal (MLA) angle during stance phase of running. The first observation is that the stance time was shown to be non-correlated to running condition. Specifically, it was shown that the shod condition that contributes to the longest duration of stance during running on each surface is varied. There are some previous studies investigated the influence of cushioning properties to stance time according to the literature, “special soft” shoes had a longer stance time than a normal shoe. Stance time was also found to be longer in shod (soft) compared to barefoot (hard). In contrast, another study reported that the stance time was longer in hard shoes compared to soft shoes even though the difference was not statistically significant. Thus, stance time and running condition can be considered as in non-linear relationship when cushioning properties and surface hardness are taken into account. In addition, duration of stance is inconstant in...
each running situation might be caused by self-selected running speed performed by each of the participant in the current study. Running speed play a major role in influencing the stance time of running.15

Another important observation in the present study is that the PFS of each shod condition was shown to be in a constant manner during running on each surface. This recurring pattern also can be seen in peak MLA angle parameter. Both PFS and peak MLA angle have the highest and lowest value during barefoot and heeled shoe condition respectively. Plantar fascia is related to MLA through “windlass mechanism”. Originally, foot and its ligaments were defined as an arch-like triangular structure or truss16. As shown in Figure 7, the triangle formed by metatarsal, midtarsal joint and calcaneus. Plantar fascia is represented by the hypotenuse (line C) and MLA is represented by the other two lines (line A and B).

Plantar fascia simulates a cable attached to the calcaneus and metatarsophalangeal joint that explained the term “windlass” which defined as the tightening of a rope or cable. The winding of plantar fascia during the propulsive phase after mid stance due to dorsiflexion decrease the distance between calcaneus and metatarsal elevate the MLA and decrease the MLA angle17. The essence of the windlass mechanism principle is the shortening of the plantar fascia by dorsiflexion. Thus, the result obtained in the present study, further explained the windlass mechanism as the higher PFS where the changing of plantar fascia length, the higher MLA angle.

The finding of the current study in respect of plantar fascia strain and MLA angle may be also essential in understanding the aetiology of plantar fasciitis which one of the common injury for runners18. Plantar fasciitis is believed caused by excessive strain appointed on plantar fascia9 and high stress that contributes by plantar fascia elongation19. Increasing in PFS and MLA angle may lead to either too much motion or too little motion of the foot. According to a review of literature, these motions can result plantar fasciitis because it was found that either lower- or higher- arches foot can expose to this injury17. On the basis that increases in PFS were observed during barefoot running in the present study, running with heeled running shoe where PFS is the lowest is best to prevent any plantar fascia pathologies.

The result obtained from the present study also show that, running condition is not correlated with MLA relative to range of motion (ROM) relationship where the angular displacement from foot strike until peak angle was calculated. The finding of the current study is supported by literature on biomechanics response research which involving kinematic reaction. Hardin et al.19 who investigated kinematic response during running with various midsole of shoes and surface hardness had found there were changes in limb posture during the contact time. Similarly, Tenbroek et al.2 reported that, different running shoes and surface condition contribute to different kinematic response. However, Dixon et al.20 and Stergiou et al.21 found that, there no significant difference in kinematic response during running on different running condition. The angular displacement basically described the biomechanical reaction of the foot in adapting to the running condition. The non-correlated relationship in the present study may be explained by the obvious difference in biomechanical reactions of the foot among individual in addition to the existence of various common structural features and shape of the foot itself22. MLA has traditionally been known play a major role that led to these differences23. A potential drawback of this study is that only three surfaces (i.e. rubber, artificial grass and rubber) were involved. The findings obtained in the current study might be different on other surfaces.

CONCLUSION

The present study provides new information on PFS due to different running conditions (i.e. BF, HS and MS on rubber, artificial grass and concrete). As the proposed relationship between the higher value of PFS and injury, it seems that BF running has the highest possibility of injury compared to HS and MS running with respect to plantar fascia. However, the injury risk can be detailed out by investigating the association of PFS and impact force in future.

ACKNOWLEDGEMENTS

This study was supported by research grant from Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme (FRGS).

REFERENCES


