The Effect of Material Characteristic of Shoe Soles during Long Duration Running

Chan Siow Cheng*, J P Tan and Tan Yin Qing

Department of Mechatronics and Biomedical Engineering Lee Kong Chian Faculty of Engineering and Science Universiti Tunku Abdul Rahman Selangor, Malaysia

*chansc@utar.edu.my

Abstract. Long duration running has been associated with musculoskeletal injuries such as patellofemoral pain syndrome and knee osteoarthritis. This study was designed to investigate the effects of two different shoe insoles on kinematic and kinetic performance during long duration running. In total 15 subjects (7 males and 8 females) were recruited to perform 15 minutes continuous running on the treadmill in 3 different shoe insole conditions: (i) no insole; (ii) Ethyl Vinyl Acetate (EVA) insole and (iii) Polyurethane (PU) insole. The result revealed a significant increase in maximum vertical ground reaction force (VGRF) with the PU insole compare with the no insole and EVA insole conditions (p<0.05). There is no difference between conditions in kinematic variables: step length, stride length and cadence (p>0.05).

1. Introduction

Recreational running is one of the common exercises that can improve our cardiorespiratory function and general well-being [1]. The popularity of running as a form of exercise and recreation in maintaining healthy life-style has grown rapidly due to its low-cost, equipment-free and time independent. The negative impact of running is the increasing incidence of running-related injuries such as patellofemoral pain syndrome, Achilles tendinopathy and medial tibial stress syndrome [2-4] especially those runners just committed into training [5]. One of the strategies to reduce the impact loading on the human locomotor system is insertion of shoe insole in running shoe to provide the shock protection and cushioning comfort [6-7]. They are many commercially shoe soles with different characteristic e.g. softness, flexible, durability, high in tensile strength etc. However, whether the available shoe soles in the market can better protect the runners from injuries is still unknown especially in long duration running.

O’Leary et al [8] has revealed that a cushioned insole (Sorbo Air, Sorbothane, Inc, Kent, Ohio) has significant reduction in mean VGRF peak impact and the loading rate. Another study conducted by Dixon et al [9] showed that running in military boots with new and degraded insoles reduce the peak loading rate as well as the peak ankle dorsiflexion. For the flat insoles, medium EVA was found to have higher peak pressures whereas low and medium density PU were effective in increasing contact area and reducing pressure time integral [10]. Wang et al [11] showed that the foam category and hardness/density affected the biomechanical performance of running shoes. There were some studies determined that the cushioned insole could minimize the risk of encountering injuries [12-14]. On the
other hand, there were other research groups showed that it did not provide any protective effect [15-16]. The purpose of this study is to investigate the biomechanical effects during long duration with different shoe insole. It would enhance the understanding of running injury mechanism on lower extremities as well as provide a recommendation on the strategy to select shoe insole for competitive and recreational runners.

2. Methodology

2.1 Subject Recruitment
The target population of this study is 15 young and healthy students (7 males and 8 females) who are free from any injuries in lower extremity and health problem such as varus, valgus, asthma and cardio diseases. The written informed consent form was signed by the participated subject before participation to this study. The physical anthropometry data is shown in Table 1.

Table 1. Anthropometry data.

| Variable    | Mean ± Standard Deviation |
|-------------|----------------------------|
| Age         | 21.67±1.05                 |
| Weight (kg) | 56.75±8.54                 |
| Height (cm) | 166.13±8.44                |

2.2 Shoe Characteristics
Two types of commercially shoe insoles: (i) EVA and (ii) PU were tested in this study (Figure 1). Table 2 summaries the maximum tensile stress for these two types of insole materials.

Figure 1. PU insole (left) and EVA insole (right).
Table 2. Tensile test for two types of insoles.

| Insole’s Material           | Maximum Tensile Stress (MPa) | Extension at Maximum Tensile stress (mm) |
|-----------------------------|------------------------------|----------------------------------------|
| Polyurethane (PU)           | > 0.66002                    | > 25.69334                             |
| Ethyl Vinyl Acetate (EVA)   | > 0.01816                    | > 27.44015                             |

Figure 2 is the plots of tensile stress as a function of applied strain. The slopes of the linear lines denote the relaxation moduli of each insole respectively. PU insole has lower relaxation modulus than EVA insole.

2.3 Experimental setup and data collection
The physical anthropometric data such as body height, weight and length of lower limb were measured. LED markers were placed at the joints of lower extremity to calculate the angular displacement on sagittal plane. Video was recorded throughout the whole experiment. The subjects were required to run with their preferable speed for 15 minutes on the H/P Cosmos Instrumented Treadmill embedded with force plate (Model: TLA10004681). Subjects were given some practice time to achieve their normal running gait before the data collection. Three trials with three different conditions were performed in three separate days.

2.4 Data analysis
The kinematic and kinetic parameters were normalized based on the anthropometry data of each subject to reduce the bias effect as shown in Table 3 [17].

Table 3. Normalization kinetic and kinematic data.

| Parameters                  | Normalized equation  |
|-----------------------------|-----------------------|
| VGRF, F                     | \( \hat{F} = \frac{F}{m_0 g} \) |
| Step Length/ Stride Length, \( l \) | \( \hat{i} = \frac{l}{l_0} \) |
Given $m_o$ is Body Mass (kg), $g$ is gravity acceleration ($9.81\text{m/s}^2$), $l_o$ is leg length and $M_o$ is moment (N.m).

### 2.5 Mathematical Modeling

Figure 3 shows the running gait cycle for three conditions. There is only single peak VGRF in all three running conditions. The corresponding free body diagram used to calculate knee joint moment is shown in Figure 4.

![Figure 3](image1.png)

**Figure 3.** Comparison of VGRF for three different conditions: PU (Polyurethane insole), EVA (Ethyl Vinyl Acetate insole) and SS (Sport Shoe).

![Figure 4](image2.png)

**Figure 4.** Example of free body diagram.

The angle between shank and horizontal axis was measured using Kinovea whereas the distance between the knee and vertical normal line, $d$ can be calculated via

$$d = L_{KA} \cos \theta$$

where $L_{KA}$ is the length from knee to joint and $\theta$ is the angle between the shank and horizontal normal line. The knee joint moment of the knee joint is denoted as

$$M = F \cdot d$$

where $F$ refer to the maximum ground reaction force.
2.6 Statistical test
All the kinematic and kinetic data were summarized using descriptive statistics of mean and standard deviation. The statistical test, Mann Whitney test was employed with the use of Statistical Package for the Social Sciences (SPSS) for between condition differences in biomechanical parameters comparison.

3. Results and discussion
Both kinematic and kinetic parameters for running gait were summarized in Table 4. The statistical results for running data were shown in Table 5.

Table 4. Kinetic and kinematic data for running gait (mean ± standard deviation).

|               | Maximum VGRF | Knee Joint Moment | Push Off Peak Force | Step Length | Cadence  |
|---------------|--------------|-------------------|---------------------|-------------|----------|
| SS            | 1.8598±0.1   | .4006 ±           | 1.5109 ±            | .6275 ±     | 1.5172 ± |
| PU            | 1.9176±0.2   | .4043 ±           | 1.6157 ±            | .6511 ±     | 1.5428 ± |
| EVA           | 1.8930±0.2   | .3988 ±           | 1.6977 ±            | .6586 ±     | 1.5253 ± |

Table 5. Statistical results for running gait.

|               | Maximum VGRF | Knee Joint Moment | Push Off Peak Force | Step Length | Cadence  |
|---------------|--------------|-------------------|---------------------|-------------|----------|
| SS vs PU      | .00001*      | .46812            | .19215              | .20327      | .26763   |
| SS vs EVA     | .49202       | .25463            | .04093*             | .18141      | .38591   |
| PU vs EVA     | .00001*      | .38591            | .18141              | .41683      | .37070   |

From Table 4, it revealed that both insoles did not reduce the maximum VGRF. It showed significant increase in VGRF when comparing PU insole with sport shoe (no extra insole). This finding is being in line with the result from Rauno et al. (2009) which suggest that insole do not attenuate shock or reduce loading rate.

There were no significant differences among insoles for knee joint moment which in line with the previous study [19]. PU insole showed no significant effect on the motion of hip and knee joint on sagittal plane.

Additionally, both insoles have higher push off peak forces. EVA insole was significantly higher than no insole condition. Similar findings have been reported on textured insoles during accelerated running [20].

Some of the earlier studies showed that different insoles would significantly affect the step length due to the increment of knee extension during the heel strike phases [20-21]. However, based on our results, the mean values of step length and cadence did not change significantly for these two types of different insoles. The insoles did not affect kinematic performance of lower extremities. The contrary finding of this study may be due to the insoles used in previous studies were much different from both EVA and PU insoles used in this study.

4. Conclusion
Insoles are often marketed to reduce impact loading force and prevent injury. However, our study did not support this assumption. The results showed that both EVA and PU insoles used in this study did not reduce the peak of VGRF as well as the knee joint moment compared to the conventional insoles
furnished in running shoes. The use of these two types of insoles does not seem to protect the lower extremity from injury.

Acknowledgments

This work was supported by a grant from UTAR Research Fund Project No. IPSR/RMC/UTARRF/2018-C2/C01.

References

[1] Bartholomew J B, Morrison D and Ciccolo J T 2005 Effects of acute exercise on mood and well-being in patients with major depressive disorder *Medicine & Science in Sports & Exercise* **37**(12) 2032-2037

[2] Williams III D, McClay I and Hamill J 2001 Arch structure and injury patterns in runners *Clinical Biomechanics* **16** 341-347

[3] Lopes A D, Hespanhol L C, Yeung S S and Costa L O P 2012 What are the main running-related musculoskeletal injuries? *Sports medicine* **42** 891-905

[4] Van Gent R, Siem D, Van Middelkoop M, Van Os, Bierma-Zeinstra S, Koes B and Taunton J 2007 Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review *British Journal of Sports Medicine* **41** 469-480

[5] Macera C A, Pate R R, Powell K E, Jackson K L, Kendrick J S and Craven T E 1989 Predicting lower-extremity injuries among habitual runners *Archives of internal medicine* **149**(11) 2565-2568

[6] Jones B, Thacker S and Gilchrist J 2002 Prevention of lower extremity stress fractures in athletes and soldiers: a systematic review *Epidemiologic Reviews* **24** 228-247

[7] Hinz P, Henningsen A, Matthes G, Jäger B, Ekkernkamp A and Rosenbaum D 2008 Analysis of pressure distribution below the metatarsals with different insoles in combat boots of the German Army for prevention of march fractures *Gait & Posture* **27** 535-538

[8] O’Leary K, Vorpahl K A, and Heiderscheit B 2008 Effect of cushioned insoles on impact forces during running *Journal of the American Podiatric Medical Association* **98** 36-41

[9] Dixon S J, Waterworth C, Smith C V and House C M 2003 Biomechanical analysis of running in military boots with new and degraded insoles *Medicine and science in sports and exercise* **35** 472-479

[10] Healy A, Dunning D N and Chockalingam N 2012 Effect of insole material on lower limb kinematics and plantar pressures during treadmill walking *Prosthetics and orthotics international* **36** 53-62

[11] Wang L, Hong Y and Li J 2012 Durability of running shoes with ethylene vinyl acetate or polyurethane midsoles *Journal of Sports Sciences* **30** 1787-1792.

[12] Schwellnus M, Jordaan G and Noakes T 1990 Prevention of common overuse injuries by the use of shock absorbing insoles: a prospective study *The American Journal of Sports Medicine* **18** 636-641

[13] Mundermann A, Stefanyshyn D and Nigg B 2001 Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors *Medicine and Science in Sports and Exercise* **33** 1939-1945

[14] Milgrom C, Finestone A, Shlamkovitch N, Wosk J, Laor A, Voloshin A and Eldad A 1992 Prevention of overuse injuries of the foot by improved shoe shock attenuation *Clinical Orthopaedics and Related Research* **281** 189-192

[15] Gardner L, Dziedos J, Jones B, Brundage J, Harris J, Sullivan R and Gill P 1988 Prevention of lower extremity stress fractures: a controlled trial of a shock absorbent insole *American Journal of Public Health* **78** 1563-1567

[16] Withnall R, Eastaugh J and Freemantle N 2006 Do shock absorbing insoles in recruits
undertaking high levels of physical activity reduce lower limb injury? A randomized controlled trial *Journal of the Royal Society of Medicine* 99 32-37

[17] Hof A L 1996 Scaling gait data to body size *Gait & posture* 3 222-223

[18] Ruano C, Powell D, Chalambaga E T and Renshaw D 2009 The effects of tempur insoles on ground reaction forces and loading rates in running *International journal of exercise science* 2 186

[19] Özman ev ra R, Angin S, Gü nal İ H and Elvan A 2018 Effect of Different Insole Materials on Kinetic and Kinematic Variables of the Walking Gait in Healthy People *Journal of the American Podiatric Medical Association* 108 390-396

[20] Kelleher K J, Spence W D, Solomonidis S and Apatsidis D 2010 The effect of textured insoles on gait patterns of people with multiple sclerosis *Gait & Posture* 32 67-71

[21] Hatton A L, Dixon J, Rome K, Brauer S G, Williams K and Kerr G 2016 The effects of prolonged wear of textured shoe insoles on gait, foot sensation and proprioception in people with multiple sclerosis: study protocol for a randomised controlled trial *Trials* 17 208