VOL. 12, NO. 7, APRIL 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

GROUND REACTION FORCE RESPONSE DURING RUNNING ON DIFFERENT SURFACE HARDNESS

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ABSTRACT

Adaptation of kinetics response when running on different surface has been commonly measured by the ground reaction force (GRF). GRF was extensively been used in studies related to surface characteristics such irregularity, incline and types. Since surface hardness effects on the ground reaction force response and the foot adaption is remain unclear, the present study was carried out to address this issue. Ten subjects among university students population was selected to perform running on three different surface hardness which is concrete, artificial grass and rubber, with three shod conditions (barefoot, minimally shoe and heeled shoe) in recreational mode. The GRF data of each trial was obtained using force plate and the stance time of running phase was recorded using motion tracking system. In barefoot running, the GRF and stance time were found decreased with increasing of surface hardness. However, the GRF and stance time were not in correlation with the surface hardness for running with minimally shoe and heeled shoe. The results showed surface types and shod conditions contributed to the foot adaptation particularly in viewpoint of GRF response and stance time of running phase.

Keywords: running surface hardness, ground reaction force, stance time, shod conditions.

INTRODUCTION

Ground reaction force (GRF) is an important parameter in the study of kinetics response with respect to gait movement on various surfaces[1]. GRF has been widely used in numerous gait analyses related to running [2]-[4] and walking [5]-[7] on different runway. GRF response would be able to describe the weight distribution, body stability and kinetics adaptation against the running surface characteristics. Dixon *et al.*[8]investigated the effect of surfaces such as a conventional asphalt surface, a new rubber-modified asphalt surface and an acrylic sports surface, on the ground reaction forces and lower extremity kinematics in running. They found that the maintenance of similar peak impact forces for different running surfaces was explained by observed kinematic adjustments. However, the results suggest the requirement of individual subject analyses since the mechanism of adaptation was varies among runners. Meanwhile, Damavandi *et al.*[5]examined the magnitude and timing adaptation of ground reaction force when walking and running on cross-slope surfaces. Most significant differences were observed in the mediolateral direction, where generally force values were larger during the cross-slope conditions compared to level for walking and running, respectively.

Moreover, Fu *et al.*[9]explored the effects of running on different surfaces on the characteristics of in-shoe plantar pressure and tibial acceleration. The experiment was conducted on concrete, synthetic track, natural grass, a normal treadmill, and a treadmill equipped with ethylene vinyl acetate (EVA) cushioning underlay. They found that no significant differences in peak positive acceleration were observed among the five tested surface conditions. There may not be an inevitable relationship between the surface and the lower-limb impact in runners. Comparison between ground reaction force response on treadmill and overground gait was also been studiedby Riley *et al.*[6]. The GRF maxima were found to be statistically significantly smaller for treadmill versus overground gait. However, the mechanics response between treadmill and overground gait were found very similar.

Although the kinetics response,particularly GRF against various running characteristics such as uneven surface[10], [11], slopes[5], [12] and types [13]-[15] have been extensively investigated, however the GRF response and foot adaptation when running on various surface hardness still remain unclear. Therefore, this study was undertaken to investigate the effect of running surface hardness on ground reaction force response, and its adaptation by analyzing the stance time of running phase.

Experimental method

The present experiment was conducted in Biomechanics Laboratory, Universiti Malaysia Perlis. Ten subjects performed recreational running with three wore conditions; barefoot (BF), heeled shoe (HS) and minimally shoe (MS), as shown in Figure-1, on three types of running surface (concrete, rubber and artificial grass) with 10 meters length. All subjects agreed to wrote informed consent prior the experiment. Each subject was male recreational runners with age 24 ± 1.2 years old, weight 67 ±6.7 kg and height 172 ± 2.7 cm. All subjects performed running on treadmill and running track prior to the experiment in order to familiarize with the test conditions. Then, each subject was running on nine test conditions. Tests were accepted if the right foot contacted with Bertex force plate. Ground reaction force (GRF) and stance time data for each test were recorded in Qualysis Track Motion (QTM) and visual 3D system. The layout of experimental setup is shown in Figure-2.

VOL. 12, NO. 7, APRIL 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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(a). Heeled shoe. **(b).** Minimally shoe.

Figure-1. Shod running types.

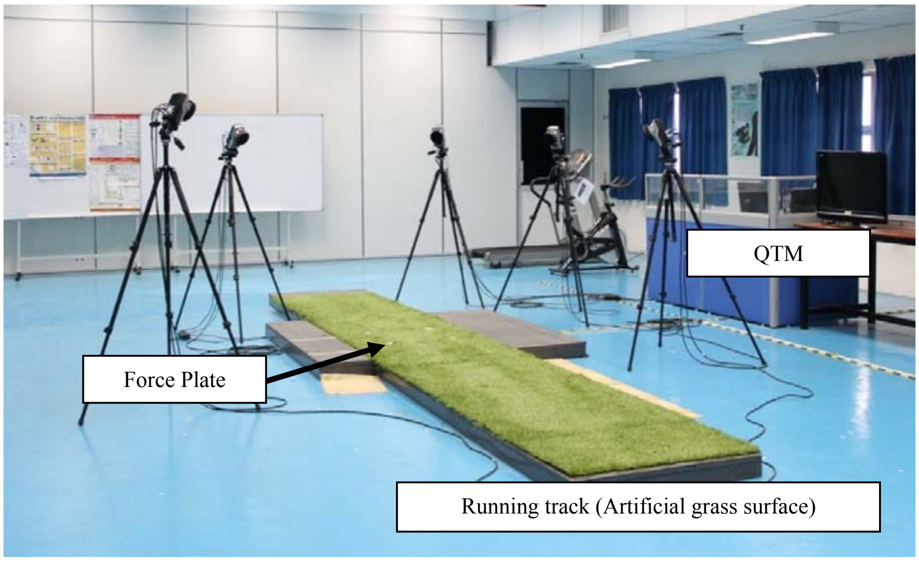

Figure-2. Layout of experimental setup.

Runway surfaces were selected based on the common surfaces used for recreational running with different hardnesswhich is concrete, rubber and artificial grass. Hardness test on all surfaces was conducted according to ASTM F2117-10, that was also been used by [9]. In this test, a basketball was dropped from a height of 2 m. The vertical rebound height of the ball was recorded for each surface. Table-1 shows the rebound height of the running surfaces in the present study. The hardest surface was concrete, followed by artificial grass and rubber.

Table-1. Ball rebound height for each running surface.

Surface	**Rebound height** (cm)
Concrete	103.04 ± 3.5
Artificial grass	97.80 ± 2.9
Rubber	79.97 ± 4.4

RESULTS

Figure-3 shows the ground reaction force (GRF) response for barefoot running on three different surfaces under stance phase. The shaded area represents the variation of GRF values obtained for each surface. The mean value of each surface was indicated by the solid line (rubber), course dotted line (artificial grass) and fine dotted line (concrete). The maximum peak GRF was found highest at the mid-stance phase when barefoot running on rubber, followed by artificial grass and concrete. It seems that the increase of surface hardness reduced the GRF response for barefoot running. However, the mean peak GRF was almost at the same level for rubber (1486.3 N) and artificial grass (1490.3 N), whereas the mean value of peak GRF for concrete was obtained at 1373.2 N).

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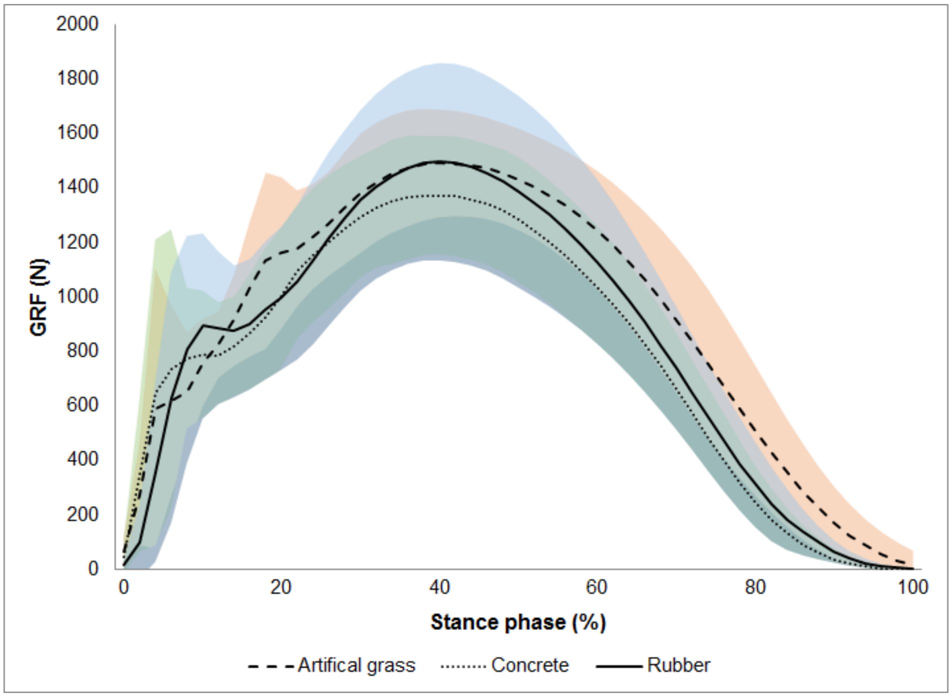

Figure-3. Effect of surfaces on ground reaction force in barefoot running.

Moreover, the effect of runway surfaces on the GRF response during running with cushion heeled shoe was shown in Figure-4. In this case, the peak GRF response on artificial grass was found higher compared to running on rubber and concrete. The result suggest that no correlation between surface hardness and GRF response. The mean values of peak GRF for rubber (1591.4 N) and artificial grass (1660.1 N) were quite closed compared to concrete (1499.0 N).

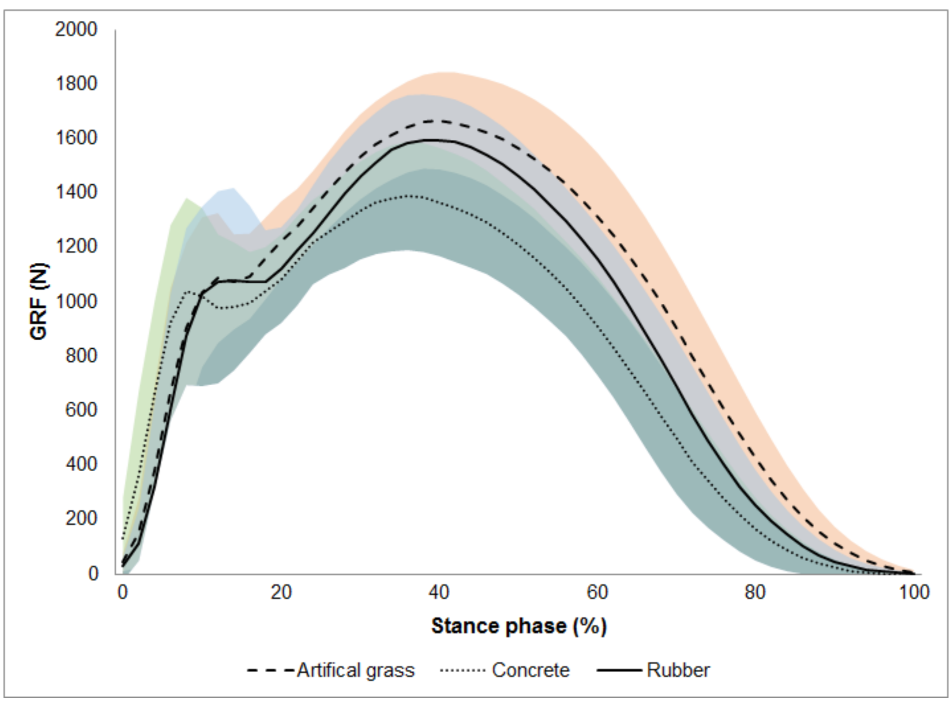

Figure-4. Effect of surfaces on ground reaction force in heeled shoe running.

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Similarly, the surface effects on the GRF along the stance phase in minimally shoe running was implied in Figure-5. The peak GRF was obtained highest when running on artificial grass, as shown in the shaded area. Minimally shoe running on rubber produced higher peak GRF response compared to concrete surface. The mean value of peak GRF response was consistently highest during running on artificial grass (1665.4 N) after the mid-stance phase, followed by rubber (1595.2 N) and concrete (1388.9 N). Interestingly, the mean value of GRF for concrete was found highest at the first peak of GRF response. No obvious apparent on the first peak GRF for running on rubber.

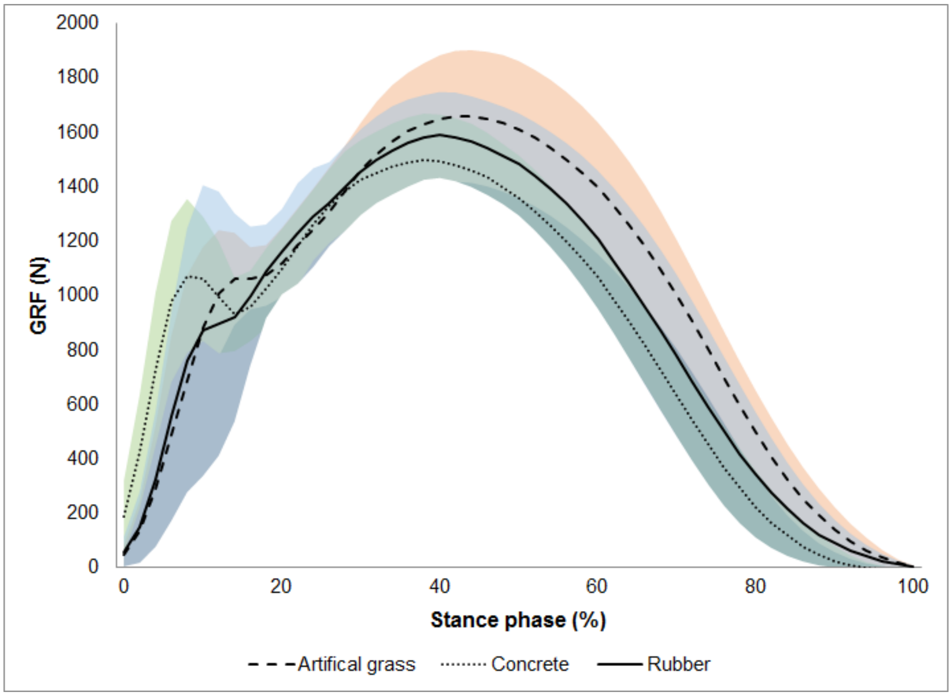

Figure-5. Effect of surfaces on ground reaction force in minimally shoe running.

On the other hand, the stance time for each subject during barefoot and shods (HS and MS) running on all surfaces was summarized in Table-2. In barefoot running, the stance time for rubber (257.1 ± 39.2 ms) was found the longest compared to artificial grass (254.0 ± 23.0 ms) and concrete (243.3 ± 20.2 ms). The result could be correlated to the surface hardness where the stance time was reduced with the increase of surface hardness. Similarly, this finding was consistent with the result for minimally shoe running. The stance time reduced from rubber (278.3 ± 25.2 ms) to artificial grass (254.2 ± 12.4 ms) and concrete (250.0 ± 22.4 ms). In contrary, it is apparent that the stance time was found highest during cushion heeled shoe running on concrete (278.3 ± 39.9 ms) followed by rubber (260.8 ± 9.2 ms) and artificial grass (247.5 ms).

Table-2. Stance time for barefoot and shod running on different surfaces.

	Stance time ($\times 10^{-3}$ s)		
	Rubber	**Artificial grass**	**Concrete**
Barefoot (BF)	257.1 ±39.2	254.0±23.0	243.3±20.2
Minimally shoe (MS)	278.3±25.2	254.2±12.4	250.0±22.4
Heeled shoe (HS)	260.8±9.2	247.5±24.0	278.3±34.9

DISCUSSIONS

The present study was undertaken to investigate the influence of surface hardness and running conditions (barefoot, minimally shoe and heeled shoe) on the ground reaction force in stance phase. The results suggest that both running surface and conditions contributed to the variation of the GRF response. In barefoot running, there are relationships between GRF response and stance time among the running surfaces. The GRF was decreased with the increasing of surface hardness and decreasing of stance time. High surface hardness result to the short contact duration between foot and running surface, that contributes to the lower GRF compared to those with low surface hardness.

However, although the trend of stance time with respect to surface hardness for minimally shoe running was similar to barefoot running, the GRF response showed no correlation to the surface hardness. Using the minimally shoe has increased the stance time compared to the barefoot running, hence contributes to the increase of the peak GRF response. Similar trend on the GRF response was found when running with cushion heeled shoe, but no correlation was shown between surface hardness and stance time.

In general, although the results of present study showed the running surface hardness and shod conditions influenced the GRF response; however the different in terms of trend and magnitude was not so obvious. Only the slightly different was observed on the mean value of GRF response between artificial grass and rubber, meanwhile running on concrete was lowest for all running conditions (barefoot, HS, MS). This findings agreed with the previous studies [8], [13]. Dixon *et al.*[8]concluded that despite the increased mechanical impact absorption provided by the acrylic surface and the rubber-modified surface, compared with the conventional asphalt, the peak impact forces were typically not influenced by the change in surface. Similarly, the findings obtained by Tillman *et al.* [13]also implies that runners who choose to run on stiffer surfaces are not exposing themselves to additional risk as a result of loading but possibly because of internal compensatory mechanisms, although it might not applicable for all runners. Hence, the results of the present study suggest that there is strong correlation between ground reaction force response and stance time during running on different surfaces and shod conditions. Adaption of foot particularly in GRF response was influenced by the characteristics of the running surface.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support provided by the Malaysian Ministry of Higher Education (MOHE), under Fundamental Research Grant Scheme (FRGS No. 9003-00489).

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