BIOMECHANICS OF RUNNING WITH FOREFOOT-SPRING FOOTWEAR

Jin-Huat Low[1], Charlton Yong-Jie Foo[2], Chen-Hua Yeow[3]

Department of Biomedical Engineering, National University of Singapore, Singapore[1, 2, 3]
Advanced Robotics Center, National University of Singapore, Singapore[1, 3]
Singapore Institute for Neurotechnology, National University of Singapore, Singapore[1, 3]

Forefoot strikers have significantly lower rates of repetitive stress injury than rearfoot strikers. The purpose of this study was to design a forefoot-spring footwear to induce habitual rearfoot runners to adopt a forefoot strike pattern and to investigate the effect of this forefoot-spring footwear on lower extremity joints biomechanics during running. Our findings indicated that different lower limb energy absorption strategies were adopted for running with the forefoot-spring footwear, as compared to control footwear. A shift from hip-dominant to ankle-dominant energy absorption strategy may reduce the loading to the hip and knee joints and could be beneficial towards the prevention of running related injuries particularly at the knee joint.

KEY WORDS: running, forefoot-spring, energy dissipation.

INTRODUCTION: Today, revolutionary footwear such as toning footwear and minimalist footwear have transformed the concept of footwear being discussed in the world (Perl, 2012). It is not simply providing protection for the foot but it can enhance the performance of athletes. It has been shown that proper footwear is essential to prevent any lower limb joint injuries, as replica shoes that are improperly constructed may increase the external loading on the body, eventually leading to running-related injuries (Azevedo, 2012).

Recently, barefoot and minimalist footwear concepts have been proposed as beneficial for running since humans historically started out as barefoot runners, and barefoot runners were found to be more economical during running than modern shod runners (Perl, 2012; Krabak, 2011), though this is still controversial between footwear scientists. The main difference between barefoot and shod runners occurs during landing, with barefoot runners mostly landing forefoot or mid-foot instead of heel-strike (Perl, 2012; Krabak, 2011). Forefoot strike results in more ankle compliance and the presence of plantarflexed foot upon landing, effectively decreasing the impact between body and ground (Biewener, 2004; Lieberman, 2009). In addition, forefoot running is good for attaining higher speed in sprinting (Ardigo, 1995). Moreover, forefoot strikers have significantly lower rates of repetitive stress injury than rearfoot strikers (Daoud, 2012). However, a recent work by Stearne et al. (2014) indicated that there is no clear mechanical advantage between habitual forefoot runners and habitual rearfoot runners.

In view of these prior studies, the benefits of forefoot running over rearfoot running remain controversial and it is unclear whether it will be advantageous for habitual rearfoot runners to adopt forefoot running techniques. Therefore, the objective of this study was to approach these issues from a different perspective by investigating the effect of a forefoot-spring footwear on the lower extremity joints biomechanics of habitual rearfoot runners during running. We hypothesize that a forefoot-spring footwear can induce habitual rearfoot runners to adopt a forefoot running pattern with a different lower extremity joint energy absorption strategy.

METHODS: Four healthy recreational rearfoot runners (2 male and 2 female; age: 24.0±1.2years) without any lower limb musculoskeletal injuries from National University of Singapore (NUS) were enrolled in this study conducted at the Gait Analysis Laboratory. They run regularly for at least three sessions a week with each session lasting at least 30 minutes. Each subject was required to perform at least three trials of running with forefoot-spring footwear prototype (Figure. 1) and control shoe (Power model, Bata). The prototype is a combination of the control shoe model and a carbon fiber forefoot spring. The shod conditions were randomized in the testing. Prior to the experiment, informed consent was obtained from all subjects, based on the approval by the Institutional Review Board.

The trials were recorded simultaneously by the 8-camera VICON Motion Systems (Oxford Metric, UK) with a sampling rate of 100Hz and two Kistler force plates (Kistler Instrument Corp., Novi, MI) with a sampling rate of 1kHz. A total of sixteen retro-reflective markers (14mm in diameter) were placed on each subject, followed the Plug-in Gait marker set. Subjects were instructed to perform warming up exercises and acclimatize to the shod conditions, prior to task execution. They were then tasked to run at their self-selected speeds across a 9m long gait platform.

All kinematic, kinetic and energetic data were averaged across all subjects. The selected parameters were maximum vertical ground reaction force (GRF), maximum joint flexion/extension angles and positive/negative sagittal plane joint work. GRF data were normalized to body weight (BW). Joint work was calculated from the time integral of joint power. Positive joint work is defined as the area under the joint power–time curve above the zero power line, while negative joint work is defined as the area under the joint power–time curve below the zero power line. Positive and negative work indicated that the muscles generated or absorbed mechanical energy respectively. Paired t-tests were used to compare the biomechanical parameters between the two shod conditions. Statistical significance was considered as $p < 0.05$. The effect size (Cohen's d) was also reported in the results.

Figure 1: (Left) schematic of the forefoot-spring footwear and (Right) photograph of the forefoot-spring footwear.

RESULTS and DISCUSSION: In this study, all the subjects ran with a forefoot pattern when they donned the forefoot-spring footwear. The design of the footwear changed the running pattern of the subjects who are habitual rearfoot runners. The forefoot-spring footwear produced a significant increase in peak ankle dorsiflexion (Cohen's d=1.24) and peak hip extension (Cohen's d=0.34). In addition, our findings indicated that there was a significant reduction in the eccentric work (energy absorption) done by the hip (Cohen's d=2.38) and knee joints (Cohen's d=1.35) during running with forefoot-spring footwear while the eccentric work done by the ankle joint (Cohen's d=2.47) was increased significantly. Moreover, the relative energy contribution to overall energy of the lower extremity joints was different between the two conditions. The ankle joint was the dominant energy absorber in the forefoot-spring condition (57%), followed by hip (29%) and knee (14%). On the other hand, the hip joint was the dominant energy absorber in the control condition (45%), followed by knee (31%) and ankle (24%). There were no significant differences in maximum vertical GRFs and positive work (energy generation) between the shod conditions.

Table 1
Means ± standard deviations of kinematic, kinetic and energetic parameters during the stance phase of running in different shod conditions. *Significant at $p<0.05$.

	Forefoot-spring	Control	Forefoot-spring	Control	Forefoot-spring	Control
Maximum Vertical GRF (BW)	2.1±0.4	2.4±0.3				
	Hip		Knee		Ankle	
Positive Sagittal Plane Work (J/kg)	0.17±0.02	0.16±0.16	0.28±0.07	0.33±0.17	0.90±0.43	0.80±0.34
Negative Sagittal Plane Work (J/kg)	-0.31±0.11*	-0.61±0.14	-0.15±0.08*	-0.41±0.26	-0.62±0.10*	-0.32±0.14
Maximum Joint Flexion Angle (˚)	29.3±5.5	23.8±3.1	35.8±14.3	37.5±15.7	31.7±5.3*	21.8±10.0
Maximum Joint Extension Angle (˚)	15.4±11.9*	19.2±10.5			17.6±7.9	27.4±5.1

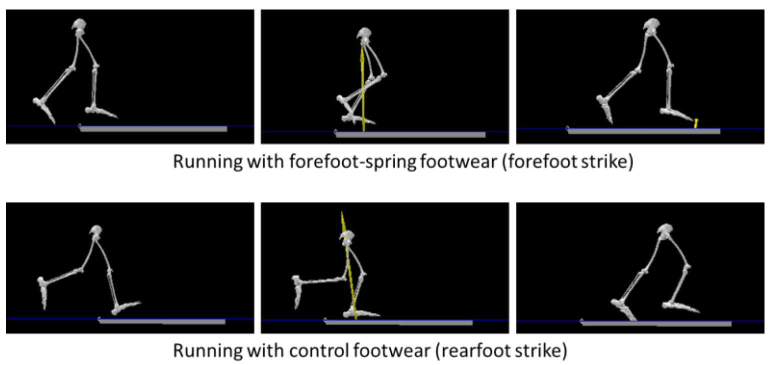

Figure 2: Typical running pattern of a subject with forefoot-spring footwear and with control footwear.

Less ankle dorsiflexion is always observed in forefoot strikers or in sprinting because of the tibial position that allows the ankle to be in relatively plantarflexed position at initial contact (Novacheck, 1998). Nonetheless, our findings demonstrated that the forefoot-spring footwear produced a significant increase in ankle dorsiflexion. This is because the carbon-fiber spring on the shoe changes the foot position into dorsiflexion even during standing (the heel is lower than the forefoot). It has been shown that a dorsiflexion shoe may induce an immediate increase in the triceps surae strength and, consequently, a reduced energy cost of running (Raphaël, 2010). The forefoot-spring footwear allows the users to perform forefoot strike while maintaining larger ankle dorsiflexion that is observed in rearfoot strikers and may enhance the running performance.

Our findings indicated that different lower limb energy absorption strategies were adopted for running with the forefoot-spring footwear, as compared to the control footwear. A shift from hip-dominant to ankle-dominant energy dissipation strategy may reduce the loading to the hip and knee joints and may be beneficial towards the prevention of running related injuries particularly at the knee joint. The larger negative work done by the ankle joint indicated that much of the impact upon contact with the ground was absorbed by the ankle plantarflexors and hence less impact was absorbed by the knee musculature. It is consistent with the shock absorption strategies in sprinting (Novacheck, 1998). Although it may be useful in preventing knee related injuries, it may cause other injuries at ankle joint. Future studies should be conducted to design proper carbon fiber spring that provides the optimized energy dissipation strategy that will reduce the risk of injuries at all the lower extremity joints.

The findings need to be viewed in light of several limitations. First, the sample size of this pilot study is small, thus the results presented here may not be completely indicative of the true effect of forefoot-spring footwear on young healthy runner population. Second, the limited length of the walkway (9 meters) is not a perfect platform to analyze the biomechanics of running as this will attenuate the accuracy of the findings due to the small running speeds caused by the limited distance. Future studies could be directed at a larger cohort to draw conclusion on the changes induced by the forefoot-spring footwear. Future efforts can also be considered to conduct the trials outdoors or with a treadmill to observe the effect of forefoot-spring footwear on the subjects during long distance running. In addition, electromyography data should be analyzed to understand the changes in muscles recruitment strategy caused by the forefoot-spring footwear.

CONCLUSION: While barefoot and minimalist footwear are known to promote forefoot/midfoot landing, our preliminary results demonstrated that normal footwear, added with a forefoot-spring, can also change the running pattern of the user towards forefoot running. The significant reduction in negative joint work at the hip and knee joint during running with forefoot-spring footwear may be beneficial towards the prevention of running-related injuries and management of knee pain. Collectively, this study may provide new insights on the comparison between forefoot and rearfoot running, especially for habitual rearfoot runners that have to adopt forefoot running due to footwear design.

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