THE INFLUENCE OF DIFFERENT STRIKE PATTERNS ON ENERGY CONTIBUTION DURING RUNNING

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Purpose: The purpose of this study was to determine the differences of joint power and work between forefoot strike (FFS) and rear-foot strike (RFS) during the stance phase of running. **Methods**: A 10-camera Vicon system and two force plates were used to collect the kinematics and kinetics data of 15 healthy male triathletes with different foot strike strategies during running. **Results**: The joint power and positive work at hip and ankle were increased in FFS during the stance phase. FFS also showed decreased knee negative work. **Conclusion**: Running with FFS would consume more energy than running with RFS at the same speed. The lack of ankle joint shock absorption in RFS might cause higher injury risk in knee.

KEY WORDS: forefoot strike, rear-foot strike, biomechanics

INTRODUCTION: Barefoot running has become more and more popular in recent year. It was considered that the advantages of barefoot running include gait changes, which resulted in a lower collision force, better running efficiency and an increased movement perception and muscle strength (Lieberman et al., 2010). Different striking patterns were considered great effects on the running injury and efficiency. The efficiency of forefoot strike (FFS) is contentious. Some researchers considered that FFS were less efficient running patterns than rear-foot strike (RFS) because the center of pressure trajectory of these strikes goes backward after landing and subsequently goes forward, whereas the center of pressure trajectory of the heel strike goes forward directly after landing (Cavanagh & Lafortune, 1980). Others thought that FFS could generate more energy by flexing ankle joint until heel contact and then doing push-off movement. These movements resulted in lower angular stiffness and longer force arm at ankle to transfer the potential energy into kinetic energy. On the other hand, RFS exhibited plantar flexion during heel contact, which caused most potential energy lost (Lieberman et al., 2010). However, from the energy contribution perspectives of different striking patterns are less documented in the literature.

Various investigations have used the joint power and mechanical work to study mechanical energy production and dissipation in the lower extremities, which had a direct influence on performance during physical activity and sports. This two parameters could also evaluate muscle function and the change in work distributed at lower extremity joints as a function of locomotion (Stefanyshyn & Nigg, 1997). It is important to understand the energy flow in different striking patterns during running for the running efficiency and training aspect, and the potential injury risk. The purpose of this study was to investigate the effects of different striking patterns on energy contribution of lower extremity during running to understand.

METHODS: Fifteen 15 healthy male triathletes (25±6.85 yrs, 1.71±0.51 m, 69.96±11.3 kg), who had no neuro-musculoskeletal injury of lower extremity history, participated in this study. They were all employed forefoot strike pattern in usual. The study protocol was approved by the local Institutional Review Board. Two Kistler force plates were placed in the center of a 10-m walkway to record the ground reaction forces (GRF). A 10-camera Vicon system (250 Hz) was used to capture three-dimensional marker trajectories. Forty-five retro-reflective markers were attached on the anatomical landmarks according to the plug-in-gait model. Participants were asked to run with barefoot at 3.5 ± 0.3 m/s in FFS and RFS respectively. Real-time Vicon system was used to monitor the running speed. The average of three successful trials was reported.

The Visual3D software (C-Motion, Rockville, MD, USA) was applied to analyze the human dynamic data. Kinematic data were low-pass filtered at 6 Hz using 4th order zero-lag Butterworth filters. Force plate data were low-pass filtered at 50 Hz. Anatomical reference frames for the body segments were defined as the positive x-axis (medial/lateral) to the right, the positive y-axis (anterior/posterior) to the forward, and the positive z-axis (superior/inferior) to the upward. All parameters were calculated in sagittal plane. The range of motion at each joint refers to the angular distance a joint can move between the flexed and extended position. The mechanical energy parameters in this study included joint power and mechanical work. Joint power at each joint was calculated by multiplying the joint moment by the angular velocity at that joint. The net work was determined by integrating the power curve over the stance time. The kinetic data were normalized to subject's body weight. All variables were analyzed with paired *t*-test comparing by using SPSS 20.0 software. An alpha level of 0.05 was chosen for indicating statistical significance.

RESULTS: Kinematic data showed that the range of motion (ROM) at hip and ankle were significantly greater in FFS during stance phase (Hip-FFS: 39.58°±5.72°; RFS: 37.46°±4.50°, t=2.386, p=.032; Ankle-FFS:47.45°±8.25°; RFS:39.69°±8.24°, t=4.131, p=.001). The mechanical hip power was positive during the first half of stance phase, while in late stance phase the hip power curve became negative. Both the positive and negative peak magnitudes at hip increased in FFS. At the knee, the mechanical power was primarily negative throughout braking phase then became positive. At the ankle, the mechanical power was negative during the braking phase with a large positive peak during late stance phase. FFS had smaller peak knee power (negative) during braking phase, but greater peak ankle power (positive) during propulsive phase (Fig.1). The positive work at hip and ankle were 1.2 times and 1.5 times higher in FFS than in RFS. The negative work at ankle was also 2.04 times higher in FFS but was 1.09 times smaller at knee than RFS (Fig.2). The maximal loading rate in FFS was lower than in RFS (FFS:45.34±6.26BW/s; RFS:72.53±5.79BW/s, t=-7.247, $p<.001$).

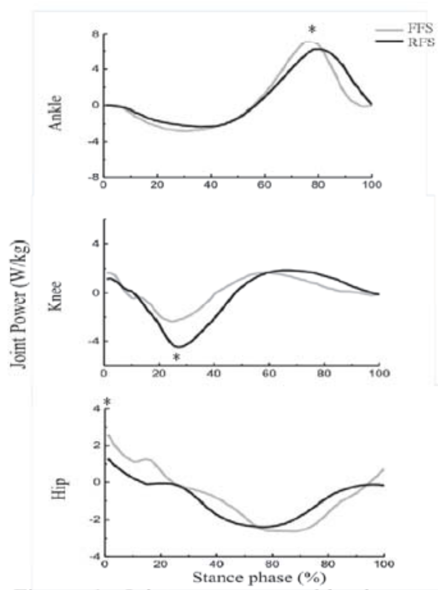

Figure 1. Joint power at ankle, knee and hip joints during the stance phase of running in FFS (gray) and RFS (black) patterns

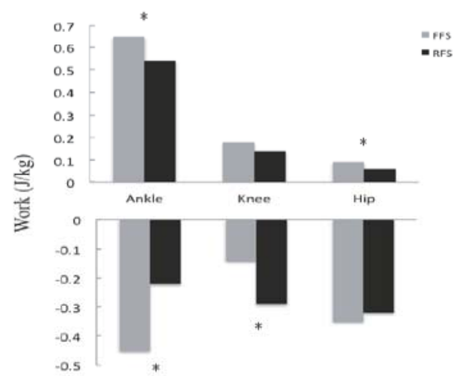

Figure 2. Positive and negative work at ankle, knee and hip joints during the stance phase of running in FFS (gray) and RFS (black) patterns

DISCUSSION: Running with the forefoot strike pattern showed different energy contribution on lower extremity. In FFS, the foot was first landed with a plantar-flexion posture and followed by a dorsiflexion movement, which increased the ROM and resulted in more power and work generating at ankle. Hip joint also exhibited greater ROM, power and work. Previous studies indicated that these movements could cause lower angular stiffness and longer force arm at ankle transfer the potential energy into kinetic energy and extend the Achilles tendon to generate more elastic energy (Lieberman et al., 2010). Our study had limited running velocity at 3.5 m/s, which meant FFS consuming more energy than RFS at the same speed.

Negative work was generated while the muscle absorbing energy in a loaded position, which occurred in eccentric muscle actions and provided a braking mechanism for muscle and tendon to protect joints from damage as the contraction was released (Bubbico & Kravitz, 2010). According to our results, the negative work at ankle was higher in FFS but smaller at knee than in RFS. It suggested that running with FFS would use the ankle as the main joint to absorb the impact force of landing. In contrast, running with RFS would use the knee joint to absorb. Higher rates of impact loading were also found in RFS. These differences presumed that FFS runner generated less impact force by flexing ankle but RFS runner would generate a rapid, high-impact peak in the GRF during the first part of stance (Lieberman et al., 2010), which might increase higher injury rates of knee pain, and medial tibial stress syndrome (Davis, Bowser, & Mullineaux, 2010). For the training and rehabilitation aspects, running with FFS mainly used hip and ankle to contribute energy, which could decrease the impact of GRF and enhance muscle groups at hip and ankle. Diebal, Gregory, Alitz, & Gerber (2012) also found that a 6-week FFS running intervention could decrease lower leg intracompartmental pressures.

CONCLUSION: Running with FFS would consume more energy at ankle and hip than running with RFS at the same speed. It could also absorb more impact force than RFS by flexing ankle and hip joints. The lack of ankle joint shock absorption in RFS would cause the knee joint moment increase, which might cause higher injury risk in knee.

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