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REDISTRIBUTION OF JOINT MECHANICAL WORK AND POWER IN REAR-FOOT STRIKE (RFS) AND FORE-FOOT STRIKE (FFS) RUNNING TECHNIQUES

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SUMMARY

This study explores the lower limb mechanical energetics of rear-foot strike (RFS) and fore-foot strike (FFS) running techniques that may be linked to running efficiency and injury risk. It also examines the mechanical consequences switching to a non-preferred foot strike technique. Significantly greater negative work was performed about the knee in RFS running and the ankle in FFS, regardless of the habitual or imposed nature of the technique. When habitual RFS runners switched to a FFS technique they significantly increased their total work out put.

INTRODUCTION

It has been suggested that FFS running is more economical and less susceptible to injury than RFS running [1,2]. These purported advantages, combined with the observation that a greater percentage of elite distance runners are FFS [3] (compared to recreational runners), is leading to coaches recommending a change in foot-strike technique to improve running performance.

Recently it has been proposed that mechanical energetics may play an important functional role in differentiating RFS and FFS [4]. Greater peak negative joint power and negative work have been reported at the ankle in FFS, while greater peak negative power and work occur at the knee in RFS [4,5]. The altered distribution of negative power and work seen in a FFS and RFS may subsequently alter muscle and tendon function leading to overall changes in running mechanics and energetics.

However, these previous studies have focused only on the ankle and knee joints and only reported on mechanical energy absorption in the stance phase of gait. To the best of our knowledge, no study has comprehensively examined the effect of foot-strike technique on joint mechanics across the entire lower limb (including positive and negative joint power and work) and across the different phases of the gait cycle. This consideration is important given that any differences at the ankle during stance may lead to functional adaptations at the more proximal joints and may also alter stance-swing dynamics. Furthermore, the inclusion of both total positive and negative joint work and its distribution across the lower-limb joints can prove essential for understanding the interaction between foot-strike technique, gait mechanics and energetics, and injury risk.

In this study we use mechanical energetics to explore factors that can help explain why a larger proportion of elite distance runners adopt a FFS compared to the general running population. We also explore the mechanical consequences of switching foot-strike technique that may be linked to both running energetics and injury mechanisms.

METHODS

Eight habitual RFS and six habitual FFS highly trained male distance runners were recruited for the study, no significant differences in age, height, weight, running experience or miles ran per week existed between groups. Participants ran at $4.5 ms^{-1}$ on an instrumented treadmill using both RFS and FFS techniques while lower limb 3D kinematics (eight camera Vicon MX 3D motion capture system, 200Hz) and ground reaction force (Bertec, 2000Hz) were collected.

Five consecutive strides were analyses. Marker trajectories and ground reaction forces were filtered using a 4^{th} order zero-lag Butterworth filter. Net hip, knee and ankle joint moments and power were calculated using BodyBuilder software. Positive and negative work for each joint was computed by integrating the positive and negative instantaneous joint power data with respect to time. Positive and negative work at each joint was divided into stance and swing phases and an average rate of work production was computed by dividing by stride time. Independent and paired samples t-tests were used to determine statistical significance followed by a Bonferoni post hoc analysis.

RESULTS AND DISCUSSION

No differences were identified in total positive or negative lower limb mechanical work between habitual RFS and FFS runners. Total work performed in the stance and swing phases were also the same between foot-strike conditions. However, significant differences were seen in the distribution of negative work between joints. These results matched those of previous studies [4,5] with RFS runners recording greater negative work and peak negative power at the knee while FFS runners produced the majority of the negative work and recorded greater peak negative powers at the ankle (Figure 1). No differences were seen at the hip, in positive joint work or in the swing phase.

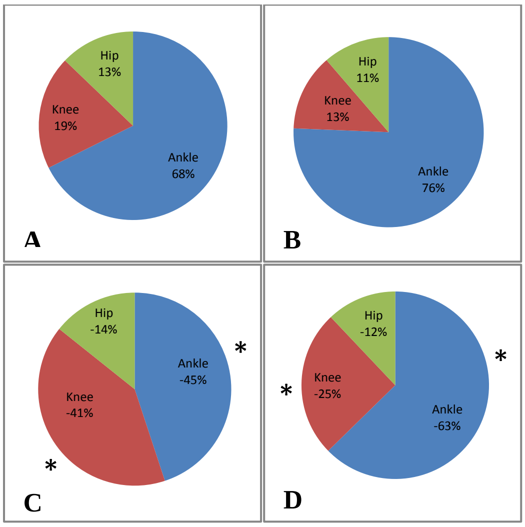

Figure 1: Distribution of mechanical work rate (average power) between joints during stance * significance p<0.0167. A) Habitual RFS positive work rate. B) Habitual FFS positive work rate. C) Habitual RFS negative work rate. D) Habitual FFS negative work rate.

Given that positive ankle work did not differ between foot-strike techniques but negative work did, the ratio of negative to positive ankle work was significantly greater in FFS runners (1:1.9 RFS vs 1:1.4 FFS). The Achilles tendon crosses the ankle joint and is capable of recycling elastic strain energy and therefore may provide FFS runners with a mechanical advantage. At an upper level, assuming all negative work is stored in the Achilles tendon, and assuming a tendon resilience of 93% [6], FFS runners would only be required to produce an extra 2.03J/Kg of positive mechanical work in stance (51% of stance total positive work) while RFS would need to produce 2.59J/Kg (67% of stance total positive work). This would theoretically substantially reduce the positive work production required from the muscle fibers in FFS, and possibly lead to an overall decrease in energy cost [7]. It is possible that a similar use of the passive-elastic mechanisms occurs about the knee in RFS runners. However, given that the knee only contributes 19% and 13% of positive mechanical work during stance in RFS and FFS, respectively, compared to the 68% (RFS) and 76% (FFS) at the ankle, the scope for reducing positive muscle fiber work through elastic contributions at the knee are likely small. .

In addition to affecting the energetics of running, foot-strike technique may play a role in the etiology of running related musculoskeletal injuries [5]. The knee is the most common site of injury [8] and RFS is the most common foot-strike technique (75% [3]). Therefore a relationship may exist between the high negative loading at the knee (41% of negative work in stance) in RFS runners and knee injuries. The same relationship may also be applicable to FFS runners and ankle related injuries, given that 63% of the negative work in stance is done at the ankle.

When habitual RFS runners switched to a FFS they were able to replicate the redistribution of negative work from the knee to the ankle observed in habitual FFS running. However, the total positive and negative work rate increased significantly by 14.6% and 8% respectively, compared to their habitual technique (Figure 2). It is possible that the elastic mechanism at the ankle is not as well developed in habitual RFS runners, and therefore increased work at the hip joint is required to maintain the required work output. A training study is needed to determine whether the elevation in mechanical work would reduce with conditioning. Habitual FFS runners easily adopted a RFS technique with the only differences being the distribution of ankle and knee negative work common between habitual RFS and FFS.

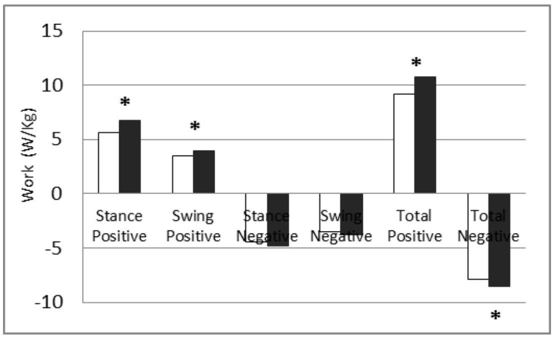

Figure 2: Total positive and negative work rate during stance and swing in habitual RFS (white) vs. imposed FFS (black) * significance p<0.0167.

CONCLUSIONS

The predominant use of the ankle to do negative work in FFS may reflect a greater storage/release of elastic energy in the Achilles tendon, possibly reducing muscle fiber work and overall metabolic cost compared to RFS running. Further research is needed to determine if the benefits of increased negative work at the ankle outweighs the increase in total work when habitual RFS runners switch to FFS. Switching between RFS and FFS may have implications for injury reduction/recovery given the altered distribution in joint loading.

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