EFFECT OF CHANGING FOOT STRIKE PATTERN FROM REARFOOT TO FOREFOOT ON FOOT EXTERNAL EVERSION MOMENT

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We aimed to illustrate the change in the foot external eversion moment of habitual rearfoot strike runners when they immediately change their foot strike pattern to an anterior foot strike pattern. Eighteen healthy males participated and were instructed to run with their habitual foot strike pattern and a modified (anterior) foot strike pattern. From the three-dimensional coordinates of running (250 Hz) and the ground reaction force (1000 Hz), the foot external eversion/inversion moments were calculated. During the stance phase of running, the modified foot strike running exhibited a significantly larger peak external eversion moment than the rearfoot strike running. Our results suggest that changing the foot strike pattern from a rearfoot to a forefoot may increase foot eversion moments and susceptibility to overuse running injuries.

KEYWORDS: foot strike pattern, ground reaction force, kinetics, external moment

INTRODUCTION: Running is the most fundamental activity yet includes several individual-based variable features. Of these, foot strike patterns are of research interest, and human runners can employ three types of foot strike patterns. It has been proposed that an anterior foot strike pattern (forefoot or midfoot strikes) provides an advantage over a rear foot strike pattern by storing greater elastic energy in the Achilles tendon and the foot arches (Perl et al., 2012). Many runners and coaches have attempted to change the foot strike pattern in order to improve running performance and reduce the risk of injury (Hamill & Gruber, 2017); however, it has been shown that forefoot and midfoot strikes are not always superior to rearfoot strikes when the habitual foot strike pattern is changed (Gruber et al., 2013; Ogueta-Alday et al., 2014).

Whether recreational or competitive, runners face overuse running injuries (van Gent et al., 2007). Rearfoot eversion motion has been considered as one of the factors causing, or at least being associated with, overuse running injuries (Rodrigues et al., 2013). Tsujimoto et al. (2017) described the background mechanics of how the external eversion moment is induced on foot. They successfully extracted the effective length of the moment arm (lateral distance between the centre of pressure and the centre of the ankle) as a main determining factor in producing the foot external eversion moment. Tsujimoto et al. (2018) also compared the mechanism of inducing the foot external eversion moment among non-rearfoot strikers with those in rearfoot strikers. They revealed that the mechanical background causing the rear foot external eversion moment would substantially differ depending on the foot strike patterns. The series of studies provided valuable insight into the injury risk when a runner tries to change his/her habitual foot strike pattern immediately. However, less research attention has been paid to runners on the external eversion moment of the foot when they immediately change the foot strike patterns from the rearfoot strike to the forefoot strike.

We aimed to illustrate the change in the foot external eversion moment of habitual rearfoot strike runners when they immediately change their foot strike pattern to anterior foot strike patterns. Based on the anatomical alignment between the lateral and medial malleoli, we hypothesised that the forefoot landing leads to a landing from the fifth metatarsal side of the toe. This would laterally situate the centre of pressure on the foot plantar surface, potentially exaggerating the external eversion moment during the stance phase of running.

METHODS: Eighteen healthy adult men participated in the present study (height 1.72 ± 0.05 m; body mass 66.3 ± 8.8kg). They were habitual rearfoot strikers and were free from lower limb injury when participating in the present study. Participants were instructed to perform runs with a habitual footfall style (rearfoot strike) and a modified style (asked to land with an anterior part of the foot). The two conditions were conducted in a randomised order. Participants wore the same model shoes with different sizes (Mizuno, Maximizer 24). The target running speed was set at 3.30 ± 0.17 m/s to be consistent with previous studies (Tsujimoto et al., 2017). Kinematic data were captured at 250 Hz using a 12-camera optoelectronic motion capture system (Vicon Vantage, Vicon Motion System, Oxford, UK). A force platform (Type9827CA; Kistler Instruments, Switzerland) embedded in the middle of a runway recorded the ground reaction forces during the stance phase at 1000 Hz. The force platform and the motion capture system were synchronised electronically.

Before testing, according to a previous study (Tsujimoto et al., 2017), four reflective markers were placed on the right foot of each participant. The marker locations used for analysis were the medial and lateral malleolus, heel, and toe (midpoint between the second and third metatarsal heads). The heel marker was placed at the same height as the toe marker. The foot contact angle (between the foot vector and the Y axis of the global coordinate system) was used to confirm the modification of the foot strike pattern. Trials with a positive value were defined as the rearfoot strike running, and those with a negative value were defined as the forefoot strike running, respectively.

The procedure of Tsujimoto et al. (2017) was applied to calculate the external eversion/inversion moment due to the ground reaction force (GRF). First, the moment vector acting on the ankle joint centre due to the GRF was computed using the cross product of the vector from the ankle joint centre (midpoint of the medial and lateral malleolus) to the centre of pressure (COP) and the vector of the GRF during the contact phase. A unit vector parallel to the longitudinal foot axis (from heel to toe) was used as the anatomically relevant axis to compute the total external eversion (+) /inversion (-) moment due to the GRF (Mtot). In addition, the external moment due to the mediolateral component of the GRF (Mx) and the vertical component of the GRF (Mz) were computed. These moments were normalised by the subject's weight (N･m/kg). The angular impulse was calculated by integrating the net external moment using the trapezoidal rule throughout contact time.

Each variable was presented as the mean ± standard deviation. Comparisons were made between the two conditions for the peak foot eversion moment, the averaged magnitude of Mtot, Mxy and Mz through the entire contact phase and angular impulse due to net external moment using a paired t-test. The level of significance was set at less than 5%. Additionally, effect sizes were calculated for these comparisons.

RESULTS: The average foot contact angle was 18.5 ± 7.5° for the rearfoot strike and -6.6 ± 3.1° for the forefoot strike.

Figure 1 illustrates the average changes (SD) in Mtot for the running with a rearfoot strike (line in red) and a forefoot strike (line in black). Both footfall running styles induced an eversion moment throughout the stance phase. The modified foot strike running (forefoot) exhibited a significantly larger peak value of the foot external eversion moment than that of the rearfoot strike running (forefoot: 0.38 ± 0.19 N･m/kg; rearfoot: 0.30 ± 0.12 N･m/kg, $p = 0.01$, $d = 0.52$). The angular impulses due to net external moment were not significantly different between the two conditions (forefoot: 0.028 ± 0.032 Nm/kg; rearfoot: 0.021 ± 0.019 Nm/kg, $p = 0.33$, $d = 0.24$).

Figure 2 illustrates the foot external moment due to the mediolateral component of the GRF (Mx, panel a) and the vertical component (Mz, panel b) of the GRF. During the mid-stance phase (from 36% to 62%), the rearfoot strike running exhibited an inversion moment, while the forefoot strike running consistently exhibited an eversion movement after the initial stance phase (>20%). There was a significant difference in the average magnitude of the Mx between the two styles of running (forefoot: 0.025± 0.047 N･m/kg; rearfoot: 0.006 ± 0.034 N･m/kg; $p < 0.01$, $d = 0.45$).

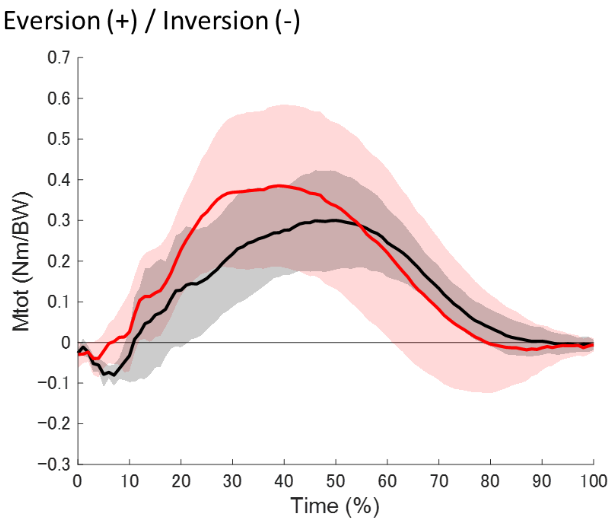

Figure 1. Average (SD) changes in foot external eversion/inversion total moment for rearfoot strike (line in black) and forefoot strike (line in red).

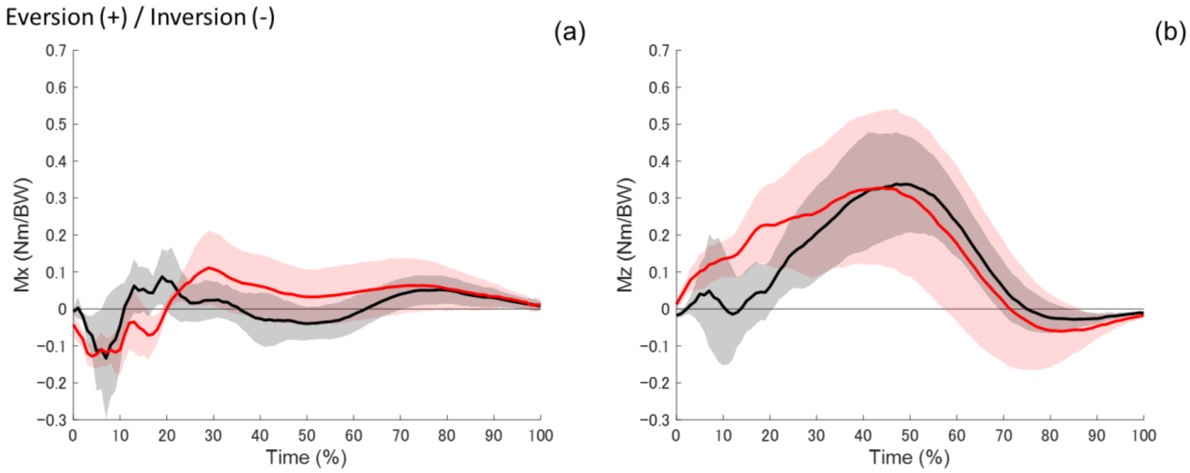

Figure 2. Average (SD) changes in foot external eversion/inversion moment due to mediolateral components of the GRF (a) and vertical components of the GRF (b) for rearfoot strike (line in black) and forefoot strike (line in red).

DISCUSSION: We aimed to illustrate the changes in the foot external moment of habitual rearfoot strike runners when they immediately change their foot strike pattern to an anterior forefoot strike pattern. First of all, we confirmed that the modification of the foot strike pattern was made successfully due to the change in the foot contact angle between the two conditions (rearfoot strike: 18.5 ± 7.5° vs. forefoot strike: -6.6 ± 3.1°). We found that the forefoot strike running exhibited a significantly larger peak value of the foot external eversion moment than that of the rearfoot strike running. The finding fully supported our initial hypothesis.

The study of Tsujimoto et al. (2019) first illustrated kinetic backgrounds of the foot external eversion/inversion moment, in which the foot external eversion moment becomes apparent from the initial stance phase and followed by the inversion moment in the mid-stance phase. As shown in Figure 1, it is interesting to note that the external inversion moment was rarely observed in the present study for both running styles, which is inconsistent with the previous finding. Tsujimoto et al. (2019) reported the effective length of the moment arm; the lateral distance between the COP and the ankle joint centre is a primitive factor in producing the foot external eversion moment. In their study, an inversion moment was initiated from the mid-stance phase when the COP shifted medially to the ankle joint centre.

Figure 3 shows the lateral distance between the centre of pressure (COP) and the ankle joint centre. It can be seen that although there was a substantial difference between the two conditions during the initial stance phase (0–26%), the two conditions followed a similar change of the moment arm length and yet remained positive value until the latter part of the stance phase. This aspect of the effective moment arm apparently differed from the previous finding, which would explain why no inversion moments were observed in this study. In the study of Tsujimoto et al. (2019), the participants ran barefoot while the present participants ran with shoes. The shod running applied in the present study is likely responsible for the difference in COP trajectory.

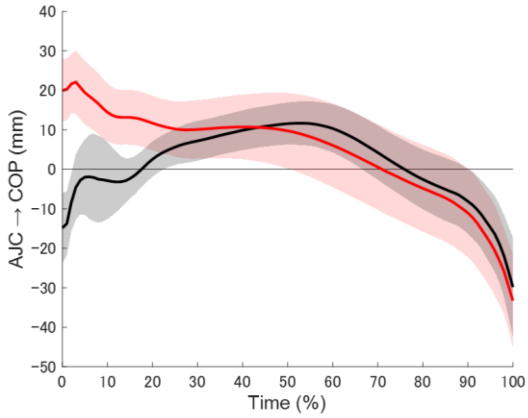

Figure 3. Lateral distance between the centre of the ankle (AJC) and the centre of pressure (COP) for rearfoot strike (line in black) and forefoot strike (line in red).

In the present study, we demonstrated that an acute change of the foot strike pattern most likely emphasises the magnitude of the foot external eversion moment due to the GRF. However, there was no difference in the net angular impulse. Foot eversion motion has been considered a risk factor for overuse running injuries because excessive muscle activity is necessary to control this motion. O'Connor et al. (2004) reported that the posterior tibialis muscle becomes active to suppress excessive eversion moments during the stance phase of running. Thus, it is reasonable to assume that an immediate change in the foot strike pattern demands runners to exaggerate the activity of the posterior tibialis muscle. This change might increase the susceptibility to lower limb overuse injuries in runners.

CONCLUSION: The immediate change of the foot strike pattern from a rearfoot strike to a forefoot strike significantly increased the magnitude of the foot external eversion moment during the stance phase of running by an average of 0.08 N･m/kg. Therefore, from the perspective of injury risk, one should be cautious regarding changing the foot strike pattern.

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