RISK OF INJURY IN TRAIL RUNNING: A PRELIMINARY STUDY

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To evaluate the biomechanical differences between 10 trained trail and matched 9 trained road runners during barefoot (BF) and shod running trials. To determine whether trail runners possess characteristics that are favourable in reducing the risk of running-related injury (RRI) when compared to their road running counterparts kinematic and kinetic data were collected during overground running. Road running controls exhibited greater mean peak knee flexion and footstrike angle while shod compared to shod trail runners. Both groups presented with greater mean vertical loading rate, mean foot pronation (velocity and magnitude) when BF, compared to shod conditions. This paper suggests that road runners may be at greater risk for RRI in comparison to trail runners. Consistent with current evidence, habitually shod runners who engage in BF running may be at greater risk of RRI.

KEY WORDS: off-road running, barefoot running, exercise, biomechanics

INTRODUCTION: Incidence rates for running-related injuries (RRI) vary greatly, with research reporting a range of 7.7 to 17.8 injuries per 1000 hours of running exposure (Videbaek, Bueno, Nielsen, & Rasmussen, 2015). Majority of these injuries are overuse injuries (cumulative micro-trauma injuries that can occur as a result of repetitive and invariant movement) (Elliott, 1990). The causes of RRI are regularly debated and multi-factorial, with previous research responses focusing on the forces applied to the body and 'abnormal' joint angle changes of the body. The working hypothesis is that excessive forces or extreme movements during the gait cycle expose the body to stresses that significantly increase injury risk (Nigg & Wakeling, 2001).

As a result of the assumption that running barefoot (BF) reduces risk of RRI, improves muscle strength and running efficiency, BF running has gained widespread popularity in the global running community (Tam, Astephen Wilson, Noakes, & Tucker, 2014). However, the available literature on the topic with regards to structural, mechanical, clinical and performance related implications of BF running are in its developmental phases. In fact, recent research suggests that when most habitually shod runners engage in BF running, impact forces and rate of loading increase significantly, which suggests that BF running may pose a greater risk of RRI in individuals that typically run in shoes (Lieberman, 2012; Tam, Astephen Wilson, Coetzee, van Pletsen, & Tucker, 2016).

Similarly, a recent development in recreational and competitive running has been the emergence of trail (off-road) running. Trail running is characterised by steep gradients, variable surfaces and uneven terrain. Due to constant exposure to unpredictable and compliant terrains, trail runners may present with altered gait patterns relative to road running counterparts, with variable joint angles and more even joint stiffness distribution that is facilitated by increased pre-activation and co-activation of the surrounding musculature. Running variability may reduce potential of RRI, and it is thus hypothesized that trail runners possess favourable characteristics in this regard. In addition, one should be careful not to extrapolate previous findings on BF runners to all running populations. It is plausible that habituated trail runners could respond favourably to the transition from shod to BF running, presenting with lower loading rates when compared to the road running population.

Consequently, the present study aimed to investigate the differences in lower limb biomechanics of trail and road runners whilst running BF and shod. This research may have practical implications for the prescription of BF running based on the habitual running terrain.

METHODS: 29 male and female participants volunteered to participate in this study. They were between the ages of 18-50 years, had at least 2 years running experience, could run a

10km race <60 minutes, were uninjured for 6 months prior to study participation and ran at least 4 hr/week. Of these 29 runners, 10 trail runners (80% of their training off-road, with varying terrain) and 9 road running controls (train predominantly on road/pavement) matched for body mass and running performance.

Participants completed 6 running trials in BF and shod conditions at a self-selected pace. Three-dimensional marker trajectories were captured using an eight-camera VICON MX motion analysis system (Oxford Metrics Ltd, UK), sampling at 250 Hz. Ground reaction force (GRF) data were collected using a floor embedded force platform (AMTI, USA), sampling at 2000Hz, synchronized with the motion capture system. Kinematic and kinetic variables were resolved using the standard PlugInGait model. Marker trajectory and kinetic data were filtered using a low-pass fourth-order Butterworth filter with a cut-off frequency of 8 and 60 Hz, respectively. Three-dimensional lower extremity joint angles and net resultant moments were calculated using a Newton-Euler inverse dynamics approach. Joint angles were described using the joint coordinate system. Sagittal plane knee and ankle stiffness were calculated for load acceptance phase according to Hamill, Gruber, and Derrick (2014).

Discrete kinetic measurements extracted were: peak vertical GRF ($BW{\cdot}s^{-1}$), medio-lateral GRF ($BW{\cdot}s^{-1}$), anterior posterior GRF ($BW{\cdot}s^{-1}$), vertical loading rate($BW{\cdot}s^{1}$) as well as vertical impulse ($N{\cdot}s^{-1}$). Kinematics extracted included foot strike angle, peak knee flexion angle, maximum pelvic obliquity (i.e., lateral pelvic drop)(°), foot pronation velocity($°{\cdot}s^{-1}$), and vertical displacement of the centre of mass (mm).

Data were screened for normality and homogeneity of variance using Shapiro-Wilk's and Levene's test, respectively. A two-way ANOVA (group x condition) assessed differences between variables of interest. Interaction effects were assessed with a Tukey's post-hoc analysis. The alpha level was set at p = 0.05.

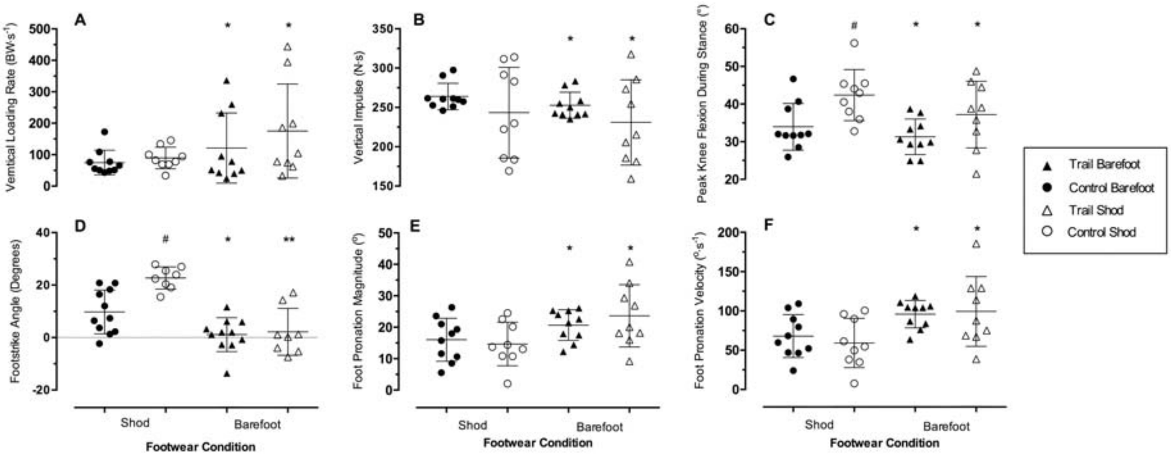

Figure 1: A comparison of biomechanical variables in habitual trail and road runners engaging in BF and shod conditions: (A) vertical loading rate, (B) vertical impulse, (C) peak knee flexion during stance (D) footstrike angle (E) foot pronation magnitude (F) foot pronation velocity

RESULTS & DISCUSSION: Differences in various biomechanical parameters were found between footwear conditions (BF and shod), and between running groups (trail and road) (Figure 1). Greater mean vertical loading rate, mean foot pronation velocity and magnitude were found in the BF condition for both groups. The presence of a greater vertical loading rate during BF running is consistent with the findings of Lieberman et al. (2010) who found that most habitually shod runners experience higher collision forces when engaging in BF running, compared to that of habitual BF runners. This increase in loading rate while BF is attributed to a habitually shod runner's tendency to continue to heel strike when transitioning to the BF condition (Tam et al., 2014). However, it is important to note the large standard deviation in loading rates for the control (SD=149.49) and trail (SD = 149.48) groups when running BF, suggesting a significant variability in both groups' responses to this unfamiliar condition (Tam et al., 2016). This variability in loading rate in both groups highlights that from a clinical perspective, caution is advised to habitual shod runners wishing to transition to BF running activities as this may increase ones risk of RRI (Ridge et al., 2013).

In addition, a greater foot pronation velocity and magnitude in both groups while BF maybe an unfamiliar response in neuromuscular control and lack of strength required to tolerate BF running. The association between foot pronation mechanics and RRI is unclear, and contrasting research has led to a debate regarding whether excessive (Willems, Witvrouw, De Cock, & De Clercq, 2007) or reduced (Thijs, Van Tiggelen, Roosen, Clercq, & Witvrouw, 2007) foot pronation mechanics result in development of RRI. There is however, literature to suggest that a larger magnitude and rate of pronation is injurious rather than pronation in itself (Hoffman et al., 2015). Specifically, stress fractures, lumbar spine pathology, achillies tendinopathies and patella femoral pain syndrome could all potentially arise as a result of excessive pronation during running (Brukner, 2012). In this regard, habitually shod runners could be at higher risk of RRI when BF (Tam et al., 2016). Another likely hypothesis for this significance is that participants would have experienced superior cushioning and support during shod running, allowing for greater neuromuscular control, thus decreasing the magnitude and speed of pronation (Hoffman et al., 2015). The absence of a difference between groups does not preclude the hypothesis that trail runners may respond more favourably to BF running, but may rather suggest that pronation variables are not as significantly affected by trail running as the authors initially thought. What this finding does provide is an indication that the prescription of BF running should not be advised for runners with injuries that are affected by excessive pronation, or for those who already excessively pronate, regardless of whether they are off-road or road runners by nature (Tam et al., 2016).

Average footstrike angle for both trail and road runners was greater in the shod condition versus BF. Controls experienced a higher footstrike angle when shod versus BF ($p=0.009$), and in addition a similarly higher footstrike angle than shod trail runners ($p=0.001$). This measurement has been correlated with higher peak knee extensor moments, larger vertical ground reaction forces and greater levels of knee energy absorption, that collectively are argued to play a role in RRI etiology (Souza, 2016). Greater footstrike angles experience by controls may predispose them to RRI such as stress fractures of the tibia, achilles tendinopathy, plantar fasciitis and patellofemoral pain (Tam et al., 2014). Average peak knee flexion was greater in the controls whilst shod when compared to trail runners engaging in either shod or BF running. The precise peak knee flexion angle that is considered pathological is debated, although an optimal value is speculated to be around 45°.Some researchers suggest that a greater degree of knee flexion during stance phase of running may load the pattellofemoral joint excessively and contribute to knee pathology (Prentice, 2015). Whereas others suggest that lower levels of knee flexion may limit the shock absorption capabilities of the knee joint and thus predispose the runner to injury. In order to generate a more accurate depiction of RRI risk, other factors that need to be considered in conjunction with peak knee flexion; total knee excursion during stance phase, knee stiffness, the magnitude of forces experienced by the knee joint and loading rates (Souza, 2016).

A logical association was made between greater knee flexion angles and footstrike angles in the control group. This is presumed to have occurred because greater levels of dorsiflexion (from a larger footstrike angle) during stance phase of running result in an obligatory increase in knee flexion up the lower limb chain (Prentice, 2015). The greater peak knee flexion observed in the controls needs to be considered prospectively to any RRI that occur in habitual road runners and thus could lay the foundation for future research on the topic.

A greater vertical impulse was observed when shod compared to BF in both groups. This finding was likely a result of an increased cushioning in the shoes provided, increasing time for force application(Knudson, 2007). However, as mentioned, a lower loading rate was found in the shod condition, which would seem at odds with a larger vertical impulse. It can be assumed that the compliance of the cushioning placed in the heel of a shoe increased temporal application of force transmission from heel strike to toe off, while decreasing the impact peak. Substantial loading rates and vertical impulses have been purported to be associated with a greater risk of RRI, but with contradictory research on this topic, it is debated as to whether either of these variables are causal factors for RRI at all, or merely contribute to a larger physiological and biomechanical chain of events resulting in RRI. Further, this study highlights the controversy, with higher loading rates in the BF condition in both groups of runners (and similarly greater magnitudes of variables associated with prospective RRI), yet greater mean vertical impulse during shod. It is apparent that a greater understanding and distinction of the biomechanical variables associated with injury risk is required to adequately describe running populations with respect to RRI risk.

CONCLUSION: Although these two distinct groups of runners appeared to have clear similarities in running style, differences were found between groups in foot strike angle and peak knee flexion angle during stance. These variables, both greater in the controls than trail runners, may suggest that habituated road runners may be at a greater risk of RRI in comparison to the habitual off-road running population. Further, greater values for foot pronation components and vertical loading rate in BF conditions suggests that habitually shod runners who engage in BF running may be at a greater risk of RRI. This finding is consistent with the current literature on BF running.

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