Rearfoot and Midfoot or Forefoot Impacts in Habitually Shod Runners

ELIZABETH R. BOYER, BRANDON D. ROONEY, and TIMOTHY R. DERRICK

Department of Kinesiology, Iowa State University, Ames, IA

ABSTRACT

BOYER, E. R., B. D. ROONEY, and T. R. DERRICK. Rearfoot and Midfoot or Forefoot Impacts in Habitually Shod Runners. *Med. Sci. Sports Exerc.*, Vol. 46, No. 7, pp. 1384–1391, 2014. **Purpose**: Shear loading rates (LR) have not been investigated in runners with a mid- or forefoot strike (FFS) versus rearfoot strike (RFS). The purpose of this study was to compare three-dimensional ground reaction forces (GRF) and LR during impact in habitual rearfoot strikers (hRF) and habitual forefoot strikers (hFF) strikers. **Methods**: Thirty competitive runners performed 10 overground running trials with both foot strike styles. Peak three-dimensional and resultant GRF and instantaneous LR during impact were compared. **Results**: Vertical LR significantly decreased for hRF using an FFS (RFS = 148 ± 36 body weight [BW]·s^{-1}, FFS = 98 ± 31 BW·s^{-1}) but was similar for hFF running with either foot strike (FFS = 136 ± 35 BW·s^{-1}, RFS = 135 ± 28 BW·s^{-1}). Posterior impact forces were present during FFS but not during RFS, and posterior LR was significantly greater for both groups during FFS (−58 ± 17 vs −19 ± 6 BW·s^{-1}). Medial impact forces were also present during FFS but not during RFS, and medial LR was significantly larger for both groups during FFS (−21 ± 7 vs −6 ± 6 BW·s^{-1}). Interestingly, hFF had greater impact peaks and LR in all directions compared with hRF during FFS. This may be explained by hFF using a smaller strike index (hFF = 62% ± 9%, hRF = 67% ± 9%; P = 0.02), which was significantly inversely related to vertical LR and impact peak. **Conclusions**: Peak resultant and vertical LR are not ubiquitously lower when using a shod FFS versus RFS despite an absence of resultant and vertical impact peaks. Furthermore, there were impact peaks in the posterior and medial directions, leading also to greater LR in these directions during FFS. Therefore, transitioning from RFS to FFS in traditional running shoes may not offer long-term protection against impact-related running injuries because hFF running with an FFS demonstrated many GRF and LR similar to or greater than RFS. **Key Words:** HEEL STRIKE, FOOT STRIKE, LOADING RATE, GROUND REACTION FORCE

The advent of minimalist shoes and barefoot running has recently caused much hype in the running community. In one study, more than 75% of runners surveyed said they were interested in running barefoot or in minimalist shoes, primarily to reduce their chance for injury in the future (25). Runners who use a rearfoot strike (RFS) style in traditional running shoes typically switch to a mid- or forefoot strike (FFS) when running in a minimalist shoe or barefoot because of the discomfort of landing on their heels (14). Because switching to minimalist shoes or barefoot usually results in a runner switching foot strike styles, it is sometimes ambiguous whether biomechanical differences are due to changes in footwear, foot strike, or a combination of the two. We are interested in the biomechanical differences between foot strike styles. Few studies have compared foot strike styles while maintaining the same shod condition, which more accurately attributes kinematic or kinetic differences to the foot strike (5,6,9,11,18,20,29). These, therefore, are the only types of studies from which we will draw comparisons.

For runners with patellofemoral pain or anterior compartment syndrome, the reduction or lack of an impact peak (transient peak within the first 20% of stance) in the vertical ground reaction force (GRF) and lower vertical GRF loading rates (LR) during mid- or forefoot running may have implications for injury and pain reduction when switching from an RFS to an FFS (6,9). One retrospective study has also shown fewer injuries among habitually shod cross-country runners with an FFS versus an RFS (8), whereas, adversely, a couple

Address for correspondence: Elizabeth R. Boyer, M.S., Iowa State University, 283 Forker Building, Ames, IA, 50011; E-mail: ehageman@iastate.edu.
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of studies noted stress reactions or fractures occurring in runners after switching to barefoot-simulating footwear (12,24). However, to date, there are no prospective studies comparing injury rates between RFS and FFS runners.

Despite an apparent elimination of a vertical impact peak with an FFS, higher impact frequencies are still present in the frequency domain (13). As demonstrated by Shorten and Mientjes (30), there may be a vertical impact in FFS, but it may not show up as a peak in the time domain. Regardless, several retrospective studies (15,19,21,22,34), a prospective study (3), and a recent review (33) found that increased vertical LR (VLR) is associated with running injuries, and VLR has been reported to be lower in shod FFS versus RFS running (6,9,11). Contrarily, one study (18) did not find differences in instantaneous or average VLR between foot strike styles when holding shoe condition constant. However, all four of these studies (6,9,11,18) looked at habitual rearfoot strikers (hRF) and asked them to convert to an FFS. Therefore, it is necessary to compare habitual mid- or forefoot strikers (hFF) to hRF to ascertain if the typical differences in kinetics remain. Recent dissertation work by Gruber (13) has compared average VLR in habitually shod groups and found it to be lower in FFS versus RFS for both groups.

In addition, bone fatigue increases as the load or load rate increases (4,27), and bone is weaker in shear than compression (23,31). As such, it is important to compare the resultant GRF and LR and the three ordinal components between foot strike styles, which has only been done for GRF but with limited discussion of the shear forces (5,18,20). Greater shear forces on the metatarsal heads are not tolerated as well as vertical forces, likely having implications for injury (1). Landing on the forefoot region, as during FFS, loads the metatarsals for a longer period than RFS. The metatarsals experience a bending moment during gait with compression on the superior surface and tension on the inferior surface (2), which necessitates an opposing moment by the plantar fascia and/or toe flexors to prevent excessive bone stress/strain. If an hRF transitions to an FFS too hastily, fatigue of the small toe flexor muscles may occur, increasing bone strains (10), or the rate of bone destruction may exceed remodeling, evidenced by expansive edema (24), either of which may be the mechanism behind the metatarsal stress fractures observed in converted forefoot strikers (i.e., hRF who switch to an FFS) (12,24).

Finally, only one study has compared select kinematics and kinetics between habitual and newly converted forefoot strikers (32), but variables such as the shear LR were not investigated. Therefore, the purpose of our study was to compare GRF and LR during the impact phase in the three planes of motion during shod rearfoot and mid- or forefoot running in healthy competitive runners who habitually run using either a mid- or forefoot or RFS. On the basis of previously reported similarities between habitual and converted forefoot strikers (32) and lower VLR in FFS versus RFS regardless of habitual foot strike (13), it was hypothesized that there would be no differences in the vertical GRF and LR between habitual foot strike groups, and VLR will be lower in FFS versus RFS.

METHODS

Participants. The participants (15 hFF and 15 hRF, 3 females in each group) were recruited from a population of competitive runners who were currently injury-free and did not report any injury in the previous 6 months. Midfoot and forefoot strikers and foot strikes were grouped together as hFF or FFS because of similar sagittal ankle kinematics and GRF observed in our runners and to increase statistical power because of the scarcity of forefoot strikers (5). The study was approved by the Iowa State University Institutional Review Board, and written informed consent was obtained before participation. Runners did not differ on age, mass, height, self-selected running speed (described later), or weekly mileage (hRF age = 20.6 ± 1.6 yr, mass = 65.7 ± 7.6 kg, height = 1.78 ± 0.07 m, velocity = 4.25 ± 0.26 $\mathrm{m \cdot s^{-1}}$, mileage = 59.9 ± 17.8 $\mathrm{miles \cdot wk^{-1}}$, hFF age = 22.0 ± 2.3 yr, mass = 63.7 ± 8.7 kg, height = 1.78 ± 0.08 m, velocity = 4.37 ± 0.23 $\mathrm{m \cdot s^{-1}}$, mileage = 63.7 ± 24.6 $\mathrm{miles \cdot wk^{-1}}$, all $P > 0.05$).

Protocol. Participants were provided with the same brand and model of running shoes. Anthropometrics were measured and recorded for each participant, including body mass, height, thigh length and circumference, calf length and circumference, foot length and breadth, and malleoli height and width. The self-selected running speed for the treadmill warm-up and all conditions was one that was comfortable and could be maintained for a long run but quicker than an easy recovery run. The same speed was used for both foot strike styles.

A 5-min warm-up on a treadmill at the self-selected speed was performed before collecting overground running trials. Sixteen retroreflective markers were placed on the right leg, pelvis, and trunk: fifth metatarsal head, dorsifoot, medial and lateral malleoli, anterior distal and proximal shank, posterior shank, medial and lateral femoral epicondyle, anterior and lateral thigh, both greater trochanters, sacrum, and both acromion processes. Five additional markers were located on the heel counter of the shoe. Marker position data were recorded using an eight-camera motion capture system (Vicon MX; Vicon, Centennial, CO), sampling at 200 Hz. Participants ran down a 30-m runway and were instructed to land with their right foot on either of two adjacent force platforms (AMTI, Watertown, MA), sampling at 1600 Hz. After they performed practice running trials to avoid targeting and allow for natural gait, 10 good trials were collected (no visual targeting; speed ±5%).

For the first condition, participants ran naturally with no mention of foot strike style, during which habitual strike style was identified. Strike index (SI) was calculated as the average center of pressure location during the first 2.5 ms of stance and reported as a percentage of foot length from the posterior calcaneus. Participants were categorized as hRF (SI < 33.3%) or hFF (SI > 33.3%). Instructions were given on how to

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run with the opposite strike style, and practice was allowed until they felt comfortable. Again, participants performed 10 acceptable running trials using the converted strike style; SI was analyzed to confirm the correct foot strike was used.

Data processing. Data processing was performed in Matlab (7.9.0, R2011b). Stance phase was defined as vertical GRF greater than 10 N. Raw kinematic and kinetic data were filtered using a fourth-order zero-lag Butterworth filter at 16 and 50 Hz, respectively. Stance phase data were interpolated to 101 points.

Variables. Three-dimensional and resultant GRF and instantaneous LR were calculated and normalized to body weight (BW). Peaks were identified from the uninterpolated data during the impact phase. The impact phase for vertical and resultant GRF and LR was considered 0%–20% of stance, whereas 0%–10% of stance was used for the anterior–posterior (AP) and medial–lateral (ML) directions based the GRF profiles obtained for mid- or forefoot striking (Fig. 1). Because there were no distinct impact peaks in the vertical or resultant GRF for FFS, nor any distinct impact peaks in the AP and ML GRF for RFS, we selected the value corresponding to the mean time when the impact peak occurred in the opposite foot strike style in that habitual foot strike group (hRF-RFS = 14% of stance for vertical and resultant GRF, hFF-FFS = 7% of stance for AP and 6% of stance for ML). Therefore, while we may refer to an impact peak for both foot strike styles, it is just the corresponding GRF value in the resultant and vertical directions for FFS and corresponding GRF value in the AP and ML directions for RFS.

Statistical analysis. The average of the 10 trials for each condition was calculated and used for comparison. A 2 × 2 (habitual group × foot strike style) repeated-measures MANOVA was run for eight dependent variables: peak impact GRF and peak instantaneous LR in the AP, ML, and vertical directions and the resultant. Experiment-wise alpha was set to 0.05. If the MANOVA was significant, the univariate ANOVAs were subsequently evaluated at a 0.05 level. *Post hoc* Pearson correlation coefficients were calculated to help explain some of the results.

RESULTS

When hRF were asked to run with an FFS, they landed farther forward on their foot than the hFF, thus a higher SI (hRF = 67% ± 9%, hFF = 62% ± 9%, $P = 0.02$). Specifically, 11 of the 15 hFF were midfoot strikers (SI > 33%–66%) and four were forefoot strikers, whereas 7 of the 15 hRF in the converted FFS would be considered midfoot strikers and eight would be forefoot strikers. When hFF ran with an RFS, hFF landed farther back on their heel, resulting in a smaller SI (hRF = 22% ± 3%, hFF = 20% ± 5%, $P = 0.03$). In both instances, the converted group exaggerated the new foot strike style.

Ensemble curves for both the GRF and the LR are shown in Figures 1 and 2. Average peak values during impact are compared in Figures 3 and 4 (also see Table, Supplemental Digital Content, http://links.lww.com/MSS/A350; Mean ± SD for peak GRF (in BW) and loading rates ($BW \cdot s^{-1}$) during the impact phase of running). Statistics from the MANOVA revealed a significant habitual group–foot strike interaction ($P = 0.009$), indicating that runners were not able to replicate the impact characteristics of the habitual foot strike style. Univariate tests revealed significant interactions for all eight variables ($P \leq 0.026$). The impact peak of the vertical and

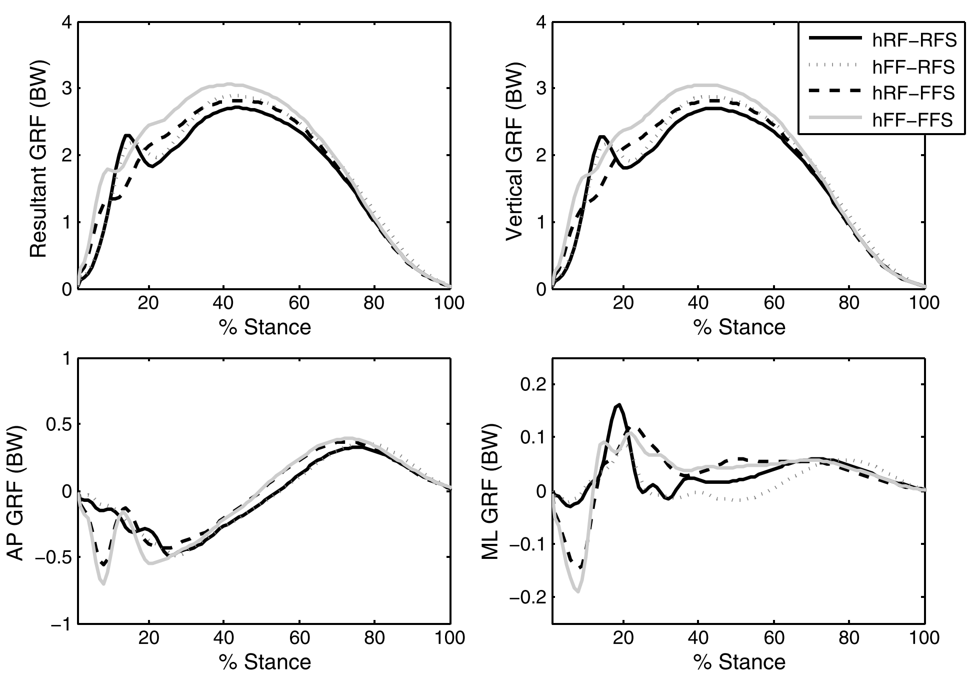

FIGURE 1—Ensemble curves for GRF for the two habitual foot strike groups (hRF and hFF) during the two running styles (RFS and FFS) normalized to stance time. Positive GRF values represent vertical, anterior, and lateral directions.

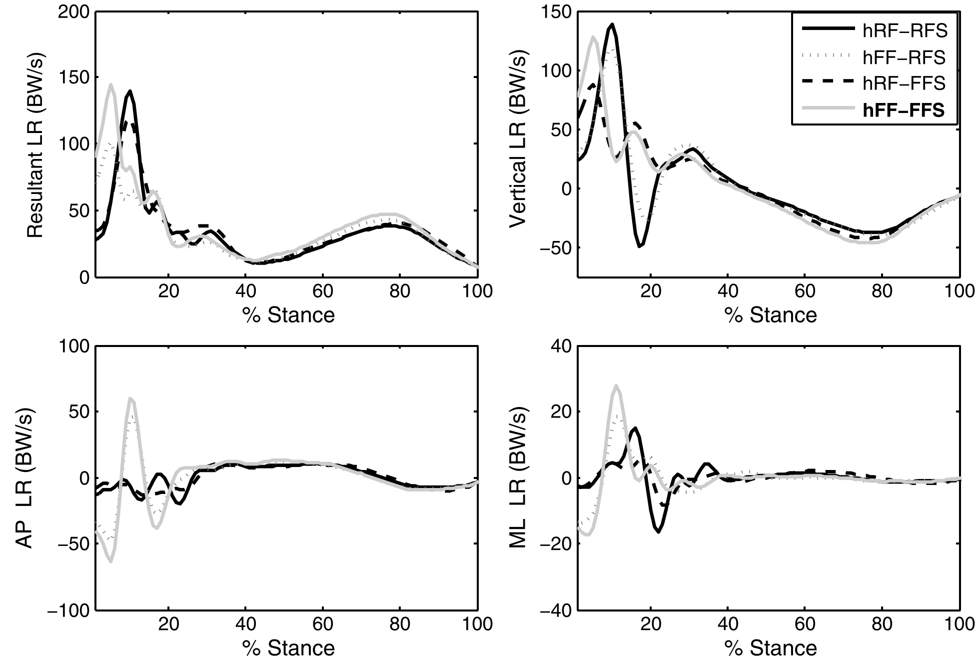

FIGURE 2—Ensemble curves for GRF LR for the two habitual foot strike groups (hRF and hFF) during the two running styles (RFS and FFS) normalized to stance time. Positive LR values represent vertical, anterior, and lateral directions.

resultant GRF was similar when both groups ran with an RFS and was decreased/absent for the FFS condition, but they were minimized more when hRF switched from an RFS to an FFS than when the hFF ran RFS versus their usual FFS. When runners used their habitual foot strike, resultant and vertical impact peaks were smaller in hFF versus hRF (Fig. 1). Impact peaks were present in the posterior and medial directions for FFS but not RFS and were approximately 0.5 and 0.2 BW higher, respectively, than the corresponding shear GRF in RFS. These peaks were also larger for the hFF group when running with an FFS than when the hRF group ran with an FFS. Resultant LR showed opposite effects depending on the group; it decreased 26% when hRF switched from an RFS to an FFS but was 11% higher when hFF ran with an FFS versus RFS. Similarly, VLR decreased 29% when hRF ran with an FFS versus RFS, but it was the same whether hFF ran with an FFS or an RFS. When runners used their habitual foot strike, peak resultant LR was similar and VLR was slightly lower in hFF versus hRF (Fig. 2). Posterior and medial LR increased for both groups when they ran with an FFS, but increased to a greater extent in the hFF group.

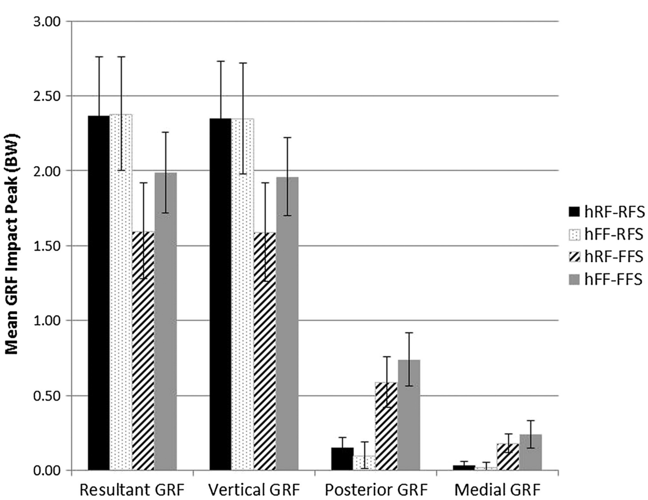

FIGURE 3—Mean GRF impact peaks (with SD bars) for the two habitual foot strike groups (hRF and hFF) during the two running styles (RFS and FFS). All values are represented as positive for comparison. Note: true impact peaks in the resultant and vertical directions were not present for FFS, so the corresponding GRF value at the time when peaks occurred during RFS was used. The same is true for peaks in the posterior and medial directions that were present for FFS but not RFS.

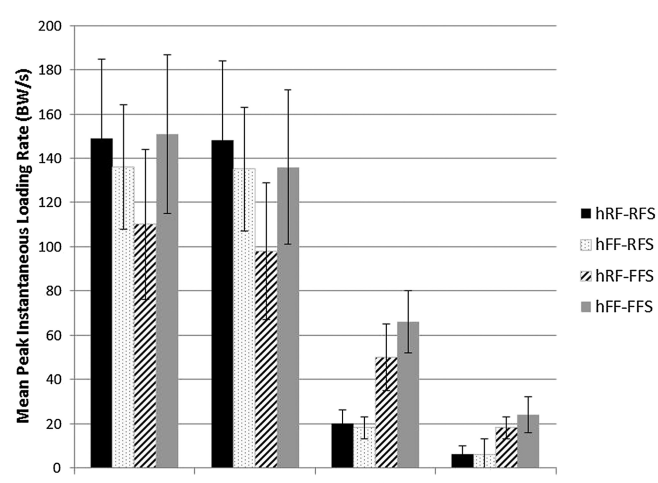

FIGURE 4—Mean peak instantaneous GRF LR (with SD bars) for the two habitual foot strike groups (hRF and hFF) during the two running styles (RFS and FFS). All values are represented as positive for comparison.

The main effect for foot strike ($P < 0.001$) was also significant in the MANOVA. The exploration of the main effect for foot strike is meaningful despite a significant habitual group–foot strike interaction because all changes in variables (besides resultant and VLR) were in the same direction but changed disproportionately between groups. All GRF impact peaks (vertical, posterior, medial, and resultant) were significantly different between foot strike style ($P < 0.001$). The resultant and vertical impact peaks were approximately 32% greater for RFS versus FFS (both $P < 0.001$), but the posterior GRF impact peak was more than 450% greater for FFS versus RFS ($P < 0.001$), and the medial GRF impact peak was approximately 950% greater for FFS versus RFS ($P < 0.001$). Peak instantaneous LR in the posterior direction was 205% greater ($P < 0.001$), and medial LR was 250% greater for FFS versus RFS ($P < 0.001$). There was no significant effect of habitual group ($P = 0.232$).

Post hoc correlations were run between SI and both vertical GRF impact peak and peak VLR. For both groups running with an FFS, the vertical impact peak significantly decreased as SI increased ($r = -0.41$, $r^2 = 0.17$, $P = 0.025$). SI predicted 18% of the variance in VLR ($r = -0.423$, $P = 0.020$) when both groups ran with an FFS, with decreasing VLR as SI increased.

DISCUSSION

The purpose of this study was to evaluate the differences between three-dimensional GRF and LR during the impact phase for rearfoot and mid- or forefoot running for both habitual rearfoot and mid- or forefoot strikers.

Group × foot strike. Peak impact GRF (resultant, vertical, posterior, and medial) were relatively similar when both groups ran with an RFS but were slightly greater for the hFF running with their natural FFS compared with when the hRF converted to an FFS. Alternatively, the newly converted FFS had lower impacts forces than the hFF. Perhaps this is because when the hRF switched to the novel task of using an FFS, they had to focus more on using an FFS and in doing so were more aware of the impacts and their neuromuscular system responded by decreasing them. These differences may have also resulted because hRF had a greater SI during FFS than the hFF, and landing further forward on one's foot allowed the plantarflexor muscles to absorb more of the impact energy. We tested this hypothesis by running correlations between SI and vertical impact peak and VLR. The moderate but significant correlations between SI and the two variables indicated that landing further forward on one's foot helps lower peak VLR and vertical GRF impact peak. These data may partially account for the lower vertical impact peak and VLR during FFS for hRF compared to hFF.

Likewise, we found that LR (resultant, vertical, posterior, and medial) were relatively similar when both groups ran with an RFS but again greater in each direction for hFF versus hRF running with an FFS. Unexpectedly, resultant LR was similar when the two groups of runners ran with their habitual foot strike (~150 $BW \cdot s^{-1}$), VLR was similar for hFF regardless of foot strike style used (~135 $BW \cdot s^{-1}$), and resultant LR was approximately 40 $BW \cdot s^{-1}$ greater during FFS versus RFS for the hFF. These results fail to support our hypotheses. The increase in resultant LR is likely a result of greater LR in the posterior and medial directions. Greater VLR during FFS between hFF and hRF groups may partly be due to the smaller SI used by the hFF, which is associated with higher VLR, or perhaps the hRF took precautions to decrease the loading their body experienced during a novel task, as mentioned previously. However, in support of our hypothesis and in agreement with previous studies (6,29), resultant LR decreased 26% and VLR decreased 29% when hRF switched from RFS to FFS, which lies within the approximate 14%–32% reduction previously reported for converted forefoot strikers (6,29).

Taken together, these data suggest that competitive hRF can successfully reduce their vertical and resultant impact GRF and LR when initially switching to a mid- or FFS, which may be beneficial for decreasing risk for running injuries. However, it is possible that after habitually using an FFS, which may lead to a shallower SI, the reduction may be attenuated. This may put habitual mid- or forefoot strikers at risk for impact-related injuries. However, to our knowledge, all the studies that have found elevated VLR in injured runners were hRF (3,15,19,21,22,34), so it remains to be seen if this association with injury holds true for converted mid- or forefoot strikers. Retrospectively, Daoud et al. (8) found that habitually shod competitive hRF had about twice the injury rates of hFF, although this association was minimized and bordered on insignificance (possibly because of lack of statistical power) after removing runners who alternated between foot strike styles. Prospective studies are necessary to substantiate these findings.

For practical purposes, these results indicate that if comparing GRF or instantaneous LR during RFS, either group of runners may be recruited for RFS, but if the activity of interest is FFS, it is best to use hFF. This contradicts Williams et al. (32) in regard to VLR, although they compared average LR and used recreational runners. Our LR are also slightly higher than those of Williams et al. and others (6,9,11,13,18,19,29,32,34), likely due to the faster running velocities and competitive level of our participants. Similarly, if the intent is to compare SI in FFS, it is best to use the habitual groups.

Foot strike styles. In agreement with previous literature, there was an obvious vertical impact peak for RFS but not for FFS, and it was larger than the corresponding value for FFS (5,11,20). However, because of the similar VLR observed for hFF performing both conditions but decrease for hRF switching to FFS (i.e., a significant interaction), there was not a significant reduction in VLR or resultant LR for FFS versus RFS across groups. This disagrees with previous studies (6,9,11,29), which may likely be because of the following: 1) these studies all used converted rather than habitually shod mid- or forefoot strikers; 2) two studies used lower cutoff

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frequencies of 10 and 20 Hz for kinetic data (6,29); 3) one study reported average VLR (11), whereas Diebal et al. (9) did not specify if VLR was average or peak instantaneous; 4) or perhaps because all four studies were sampled from military recruits or recreational runners and we compared competitive runners. In this case, our data would concur because hRF had lower VLR when they switched to an FFS from an RFS. Gruber (13) compared hFF and hRF and found lower rates in the hFF, which conflicts with our findings. This may be because we grouped all midfoot strikers (as defined by SI) into the hFF group, whereas Gruber (13) grouped midfoot strikers that displayed a vertical impact peak into the hRF group and those without into the hFF group. Regardless, a recent meta-analysis found that VLR (but not vertical impact peak) is significantly elevated in runners with a history of stress fractures (33), possibly making it a more pertinent variable to investigate. To the authors' knowledge, resultant impact peak and LR have not been reported and bears further investigation because the resultant is what the body experiences and is at least as high as or higher than the vertical component.

We also observed that posterior and medial impact forces occurred in FFS and not in RFS, which is consistent with others' findings (5,18,20). The posterior (i.e., braking) impact peak appears to occur in FFS but not in RFS because of the rapid change in velocity and direction of the center of mass (COM) of the foot. During an FFS, the COM of the foot is accelerating forward right before foot strike but then slows to a stop and shifts posteriorly as the ankle dorsiflexes after contact before it begins moving anteriorly again during the propulsion phase. This is balanced by an opposing force and shows up as an impact. With an RFS, however, the COM does not reverse directions and travels from posterior to anterior. Similarly, the impact peak in the medial direction in mid- or forefoot striking, but not RFS, appears to reflect a faster shift of the center of pressure from the lateral border to midline of the foot after contact (5). This quicker shift may be because our runners landed 3.5° more inverted at contact when mid- or forefoot striking than RFS (averaged across group, FFS = 7.7°, RFS = 4.2°).

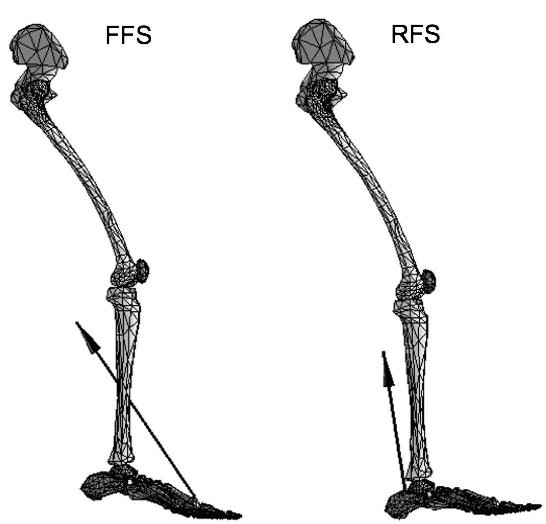

FIGURE 5—Representative resultant GRF vector orientation during FFS for a hFF using an FFS (left) and for an hRF using an RFS (right) at 7% of stance (mean occurrence of posterior impact peak for FFS).

The posterior and medial GRF component during impact of FFS acts to orientate the resultant GRF vector more parallel to the ground in the first ~10% of stance (Fig. 5), resulting in greater shear forces, and it is well known that bones are weaker in shear versus compression (23,31). Creaby and Dixon (7) noted that a more medially directed GRF around 30%–50% of stance in RFS was found in military recruits who sustained a tibial stress fracture versus controls, speculating that it may have increased the medial bending moment on the tibia because of its typical 10° varus orientation during running (17). At midstance, the resultant GRF was slightly lateral for FFS and around zero or slightly medial for RFS, which may be significant given that the magnitude of the GRF is greater, and it is estimated that tibial loads are greatest around midstance when muscle forces peak (26,28). However, the resultant GRF was significantly more medially directed for FFS versus RFS during the impact phase, which may be more significant given the resultant LR is much greater during this phase and LR seems to have a greater association with tibial stress fractures than GRF magnitude (33). In addition, the bones of the foot may also be susceptible to injury as a result of elevated shear GRF and LR (1,24).

Because the magnitudes of the shear GRF and LR are several times smaller than the vertical magnitudes, their contribution to injury potential may be minute. This notion is supportive of Milner et al. (19), who did not find a retrospective association between posterior LR and stress fracture history in hRF. However, we found that posterior LR during RFS, as studied by Milner et al. (19), is over three times smaller than FFS values, so this potential injury association has yet to be established for the much higher shear rates of loading in FFS.

Implications. Shod rearfoot strikers wishing to decrease their resultant or VLR may consider switching to an FFS because these variables decreased in our study as well as others (6,9,11,29), and elevated VLR is associated with a history of stress fracture (33). These decreases in LR, however, may be temporary as hFF running with an FFS had higher LR than RFS. Runners must also be aware of the increased shear GRF and LR associated with an FFS, which may be important from an injury perspective because bones cannot withstand shear forces as well (23,31). If choosing to convert from an RFS to an FFS for long distance running (especially if also changing to minimalist footwear or barefoot), it should be done progressively and with caution to avoid injuries (12,24). As we have discussed, the metatarsals may be more susceptible to injury if converting to an FFS (12,24) because the mid- or forefoot regions are loaded continuously throughout stance and experience greater shear forces at higher LR based on our findings. However, shod runners who are plagued by knee injuries or anterior compartment syndrome may benefit by converting (6,9).

Therefore, whether converting is appropriate may depend on which joint/segment is currently experiencing excessive loading.

Finally, the converse train of thought should not be discounted. Bones need adequate stimulation to maintain and improve their integrity; as strain magnitude increases, the necessary loading frequency to induce osteogenesis decreases, and vice versa (16). Hence, although each foot strike style and habitual group has its respective larger GRF impact magnitude and LR, the runner's bones may have adapted to those loads and require these forces and loading frequencies to stay healthy. Therefore, while higher LR may be associated with bone fatigue and running injuries, other causal mechanisms contribute to an overuse injury (e.g., previous injury history, excessive training, anatomical misalignments, inadequate diet, etc.).

Although the same running shoe was used to abate any effect of shoe type, it is likely that runners with different habitual foot strike styles select different shoes that most appropriately fit their needs. As such, actual GRF and LR experienced routinely may be different than those represented here, representing a limitation of the study. Second, all variables were analyzed in the time domain; slightly different conclusions may have been drawn if variables were analyzed in the frequency domain. Lastly, GRF and LR only represent the net external loading experienced by the body and not the internal bone loading, which is dominated by muscle forces (28) and may contribute more to running injuries. Therefore, studies analyzing bone loading environment may be more meaningful when trying to identify injury risk potential between foot strike styles.

CONCLUSIONS

In summary, there was an absence of obvious vertical and resultant impact peaks when both groups of competitive runners ran with a mid- or FFS versus RFS but no overall reduction in peak instantaneous resultant or VLR across groups. This was because peak resultant and VLR during FFS in hFF was still as high as or only slightly lower than the LR of hRF running with their typical RFS. In addition, impact peaks were present in the posterior and medial GRF profiles when both groups ran with an FFS versus RFS, and the associated shear LR were also greater. When both groups ran with an FFS, hFF had greater GRF and LR than hRF in all directions, which may partially be explained by a smaller strike index. However, hRF did significantly decrease their resultant and vertical impact peaks and LR when switching to an FFS, but these changes may just be acute effects considering that hFF did not mirror these decreases, assuming both groups of competitive runners are similar. Therefore, switching to a mid- or FFS may not result in long-term decreased impact-related injury risk; in fact, given the additional shear impact forces at higher LR and reduced corresponding shear strength of bone, injury risk may increase. These findings should be substantiated by prospective studies of impact-related injuries in mid- or forefoot and rearfoot strikers and the internal bone loading environments associated with these foot strike styles.

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