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Invited review

Is changing footstrike pattern beneficial to runners?

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Abstract

Some researchers, running instructors, and coaches have suggested that the "optimal" footstrike pattern to improve performance and reduce running injuries is to land using a mid- or forefoot strike. Thus, it has been recommended that runners who use a rearfoot strike would benefit by changing their footstrike although there is little scientific evidence for suggesting such a change. The rearfoot strike is clearly more prevalent. The major reasons often given for changing to a mid- or forefoot strike are (1) it is more economical; (2) there is a reduction in the impact peak and loading rate of the vertical component of the ground reaction force; and (3) there is a reduction in the risk of a running-related injuries. In this paper, we critique these 3 suggestions and provide alternate explanations that may provide contradictory evidence for altering one's footstrike pattern. We have concluded, based on examining the research literature, that changing to a mid- or forefoot strike does not improve running economy, does not eliminate an impact at the foot-ground contact, and does not reduce the risk of running-related injuries.

Keywords: Epidemiology; Footfall patterns; Forefoot; Ground reaction force; Impacts; Midfoot; Rearfoot; Running economy

1. Introduction

There are 3 types of footstrike patterns that human runners can employ. These are generally referred to as (1) rearfoot, (2) midfoot, and (3) forefoot. Footstrike patterns are categorized depending on the portion of the foot that initially contacts the running surface. For example, when using a rearfoot strike, a runner will contact the ground with the lateral aspect of the heel eventually toeing off as in the other footstrikes. Here, we use operational definitions for mid- and forefoot striking. A midfoot strike is one in which the runner initially contacts the ground across the metatarsal heads with the heel subsequently contacting the running surface while the forefoot strike is also one in which the initial contact is also on the metatarsal heads but the heel never touches the ground.

A study by Lieberman and colleagues[1] reported that individuals who have never worn shoes used a forefoot strike whereas those who are habitually shod used a rearfoot strike when running. This finding has been recently disputed by Hatala and associates[2] who reported that 72% of habitually barefoot African runners ran with a rearfoot strike although these data were collected in a different region of Africa than the previous study. However, Lieberman's findings led to the notion that humans may have evolved to be forefoot runners thus the forefoot pattern was the more "natural" footstrike compared to a rearfoot strike.[1] Lieberman's suggestions have led to several papers in the literature on barefoot versus forefoot running, many of which appear to promote a mid- or forefoot strike (e.g., Ahn et al.[3] and Paavolainen et al.[4]). Extending the notion that mid- or forefoot running is optimal for barefoot running is the suggestion that mid- or forefoot running is also optimal for shod running. Many running coaches have then suggested that changing a runner's footfall pattern from an "unnatural" rearfoot strike to a "more natural" forefoot strike, whether unshod or shod, may be a propitious way to improve performance and possibly reduce running-related injuries.[5–7]

There are many programs such as Pose running[8,9] or Chi running[10] that have influenced numerous running coaches to instruct runners to alter their footstrike to an mid- or forefoot strike. While some papers in the literature have suggested such a change to a mid- or forefoot strike,[3,4,11–14] to our knowledge, currently little evidence exists in the literature that conclusively demonstrates that runners would benefit from altering their footstrike in the long term.

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It is possible that switching from one footstrike pattern to another has become popular because of reports of isolated anecdotes rather than examining the idea that switching footstrike pattern would benefit all runners. Findings from a survey study indicate that 46% of those that switched from a rearfoot to a mid- or forefoot strike (n = 397/866) changed their footstrike because of previous injuries and this group reported experiencing a total of 500 injuries before they switched.[12] However, the authors did not report any data on the number of injuries that occurred in these participants after they changed their footstrike. No doubt there are some runners who benefitted from altering their habitual footstrike, but which runners and for what reasons are currently unknown. Studies have suggested that some individuals accrue some benefits by changing to a mid- or forefoot strike.[11–14] However, to extend this notion to all runners may not be a prudent or beneficial recommendation.

There are 3 major reasons that those who support altering one's footstrike give for changing to a mid- or forefoot strike from a rearfoot strike. These are (1) it is more economical; (2) there is a reduction in the impact peak and loading rate of the vertical component of the ground reaction force (VGRF); and (3) there is a reduction in the risk of a running-related injury. In this paper, we will critique these "reasons for change" and discuss alternate explanations that may provide contradictory evidence for altering one's footstrike to a mid- or forefoot strike. We focus on differences between shod rearfoot and shod mid- or forefoot strike running to isolate the differences between footstrike patterns without the influence of footwear.

2. Footfall pattern frequency and selection

The prevalence of the different footstrike patterns in the running population and how footstrike has been determined in the literature is a very important aspect of understanding footstrike behavior. There are at least 2 methods of determining a runner's footstrike. Cavanagh and Lafortune[15] suggested a method of determining footstrike pattern based on the location of the center of pressure pattern at initial ground contact termed the strike index. With a rearfoot strike, the foot initially contacts the ground in the posterior 1/3 of the length of the foot. In a forefoot strike, initial contact is on the anterior 1/3 of the foot generally in the area of the metatarsal heads. A midfoot strike is the most difficult to determine as the strike index suggests that initial contact is in the middle 1/3 of the foot. Recently, a study by Gruber et al.[16] suggested that, in addition to the strike index, the position of the ankle joint at foot contact (i.e., dorsiflexed for the rearfoot strike and plantar flexed for the mid- or forefoot strikes) and the presence (rearfoot runner) or absence (forefoot runner) of an impact peak in the component VGRF should be used together as indicators of a footstrike, rather than 1 metric alone as seen in many studies. However, in this paper, we will combine the mid- and forefoot strikes into a mid- or forefoot strike because the initial contact in both is on the metatarsal heads of the forefoot.

Interestingly, the epidemiologic data on footstrike demographics show that the rearfoot strike is one that is used by the greatest percentage of runners while the forefoot strike is used by a significantly lesser number of runners. Kerr et al.[17] found that 81% of runners at the 10 km and 20 km point of a marathon used a rearfoot strike while 19% used a midfoot strike. In an elite half-marathon, Hasegawa et al.[18] reported that 75% of runners used a rearfoot strike, 23% a midfoot strike, and 2% a forefoot strike. More recently, Larson et al.[19] concurred with the results of both the Kerr et al.[17] and Hasegawa et al.[18] studies. The prevalence of rearfoot runners has also been reported to be as high as 94% of 1991 runners in a competitive road race[20] and 95% of 514 runners tested in a laboratory setting.[21] Each of these studies reports a very low percentage of runners using a true forefoot strike. It has been argued that the high prevalence of the rearfoot strike is a result of the modern cushioned running shoe facilitating a rearfoot strike;[22] however, this speculation has been recently refuted.[23]

Which footfall pattern an individual selects may depend on a number of factors. In a forward dynamics simulation modeling study, it was reported that the rearfoot strike was optimal for the greatest number of goals of running, which include minimizing metabolic cost.[24] However, the model selected a more anterior footstrike (i.e., mid- or forefoot) to optimize for higher running speeds but at a greater metabolic cost. This result is supported by a human study for which increasing running speed resulted in 45% of runners switching to a more anterior footstrike.[25] Thus, it appears that the choice of footstrike may be task-specific. Running a long distance may require a rearfoot strike to minimize the metabolic cost of running while a more anterior footstrike may be necessary to run faster.

3. Changes in the economy of running

Several studies have observed that the top finishers of short, middle, and long distance events tended to use a mid- or forefoot strike.[17,18,21] Similar findings from earlier studies speculated that a mid- or forefoot strike increases the effective storage and release of elastic energy compared with a rearfoot strike and has led some to suggest that it is more economical (i.e., consume less submaximal oxygen for a given task) to run with either a mid- or forefoot pattern.[17,18,26–29] However, several studies, each with a small sample size and thus low statistical power, directly compared running economy between rear- and forefoot strike and reported no statistically significant differences in intra-subject oxygen consumption between these footstrike patterns.[29–31]

Ardigo and colleagues[30] reported no difference in oxygen uptake or internal mechanical work between a group of habitual rearfoot runners using both a rear- and forefoot strike pattern. These results were supported by later studies also showing no difference in running economy between rear- and forefoot strike patterns.[29,31] However, these studies were limited by low sample sizes and used only habitual rearfoot runners[31] or only habitual midfoot runners.[29] Recent studies have reported that there was little or no difference in the net mass normalized oxygen consumption or the net metabolic rate between mid- or forefoot runners versus rearfoot runners performing with their habitual footstrike pattern across submaximal running speeds (Fig. 1).[32,33]

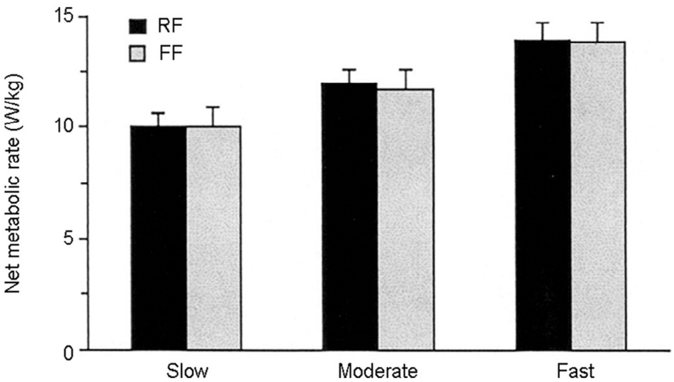

Fig. 1. The net metabolic rate of rearfoot (RF) and forefoot (FF) runners running with their habitual footfall pattern at 3 different speeds. There was no statistically significant difference between conditions ($p > 0.05$). Adapted with permission.[32]

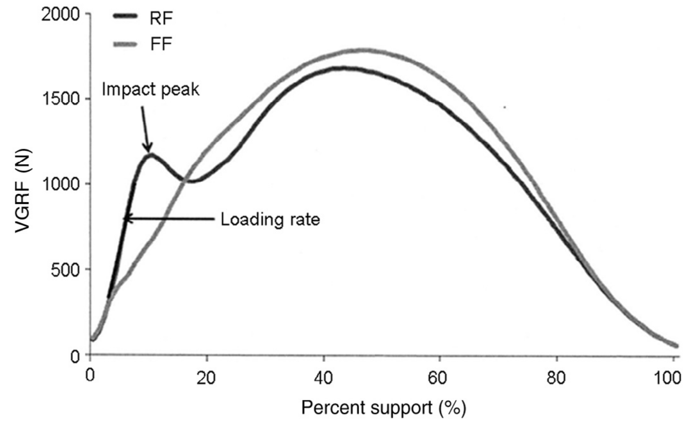

Fig. 2. An exemplar vertical ground reaction force (VGRF) component versus time for a runner with a rearfoot (RF) footfall pattern and a runner with a forefoot (FF) footfall pattern.

Gruber et al.[32] investigated running economy when rear- and forefoot runners were asked to run with the alternative footstrikes. When the participants were asked to run with their non-habitual footstrike, the habitual rearfoot group experienced a significant increase in oxygen consumption but there were no statistically significant changes in oxygen consumption in the habitual forefoot group. Given that performing a new running form or style typically increases oxygen consumption before habituation,[34,35] it would be expected that participants would perform better with their habitual pattern. Although this expectation was true for the rearfoot group, this was not the case with the forefoot group. Alternatively, a new running form or style is considered more economical if it results in a reduction of oxygen consumption without a habituation period.[36] The results from Gruber et al.[32] indicated that habituation was not necessary in order for the forefoot group to have a similar running economy between footstrikes across the 3 tested speeds. In the rearfoot group, performing a forefoot strike increased oxygen consumption to a large enough degree that habituation would not eventually result in forefoot running becoming more economical. Therefore, the assumption that rearfoot runners would improve their performance by changing their footstrike, either immediately or after training, appear unfounded.

A further analysis of the data in the Gruber et al.[32] study included an investigation of carbohydrate oxidation between footfall patterns. Carbohydrate oxidation is a limiting factor for endurance exercise.[32] At the slow and moderate speeds of running selected in the Gruber study, carbohydrate oxidation was greater in a forefoot foot strike than in a rearfoot strike. The implication here is that a forefoot strike would deplete their carbohydrate stores sooner compared to a rearfoot strike at the same running speed. Therefore, switching from a mid- or forefoot strike to a rearfoot strike may also be a mechanism to conserve glycogen stores and delay when a runner would "hit the wall" during an endurance race.[36] This assumption is somewhat supported by Jewell and colleagues[37] who found that habitual mid- and forefoot runners tended to adopt a more posterior landing pattern, which was characterized by longer contact times and the visual appearance of an impact peak within the VGRF during the progression of a fatiguing run.

4. Changes in the VGRF impact peak

In a plot of the VGRF versus time for a rearfoot strike, there is a distinct first peak referred to as the impact peak and, later in the ground contact phase, a second peak referred to as the active peak. In the mid- or forefoot strike, there may not be a visible impact peak in the VGRF plotted across stance time but there will be an active peak (Fig. 2).

Running with a mid- or forefoot strike substantially diminishes the appearance of the vertical impact peak or causes it to be visually absent. This observation has led many to speculate that changing one's footstrike to a mid- or forefoot strike would significantly reduce the vertical impact peak and the vertical rate of loading during a ground contact compared to the rearfoot strike.[38–41] Furthermore, the implication is that, because of the absence of the impact peak and the lesser loading rate, there would be a lower risk of impact related injuries to the lower extremity.[1,11,42,43]

Vertical impact peaks are not conspicuous in the VRGF versus time plots of runners with a mid- or forefoot strike. Recent studies have found evidence of the vertical impact force in mid- or forefoot running although it was visually absent in the time-domain plots. In a study by Gruber et al.[44] the VGRF was analyzed in the frequency domain using a Fourier analysis. It was reported that frequencies in the 10–20 Hz range (i.e., the range of frequencies of the impact peak in rearfoot running[44]) were observed in forefoot strike runners although the amplitude of these frequencies was less than rearfoot runners (Fig. 3). While there is no obvious impact peak seen in the time domain, it appears that there is an impact in forefoot running although it may occur with a lower magnitude and loading rate than that in rearfoot running.[44]

Then the question that arises is why the vertical impact is not visually obvious in the time domain. This question can be answered by referring to Bobbert et al.[45,46] and Shorten and Mientjes.[47] These researchers showed that the impact peak in rearfoot running was determined by the force of the lower extremity of the landing limb colliding with the ground while the active force is a result of the motion of the rest of the body.

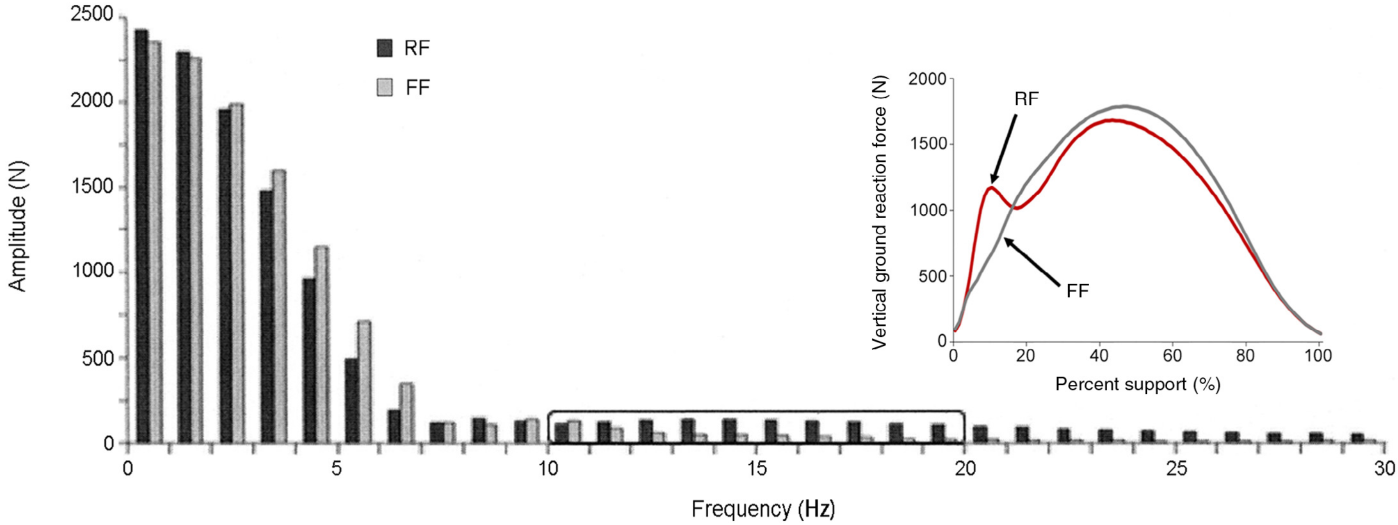

Fig. 3. An exemplar amplitude versus frequency plot showing frequencies in the 10–20 Hz range for both rearfoot (RF) and forefoot (FF) footfall patterns.

This lower extremity impact force (i.e., passive peak) is superimposed on the active force of the rest of the body as it contacts the ground, which results in the typical VGRF that we often see. This is illustrated in the schematic in Fig. 4. In this figure, for a rearfoot strike, we see that there are 2 different portions of the VGRF component, which represent limb contact and the contact of the rest of the body, that are ultimately added together to produce the total VGRF component that we usually see. The impact and active forces are also superimposed in a forefoot strike; however, the timing of the peak deceleration of the contacting limb may occur much later in the support phase and thus is "hidden" by the active force of the rest of the body. Gruber and colleagues[48] illustrated the impact and passive peaks in both rearfoot and forefoot strikes using a wavelet analysis. In their analysis, it is clear that an impact peak exists in both rearfoot and forefoot strikes but the impact peak in forefoot running is of lesser magnitude and occurs later in the support period (Fig. 5).

Furthermore, we must ask whether the visual appearance or the reduction of the vertical impact peak is a reason to change footstrike pattern. The influence of the impact peak and loading rate on the risk of running injury development has been a source of debate and discussion in biomechanics for many years. Reducing impact forces and the rate at which they are imposed has been suggested to reduce the risk of impact related injuries. However, the relationship between impact characteristics and injuries has not been established conclusively. There are similar number of retrospective studies[49–52] and prospective studies[53–55] that have found an association with impact characteristics and injury. However, there are other studies that found no relationship between impact characteristics and injury either retrospectively[56–59] or prospectively.[60–64] Studies by several researchers have reported a link between a higher vertical impact peak or vertical loading rate or both resulting in an impact running-related injury.[49–55] However, other researchers have shown little or no relationship between VGRF parameters

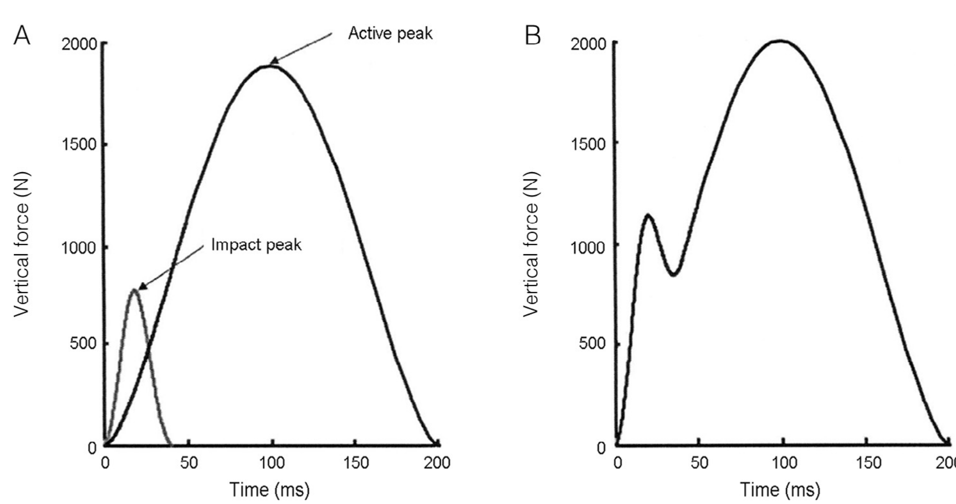

Fig. 4. A schematic of a decomposed vertical ground reaction force component of a rearfoot footfall pattern (A) and the sum of the 2 components (B).

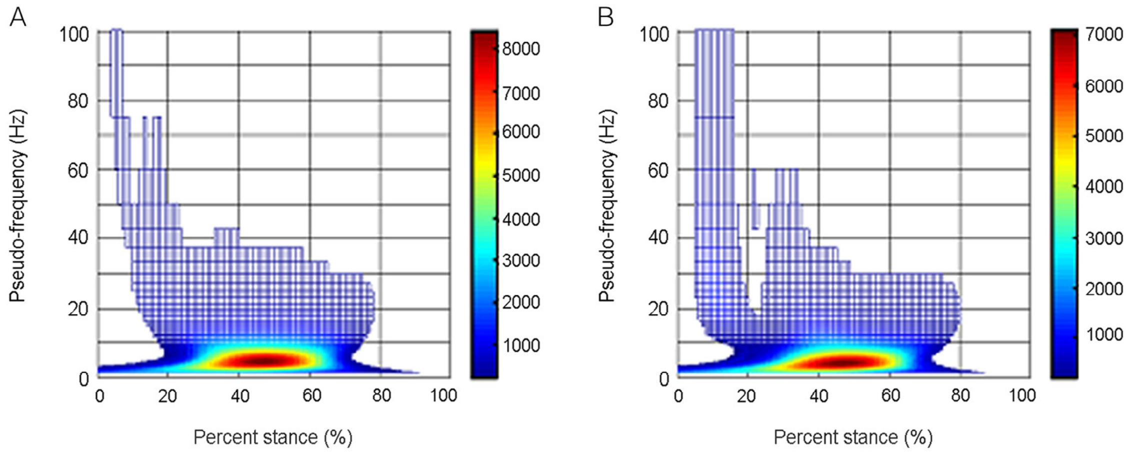

Fig. 5. Continuous wavelet transform of the resultant ground reaction force generated during rearfoot running (A) and forefoot running (B). The results indicate both footstrike patterns generate signal frequencies representative of the force of impact (i.e., 10–20 Hz). Values are wavelet coefficient magnitudes indicated by color intensity. Results are plotted across the stance phase for pseudo-frequencies 0–100 Hz (top row). 101 × 63 mm (72 × 72 dpi). Adapted with permission.[48]

and the risk of injury.[56–64] It is quite apparent that some level of force application is necessary for bone health.[65] However, it is unknown how much loading is necessary for bone health versus how much is detrimental to bone health. For example, some studies have reported that greater impact magnitudes and loading rates were observed in samples that had fewer running injuries than those with reduced impact characteristics. Nigg[66] reported that runners with greater impact peaks and higher loading rates had significantly fewer running-related injuries compared with runners with lower impact peaks and loading rates. Van Mechelen[67] found that running on firmer surfaces, which would theoretically increase the impact load on the body, was not associated with the incidence of injury. The argument, therefore, that reducing the impact peak and loading rate is questionable at best in terms of running-related injuries.

The fact that there is a force resulting from the foot-ground collision not only in a rearfoot strike, but in the mid- or forefoot strikes as well, and that relationship between these kinetic parameters and injury is tenuous at best, are both evidence that the appearance or non-appearance of an impact peak in the time domain is not sufficient for changing one's footstrike. Additionally, prospective running injury studies have yet to demonstrate whether one footstrike is less injurious than the other. Using the VGRF to infer that forefoot running is "safer" than rearfoot running is not supported by evidence.

Many other parameters, such as spatio-temoral variables and sagittal and frontal plane kinematics,[68] apart from VGRF characteristics, have been compared between footstrikes that may be related to the development of running-related overuse injuries. For example, Boyer and Derrick[69] examined the differences in several factors that may contribute to the development of iliotibial band strain between habitual rearfoot and habitual mid- and forefoot runners including step width, pelvic drop, hip adduction angle, and iliotibial band strain among other variables. Although some variables were statistically different between footstrikes—with some differences indicating rearfoot to be "better" and others indicating forefoot to be "better"—the authors concluded that the magnitude of the differences were small enough to suggest that one footstrike does not appear to be universally more protective against running-related injuries than the other.[69] Other investigators have also observed that a rearfoot strike may be better for one parameter but a forefoot strike may be better for another parameter. In particular, there may be a shift to a greater demand on knee structures and musculature than the ankle with rearfoot running but a greater demand on ankle and foot structures and musculature than the knee with forefoot running.[14,70–73] For example, Kulmala and colleagues[14] found that forefoot runners had less patellofemoral stress than rearfoot runners but that rearfoot runners had lower plantar flexor muscle and Achilles tendon loading than forefoot runners. Similarly, Rooney and Derrick[74] found that a forefoot strike resulted in greater axial ankle joint contact force compared with a rearfoot strike. Collectively, this evidence suggests that switching from one footstrike to another may result in exposure to different types of injury mechanisms rather than one footstrike being more or less injurious than the other.[75,76]

5. Changes in the risk of running-related injuries

Most studies that have investigated injury rates between footstrike patterns have examined the rate of injury in either habitual rearfoot or habitual mid- or forefoot strikers. While this is important, it does not give us any insight as to the injury rate when runners change their footstrike either from rearfoot to forefoot or from forefoot to rearfoot. Prospectively measuring injury rates in those that have switched their footstrike is the only definitive way to determine if one footstrike is more protective against injury than the other.

Until recently, the inconclusive and speculative links between impact characteristics and running injury risk were the only evidence to support that mid- or forefoot strikers may be beneficial for preventing injury. The author of a previous review paper found little to no evidence to support that alternative running styles (i.e., a forefoot strike) such as from shod using a rearfoot strike were beneficial.[76] To our knowledge, Daoud et al.[42] published the first cohort study that suggested that the occurrence of injuries was reduced in those that habitually used a mid- or forefoot strike compared to a rearfoot strike. Their study reported a statistically greater incidence of running injuries per 10,000 miles of running using a rearfoot strike compared with a mid- or forefoot strike when the data were combined across sex and level of injury severity or both. When the data were separated by sex and injury severity type, the only statistically significant difference was observed between female mid- or forefoot runners ($n = 5$) and the female rearfoot runners ($n = 18$). Although this study was an informative first look at the rate of injury between footfall patterns, it was retrospective in design, used a very specific sample of runners (i.e., Division 1 Cross Country Collegiate Athletes) and had a relatively small sample size.[42]

To conclusively assess the risk of incurring an injury, prospective, epidemiologic studies with a large sample size must be conducted in those who have switched footstrike patterns. Unfortunately, such studies are not prominent in the running injury literature to date. To conduct a large prospective study, a large number of participants who utilized different footfall patterns need to be followed over a significant period of time. During the time that they are followed, the participants should maintain their usual training schedule and report on any injury that is sustained. In 3 relatively large-scale epidemiologic studies, investigators reported the injury risk on samples of 471[76] and 1203[77] runners and a sample of 341 male U.S. army soldiers.[78] The results in these studies were similar. Neither study reported statistically significant differences in the injury rates between habitual rearfoot and mid- or forefoot strikers. The 2 epidemiologic studies of Kleindienst[76] and Walther[77] reported a difference in the injury site and the type of injury incurred between footstrike pattern groups. In those 2 studies, the most prevalent injuries that were incurred were midfoot dorsal pain, metatarsal stress fractures, Achilles tendinitis, and post tibial tendinitis. In another study, Warr et al.[79] did not find a difference in injury rates, running mileage, or 2-mile run time between footstrike groups, indicating no performance or injury prevention benefits for either footstrike pattern.

More prospective randomized control trials investigating the risk of injury in both forefoot and rearfoot running are needed. The question of whether mid- or forefoot striking reduces running-related injuries compared with rearfoot running cannot be answered completely without such studies. The current claim that runners running using a mid- or forefoot strike have fewer running-related injuries than those running with a rearfoot strike is speculation at best and so far is unsupported by prospective epidemiologic studies.

6. Conclusion

Research conducted on the efficacy of changing one's footstrike from a rearfoot to a mid- or forefoot strike suggests that there is no obvious benefit to such a change for the majority of runners. In fact, it may be that the change in footstrike may result in stressing tissue that is not normally stressed when running with one's habitual pattern, thus leading to the possibility of incurring a secondary injury. Changing one's footstrike to a mid- or forefoot strike may be beneficial to some but, based on the current biomechanical, physiological, and epidemiologic literature, it should not recommended for the majority of runners, particularly those who are recreational runners.

In summary, there are 3 key points: (1) the scientific basis for encouraging runners to change their footstrike pattern is not warranted; (2) there is little conclusive scientific evidence that a mid- or forefoot strike improves running economy, eliminates a vertical impact force at the foot-ground contact, or reduces the risk of running-related injuries; and (3) there is a need for large, prospective randomized control trials investigating the risk of injury in both forefoot and rearfoot running.

Authors' contributions

The two authors contributed equally to the manuscript. The authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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