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# Is the rearfoot pattern the most frequently foot strike pattern among recreational shod distance runners?

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ABSTRACT

*Objective:* To determine the distribution of the foot strike patterns among recreational shod runners and to compare the personal and training characteristics between runners with different foot strike patterns.
*Design:* Cross-sectional study.
*Setting:* Areas of running practice in São Paulo, Brazil.
*Participants:* 514 recreational shod runners older than 18 years and free of injury.
*Outcomes measures:* Foot strike patterns were evaluated with a high-speed camera (250 Hz) and photocells to assess the running speed of participants. Personal and training characteristics were collected through a questionnaire.
*Results:* The inter-rater reliability of the visual foot strike pattern classification method was 96.7% and intra-rater reliability was 98.9%. 95.1% ($n = 489$) of the participants were rearfoot strikers, 4.1% ($n = 21$) were midfoot strikers, and four runners (0.8%) were forefoot strikers. There were no significant differences between strike patterns for personal and training characteristics.
*Conclusion:* This is the first study to demonstrate that almost all recreational shod runners were rearfoot strikers. The visual method of evaluation seems to be a reliable and feasible option to classify foot strike pattern.



## 1. Introduction

Foot strike patterns during running have been the subject of investigation for the past three decades (Cavanagh & Lafortune, 1980; Kerr, Beauchamp, Fikhkr, & Neil, 1983); however comparisons between studies are difficult because different classification criteria exist (Lieberman, 2012). Conventionally, foot strike patterns are defined by the part of the foot that first contacts the running surface and this is typically divided into three categories: (1) rearfoot strike, when the runner lands with the heel; (2) midfoot strike, when the runner simultaneously lands with the heel and ball of the foot; and (3) forefoot strike, when the ball of the foot lands first (Fellin, Rose, Royer, & Davis, 2010; Lieberman et al., 2010).

Several factors can influence the adoption of foot strike patterns during running. The use of running shoes with cushioning on the posterior portion of the shoe may induce a rearfoot pattern (Lieberman et al., 2010; Squadrone & Gallozzi, 2009), while running speed and instructions from coaching staff could also influence the pattern adopted by runners (Giandolini et al., 2013; Nilsson & Thorstensson, 1989).

The adoption of certain foot strike strategies has received special attention because how the foot lands during running can lead to different kinematic and kinetic characteristics of the lower extremities (Goss & Gross, 2012b). The rearfoot pattern is characterized by a rapid, high impact peak in the ground reaction force after the initial contact with the ground (Cavanagh & Lafortune, 1980; Laughton, McClay Davis, & Hamill, 2003; Lieberman et al., 2010), generating high vertical loading rates (Arendse, Noakes, Azevedo, Romanov, Schwellnus, & Fletcher, 2004; Shih, Lin, & Shiang, 2013; Williams, McClay, & Manal, 2000). On the other hand, forefoot and midfoot patterns do not demonstrate a marked impact peak, and the vertical forces are transmitted to the lower extremities in a more spread out way, attenuating the overload that occurs when the foot collides with the ground through eccentric control of the triceps surae (Cavanagh & Lafortune, 1980; Lieberman et al., 2010).

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It is believed that high vertical loading rates transmitted to the lower limbs during running may contribute to the high incidence of specifically running-related injuries (Pohl, Hamill, & Davis, 2009; Zadpoor & Nikooyan, 2011). Because of that, rearfoot strikers may be more susceptible to injuries characterized by overloads in the lower extremities, such as tibial stress fractures, plantar fasciitis, and anterior knee pain (Davis, Bowser, & Mullineaux, 2010; Pohl et al., 2009; Zadpoor & Nikooyan, 2011). In contrast, forefoot strikers, due to the increased eccentric activity of the triceps surae and high demand at the foot and ankle (Williams, Green, & Wurzinger, 2012; Williams et al., 2000), may be more at risk of developing Achilles tendinopathy and calf muscle injuries. Unfortunately, investigation of injury rates comparison between foot strike patterns is scarce in the literature. Only two retrospective studies examined and found significantly higher rates of injury in rearfoot strikers (Daoud, Geissler, Wang, Saretsky, Daoud, & Lieberman, 2012; Goss & Gross, 2012a).

Some studies (Hasegawa, Yamauchi, & Kraemer, 2007; Kerr et al., 1983; Larson et al., 2011) evaluated the distribution of the foot strike patterns among shod runners at different levels (elite, sub-elite and recreational) and found that the rearfoot pattern is the most common. However, important differences in the distribution of patterns were found, principally when elite runners are compared with recreational runners, suggesting that runners at different levels may demonstrate different foot strike patterns. Furthermore, all these studies were conducted during a competitive race setting and foot strike patterns were determined through the analysis of only a single stride. These factors may limit their findings of foot strike pattern distribution only to the conditions cited above. The previous studies (Hasegawa et al., 2007; Kerr et al., 1983; Larson et al., 2011) also did not account for running speed during data acquisition or other personal characteristics that may influence strike patterns.

While the available literature highlights the possible effects of running pattern on injury risk, the knowledge of foot strike pattern distribution among recreational runners is an important first step for clinicians and researchers that deal with running injuries. Therefore, the main objective of this study was to determine the distribution of the foot strike patterns among recreational shod runners not in race conditions. We also aimed to compare the personal and training characteristics between runners with different foot strike patterns.

## 2. Methods

A convenience sample of 514 runners was used in this cross-sectional study. The participants were recruited in areas of high runner traffic (such as public parks) in São Paulo, Brazil. Participants were eligible for inclusion if they were recreational runners at least 18 years old and free of musculoskeletal injury at the time of data acquisition. Participants were evaluated in shod conditions (conventional running shoes).

### 2.1. Data collection

The 514 shod runners completed a questionnaire that contained demographic information (gender, age, weight and height) and running routine (predominant type of surface, special insoles, weekly distance, coach instruction and years of experience). Participants were also asked to identify any previous musculoskeletal injuries related to running in the last 12 months. The injury definition adopted was: “any musculoskeletal running related injury that was severe enough to prevent running practice during the last 12 months”.

Hereafter, the participants were instructed to run two 25 m laps on the track and run back to the start. A high-speed digital camera (Casio EXFX1) recording at a frequency of 250 Hz was located perpendicular to the runway at 12.5 m from the starting point. The camera was positioned on a tripod 15 cm above the floor and 2 m away from the runway (Fig. 1). The participants were instructed to run at a comfortable speed that was measured by a photocell timing mode (TC-Timing System). All data acquisition was done by three researchers.

### 2.2. Image analysis

The videos with foot strike images were captured and subsequently analyzed visually in a subjective way using a video analysis program (Kinovea™ 0.8.15). Each video was evaluated independently by two observers. In instances where there was disagreement among the observers, a third one was used. The foot strike pattern for each participant was analyzed from the lateral view of the foot and evaluated four times; two times on each foot. When the same runner demonstrated different patterns, the most frequently chosen pattern was used in the analysis. Foot strike patterns were classified in three categories (Lieberman et al., 2010): (1) rearfoot, when the heel is the first region to contact the ground (Fig. 2a); (2) midfoot, when the heel and ball of the foot simultaneously contact the ground (Fig. 2b); and (3) forefoot, when the ball of the foot contacts the ground prior to the heel (Fig. 2c).

### 2.3. Statistical analysis

Descriptive analyses were used to evaluate the relationship between foot strike patterns and the participants' characteristics. Normality of continuous data (age, weight, body mass index, weekly distance, years of practice, average speed and $H_{shoes}$) was evaluated using curve symmetry analysis. Data with normal distribution were described in mean and standard deviation. Median and interquartile ranges were used for non-normally distributed data.

A Kruskal–Wallis test was conducted to compare the personal and training characteristics among rearfoot, midfoot and forefoot patterns. For all analyses, $p < 0.05$ was assumed to be statistically significant. Intra and inter-rater reliabilities of the evaluation of the foot strike pattern from participants were evaluated using the agreement percentage. All analyses were performed in SPSS 17.0.

### 2.4. Sample size

The sample size of this study was estimated based on a pilot study (Uribe, Almeida, Hespanhol Junior, & Lopes, in press) that

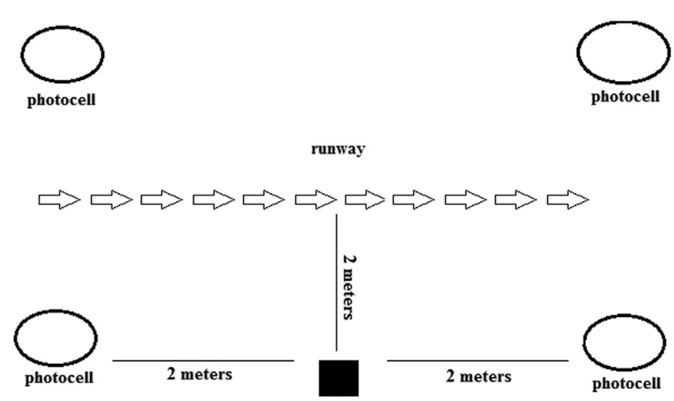


**Fig. 1.** Schematic representation of the area for image acquisition.


**Fig. 2.** Foot strike patterns during running (2a – Rearfoot pattern; 2b – Midfoot pattern; 2c – Forefoot pattern).

determined that 95% of participants would be rearfoot strikers. Statistical precision was assumed to be 2.5% with a significance level of 0.01, which revealed a need for 506 runners. In this study, 514 runners were included to account for potential withdrawal or technical problems with data collection and video analysis.

## 3. Results

Our sample was comprised of mostly males (68.9%, $n = 354$), with a mean age of 41.7 (SD = 12.2) years and a weekly running distance of 24.8 km (SD = 20.7). The average speed from our sample during data collection was 12.2 km/h (SD = 2.4). All the runners' characteristics are detailed in Table 1.

The inter-rater reliability of the visual foot strike pattern evaluation method was 96.7%, while the intra-rater reliability was 98.9%. None of the participants demonstrated an equal number of patterns (e.g., rearfoot twice and midfoot twice). 489 (95.1%) of the runners were rearfoot strikers, 21 (4.1%) were midfoot strikers, and only four runners (0.8%) were forefoot strikers (Table 2). The rate of the midfoot pattern was higher in male runners (5.1%, $n = 18$) than in female runners (1.9%, $n = 3$). There was no significant difference for the average speed when the characteristics between foot strike patterns were compared. The average speed was 12.2 km/h (SD = 2.3) in rearfoot strikers, 12.9 km/h (SD = 3.3) in midfoot strikers and 12.9 km/h (SD = 8.8) in forefoot strikers. There were no statistical differences among the three patterns for the other personal and training characteristics (Table 3).

## 4. Discussion

This is the first study to evaluate foot strike patterns among recreational shod runners not in race conditions. We found that nearly all of these recreational runners used a rearfoot pattern (95.1%) and only four runners (0.8%) were forefoot strikers. There were more male midfoot strikers compared with female runners. No significant differences were noted between rearfoot, midfoot and forefoot patterns for personal and training characteristics.

In this study, we found a greater number of rearfoot strikers compared to previous studies. Larson et al. (2011), Kerr et al. (1983) and Hasegawa et al. (2007) found, respectively, that 88%, 80% and 75% of their participants were rearfoot strikers. These differences may be attributed to the subject sample and lower self-selected running speed. While we evaluated recreational runners who ran at an average of 12.2 km/h, Hasegawa et al. (2007) evaluated elite marathoners who ran between 17.7 and 19.6 km/h. Similarly, Kerr et al. (1983) used a sample of competitive runners who ran between 12.4 and 19.9 km/h. In the study by Larson et al. (2011), participants ran at a slower average pace of 11 km/h, which may explain the higher rate of rearfoot strikers. This was similar to our findings. The higher percentage of rearfoot strikers in our study and in Larson et al. (2011) confirms that runners at different levels use different foot strike patterns.

It is also possible that different methodologies of image acquisition contributed to a lower incidence of rearfoot strikers in the previous studies. It has been shown that the accuracy of foot strike classification is directly related to the image acquisition frequency (Fellin et al., 2010). Previous studies that used video acquisition to determine strike pattern used cameras with video capture rates of 60 Hz (Kerr et al., 1983) and 120 Hz (Hasegawa et al., 2007). When image acquisition frequency is low, the exact moment of initial foot contact may not be discernible. Thus, the foot strike pattern may be erroneously classified; in particular, those who may have been rearfoot strikers may be identified as midfoot strikers. The method used to classify foot strike pattern in this study demonstrated an inter-rater reliability and intra-rater reliability of 96.7% and 98.9%, respectively. So, it is possible to conclude that the subjective visual method of foot strike pattern classification is a reliable method, besides being a cheap and feasible way in comparison to methods used in other studies (Altman & Davis, 2012).

There was a higher percentage of female rearfoot strikers runners compared to male runners. Similarly, there was a higher percentage of male midfoot strikers than female midfoot strikers, which is consistent with the results from Hasegawa et al. (2007). Despite this difference in foot strike patterns between genders,

**Table 1**
Characteristics of the recreational runners included in the study.

| | | | |
|---|---|---|---|
| Gender | | Insoles | |
| Male | 68.9% (354) | Yes | 14% (72) |
| Female | 31.1% (160) | No | 86% (442) |
| Age (years) | 41.7 (12.2) | Coach instruction | |
| Weigth (kg) | 71.6 (12.7) | Yes | 47.1% (242) |
| Heigth (m) | 1.71 (0.09) | No | 52.9% (272) |
| BMI (kg/cm$^2$) | 24.4 (3.0) | Surface | |
| Average Speed (km/h) | 12.2 (2.4) | Hard | 83.3% (428) |
| Km/week | 24.8 (20.7) | Sand | 6.4% (33) |
| Time of practice (years)* | 5 (9) | Grass | 0.6% (3) |
| Previous injury | | Treadmill | 9.7% (50) |
| Yes | 33.1% (170) | | |
| No | 66.9% (344) | | |

Continuous data with normal distribution are expressed in mean and standard deviation. Continuous data with non-normal distribution are expressed in median and interquartile range (Time of practice*). Categorical data are expressed in percentage and number of runners.

**Table 2**
Foot strike patterns of recreational runners.

| | Total $n = 514$ | Males $n = 354$ | Females $n = 160$ |
|---|---|---|---|
| Rearfoot | 95.1 (489) | 94.1 (333) | 97.5 (156) |
| Midfoot | 4.1 (21) | 5.1 (18) | 1.9 (3) |
| Forefoot | 0.8 (4) | 0.8 (3) | 0.6 (1) |

All data were expressed in percentage and numbers of runners.

**Table 3**
Comparison of the recreational runners' characteristics between foot strike patterns.

| | Rearfoot $n = 489$ | Midfoot $n = 21$ | Forefoot $n = 4$ | *p* |
|---|---|---|---|---|
| Gender | | | | 0.22 |
| Male | 68.1% (333) | 85.6% (18) | 75% (3) | |
| Female | 31.9% (156) | 14.4% (3) | 25% (1) | |
| Age (years) | 41.7 (12) | 40.9 (14.9) | 39.5 (48)[a] | 0.90 |
| Weigth (kg) | 71.6 (12.7) | 73.4 (13.9) | 63.5 (17.1)[a] | 0.32 |
| Heigth (m) | 1.70 (0.1) | 1.74 (0.1) | 1.70 (0.1)[a] | 0.26 |
| BMI (Kg/cm$^2$) | 24.4 (2.3) | 24 (3) | 21.4 (3.5)[a] | 0.10 |
| Average speed (km/h) | 12.2 (2.3) | 12.9 (3.3) | 12.9 (8.8)[a] | 0.52 |
| Distance (km/week) | 24.4 (20.7) | 28.4 (17.9) | 37.5 (66)[a] | 0.09 |
| Experience (years)[a] | 5 (9) | 5 (9) | 15 (36) | 0.26 |
| Previous injury | | | | 0.70 |
| Yes | 33.1% (162) | 28.6% (6) | 50% (2) | |
| No | 66.9% (327) | 71.4% (15) | 50% (2) | |
| Insoles | | | | 0.06 |
| Yes | 14.3% (70) | 0% (0) | 50% (2) | |
| No | 85.7% (419) | 100% (21) | 50% (2) | |
| Coach instruction | | | | 0.33 |
| Yes | 46.4% (227) | 57.1% (12) | 75% (3) | |
| No | 53.6% (262) | 42.9% (9) | 25% (1) | |
| Surface | | | | 0.90 |
| Hard | 83.2% (407) | 85.6% (18) | 75% (3) | |
| Sand | 6.3% (31) | 4.8% (1) | 25% (1) | |
| Grass | 0.4% (2) | 4.8% (1) | 0% (0) | |
| Treadmill | 10% (49) | 4.8% (1) | 0% (0) | |

Continuous data with normal distribution are expressed in mean and standard deviation.
Categorical data are expressed in percentage and number of runners.
[a] Continuous data with non-normal distribution are expressed in median and interquartile range.

researchers who evaluated biomechanical variables found no significant differences between genders for kinematic variables at the ankle, foot joint or the knee joint during the foot's initial contact during running (Chumanov, Wall-Scheffler, & Heiderscheit, 2008; Ferber, Davis, & Williams, 2003). However, the influence of foot strike pattern was not specifically evaluated in those previous studies.

Interestingly, we found no significant differences in personal or training characteristics among the different foot strike patterns. Despite the low number of runners with midfoot and forefoot patterns that limited the comparative analyses, we expected to find significant differences between patterns, in particular, related to running speed and previous injuries. We believed that speed would be slower in rearfoot strikers as compared to midfoot and forefoot runners, as found in previous studies (Hasegawa et al., 2007; Kerr et al., 1983), but the difference was not significant. We think a threshold of speed may exist to differentiate rearfoot strikers who are normally slower than midfoot and forefoot runners.

Regarding previous injuries, 33% of the participants reported previous injuries in the last 12 months, but the difference was also not significant among the different foot strike patterns. Although the possible effects of foot strike patterns on injury development has been not established in the literature, this rate of previous injury may be attributed to the fact that almost all of the participants in our study were rearfoot strikers. Because a rearfoot pattern is characterized by increased vertical loading rates, as compared to forefoot and midfoot patterns (Arendse et al., 2004; Shih et al., 2013; Williams et al., 2000), rearfoot strikers may be more susceptible to developing running injuries that are commonly related to overuse in the lower extremities (Hreljac, 2005).

Despite a large sample size and high frequency of image acquisition, this study does have some limitations. Firstly, despite the subjective visual method of foot strike pattern classification being a reliable and feasible method, it has limited ability to accurately classify runners with the midfoot pattern (Altman & Davis, 2012). Maybe the use of automatic foot strike detection algorithms could be an alternative method to avoid bias on foot strike classification (De Witt, 2010; Hreljac & Marshall, 2000). Secondly, the time at which runners participated in this study was not standardized and thus occurred either before or after a recreational run. It is possible that fatigue may have affected the running pattern in these individuals, although the effect of fatigue on strike pattern preference has not been evaluated. Thirdly, we did not ask the participants about the length of time that they had been free of injury. We also did not attempt to measure the typical training pace of the participants which would have allowed us to confirm if the speed collected during data acquisition was truly representative of the participants' typical pace.

Another limitation of this study was that we did not evaluate the stride length and step frequency of participants, although there is no consensus in the literature as to whether there are significant differences among the different foot strike patterns regarding these aspects (Ardigo, Lafortuna, Minetti, Mognoni, & Saibene, 1995; Arendse et al., 2004; Squadrone & Gallozzi, 2009). Lastly, our study lacks additional comparative analysis between foot strike patterns due to the low number of runners from the midfoot and forefoot groups, preventing any inference from such analysis.

The results of the present study are important because they demonstrated for the first time that the great majority of recreational shod runners, when evaluated not in race conditions, are rearfoot strikers. The knowledge that the rearfoot pattern, the most common, is important for clinicians who that should be aware about the biomechanical characteristics of this pattern and its implications on running practice. Future studies should elucidate the possible relationship between foot strike pattern and injuries in recreational runners through studies with longitudinal design.

## Conclusions

This is the first study done not in race conditions to show that almost all recreational runners are rearfoot strikers. There were no significant differences in personal or training characteristics between the three foot strike patterns. The visual method of evaluation seems to be a reliable and feasible option to classify foot strike pattern.

*Conflict of Interest*

None declared.

*Ethical Approval*

This study was approved in April 2011 by the Ethics Committee of the University of the City of São Paulo.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ptsp.2014.02.005

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