Footstrike evaluation in male runners: A comparison of lateral and medial video views against traditional motion capture

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Word count: 1,949

Abstract

Footstrike evaluation is essential for understanding running biomechanics and is often performed in research and clinical settings using 2D video analysis. However, whether it is appropriate to analyse both right-left footstrike patterns from a single sagittal plane video is unclear. This study compared medial and lateral video views in assessing footstrike pattern and footstrike angle, using a motion capture system as the gold standard. We analyzed 4,800 footfalls from 20 healthy recreational runners during self-paced treadmill running, recruited through convenient sampling. Footstrike angle agreement was evaluated using Bland-Altman analysis, intraclass correlation coefficients (ICC), and root mean square error (RMSE). The mean difference in footstrike angle between the gold standard and lateral view was 0.40° (95% limits of agreement: 6.05° to -5.25°), while the medial view showed a mean difference of -1.31° (95% limits: 8.37° to -10.99°). ICC values indicated excellent agreement for both lateral (0.979) and medial (0.940) views to the gold standard. RMSE was lower for the lateral (2.91°) than medial (5.11°) view, suggesting greater precision. Footstrike pattern classification was assessed using Cohen's kappa, revealing substantial agreement for the lateral view ($\kappa=0.785$, $p<0.001$) and good agreement for the medial view ($\kappa=0.606$, $p<0.001$). These results indicate that while both views demonstrate strong agreement, the lateral view aligns more closely with the gold standard in continuous and categorical assessments. Our findings suggest lateral video analysis may be preferable for footstrike evaluation in applied and clinical settings.

Keywords: Gait; Kinematics; Validation; Landing pattern

1. Introduction

Footstrike pattern (FSP) in running has been extensively investigated (Anderson et al., 2020; Burke et al., 2021). Traditionally, FSP is assessed either kinetically by identifying the center of pressure location (Cavanagh and Lafortune, 1980) or kinematically by measuring the angle between the foot segment and the ground (Altman and Davis, 2012), i.e., footstrike angle (FSA) measurement. However, these methods require force plates and motion capture systems, limiting accurate measurements to laboratory settings.

Video analysis is widely used to assess FSP and FSA owing to its affordability and applicability across running environments. Researchers have employed this method in diverse contexts ranging from middle-distance races (Hayes and Caplan, 2012) to marathons (Patoz et al., 2019) and ultramarathons (Kasmer et al., 2014). However, it lacks robust validation evidence. Most previous studies have primarily assessed intra- and inter-tester reliability (de Oliveira et al., 2019). Only few studies (Esculier et al., 2018; Goto et al., 2024) have examined the measurement agreement between video analysis and gold-standard motion capture. These studies demonstrated high agreement, though with some limitations. Esculier's study focused on runners with patellofemoral pain, while Goto's study validated only FSP but not FSA.

Importantly, FSP and FSA are typically measured using lateral foot images, as cameras are often positioned on the lateral side. Some studies have used medial foot images (Hasegawa et al., 2007) or images from both sides (Damsted et al., 2015; Kasmer et al., 2014). Given potential biomechanical differences between the medial and lateral foot, FSP and FSA evaluation may yield different results. Despite these concerns, no studies to date have compared the accuracy of footstrike evaluation using lateral versus medial views, highlighting a key gap in the current literature.

This study aimed to evaluate the accuracy of FSP classification and FSA measurements using video analysis by comparing lateral and medial video and assessing their agreement with a motion capture system as the gold standard.

2. Methods

2.1 Participants

Participants aged 18-35 with treadmill running experience and no known running-related conditions were recruited via convenience sampling. Those with a history of lower limb surgery were excluded. Twenty healthy male adults (age=20.8±2.1 years old; height=1.77±0.05 m; mass=68.1±5.8 kg; and body mass index=21.9±1.6 kg/m^2) participated in the study. The sample size was informed by previous similar studies (García-Pinillos et al., 2019; Gindre et al., 2016). This study protocol was reviewed and approved by the Medical Ethics Committee, Shenzhen University (#PN-202400042), and all participants provided written consent before participation.

2.2 Data Collection

All participants completed four self-paced 3-minute running trials on a commercial treadmill in a randomized order: habitual FSP and three assigned FSPs (i.e., rearfoot strike (RFS), midfoot strike (MFS), or forefoot strike (FFS)). Data collection under various conditions was essential for validation and ensuring heterogeneity, as 90% of recreational runners naturally adopt a RFS (Cheung et al., 2017). Before the running trials, participants underwent a 15-minute warm-up, treadmill familiarization, and determination of their preferred running speed based on an established method (Mo et al., 2023). The average test speed for participants during the running trials was 10.0±1.5 km/h, with a range of 8.0-14 km/h.

Twenty reflective markers were firmly attached to both feet according to the foot model used in the previous research (Altman and Davis, 2012). On top of the markers on the lateral and medial malleolus, the 1^{st} and 5^{th} metatarsal heads, and the tip of the second toe, five tracking markers were also affixed to the shoe. Two synchronized smartphones (Mate60pro, Huawei®, Shenzhen, China) were placed on the lateral and medial sides of the treadmill to record running trials, positioned 50 cm high and 150 cm from the treadmill's midline for optimal capture.

Marker trajectory data and video recordings were simultaneously captured. A motion capture system (Mars2H, Beijing NOKOV® Science & Technology Co., Ltd., Beijing, China) with 12 infrared cameras sampling at 240 Hz was used to record marker trajectory. The two smartphones captured lateral and medial side video footage at the same sampling rate. During the trials, participants wore their usual running shoes. A 5-minute rest period was provided between trials.

2.3 Data Analysis

Marker trajectory data were imported into Visual3D (C-Motion Inc., Rockville, MD, USA) for analysis, including foot model construction and filtering with a fourth-order low-pass Butterworth filter at 8 Hz. The processed data were used to calculate the FSA, which was defined as the foot angle at initial foot contact subtracting the foot angle during static standing (Altman and Davis, 2012). Initial foot contact was defined as when the heel marker reached its lowest vertical position. FSAs were used to determine the FSP according to the criteria (Altman and Davis, 2012): a MFS was defined as $-1.6° < FSA < 8.0°$; a RFS as $FSA > 8.0°$; and a FFS as $FSA < -1.6°$. This study considered the FSA and FSP measurement from motion capture to be the gold standard.

Video data were processed using an open-source software (Version 2023.1.1, Kinovea, Bordeaux, France). The FSA from lateral and medial views was measured as the vector from the heel marker to the 5th or 1st metatarsal head marker, respectively, relative to the treadmill surface at initial foot contact. The resting stance FSA was subtracted from all measured values to account for baseline differences (Giandolini et al., 2014; Zhang et al., 2025). Finally, the FSP was determined according to the FSA.

For each participant, the 30 continuous footfalls from the middle 1-minute segment of data from each foot were extracted for statistical analysis, resulting in a total of 4,800 footfalls included in the study.

2.4 Statistical Analysis

FSP classification agreement between the lateral view, medial view, and the gold standard (motion capture) was evaluated using Cohen's kappa (κ). The agreement of the categorical ratings was interpreted as poor (κ<0.40), fair (0.40 to 0.60), good (0.60 to 0.80), and excellent (≥0.80) (Murray et al., 2019) A confusion matrix was also used to illustrate percentage agreements. FSA agreement was assessed using Bland-Altman analysis to determine mean differences and 95% limits of agreement, two-way random effects single measurements intraclass correlation coefficients (ICC) to evaluate the relative agreement, and root mean square error (RMSE) to quantify measurement precision. For interpreting the ICC, the relative reliability of measures was considered to be poor (ICC<0.40), fair (0.40 to 0.75), good (0.75 to 0.90), and excellent (≥0.90) (Murray et al., 2019). All statistical analyses were performed using SPSS software (version 26.0, SPSS Inc., Chicago, USA).

3. Results

Of the 4,800 footfalls analyzed, motion capture data identified 2,704 as RFS (56.3%), 1,224 as MFS (25.5%), and 872 as FFS (18.2%). The mean FSA was 9.62° ± 10.12°, ranging from -17.21° to 36.96°.

In terms of FSP classification, the lateral view demonstrated substantial agreement with the gold standard (κ=0.785 [0.769, 0.801], p<0.001), while the medial view showed good agreement (κ=0.606 [0.586, 0.626], p<0.001). Table 1 further details the percentage agreements across the three footstrike patterns. For RFS, the lateral view agreed with the gold standard in 92.9% of cases, compared to 85.6% for the medial view. MFS showed 79.2% agreement for the lateral view and 56.7% for the medial view. The lateral view achieved 81.2% agreement for FFS, while the medial view reached 78.1%. These results indicate that the lateral view consistently provided higher agreement with the gold standard across all FSP types than the medial view.

Regarding FSA measurement agreements, Bland-Altman analysis revealed a mean difference of 0.40° (95% limits of agreement: 6.05° to -5.25°) between the gold standard and the lateral view, compared to a mean difference of -1.31° (95% limits of agreement: 8.37° to -10.99°) for the medial view (Figure 1). ICC values indicated excellent agreement for both views, with the lateral view showing slightly higher consistency (ICC=0.979 [0.978, 0.980]) than the medial view (ICC=0.940 [0.936, 0.943]). Additionally, the lateral view demonstrated greater precision, with a lower RMSE of 2.91°, compared to 5.11° for the medial view. These results suggest that while both views strongly agree with the gold standard, the lateral view provides more precise and consistent FSA measurements.

4. Discussion

The present results suggest that while both lateral and medial views are viable, the lateral view offers greater consistency, making it the preferred approach for footstrike analysis using video cameras. The lateral view provides more consistent footstrike measurements than the medial view, likely due to anatomical and biomechanical factors. During initial contact, the medial longitudinal arch compresses to absorb ground reaction forces (Cheng et al., 2022), increasing medial marker variability (e.g., the first metatarsal). Transverse plane motions, such as foot supination and pronation, further influence medial marker stability. Supination elevates the arch, while pronation lowers it, affecting marker position. In RFS, initial contact at the lateral heel induces supination, slightly elevating the medial arch and causing minor marker displacement. While the arch remains stable in RFS, MFS and FFS cause greater arch deformation, increasing medial markers displacement and variability (Lees et al., 2005). In contrast, lateral markers remain more stable across all FSPs due to their placement on the structurally more stable lateral longitudinal arch. These factors explain the inconsistencies in medial view footstrike measurements compared to the greater stability and reliability of lateral view data.

We employed Kappa to assess the agreement between video-based and gold-standard FSP classifications, allowing direct comparison with the findings reported by Goto et al., 2024. Our observed agreement (κ=0.606-0.785) was higher than the values reported by Goto et al. (κ=0.58-0.71), which may be attributed to their use of a lower sampling rate video camera (120 Hz) and reliance on visual estimation to determine FSA. A previous study used Gwet's AC1 to assess agreement (Esculier et al., 2018), reporting values of 0.906 and 0.936, while we found κ of 0.606 (medial) and 0.785 (lateral). Although these may seem comparable, the metrics differ fundamentally in calculation. Kappa accounts for expected agreement, whereas AC1 is based on expected disagreement (Vach and Gerke, 2023). Kappa is sensitive to category prevalence, making direct comparison inappropriate, and its interpretation scale (Landis and Koch, 1977) does not apply to AC1. Nonetheless, both metrics indicate strong agreement between video-based and motion-capture methods, supporting the validity of video analysis for FSP classification. Using Bland-Altman analysis, ICC, and

RMSE, we have quantified the FSA measurement agreement between medial and lateral views. Such differences underscore the need for further research to develop correctional algorithms for medial view analysis.

Our findings have practical implications for clinicians and practitioners who rely on video-based gait analysis. Given its higher precision and stronger agreement with gold-standard measurements, the lateral view offers a more reliable option for evaluating footstrike angle and footstrike patterns in routine clinical assessments, injury prevention strategies, and running retraining programs.

While the present study is the first to systematically compare medial and lateral perspectives in FSA measurement, it is essential to acknowledge its key limitations. First, only male participants were recruited. Given known sex-related differences in running biomechanics (Xie et al., 2022), the results may not fully translate to female runners. Second, the relative slow test speed of our participants (i.e., 10.0±1.54 km/h) may limit the generalizability of our observations to more competitive runners, who typically maintain significantly higher speeds (Jones et al., 2021). Another limitation is the lack of footwear control, as participants ran in their habitual shoes, mostly traditional or maximalist, whereas minimalist shoes may alter landing technique (Mo et al., 2021). Lastly, our methods differ from standard clinical or on-field approaches, which do not use foot markers for FSP classification or FSA extraction. Replicating this study with a markerless approach would be valuable.

5. Conclusion

In male runners, both lateral and medial view video methods strongly agreed with the gold standard in FSP and FSA analysis. However, the lateral view showed greater accuracy and consistency, aligning more closely with the gold standard.

Conflicts of interest

None.

Acknowledgments

This study was supported by the China Scholarship Council (File No. 202408440353). The authors sincerely thank all the participants for their voluntary participation.

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Captions for table and figure

Table 1. Percentage agreements between video analysis and gold standard across three different footstrike patterns

Figure 1 Bland-Altman analysis for gold standard vs. lateral view (a) and vs. medial view (b). Notes: blue dot line indicates mean differences, and red dot line indicates upper and lower limits.

Table 1. Percentage agreements between video analysis and gold standard across three different footstrike patterns

		Video analysis					
		RFS		**MFS**		**FFS**	
		Lateral	**Medial**	**Lateral**	**Medial**	**Lateral**	**Medial**
Motion capture	**RFS**	92.9%	85.6%	7.1%	14.1%	0.0%	0.2%
	MFS	14.8%	19.5%	79.2%	56.7%	6.0%	23.7%
	FFS	0.0%	0.1%	18.8%	21.7%	81.2%	78.1%

Key: RFS=Rearfoot strike; MFS=Midfoot strike; FFS=Forefoot strike

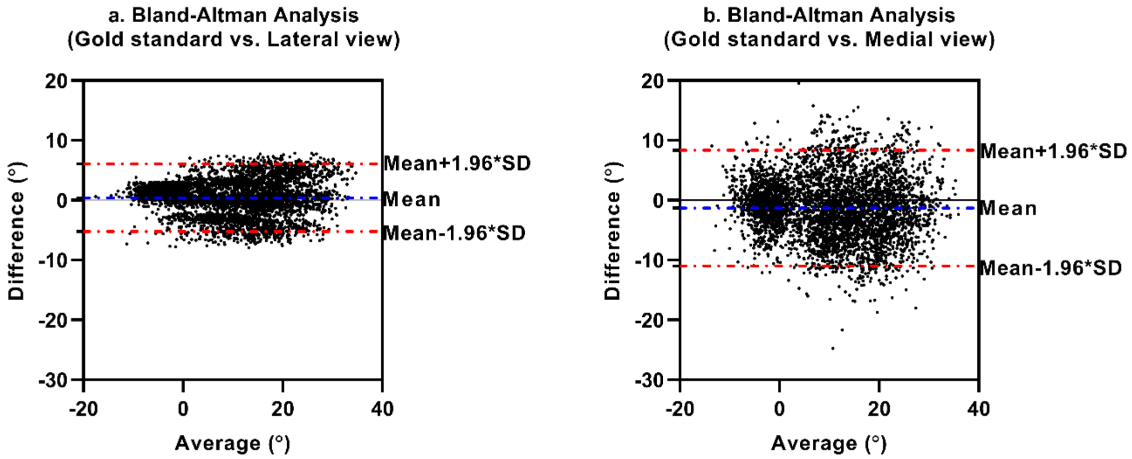

Figure 1 Bland-Altman analysis for gold standard vs. lateral view (a) and vs. medial view (b). Notes: blue dot line indicates mean differences, and red dot line indicates upper and lower limits.