SPATIOTEMPORAL AND JOINT KINEMATIC DIFFERENCES BETWEEN FOOTSTRIKE PATTERNS IN MALE AND FEMALE 10,000M ATHLETES

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The aim of this study was to examine biomechanical differences between footstrike patterns in elite 10,000m racing. Video data of 53 men and 33 women were recorded in competition and used to compare spatiotemporal and joint kinematic variables between rearfoot, midfoot and forefoot strikers, and to find associations. There were no differences between footstrike patterns for speed, step length or cadence, but rearfoot strikers had longer contact times than forefoot and midfoot strikers by 0.017 and 0.014 s, respectively, and shorter flight times by 0.023 and 0.021 s, respectively. The main causes of different footstrike patterns were the ankle and foot angles at initial contact; thigh, knee and shank angles differed little. In women, longer hip-ankle “overstriding” distances were associated with faster running speeds (r = 0.58), and so were a positive contributor to performance.

KEYWORDS: lower limb, overstriding, running, videography.

INTRODUCTION: Footstrike patterns in running have been analysed with regard to race performance, injury, and energy consumption (e.g., Hasegawa et al., 2007). Most World Championship marathon runners were rearfoot strikers (RFS), rather than midfoot (MFS) or forefoot strikers (FFS) (Hanley et al., 2019), which might have been related to running surface, footwear, running speed or fatigue. By contrast, none of the world’s best male 10,000m track runners were RFS (Hanley et al., 2021). Previous studies on non-elite long-distance runners have suggested that forefoot striking is accompanied by a more vertical shank angle at touchdown (Preece et al., 2019), and better runners had smaller (more vertical) shank angles (Folland et al., 2017). This angle is also sometimes known as the overstride angle (Squadrone et al., 2015), and the horizontal distance between the hip and foot has similarly been described colloquially as “overstriding” (Lieberman et al., 2015). There is therefore a rationale that RFS running might result in greater overstriding and hence longer contact times (van Oeveren et al., 2021), and thus lower cadence, but most of this research has been conducted in laboratory experiments or under controlled conditions. However, there is still limited knowledge of the footstrike patterns used in long-distance running competitions and their relationship with key performance variables. The aim of this study was to examine differences in spatiotemporal and joint kinematic variables between footstrike patterns in 10,000m racing, and to analyse associations between these variables amongst all athletes.

METHODS: Data collection took place at the 2021 European 10,000m Cup event and three other associated races (same day and location). Fifty-three men and 33 women were analysed in their respective races. Athletes who did not finish or were obscured by other competitors were not analysed, and only those athletes with non-asymmetric footstrike patterns were included for analysis. A 6-m section of the track on the back straight, approximately 20 m after the starting line used for the 1500m event, was used for video capture. Video data were collected during lap 15, which corresponded to a race distance of ~5720 m. Two Sony FS5 high-speed cameras (200 Hz), used to identify footstrike patterns based on the methods of Hasegawa et al. (2007), and two Sony FS7 high-speed cameras (150 Hz), used to measure spatiotemporal data from one full gait cycle, were placed to the side of the track farthest from the inside lane. A rigid cuboid reference frame with multiple markings (known distances) was used to create multiple reference scaling measurements for different athletes based on their position on the track. The videos were analysed using SIMI Motion version 9.2.2. Distances and angles were calculated using 2D coordinate data found using the 2D still image measurement tool in SIMI Motion; segment endpoints were estimated using joint centres as defined by the models of de Leva (1996). Running speed was calculated by finding the product of step length and cadence. Duty factor was calculated by dividing contact time by stride time (the latter being the sum of contact time and swing time). The hip-ankle distance was calculated as the horizontal distance between the hip and ankle joints. This distance and segment and joint angles were measured at initial contact (the frame when the foot first visibly contacted the ground). One-way within-groups analysis of variance (ANOVA) was conducted with Bonferroni post hoc tests used to identify differences between laps. Effect sizes for differences between footstrike patterns were calculated using Cohen's *d* (Cohen, 1988). Pearson correlations (*r*) were calculated between variables. Alpha was set at 0.05 for all statistical tests.

RESULTS: The mean finishing time (min:s) was 29:03 (± 0:51) in the men's races, and 33:25 (± 1:20) in the women's races. Differences between groups based on the Bonferroni tests are shown in Table 1; all effect sizes for significantly differences were moderate or larger ($d > 0.80$).

Table 1: Spatiotemporal and angular variables in each footstrike group in men and women (mean ± SD).

	FFS	MFS	RFS
Men	N = 29	N = 13	N = 11
Speed (km/h)	20.63 (± .87)	20.91 (± .90)	20.24 (± .82)
Step length (m)	1.88 (± .11)	1.91 (± .11)	1.81 (± .11)
Cadence (Hz)	3.05 (± .15)	3.04 (± .12)	3.11 (± .11)
Contact time (s)	.179 (± .011)*	.182 (± .009)†	.196 (± .013)†*
Flight time (s)	.149 (± .012)*	.147 (± .011)†	.126 (± .011)†*
Swing time (s)	.478 (± .026)*	.476 (± .022)†	.448 (± .018)†*
Duty factor	.27 (± .01)*	.28 (± .01)†	.30 (± .02)†*
Hip-ankle distance (m)	.25 (± .02)	.24 (± .03)†	.27 (± .02)†
Thigh angle (°)	61 (± 3)*	60 (± 3)	58 (± 2)*
Knee angle (°)	158 (± 4)	156 (± 3)	156 (± 3)
Shank angle (°)	5 (± 3)	5 (± 2)	6 (± 3)
Ankle angle (°)	108 (± 5)§*	100 (± 3)§†	92 (± 4)†*
Foot angle (°)	–11 (± 4)§*	–5 (± 2)§†	6 (± 4)†*
Women	N = 11	N = 12	N = 10
Speed (km/h)	17.89 (± .81)	17.83 (± .83)	17.68 (± .72)
Step length (m)	1.56 (± .12)	1.62 (± .11)	1.59 (± .08)
Cadence (Hz)	3.19 (± .15)	3.06 (± .13)	3.10 (± .11)
Contact time (s)	.186 (± .007)*	.188 (± .009)†	.203 (± .014)†*
Flight time (s)	.129 (± .016)	.140 (± .017)†	.120 (± .013)†
Swing time (s)	.443 (± .030)	.467 (± .030)	.444 (± .020)
Duty factor	.30 (± .02)	.29 (± .02)†	.31 (± .02)†
Hip-ankle distance (m)	.22 (± .03)	.23 (± .03)	.25 (± .02)
Thigh angle (°)	60 (± 2)	60 (± 3)	58 (± 2)
Knee angle (°)	155 (± 4)	155 (± 2)	154 (± 3)
Shank angle (°)	7 (± 2)	6 (± 1)	8 (± 2)
Ankle angle (°)	108 (± 4)§*	101 (± 3)§†	91 (± 4)†*
Foot angle (°)	–13 (± 2)§*	–7 (± 3)§†	5 (± 7)†*

* Difference between FFS and RFS; § Difference between FFS and MFS; † Difference between MFS and RFS ($p < 0.05$).

With regard to the angle conventions, the thigh was more flexed in the RFS group than in the FFS group (men only), whereas there was no difference in knee flexion between any group. The ankle was more dorsiflexed in the RFS runners than either the FFS or MFS runners in both sexes, and more dorsiflexed in the MFS than the FFS group. Negative foot angles indicate a foot position with the forefoot inferior to the ankle; the male and female RFS runners were therefore the only groups with mean positive values for foot angle (because of heel-striking). Correlations between key spatiotemporal and joint kinematic variables are shown in Table 2. Only those correlations that were significant are included.

Table 2: Significant correlations between key variables in men and women; all athletes within each category were combined for these analyses, regardless of footstrike pattern.

	Speed	Step length	Cadence	Hip-ankle distance	Shank angle
Men					
Contact time	r = –0.35 p = 0.009		r = –0.43 p = 0.001		
Flight time		r = 0.64 p < 0.001	r = –0.62 p < 0.001		
Swing time		r = 0.75 p < 0.001	r = –0.90 p < 0.001		
Duty factor	r = –0.34 p = 0.012	r = –0.41 p = 0.002			
Hip-ankle distance		r = 0.41 p = 0.002	r = –0.38 p = 0.005		r = 0.53 p < 0.001
Thigh angle	r = –0.32 p = 0.020	r = –0.38 p = 0.006		r = 0.80 p < 0.001	
Knee angle					r = 0.67 p < 0.001
Shank angle				r = 0.67 p < 0.001	
Ankle angle		r = 0.27 p = 0.049		r = 0.36 p = 0.009	
Women					
Contact time	r = –0.43 p = 0.012				
Flight time	r = 0.41 p = 0.017	r = 0.75 p < 0.001	r = –0.69 p < 0.001		
Swing time		r = 0.82 p < 0.001	r = –0.90 p < 0.001		
Duty factor	r = –0.47 p = 0.006	r = –0.61 p < 0.001	r = 0.44 p = 0.011		
Hip-ankle distance	r = 0.58 p < 0.001	r = 0.54 p = 0.001			r = 0.75 p < 0.001
Thigh angle	r = –0.39 p = 0.024			r = 0.53 p = 0.001	
Knee angle					r = 0.62 p < 0.001
Shank angle	r = 0.50 p = 0.003			r = 0.62 p < 0.001	
Foot angle					r = 0.42 p = 0.014

DISCUSSION: There were no differences between footstrike patterns for running speed, step length or cadence, and thus the spatiotemporal and angular differences found between groups were related to the footstrike pattern adopted, rather than to performance variables. Contrary to previous research (Preece et al., 2019), there was no difference between footstrike patterns for shank angle, but the hip-ankle distance was longer in male RFS athletes than in MFS. Although the footstrike pattern adopted is the result of the joint and segment angles from the hip downwards, it was mostly the ankle angle that was different between groups (which determined the foot angle). In men, the thigh angle also differed between FFS and RFS only; overall, both male and female athletes with more flexed thighs were faster.

Although there were few differences in hip-ankle distance or shank angle, contact times were nonetheless longer in RFS than in FFS or MFS in both sexes (van Oeveren et al., 2021).

However, because flight times were shorter in RFS, there was no difference in cadence, showing that adopting an anterior footstrike pattern did not achieve a greater step rate. Although running FFS or MFS did not lead to higher cadences, their duty factors were mostly lower than RFS, suggesting that these footstrike patterns potentially benefit from better usage of elastic properties of the muscular-tendon complex (van Oeveren et al., 2021). Indeed, athletes with lower duty factors were faster and had longer steps (partly because of longer flight times) and these results would support adopting an anterior footstrike pattern in 10,000m racing. However, as there were no performance differences found between the groups, it is possible that any elastic energy benefits were small, and RFS athletes were still able to achieve similarly fast running speeds.
Larger, less vertical shank angles were associated with longer hip-ankle distances in men and women, and both of these variables were positively correlated with speed in women, showing that greater overstriding could be an important factor in faster running amongst elite women. This is especially important given the positive correlation between hip-ankle distance and step length (in both sexes). The results therefore show that these lower limb touchdown positions indicate that “overstriding” is not a negative, undesirable action, but a normal, potentially beneficial aspect of elite track distance running.

CONCLUSION: The distinction between footstrike patterns observed in elite 10,000m runners occurred primarily because of different ankle angles, and hence different foot angles. There were fewer differences between thigh, knee and shank angles, especially in women. This meant that the overstriding distance from the hip to the ankle differed only between MFS and RFS men. RFS athletes had longer contact times and shorter flight times (and hence higher duty factors) but, as there were no differences between step length, cadence or speed, faster running is not greatly determined by footstrike pattern in long-distance running.

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