FOOTSTRIKE PATTERNS AND RACE PERFORMANCE IN THE 2017 IAAF WORLD CHAMPIONSHIP MEN'S 10,000 M FINAL

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Running title: Footstrike patterns in elite 10,000 m runners

Abstract

Midfoot- (MFS) and forefoot-striking (FFS) runners usually switch to rearfoot-striking (RFS) during marathons. However, world-class runners might resist modifications during shorter races. The purpose of this study was to analyse footstrike patterns, ground contact times and running speeds in a World Championship men's 10,000 m final. Footstrike patterns and contact times of the top 12 finishing men (24 ± 5 years) were recorded (150 Hz) during laps 1, 5, 11, 15, 20 and 25. Split times for each 100-m segment were obtained. No RFS patterns were observed; there was no difference between the number of FFS and MFS athletes at any distance ($p \geq 0.581$) and no change in the proportions of FFS and MFS occurred ($p = 0.383$). No link between race performance and footstrike pattern appeared given the similar number who used FFS or MFS and their similar finishing times. Despite slower running speeds and longer contact times in the middle of the race ($p \leq 0.024$), no effect on footstrike patterns occurred. The prevalence of anterior footstrike patterns in this world-class race reflects the capability of maintaining fast paces (>22 km/h). Changes in footstrike pattern might accompany the physiological and neuromuscular effects of fatigue over longer distances.

Keywords: athletics, competition, endurance, fatigue, performance

Introduction

The 10,000 m event is the longest track race held as part of the athletics programme at all major championships. In contrast to those who race the marathon (42.2 km) and usually suffer considerable neuromuscular fatigue and glycogen depletion (Jeukendrup, 2011; Nikolaidis & Knechtle, 2019), world-class male 10,000 m athletes are capable of maintaining fast paces (>21 km/h) for the entire race, and medallists typically increase pace during the last lap to speeds faster than 26 km/h (Hettinga, Edwards, & Hanley, 2019). One important aspect of running technique is footstrike pattern, with athletes adopting one of three recognised patterns: forefoot (FFS), midfoot (MFS) and rearfoot striking (RFS); however, these have not been analysed to date in world-class track distance runners. Athletes with anterior footstrike patterns (FFS and MFS) might benefit from greater elastic energy storage in the Achilles tendon and foot arches (Perl, Daoud, & Lieberman, 2012). For example, Hayes & Caplan (2012) found that 85% of high-calibre men competing over 800 m, and 74% of those competing over 1500 m, were either FFS or MFS, with the remainder having RFS patterns. RFS runners were also slower and had longer ground contact times than non-rearfoot strikers (i.e., FFS and MFS) (Hayes & Caplan, 2012). This proportion of RFS found in middle-distance running was lower than that found in World Championship marathons (65% at 29.5 km) (Hanley, Bissas, Merlino, & Gruber, 2019) and hence the faster paces and greater intensity of sprint and middle-distance races could explain the higher proportion of FFS and MFS in middle-distance running compared with long-distance races (Forrester & Townend, 2015).

Despite the potential benefit of anterior footstrike patterns, most World Championship marathon runners are RFS throughout the race, and many FFS and MFS runners across abilities switch to RFS patterns by the end of half-marathons, marathons and ultramarathons (Hanley et al., 2019; Hasegawa, Yamauchi, & Kraemer, 2007; Hébert-Losier, Patoz, Gindre, & Lussiana, 2020; Kasmer, Liu, Roberts, & Valadao, 2013; Kasmer, Wren, & Hoffman, 2014; Larson et al., 2011). This switch to a more posterior footstrike pattern might occur to compensate for decreases in plantarflexor torques and muscle activity by the end of a prolonged run (Jewell, Boyer, & Hamill, 2017). As running ability increases, the proportion of runners who begin long-distance races with an RFS pattern reduces (e.g., 93% of recreational runners in Larson et al. (2011) vs. 70% of World Championship competitors in Hanley et al. (2019)), as does the proportion of runners who switch from RFS to either FFS or MFS (Hanley et al., 2019; Larson et al., 2011). Nonetheless, the length of the race, and not solely the ability of the athletes, could be the key influencing factor on the proportion of runners who switch footstrike pattern. For example, by the end of a 15-min run to volitional exhaustion, habitual forefoot runners ran with more posterior footstrike patterns than at the start (Jewell et al., 2017). Although that sample was recreational runners (mean running speed of 14 km/h), they could have been running at a relative intensity similar to higher-calibre runners competing in distance events (as a percentage of maximum heart rate, for example), but whether this shift in footstrike pattern occurs in practice has not been examined to date.

Running ability is likely related to the capability of resisting feelings of exhaustion and maintaining a gait strategy during an intense, prolonged run (Sanno, Willwacher, Epro, & Brüggemann, 2018). Therefore, highly trained runners might be able to resist modifications to footstrike pattern during distance races in contrast to recreational and club runners, yet no studies to date have analysed the footstrike patterns adopted by world-class 10,000 m runners or how footstrike changes during this race, despite suggested performance benefits of adopting FFS or MFS. Given how running speeds change in 10,000 m running, particularly during championship racing (Hettinga et al., 2019), it is important to evaluate the effect of different running speeds on footstrike pattern within a race, as well as any potential relationship between footstrike pattern and ground contact time (Hayes & Caplan, 2012). A novel study on how world-class athletes maintain or alter footstrike pattern to cope with the changing demands in pace during racing could be important for coaches and athletes in their physical preparation for competition, e.g., through training drills designed to encourage a particular running technique. The aim of this study was to analyse the footstrike patterns and contact times used by a sample of the world's best male distance runners during the highly ecological and elite-standard setting of a World Championship 10,000 m final. Given the findings of prior work (Hayes & Caplan, 2012; Jewell et al., 2017), we hypothesised that most of these world-class runners would be either FFS or MFS runners and that footstrike pattern would be maintained throughout the race.

Methods

Participants

Data were collected as part of the London 2017 World Championships Biomechanics Research Project, and the use of those data was approved by the IAAF (since renamed as World Athletics), who control the data, and subsequently locally through Leeds Beckett University Carnegie School of Sport Ethics Committee procedures (application no.: 52836, 8/11/'18). The participants provided their written informed consent. The top 12 finishers in the men's 10,000 m final were analysed; their mean age (± one standard deviation (SD)) was 24 years (± 5). Personal best (PB) and finishing times (min:s) were obtained from the open-access World Athletics website (World Athletics, 2019).

Data collection

A 5-m section of the track on the back straight, approximately 20 m before the starting line used for the 200 m sprint, was chosen for video capture. The 10,000 m race comprises 25 laps, and in this study video data were collected during laps 1, 5, 11, 15, 20 and 25, which thus corresponded to completed running distances of approximately 180, 1780, 4180, 5780, 7780 and 9780 m. A Sony PXW-FS7 camera (Sony, Tokyo, Japan) operating at 150 Hz (shutter speed: 1/1600 s; ISO: 1600; 1920x1080 px) was placed on the side of the track farthest from the inside lane of the track. The camera was positioned on a tripod approximately 1 m above the running surface to account for the advertising hoarding (which it had to be placed behind) with its optical axis perpendicular to the running direction.

Data analysis

All videos were analysed by two independent assessors using SIMI Motion version 9.2.2 (Simi Reality Motion Systems GmbH, Unterschleissheim, Germany). Athletes were identified using their lane number, which was indicated by a label worn on their shorts. Similar to previous field-based research conducted on runners in competition (Hayes & Caplan, 2012; Larson et al., 2011), footstrike patterns for each athlete (Figure 1) were defined using the foot position at first contact with the ground using the methods of Hasegawa et al. (2007) as either: RFS (the heel contacted the ground first without simultaneous contact by the midfoot or forefoot), MFS (the heel and midfoot, or occasionally the entire sole, contacted the ground together) or FFS (the forefoot / front half of the sole contacted the ground first with a clear absence of heel contact). As in a previous study (Hanley et al., 2019), the heel was considered the proximal one-third of the shoe. The split times for the athletes were obtained for each 100-m segment (e.g., the 100 – 200 m segment) via wearable radio-frequency identification transponders attached to the runner's bibs (Hanley, Bissas, & Merlino, 2018), and the mean time per 100-m segment analysed for footstrike patterns subsequently calculated (Figure 2A). The total ground contact time was calculated for each footstrike (Figure 2B) as time from initial contact (first frame when the foot visibly contacted the ground) to toe-off (last frame of visible foot contact with the ground) (Padulo, Chamari, & Ardigò, 2014). Two footstrikes (one left and one right) were analysed for each athlete on each lap; athletes were considered to have asymmetrical footstrike patterns when their footstrikes differed between left and right foot contacts. Left and right footstrikes could not both be identified in eight instances out of 72 (11%) analyses of athletes because the view was obscured by other runners. Ground contact times were averaged between left and right footstrikes for each athlete on each lap. For those instances where only one footstrike was completely visible, the contact time for that single foot contact was used.

Statistical analysis

Pearson's chi-squared test of association (χ^2) compared observed counts of categorical data between footstrike patterns on each lap. Cochran's Q was used to measure whether the proportion of athletes who had each type of footstrike pattern changed during the race. Athletes with asymmetrical footstrike patterns were designated as 0.5 for the footstrike type identified on each foot. Results for mean running speeds and contact times are reported as mean ± one SD. One-way within-groups analysis of variance (ANOVA) was conducted with Bonferroni post hoc tests used to identify differences between laps (Field, 2009) for the conditions of ground contact times and running speeds (per 100-m segment analysed). Greenhouse-Geisser corrections were used when Mauchly's test for sphericity was violated. Statistical significance was accepted as $p < 0.05$, and because of the small sample size, exact significance was calculated for the comparisons of count data (Mehta & Patel, 2011). Effect sizes for differences between 100-m segment speeds and ground contact times were calculated using Cohen's *d*

(Cohen, 1988) and included when the effect size was moderate or larger only ($d \geq 0.61$) (Hopkins, Marshall, Batterham, & Hanin, 2009).

Results

All athletes were either FFS (50%) or MFS (50%) at the start of the race; no RFS patterns were recorded at any distance (Table 1). There was no difference between the number of athletes who were FFS or MFS at any distance (χ^2 (1) $\leq$ 0.69, p $\geq$ 0.581), and Cochran's Q test determined that there was no change in the proportion of athletes who were FFS or MFS with distance run (χ^2 (5) = 6.61, p = 0.383). No clear trend between footstrike pattern and finishing time was observed through a cursory inspection of the data given the similar number of athletes who used an FFS or MFS at all measurement distances or switched footstrike pattern at least once (Figure 1). Asymmetry was observed in three of the five athletes who switched footstrike pattern. Athletes' mean running speeds (per 100-m segment analysed) and contact times are shown in Figure 2A-B, with annotations indicating where differences occurred. The athletes' mean PB before competition was 27:09.03 (± 17.46). Their mean finishing time in the race was 26:59.59 (± 8.22) with less than 22 s separating 1st position from 12th. Relative to PB, the faster mean finishing time reflects that eight of the 12 athletes observed recorded PBs in this race.

Discussion and Implications

The purpose of this study was to analyse the footstrike patterns and contact times used by a sample of the world's best male distance runners during a World Championship 10,000 m race. Our hypothesis that most of these world-class runners would be either FFS or MFS runners was supported; indeed, all athletes were either FFS or MFS as no RFS was observed at all. We rejected the second hypothesis that footstrike pattern would be maintained throughout the race because five of the 12 runners (42%) altered their footstrike pattern during the race, albeit this was from either of the two anterior footstrike patterns (MFS or FFS) to the other. These results support previous work that elite-standard runners are FFS or MFS runners more so than recreational runners (Hanley et al., 2019; Hasegawa et al., 2007; Kasmer et al., 2013; Kasmer et al., 2014; Larson et al., 2011), and that track runners tend to have a greater proportion of FFS and MFS patterns than in races longer than a half-marathon held on roads (Hayes & Caplan, 2012). Because the 10,000 m race is held on compliant tracks that allow running spikes to penetrate the surface, this shoe-surface interface helps facilitate an anterior footstrike pattern compared with the road surfaces used in marathons, upon which athletes wear more cushioned, thicker heels (Barnes & Kilding, 2019; Logan, Hunter, Hopkins, Feland, & Parcell, 2010). The use of MFS and FFS patterns by these elite-standard runners instead of an RFS pattern also reflects the fast pace of the race (>22 km/h) (Forrester & Townend, 2015). In addition, it is also possible that these track runners were coached to use an FFS or MFS pattern, and whether the shoe-surface interaction was a likely factor in the footstrike pattern adopted could be established with future studies on world-class athletes racing 10 km on the road at similar running speeds.

The runners in the present study tended to hold their position throughout the race and run together in a pack so there is no clear reason associated with race strategy for the five runners who changed footstrike pattern. Although four of the top six finishers predominately used an MFS pattern, whereas four of the bottom six finishers used an FFS pattern, the athletes' finishing times were too similar to draw any conclusions regarding footstrike pattern and race performance. There was also no clear link between footstrike pattern adopted and running speed; for example, even though the athletes ran at slower speeds at 1780 and 5780 m than at 180 and 7780 m, the proportion of athletes who were MFS was the same (50%). At all measurement distances, the athletes ran faster than ~22 km/h (Figure 2A), which is consistent with speed and footstrike pattern trends observed previously (Forrester & Townend, 2015). It is therefore possible that these athletes adopted MFS and FFS patterns because those patterns were the most habitual to them (Francis & Schofield, 2020), and small differences in speed were insufficient to cause them to substantially change whatever footstrike pattern they had developed over time in training and racing (Forrester & Townend, 2015). With regard to contact times, these were largely the same throughout the race despite the changes in speed and could relate to how all athletes maintained anterior footstrike patterns. One exception was that contact time was greater at 5780 m, which corresponded with the slowest running speed, and indeed the trend shown in Figure 2A-B illustrates that a U-shaped pacing profile (fast at the start and end of the race, slow in the middle) (Abbiss & Laursen, 2008) was adopted, with contact times appearing inverted relative to this trend, but ultimately these trends had no clear effects on footstrike pattern. This might be because the athletes were well-trained in using anterior footstrike patterns, ensuring they obtained the mechanical benefits of this technique (Perl et al., 2012), and running speed did not decrease enough to encourage the adoption of an RFS.

Most of the observed runners recorded PBs at this race, with the others achieving season's best times, indicating that nearly all analysed athletes ran to the maximum of their ability. Given that the present sample included the best male distance runners in the world, it is nevertheless probable that most were not fully exhausted by the end of the race, and the small difference in finishing times were more reflective of their ability to sprint the last 400 m by having a higher critical speed, for example (Burnley & Jones, 2010). Compared with a marathon (Hanley et al., 2019), the resistance to change footstrike pattern in elite-standard runners during this shorter but more intense (absolute pace) race suggests that exertion-related changes in footstrike pattern might require glycogen depletion, heat accumulation affecting enzyme function or peripheral neuromuscular fatigue to occur. Indeed, Gruber, Umberger, Braun, & Hamill (2013) found that carbohydrate oxidation rates were greater during FFS than RFS, but this study's results indicate that the athletes did not forego this potential benefit of RFS running as the distance raced and its duration were short enough that detrimental glycogen depletion did not occur, notwithstanding that the low-heeled footwear used in 10,000 m track running does not support RFS in the same way as road running shoes (Barnes & Kilding, 2019; Logan, Hunter, Hopkins, Feland, & Parcell, 2010). Although the results of this study show that FFS and MFS patterns were adopted by the world's best distance runners, sub-elite and recreational runners should note that running at slower speeds, with less physical fitness, and on roads might result in RFS patterns being adopted (Hébert-Losier et al., 2020), but which are nonetheless optimal for them and the surface conditions. Indeed, different footstrike patterns were not found to result in performance differences or to prevent fatigue-related changes even in world-class marathon runners (Hanley, Bissas, & Merlino, 2020).

The key strength of this novel study was that it was conducted on world-class athletes in a major championship final, where the athletes strived to achieve their best performance and adopted their natural running technique, including footstrike patterns. There was no instruction given to the athletes or any intervention involved and therefore we have described world-class runners in their 'natural habitat' with no researcher influence on participant behaviour. With regard to limitations, we were unable for logistical reasons related to data collection to analyse more than the top 12 athletes in this race, or the 10,000 m women in theirs, so future research should examine a wider range of athletes and race conditions. We also chose to record on specific laps and therefore can only speculate that the measurements made were consistent for all race laps (although the laps analysed did feature a range of running speeds). It was not possible to obtain video images of two full contact phases for each athlete on all laps because of obscuring by other athletes, and future studies could consider using multiple cameras to help identify more footstrikes. Notwithstanding these limitations, the study showed clearly that the world's best male distance runners all adopted anterior footstrike patterns throughout the 10,000 m final despite changes in speed. The benefits of FFS and MFS footstrike patterns are therefore important in fast running and coaches of top track athletes should note that developing an anterior footstrike pattern, and the ability to maintain it, are key aspects of elite-standard running performances.

Conclusions

This was the first study to analyse footstrike patterns in world-class 10,000 m distance runners in the highly ecological setting of a World Championship final. The main finding was that all of the top 12 finishers had either MFS or FFS patterns, which differed from a predominant RFS pattern found in World Championship marathon racing, and are most likely optimal for their ability and techniques. The athletes analysed were homogenous in that they ran at similar speeds at the measurement distances, had similar finishing times, and experienced little difference in ground contact times; athletes who differ greatly from this cohort should therefore be cautious about applying these findings to change their own technique, including slower championship competitors. Given the findings of this new research, and that of athletes across a range of running distances and conditions, it is probable that footstrike patterns are affected by a combination of factors including athlete ability, running shoe construction, underfoot surface, fatigue and training history.

Acknowledgements

The authors would like to thank Dr Jim Maciukenas of the School of Public Health-Bloomington for his assistance in creating the artwork used in the Figures.

Declaration of interest statement

The data collection and initial data analysis were supported by funding provided by the IAAF as part of a wider development / education project; however, the nature of the data is purely descriptive and not associated with any governing body, commercial sector or product. No funding was provided for the writing of this manuscript. The results of the present study do not constitute endorsement by the IAAF / World Athletics.

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Table 1. The number (and percentage) of the top 12 finishers with each type of footstrike pattern at each analysed distance. Asymmetric athletes were those who had a different footstrike pattern on their right and left feet. No RFS patterns were recorded in any athlete at any distance.

Distance	180 m	1780 m	4180 m	5780 m	7780 m	9780 m
MFS	6 (50%)	6 (50%)	5 (42%)	6 (50%)	6 (50%)	7 (58%)
FFS	6 (50%)	6 (50%)	6 (50%)	5 (42%)	4 (33%)	5 (42%)
Asymmetric (MFS / FFS)	0 (0%)	0 (0%)	1 (8%)	1 (8%)	2 (17%)	0 (0%)

Figure 1. Observed counts of midfoot (MFS) and forefoot (FFS) footstrike patterns among finishers in the men's 2017 IAAF World Championship 10,000 m final. Each bar indicates the footstrike pattern used by each runner at each measurement distance. 'FFS / MFS' indicates that the runner exhibited an asymmetrical footstrike pattern at the indicated measurement distance.

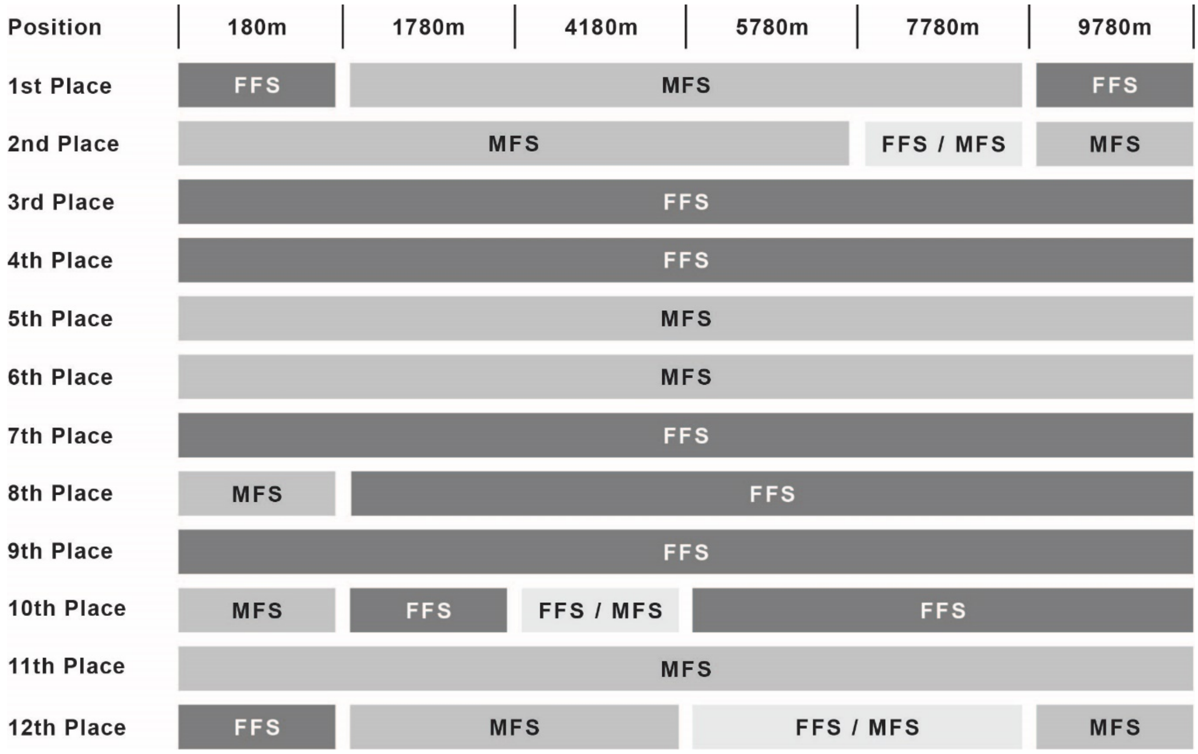

Figure 2A-B. The mean (± SD) running speed and contact time at each measurement distance. Differences between distances with a moderate or larger effect size ($d \geq 0.61$) are annotated as:

§ Mean running speed was significantly slower than at 180 m ($p < 0.001$).

Mean running speed was significantly slower than at 7780 m ($p \leq 0.001$).

* Mean running speed was significantly slower than at 9780 m ($p = 0.024$).

† Mean contact time was significantly greater than at 180 m ($p = 0.007$).