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Current perception and practice of athletics coaches about the modification of footstrike pattern in endurance runners: A survey

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Abstract

Purpose: To date, the relationship between footstrike pattern and performance, as well as with injury incidence in endurance running remains unclear. For these reasons, it is currently not recommended to modify footstrike pattern in an uninjured long-distance runner. The purpose of this study was to analyse whether athletic coaches apply these current scientific recommendations with their endurance runners on the field.
Methods: A Delphi method study was used to develop an online survey that was administered to French-speaking athletic coaches in Belgium. The survey comprised three sections: 1) coaches' profile, 2) coaches' perception of footstrike patterns, 3) practices pertaining to footstrike patterns.
Results: One hundred and fourteen respondents completed the entire questionnaire. Ninety-six (84%) athletic coaches reported modifying the footstrike pattern of their endurance runners. They reported that they modify their runners' rearfoot and forefoot strike more often than a midfoot strike ($P < 0.0001$) to prevent injury (83%) and to improve performance (66%). According to them, midfoot strike is considered as the best landing pattern for endurance performance (47%) and injury prevention (36%) whereas rearfoot strike is considered as the worst (respectively, 50% and 52%).
Summary and conclusion: This study highlights the disparities between scientific recommendations and athletic coaches' field practices for modifying footstrike patterns in endurance runners. Contrary to current scientific literature recommendations, a large proportion of coaches modify the natural footstrike pattern of their endurance runners towards a midfoot strike pattern to improve performance and prevent injury.

Keywords

Drills, gait retraining, injuries, sport technique

Introduction

Running is one of the most popular physical activities in the world, mostly done to achieve or maintain good physical and psychological health.[1,2] The amount of runners has doubled during the last ten years and is ever-increasing.[2] The participation in long-distance running events is also growing increasingly popular.[3] In terms of competition, long-distance running races can range from 5.000 m to a marathon in length.[4] Unfortunately, along with the positive effects of running comes a high risk of sustaining an injury.[1,2,5] The incidence of running-related injuries per 1000 h is around 6.3 compared to 3.4 in all other sports combined.[6]

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Footstrike pattern is often cited as a biomechanical component impacting the risk of injury.[7] Lieberman[8] distinguished three different types of landing during running, based on initial contact: rearfoot strike (RFS), midfoot strike (MFS) and forefoot strike (FFS). A large proportion of long-distance runners land with a RFS (65% to 94%) and a minority land with a MFS (5% to 25%) or a FFS (1%).[9–13] In a cohort study, Daoud et al.[14] were the first authors to conclude that running with a MFS or a FFS could decrease the risk of injury by a factor of two. The absence of an impact peak in ground reaction forces in FFS runners is the main hypothesis to justify this result. However, Gruber et al.[15] later observed that this impact peak was present in FFS runners, but was delayed. This delay is explained by the deceleration of the lower limb which occurs later compared to RFS runners. Loading rate is another argument in the literature in favour of the protective nature of landing with a more anterior part of the foot. Indeed, loading rate is lower with a FFS than a RFS. However, the association between loading rate and injury remains inconsistent between studies.[16] Following the retrospective study by Daoud et al.,[14] there is an equal number of studies (both prospective and retrospective) which have weighed in whether MFS/FFS is protective or not.[17–20] Because of these findings, Anderson et al.[21] do not recommend in their systematic review with meta-analysis to modify their endurance runners' footstrike pattern to prevent running-related-injuries. Indeed, they emphasise that the current level of evidence to modify footstrike pattern to prevent injury occurrence is insufficient.

The footstrike pattern is also cited in running as a relevant factor of performance. The main reason which is suggested is that FFS increases elastic energy storage and release compared with RFS.[22] However, several studies analysing performance in middle and long-distance races report inconsistent results. Several studies concluded that better results are achieved by midfoot and forefoot runners while other studies did not reach the same conclusion.[9–13] Therefore, the association between footstrike pattern and performance remains unclear. In the same way, there seems to be no difference in running economy between footstrike patterns. Indeed, several studies report similar oxygen uptake (for a normalised mass) and net metabolic rate between RFS and FFS runners at different sub-maximal speeds.[23–25] Again, Anderson et al.[21] do not recommend, following their systematic review with meta-analysis, to modify the footstrike pattern of their endurance runners to improve their running economy.

Considering their recommendations,[21] it appears to be crucial to determine if athletic coaches are aware that footstrike pattern modification does not appear to prevent injury and increase running economy. Indeed, athletic coaches are at the forefront of runners' performance preparation and running injury prevention. In addition to the current lack of evidence demonstrating the effectiveness of footstrike pattern modification on performance and injury prevention, modifying the footstrike pattern of an uninjured endurance runner may be detrimental. In fact, modifying footstrike patterns shifts anatomical strain areas and could expose runners to an increased risk of injury.[21,26] The occurrence of an injury has a direct impact on the level of performance, so it is crucial for coaches to minimise risk exposure.[27] Finally, the time consumed to modify the footstrike pattern could be used to correct other technical parameters which could have a higher impact on performance according to the current scientific evidence.[28]

The purpose of this study was to analyse whether athletic coaches' apply the current scientific recommendations about footstrike pattern modification with their endurance runners on the field. Considering the difficulties highlighted by Fullagar et al.[29] in other sports to transfer scientific knowledge to the field, our hypothesis is that a gap exists between current scientific recommendations and field practices for modifying footstrike patterns in endurance running.

Methods

Participants

A total of 500 athletic coaches from 50 clubs in Wallonia (Belgium) were invited to participate in an online survey (sondage Online, https://www.sondageonline.com). Coaches were invited to answer the survey regardless of their qualification level, their experience, or their athletes' competition standard. An e-mail invitation was sent to each coach to explain the purpose and procedure of the survey.

Data was collected between 1st July and 1st September 2021 and coaches were asked to answer without using additional resources and in accordance with their practices and experience. Coaches were free to participate and provided consent through the survey platform. Answers were anonymous and confidential. This study was approved by the Ethics Committee of Liege Hospital Faculty prior to data collection.

Survey

To elaborate the questionnaire, a Delphi method study (including 12 experts (four official medical officers of the Belgian League of French-speaking Athletics (LBFA), two official physiotherapists of the LBFA, two Olympic athletes' coaches, one personal trainer following high-level athletes, one expert in epidemiology and two experts in motricity sciences)) was conducted. For each section of the questionnaire, experts were asked to indicate the level of relevance of the questions (in regards to the objectives of the section) on a scale: 1 = strongly agree; 2 = agree; 3 = disagree; 4 = strongly disagree. They could also write a suggestion about the questionnaire in open-ended questions. To establish the level of agreement, the total percentage of "strongly agree" and "agree" responses were calculated. Consensus agreement was defined as ≥75%, partial agreement was defined as 50%–75% agreement, while no agreement was defined as <50%. Qualitative data (*i.e.* open-ended answers to questions as part of the online questionnaire) and answers that reached consensus agreement were used to enhance the questionnaire in the following round of the Delphi process. Each expert was contacted individually to participate in the Delphi study and after their consent, they were invited to the first Delphi round. All experts (100%) participated in round 1. Expert consensus (≥75% agreement) was reached on two of the three sections included in the online questionnaire. One section reached partial agreement (50%–75%) and some modifications were done before the second round of the Delphi process. All experts (100%) participated in round 2 and expert consensus (≥75% agreement) was reached for all sections included in the final version of the online questionnaire. The Checklist for Reporting Results of Internet E-Surveys (CHERRIES checklist) was completed during the survey's design and is presented in the supplementary material.[30]

The survey was written in French and consisted of 17 questions (14 closed and 3 open) with three sections : 1) coaches' profile, 2) coaches' perception of footstrike patterns, 3) practices pertaining to footstrike patterns. In the first section, coaches were asked about their age, years of experience, athlete's standard of competition (elite; high level; competitive; recreational), personal level of qualification and field of expertise (related to "running" including sprint, middle distance, long-distance, hurdles, trail, multi-events; or "other" including throwing, high jump, long jump). In the second section, coaches were invited to indicate how often they modify the landing pattern in a competitive long-distance runner with either a RFS or a MFS or a FFS (0 = never; 10 = every time). If they answered that they never modify footstrike patterns (0 for each of the three questions), they were not asked a supplementary conditional question. If they do modify footstrike patterns, they were asked to indicate one or several reasons to justify why (1 = to decrease the injury risk; 2 = to increase performance (increase of running economy or VO2max); 3 = to shift the load in an injured runner; 4 = other (give details)). In the same section, coaches were asked to rank each pattern (RFS, MFS, FFS) according to their belief in the incidence of injuries (1 = highest injuries incidence; 3 = lowest injuries incidence) and according to the level of performance that each footstrike patten can allow athletes to reach (1 = best performance; 3 = weakest performance). They could also answer "all similar" for these two questions. In the last section, coaches were to rank the effectiveness of several methods of modifying footstrike patterns (1 = global mobility; 2 = global strengthening; 3 = running drills; 4 = verbal advice; 5 = step rate modification; 6 = shoes modification). If their athletes also undergo a strengthening program, coaches were to select the three main muscle groups strengthened (1 = no strengthening; 2 = hip flexors; 3 = hip extensors; 4 = hip abductors; 5 = knee extensor; 6 = knee flexors; 7 = ankle dorsiflexors; 8 = ankle plantar flexors; 9 = intrinsic foot muscles; 10 = "I do, but I don't know which ones"). All possible answers for each question came from the Delphi consensus with the field experts. The entire survey is available in the supplementary material.

Survey analysis

Raw data was exported from "SondageOnline®" to Microsoft "Excel®" software (Version 2110, Microsoft® Excel®, USA) and analysed independently by the research team. Only fully completed questionnaires were taken into consideration in the statistical analysis. Normality conditions were checked for each quantitative variable of the survey. A descriptive analysis based on the coaches' profile was done (means and standard deviation for quantitative variables, number and frequency for qualitative variables). In the "coaches' perception of footstrike patterns" section, a statistical model with a comparison of the frequency of footstrike pattern modifications according to the initial footstrike pattern was performed with a Repeated Measures Analysis of Variance (ANOVA). If significant p-values were found, Bonferroni's post-hoc test was applied. Then, effect of coaches' profile (experience, qualification, competition's standard) was also tested with the same statistical model. In the same section, a Pearson Chi-square test was used to compare the distributions of both the "best" and the "weakest" footstrike pattern related to performance. Then, a Pearson Chi-square test was used to compare the distributions of footstrike patterns causing both the "most injuries" and the "least injuries". A Pearson Chi-square test was used to compare the distribution of footstrike patterns of each category ("best", "weakest", "most injuries", "least injuries") first for competition standard and then for each level of the coaches' qualification. Then, a One-Way Analysis of Variance (ANOVA-1) was used to compare footstrike patterns of each category ("best", "weakest", "most injuries", "least injuries") according to coaches' experience. If significant p-values were found, Tukey's post-hoc test was applied. Description of answer distribution obtained from "field practices pertaining to footstrike patterns" section was calculated in percentages. A sub-analysis including only athletics coaches who described themselves as specialists in long-distance running was performed with the same statistical models presented previously. Statistical analyses were performed using R (Version 4.1.1, R Core

Team, 2017).[31] An alpha level of 0.05 was used for all inferential statistics.

Results

After closing the survey, 172 coaches of the 500 invited participated (34.4%) and among them 114 completed the whole survey (66.2%) and 58 partially completed the survey (33.7%). Table 1 describes coaches' profile (age, experience, personal level of qualification, competition's standard and field speciality). Coaches who completed the survey are essentially specialised in running (90%) and support athletes in competition (76%). One third of coaches train athletes with a national or international level of competition.

Ninety-six (84%) athletics coaches claimed to modify the footstrike pattern of their endurance runners. Repeated Measures ANOVA showed that coaches do not modify the three footstrike patterns with the same frequency ($p < 0.0001$). Bonferroni's test showed that coaches change RFS and FFS more frequently than MFS ($p < 0.0001$). However, they modify RFS and FFS similarly (Figure 1). Repeated Measures ANOVA showed that the frequency of modification does not depend on coaches' experience, qualification level or competition standard ($p = 0.74$; $p = 0.94$; $p = 0.53$ respectively). Reasons indicated by coaches to modify footstrike patterns are first to prevent injury (83%), then to increase performance (66%) and finally to shift the load in an injured runner (37%).

According to 47% of participants, MFS represents the footstrike pattern associated with the best performance during long distance running, while RFS is mostly associated with the weakest performance level (Table 2). Finally, it appears that MFS and FFS are similar in reducing injury prevalence (both have 35%). Coaches' qualification and competition standard do not influence these answers. Experience only influences the choice of the footstrike pattern causing the weakest performance ($p < 0.01$). Tukey's test highlights a difference between MFS - RFS ($p < 0.01$). Coaches with more experience indicated that MFS is weaker than RFS relative to performance. Thirty-two (28%) athletics coaches claim to be specialist in long-distance running. The results of the statistical sub-analysis of the coaches specialised in long distance running were identical to those of the entire sample.

Forty percent of the coaches panel reported the use of "running drills" to modify footstrike patterns. In contrast, 51% and 23% consider footwear and cadence respectively as the least popular methods in practice (Figure 2). In parallel, almost all respondents consider it important to strengthen muscles for modifying footstrike patterns. Coaches firstly strengthen ankle plantar flexors (35,1%), foot intrinsic muscles (29,8%) and ankle dorsiflexors (27,2%).

Table 1. Baseline characteristics of the participants. Qualification corresponds to level of the Belgian League of French-speaking Athletics (LBFA) qualification according to the total number of hours spent in training in their lifetime (1st level = 15 h; 2nd level = 50 h; 3rd level = 120 h; 4th level = 320 h). Competition's standard corresponds to the highest level of competition of their athletes (Recreational = no competition; competitive = regional competition standard; high level = national competition standard; Elite = international competition standard). Field's speciality corresponding to "running" include sprint, middle distance, long-distance, hurdles, trail, multi-events and field's speciality corresponding to "other" include throwing, high jump, long jump.

Variables		Number	(%)	Mean ± SD
Age (years)		114		41.7 ± 16.3
Experience (years)		114		12.3 ± 11.9
Qualification level	None	28	(24.5)	
	1st level (15h)	16	(14.0)	
	2nd level (50h)	20	(17.5)	
	3rd level (120h)	30	(26.3)	
	4th level (320h)	20	(17.5)	
Competition's standard	Recreational	27	(23.6)	
	Competitive	51	(44.7)	
	High level	27	(23.6)	
	Elite	9	(7.8)	
Field's speciality	Running	103	(90.3)	
	Others	11	(9.6)	

Discussion

The purpose of this study was to analyse whether athletic coaches apply the current scientific recommendations on footstrike pattern modification with their endurance runners in practice. Athletic coaches appear to support landing on the midfoot in long-distance runners to increase performance and prevent injuries. Likewise, they seem to largely proscribe RFS which they consider to be more harmful both for performance and injuries. However, according to the current literature, there is no study affirming that the footstrike pattern affects the incidence of sustaining a running-related injury or parameters related to performance in endurance running.[21] Contrariwise, shifting the landing pattern to a FFS in habitual RFS runners could be detrimental to running economy in the short term and increase the load on different anatomical structures.[23,32] The most original finding of this study is the highlighting of a gap between current scientific recommendations and

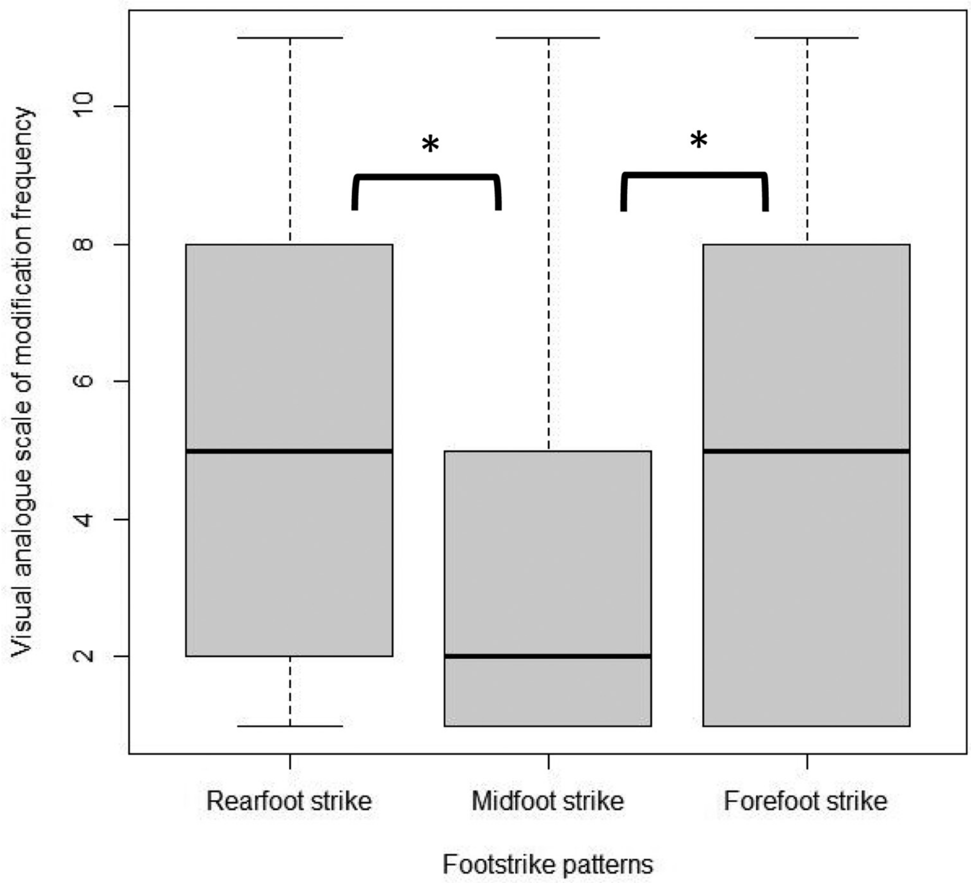

Figure 1. Visual analogue scale of modification frequency according to each footstrike pattern. Boxplots illustrating average and standard deviation of modification frequency in a visual analogue scale (0 = Never; 10 = Every time) obtained for each pattern. "*" highlights significant differences of the average of modification frequency between midfoot strike - rearfoot strike and midfoot strike – forefoot strike according to Bonferroni's test There is no difference of modification frequency between rearfoot strike and forefoot strike.

field practices on the modification of footstrike patterns in endurance running.

For injury prevention, coaches indicate that RFS is more dangerous than the other footstrike patterns and, contrariwise, FFS and MFS are more protective. Only twelve percent of the panel responded that all the footstrike patterns are equivalent in regard to injury prevalence, in agreement with the current recommendations. Indeed, to date, there is no good evidence linking prospectively a biomechanical parameter with running-related injury.[33] The footstrike pattern does not appear to change injury prevalence but may modify injury location in response to their respective joint stresses. Hollander et al.[34] described that running with a MFS has twice the odds of sustaining an injury to Achilles tendon than injured runners using a FFS or a RFS. They also describe that runners with a FFS sustain 2.6 times more calf injuries than the MFS or RFS ones. In contrast, they did not find any relationship between RFS and a specific injury location. However, previous studies have shown that mechanical constraints on the joint and on the eccentric work at the knee are higher in RFS compared to the FFS pattern.[35–37] Among coaches who modify the habitual footstrike, only 3% answered simply "to shift the load in an injured runner". In some cases, the scientific literature recommends temporarily modifying the footstrike pattern of an injured runner to reduce overall load and to shift it. In parallel, a specific strengthening intervention has to be added to prevent another injury.[38] Reassuringly, 99% of the coaches in this survey add strengthening of the foot-ankle muscles to support a change of the landing pattern. Strengthening sessions of foot-ankle muscles allow improvements of the physical capacity of the tissue undergoing the most stress for MFS and FFS runners to reduce loads.[39] This is consistent with the suggested hypothesis of running related injuries which are ultimately due to an excess of loading on anatomical structures compared to their capacity to support it. However, excessive loading is athlete-specific and depends on various factors including lifestyle, recovery, psychological, training load factors.[39]

Table 2. Distribution and p-value of Pearson chi-square test of the best, weakest, most dangerous, safest footstrike patterns in long-distance running according to the coaches panel.

Variables		Rearfoot N (%)	Midfoot N (%)	Forefoot N (%)	All equivalent N (%)	p-value
CONSIDERATION FOR PERFORMANCE	Best Performance	12 (10.5%)	54 (47.3%)	25 (21.9%)	23 (20.1%)	$p < 0.0001$
	Weakest Performance	57 (50.0%)	7 (6.1%)	27 (23.6%)	23 (20.1%)	$p < 0.0001$
CONSIDERATION FOR INJURY	Most Injuries	60 (52.6%)	9 (7.8%)	31 (27.1%)	14 (12.2%)	$p < 0.0001$
	Least Injuries	19 (16.6%)	41 (35.9%)	40 (35.0%)	14 (12.2%)	$p < 0.0001$

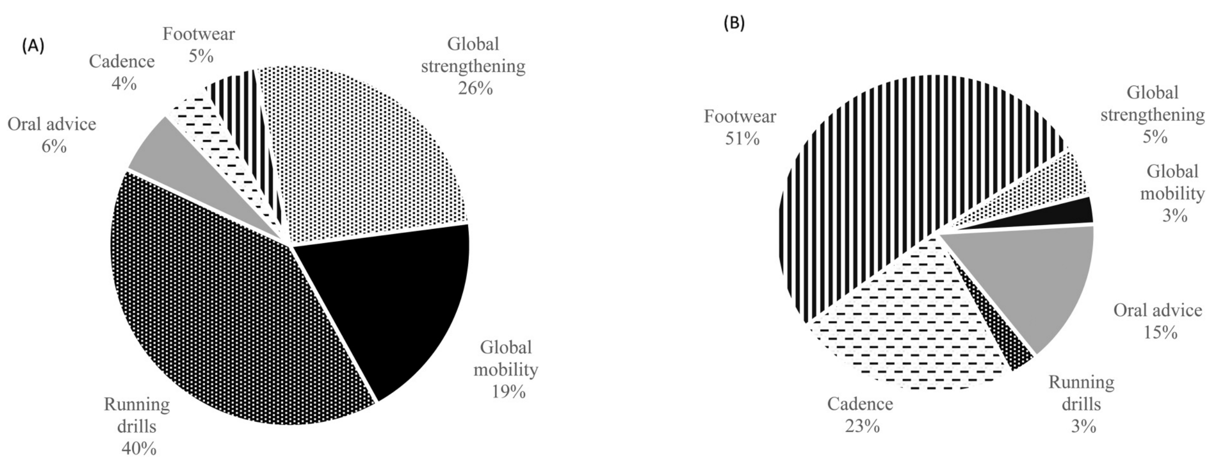

Figure 2. Pie charts of the most (a) and the least (b) popular methods used by coaches to modify footstrike patterns in a runner according to the panel. Running drills are the most popular methods (40%) followed by overall strengthening and mobility (26% and 19% respectively). Footwear is the least popular method (51%) followed by cadence (23%).

Related to performance, RFS is also considered by coaches to be the weakest technique and MFS as the best to perform in a marathon race. A larger part of the panel (20%) consider that all footstrike patterns are equivalent for this kind of event and the reason could be the difficulty in maintaining a MFS or FFS during a very long distance. Indeed, several studies have shown that recreational runners with a MFS or a FFS evolve towards a RFS during a long-distance race and the main cause seems to be plantarflexor fatigue.[10,40,41] The Achilles tendon strength is 18% greater for FFS than MFS and could be harder to maintain in long-distance running.[42] This difference could explain the coaches' preferences for MFS. On the other hand, there is no argument to favour a MFS for a runner compared to a RFS.

MFS appears to be the most desired pattern by athletics coaches to improve performance and decrease injury rates but there is very little evidence of this footstrike pattern in literature. The few studies that included MFS runners have typically grouped them together with FFS to obtain a group with a sufficient number of runners. However, studies which have dissociated MFS and FFS showed differences in tibial shock, peak ground reaction force and loading rate between them.[43,44] According to these two studies, MFS kinetics seems to be closer to the RFS than the FFS kinetics.

Another original finding of this study is the difference between methods described in the scientific literature and those used in the field to modify the footstrike pattern in a runner. The most popular methods found in the literature are changing step rate or footwear.[27,45–47] However, according to the surveyed coaches these two methods are the least popular with 23% and 51% respectively. Interestingly, the most popular method in their view, and used in practice, are "running drills". This is in accordance with Whelan et al.[48] who highlighted the coaches' interest in using running drills to improve running technique. Running drills are defined as repeated movements produced during the running cycle.[47] In the literature, there is a lack of evidence on the implication of running drills to change running technique. Only Azevedo et al.[49] have investigated the effect of adding a running drills program in recreational runners but they did not highlight any modification of kinetic and spatiotemporal parameters. Future studies should analyse the effect of running drills program on running kinematics and on lower limbs characteristics.

This study has some limitations that should be taken into account before generalising the results. Firstly, only fully completed questionnaires were integrated into statistical analysis. Considering that one third of questionnaires were only partially completed, a high number of answers were not taken into consideration. This could lead to a selection bias accounting for the answers of the most "motivated" coaches to finish the survey. This choice allows however to analyse each coaches' profile with their own answers. Secondly, the survey did not include questions about the main sources of information and the limits of accessibility for coaches to the scientific literature. It could be relevant in a future study to understand the reasons, in the athletics field, which could explain the differences between the scientific evidence and current coaches' practices of. Finally, this survey was only distributed in the French-speaking part of Belgium (i.e. Wallonia), so the conclusions drawn from our findings might have limited external validity and differ in other countries or environments.

Conclusion

This study highlights the disparities between scientific recommendations and field practices of athletics coaches for modifying footstrike patterns in endurance runners. Contrary to current scientific literature recommendations, a large part of the coaches modify the habitual footstrike pattern of their endurance runners towards a midfoot strike pattern to improve performance and prevent injury. On the other hand, there are several shortcomings in the scientific literature, such as the lack of studies concerning running drills which are the most popular methods of gait retraining according to the coaches. This study underlines the gap between research and practice and emphasises the need for sports researchers to get closer to the field practices and to the coaches to keep them up to date on the latest scientific evidence. Simultaneously, researchers should prioritise the collection of scientific data related to current track and field coach practices.

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Supplemental material

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References

1. Hulme A, Nielsen RO, Timpka T, et al. Risk and protective factors for middle- and long-distance running-related injury. *Sports Med* 2017; 47: 869–886.
2. Van Poppel D, Van der Worp M, Slabbekoorn A, et al. Risk factors for overuse injuries in short- and long-distance running: a systematic review. *J Sport Health Sci* 2021; 10: 14–28.
3. Ogueta-Alday A, Morante JC, Gómez-Molina J, et al. Similarities and differences among half-marathon runners according to their performance level. *PLoS ONE* 2018; 13: e0191688–e0191698.
4. Casado A, Hanley B, Santos-Concejero J, et al. World-Class long-distance running performances are best predicted by volume of easy runs and deliberate practice of short-interval and tempo runs. *J Strength Cond Res* 2021; 35: 2525–2531.
5. Fokkema T, de Vos R-J, Visser E, et al. Enhanced injury prevention programme for recreational runners (the SPRINT study): design of a randomised controlled trial. *BMJ Open Sport Exerc Med* 2020; 6: e000780–e000787.
6. Stam C and Valkenberg H. Sportblessures in Nederland. 2019; 44.
7. Burke A, Dillon S, O'Connor S, et al. Risk factors for injuries in runners: a systematic review of foot strike technique and its classification at impact. *Orthop J Sports Med* 2021; 9: 9–19.
8. Lieberman DE. What we can learn about running from barefoot running: an evolutionary medical perspective. *Exerc Sport Sci Rev* 2012; 40: 10.
9. Hasegawa H, Yamauchi T and Kraemer WJ. Foot strike patterns of runners at the 15-km point during an elite-level half marathon. *J Strength Cond Res* 2007; 21: 888–893.
10. Larson P, Higgins E, Kaminski J, et al. Foot strike patterns of recreational and sub-elite runners in a long-distance road race. *J Sports Sci* 2011; 29: 1665–1673.
11. Kasmer ME, Wren JJ and Hoffman MD. Foot strike pattern and gait changes during a 161-km ultramarathon. *J Strength Cond Res* 2014; 28: 1343–1350.
12. Hanley B, Tucker CB, Bissas A, et al. Footstrike patterns and race performance in the 2017 IAAF world championship men's 10,000 m final. *Sports Biomech* 2021: 1–10.

13. Hébert-Losier K, Patoz A, Gindre C, et al. Footstrike pattern at the 10 km and 39 km points of the Singapore marathon in recreational runners. *Footwear Sci* 2021; 13: 43–53.
14. Daoud AI, Geissler GJ, Wang F, et al. Foot strike and injury rates in endurance runners: a retrospective study. *Med Sci Sports Exerc* 2012; 44: 1325–1334.
15. Gruber AH, Edwards WB, Hamill J, et al. Ground reaction forces in rearfoot and forefoot running assessed by a continuous wavelet transform. *Med Sci Sports Exerc* 2015; 47: 710.
16. Van der Worp H, Vrielink JW and Bredeweg SW. Do runners who suffer injuries have higher vertical ground reaction forces than those who remain injury-free? A systematic review and meta-analysis. *Br J Sports Med* 2016; 50: 450–457.
17. Goss DL and Gross MT. Relationships among self-reported shoe type, footstrike pattern, and injury incidence. *US Army Med Dep J* 2012: 25–30.
18. Davis IS, Bowser BJ and Mullineaux DR Greater vertical impact loading in female runners with medically diagnosed injuries: a prospective investigation. *Br J Sports Med* 2016; 50: 887–892.
19. Warr BJ, Fellin RE, Sauer SG, et al. Characterization of footstrike patterns: lack of an association with injuries or performance in soldiers. *Mil Med* 2015; 180: 830–834.
20. Messier SP, Martin DF, Mihalko SL, et al. A 2-year prospective cohort study of overuse running injuries: the runners and injury longitudinal study (TRAILS). *Am J Sports Med* 2018; 46: 2211–2221.
21. Anderson LM, Bonanno DR, Hart HF, et al. What are the benefits and risks associated with changing foot strike pattern during running? A systematic review and meta-analysis of injury, running economy, and biomechanics. *Sports Med* 2020; 50: 885–917.
22. Perl DP, Daoud AI and Lieberman DE. Effects of footwear and strike type on running economy. *Med Sci Sports Exerc* 2012; 44: 1335–1343.
23. Gruber AH, Umberger BR, Braun B, et al. Economy and rate of carbohydrate oxidation during running with rearfoot and forefoot strike patterns. *J Appl Physiol* 2013; 115: 194–201.
24. Patoz A, Lussiana T, Breine B, et al. There is no global running pattern more economic than another at endurance running speeds. *Int J Sports Physiol Perform* 2022; 10: 1–4.
25. Nichols R, Germano C, Burke M, et al. The effects of foot strike on running economy in distance runners: a narrative review. *Phys Ther Rev* 2016; 21: 32–37.
26. Barton CJ, Bonanno DR, Carr J, et al. Running retraining to treat lower limb injuries: a mixed-methods study of current evidence synthesised with expert opinion. *Br J Sports Med* 2016; 50: 513–526.
27. Vella S, Bolling C, Verhagen E, et al. Perceiving, reporting and managing an injury – perspectives from national team football players, coaches, and health professionals. *Sci Med Footb* 2021: 1–13.
28. Moore IS. Is there an economical running technique? A review of modifiable biomechanical factors affecting running economy. *Sports Med* 2016; 46: 793–807.
29. Fullagar HHK, McCall A, Impellizzeri FM, et al. The translation of sport science research to the field: a current opinion and overview on the perceptions of practitioners, researchers and coaches. *Sports Med* 2019; 49: 1817–1824.
30. Eysenbach G. Improving the quality of web surveys: the checklist for reporting results of internet E-surveys (CHERRIES). *J Med Internet Res* 2004; 6: e34.
31. Fox J. The R commander: a basic statistics graphical user interface to R. *J Stat Softw* 2005; 14: 1–42.
32. Almeida MO, Davis IS and Lopes AD. Biomechanical differences of foot-strike patterns during running: a systematic review with meta-analysis. *J Orthop Sports Phys Ther* 2015; 45: 738–755.
33. Ceyssens L, Vanelderen R, Barton C, et al. Biomechanical risk factors associated with running-related injuries: a systematic review. *Sports Med* 2019; 49: 1095–1115.
34. Hollander K, Johnson CD, Outerleys J, et al. Multifactorial determinants of running injury locations in 550 injured recreational runners. *Med Sci Sports Exerc* 2021; 53: 102–107.
35. Arendse RE, Noakes TD, Azevedo LB, et al. Reduced eccentric loading of the knee with the pose running method. *Med Sci Sports Exerc* 2004; 36: 272–277.
36. Vannatta CN and Kernozek TW. Patellofemoral joint stress during running with alterations in foot strike pattern. *Med Sci Sports Exerc* 2015; 47: 1001–1008.
37. Kuhman D, Melcher D and Paquette MR Ankle and knee kinetics between strike patterns at common training speeds in competitive male runners. *Eur J Sport Sci* 2016; 16: 433–440.
38. Barton CJ. Managing RISK when treating the injured runner with running retraining, load management and exercise therapy. *Phys Ther Sport* 2018; 29: 79–83.
39. Fredette A, Roy J-S, Perreault K, et al. The association between running injuries and training parameters: a systematic review. *J Athl Train* Epub ahead of print 3 September 2021. DOI: 10.4085/1062-6050-0195.21
40. Bovalino SP, Cunningham NJ, Zordan RD, et al. Change in foot strike patterns and performance in recreational runners during a road race: a cross-sectional study. *J Sci Med Sport* 2020; 23: 621–624.
41. Jewell C, Boyer KA and Hamill J. Do footfall patterns in forefoot runners change over an exhaustive run? *J. Sports Sci* 2017; 35: 74–80.
42. Hashizume S and Yanagiya T. A forefoot strike requires the highest forces applied to the foot among foot strike patterns. *Sports Med Int Open* 2017; 01: E37–E42.
43. Ruder M, Jamison ST, Tenforde A, et al. Relationship of foot strike pattern and landing impacts during a marathon. *Med Sci Sports Exerc* 2019; 51: 2073–2079.
44. Jamison ST, Young B and Davis IS. Are midfoot strike patterns similar to forefoot strike patterns when running in minimal footwear? In: Proceedings of the 40th Conference of the American Society of Biomechanics. Raleigh, USA, August 2nd – 5th, 2016.
45. Allen DJ, Heisler H, Mooney J, et al. The effect of step rate manipulation on foot strike pattern of long distance runners. *Int J Sports Phys Ther* 2016; 11: 54–63.
46. Hall JPL, Barton C, Jones PR, et al. The biomechanical differences between barefoot and shod distance running: a systematic review and preliminary meta-analysis. *Sports Med* 2013; 43: 1335–1353.
47. Moore IS, Pitt W, Nunns M, et al. Effects of a seven-week minimalist footwear transition programme on footstrike modality, pressure variables and loading rates. *Footwear Sci* 2015; 7: 17–29.

48. Whelan N, Kenny IC and Harrison AJ. An insight into coaches' knowledge and use of sprinting drills to improve sprinting technique and performance. *Int J Sports Sci* 2016; 16: 182–190.

49. Azevedo APS, Barbanti VJ and Amadio AC. Usage of running drills in an interval training program: implications related to biomechanical parameters of running. *J Strength Cond Res* 2015; 29: 1796–1802.