ACUTE EFFECTS OF SHOE CONDITIONS ON FOOT STRIKE PATTERN OF RUNNERS WITH DIFFERENT HABITUAL PATTERNS

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Multiple influential studies argued that minimal footwear promotes forefoot running whereas cushioned footwear promotes rear foot strike. We readdressed effects of footwear on the foot strike pattern considering runners' habitual patterns. Based on the observed foot strike angle, we divided 9 participants into rearfoot, midfoot and forefoot runners. All participants then ran wearing 3 different shoes: performance boosting shoes, conventional shoes, and minimal shoes. We found a significant effect of shoes on foot strike angle and the interaction between the group and shoes. Contrary to well accepted arguments of previous studies, performance boosting shoes with thick outsoles induced the rearfoot group to run with decreased foot strike angle more effectively than minimal shoes. Our finding also revealed the hitherto seldom investigated effect of habitual patterns on adaptability.

KEYWORDS: endurance running, running shoes, running pattern, foot strike angle

INTRODUCTION: The growing popularity of endurance running has led to increased research on racing shoes (Hoogkamer, 2020). In particular, highly cited previous studies claimed that minimal footwear (MIN) promotes forefoot running, and enables the wearer to take mechanical advantages of the forefoot running pattern like short stance period (Lieberman, 2010; Davis, 2021). Therefore, compared with conventional footwear (CON) with more cushioned soles, MIN, which minimizes interference with natural foot motion due to its low heel drop and light weight, has long been preferred by recreational runners and professional marathoners (Esculier, 2015; Coetzee, 2018).
More recently, shoes with structures completely different from MIN or CON have been devised (Hébert-Losier, 2022; Hoogkamer, 2020). The prototype of Alphafly (AF) equipped with air springs, thick curved midsole, and carbon-fiber plates with high energy return especially earned great attention. Prior research compared the effects of AF on running economy with those of other racing shoes (Hoogkamer, 2018), and the effect of the structure of AF on the performance of middle and long-distance runners was also studied (Hébert-Losier et al., 2022). However, the effects of the entirely distinct structure of AF on the running pattern has not yet been addressed. Specifically, the differences in sole thickness, curvature between the AF and MIN may impact foot strike pattern, but this has not yet been systematically investigated. In addition, although multiple studies tried to address the effect of AF or MIN on performance or the risk of injury (Hoogkamer, 2019; Firminger, 2016; Dinato, 2021; Linares-Martín, 2022), their results are applicable only to habitual rearfoot runners.
In this study, we examine the effect of habitual foot strike pattern and distinct shoe structures on the change in the foot strike pattern. We also aim to investigate any possible interaction between the two factors of habitual running patterns and shoe structures.

METHODS: Nine male recreational runners (Mean ± SD: age 29.0 ± 3.8 years; height 1.75 ± 0.04 m; body mass 73.7 ± 4.8 kg) participated in this study. All aspects of the study conformed to the principles and guidelines described in the Declaration of Helsinki, and the Institutional Review Board of approved the protocol. Participants, who 1) ran more than twice per week with at least 30 min duration per each run, 2) completed a 10 K run in less than 40 min within the past year, and 3) had not have any injury in the previous 6 months, voluntarily provided written informed consent prior to participation.

Participants visited the laboratory on two separate days at least 48 h apart but within 2 weeks. On the first visit, after the anthropometric measurements, the participants performed an incremental test to exhaustion in order to determine the intensity of running on the next visit and to measure the habitual foot strike angle (FSA) when running with their own shoes. We calculated FSA by subtracting the angle of the foot during standing from the angle at foot strike (Altman, 2012). On the second visit, we provided the participants with three pairs of shoes: minimal shoes (MIN, Asics SORTIEMAGIC RP5, average shoe mass: 160 g, heel drop: 0 mm, minimalist index: 76%), conventional cushioned running shoes (CON, Adidas UltraBoost 20, average shoe mass: 310 g, heel drop: 10 mm, minimalist index: 12%) and performance boosting shoes (AF, Nike Air zoom α-fly next%, average shoe mass: 210 g, heel drop: 8 mm, minimalist index: 20%). Any participant had not used any of these shoes before the experiment. After 5 min warmup, each participant performed 3 sets of 7 min run (1 min at 70%, 1 min at 80%, and 5 min at 90% of maximal velocity). During each set, the participant wore each of the three footwear in a randomized order. 30 min break was provided between each 7 min run.
Kinematic data were collected by a motion capture system with 12 cameras (Optitrack Prime 13, Natural Point, Oregon, USA; acquisition rate 200 Hz). Ground reaction force (GRF) data were collected using an instrumented treadmill (Bertec Corporation, OH, USA; acquisition rate 1000 Hz). Forty reflective markers were placed on the whole body. Both motion capture and GRF data were filtered with a zero-lag low-pass fourth order Butterworth filter with a cut-off frequency of 20 Hz (Kristianslund, 2012). Each event of foot strike was determined based on vertical GRF thresholds of 40 N. Data during the last 2 min (at least 158 steps) of the entire 7 min run were used for analysis (Riazati, 2019).
Multiple 3 × 3 factor (3 shoe conditions × 3 habitual FSA group) repeated measures ANOVAs were used to assess the effects of factors on the outcome variables (average and standard deviation of FSA) and the interaction between the factors if any. The post-hoc test using the Bonferroni method was employed where appropriate. SPSS (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses with a criterion alpha level of 0.05.

RESULTS: Table 1 shows the results of the incremental tests on the first visit. Depending on the FSA measured in the test, participants were divided into rearfoot, midfoot or forefoot group.

Table 1: Results of incremental test

Group	Habitual foot strike angle	Maximal velocity
Rearfoot (n=3)	18.83 ± 5.92°	4.12 ± 0.41 m/s
Midfoot (n=5)	6.86 ± 2.53°	4.35 ± 0.22 m/s
Forefoot (n=1)	-1.04°	3.96 m/s

Figure 1 shows the results from post-hoc multiple comparisons. Average FSA significantly decreased in AF and MIN conditions compared to CON condition for the rearfoot group. Standard deviation of FSA significantly decreased for the midfoot group compared to the rearfoot group. During the 3 sets of 7 min run on the second visit, participants tend to have smaller FSA than their habitual FSA measured on the first visit. Figure 1-(c) shows the data from a representative participant.

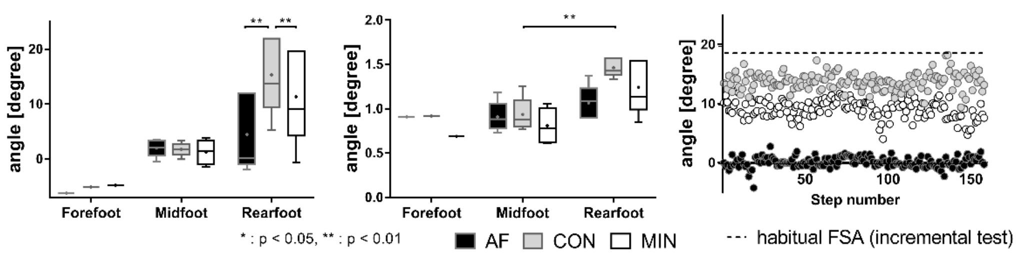

Figure 1: The distribution of FSA values for each group (Forefoot, Midfoot or Rearfoot) and shoe condition (AF, CON or MIN). (a) Average of FSA during the 2 min. (b) Standard deviation of FSA

during the 2 min. Dots and lines in the box indicate mean and median values, respectively. (c) FSA of a representative participant (SUB1) during the 2 min.

The results of two-way ANOVA for the average and standard deviation of FSA are reported in Table 2. A significant main effect of shoe condition and group × shoe condition interaction was observed for the average of FSA, and significant main effect of the group was observed for the standard deviation of FSA.

Table 2: Statistical analysis results of all outcome measures for group of habitual FSA (G), shoe condition (C), and interaction (G × C). (* : $p < 0.05$, ** : $p < 0.01$)

Dependent variable	Effects	F value	*p*-value
Average of FSA (deg)	G	3.666	0.091
	C	4.604	0.033 *
	G × P	6.122	0.006 **
SD of FSA (deg)	G	16.414	0.004 **
	C	1.186	0.339
	G × P	0.462	0.763

DISCUSSION: We found a significant main effect of the shoe properties on FSA and the interaction between the group and shoe condition. The effect of the shoe structures on running pattern was the largest in the rearfoot group, and AF induced the lowest FSA. These results show that AF can reduce FSA of rearfoot runners and change the patterns of rearfoot runners to different patterns that are closer to forefoot running pattern. In addition, comparing the shoe-induced change in FSA between AF and MIN, it is clear that AF induces forefoot running more effectively than MIN.

Furthermore, rearfoot group show relatively higher deviation of FSA compared to the midfoot group. A previous study (Giandolini, 2017) also reported that the rearfoot runner has large deviation of the running pattern. However according to our results, AF yielded the smallest deviation even for the rearfoot group. Furthermore, comparing the shoe-induced change in the variability of FSA between AF and MIN, it can be claimed that the effect of AF on running pattern change is more consistent and robust than that of MIN.

To summarize, our results support that AF, even compared with MIN, changes the running pattern more effectively and more robustly. This finding can be an important counterexample to the well accepted claim by influential previous studies. Linares et al. reported that MIN induces barefoot running with midfoot or forefoot strike, and attributed such pattern changing function of MIN to the thin soles that allow the runners to exploit the anatomical structure of human foot soles (Linares-Martín, 2022). However, AF changed the pattern of habitual rearfoot runners towards barefoot running better than MIN despite the soles which are much thicker than the soles of MIN. At least, the general opinion that habitual shod runners are mostly rearfoot strike runners (Lieberman, 2010) needs to be reassessed and updated; the development of the new shoe techniques can provide more counterexamples.

However, exactly which feature of AF affects the running performance is still controversial (Hébert-Losier, 2022), and likewise, we cannot conclude the main mechanism how AF induced rearfoot runners to run with decreased FSA better than other shoes. Another limitation of this initial pilot study is insufficient number of participants in each group.

Nevertheless, to our knowledge, this is the first study that addressed the acute change from the habitual running pattern to the shoe-induced pattern. Our results suggest that recreational runners need to consider their habitual patterns as well as the biomechanical effects of shoes when they intend to train their running pattern. As a future work, research on physiological and biomechanical effects of the shoe-induced pattern and their dependence on the existing habitual pattern needs to be performed.

CONCLUSION: This study shows that AF reduces FSA more effectively and more robustly compared CON or MIN. According to previous studies, more minimal footwear changes the running pattern from rearfoot strike pattern to midfoot or forefoot strike pattern more effectively (Sinclair, 2014; Wang, 2020; Linares-Martín, 2022). However, as shoe technology develops and the structure of footwear diversifies, this commonly accepted statement is no longer valid. There exists non-minimal footwear that changes the rearfoot strike pattern into midfoot or forefoot strike more effectively than minimal footwear.

Our finding also concludes that habitual running patterns can affect the extent to which the shoe structure changes the running pattern. Therefore, it is necessary to consider both runners' habitual pattern and the mechanical property of the shoes to maximize the effects of training for running pattern modification.

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