FOOTSTRIKE PATTERNS OF HIGH AND MID-MILEAGE NON-REARFOOT RUNNERS DURING AN EXHAUSTIVE RUN

Jan Urbaczka[1] and J. Freedman Silvernail[2] and Daniel Jandacka[1]

Department of Human movement studies, University of Ostrava, Ostrava, Czechia[1]; Department of Kinesiology and Nutrition Sciences, University of Nevada Las Vegas, Las Vegas NV 89154, USA[2]

The purpose of this study was to identify the effect of fatigue on footstrike patterns in two groups of habitually non-rearfoot runners. Twenty-eight runners participating in this study were divided into two groups by their weekly mileage. Participants completed a VO2max test to determine the velocity for the fatiguing run. Kinematic, physiological and biochemical data from the beginning and the remaining 3 minutes of fatiguing treadmill run were obtained. The overall time for fatiguing run exceeded 40 minutes (t = 48,1 ± 3,6 min.). The foot angle at the instant of initial contact significantly changed in both groups following fatigue. However, there was significantly less change in the high-mileage group of runners than in the mid-mileage group. The findings of the study suggest that utilizing consistent footstrike patterns in fatigue could probably depend on the fitness level of particular runner.

KEYWORDS: running, fatigue, minimalist shoes.

INTRODUCTION: To date, there has been little agreement on what is an appropriate running technique to prevent injuries and run economically (Lorenz & Pontillo, 2012; Moore, 2016; Thompson, Lee, Seegmiller, & McGowan, 2015). The majority of runners still contact the ground with a rearfoot strike, usually wearing cushioned running shoes (Hasegawa, Yamauchi, & Kraemer, 2007). However, over past two decades, there is an increasing number of athletes utilizing non-rearfoot footfall patterns (i.e. midfoot or forefoot), sometimes using minimalist shoes or running barefoot (Daoud et al., 2012; Davis, 2014; Gruber, Edwards, Hamill, Derrick, & Boyer, 2017; Lieberman et al., 2010).
Most studies in running biomechanics are carried out on rearfoot strikers. Previous studies have shown kinematic and kinetic changes in fatigue leading to possible injury occurrence and performance declines (J. Mizrahi, Verbitsky, & Isakov, 2000; Joseph Mizrahi, Verbitsky, Isakov, & Daily, 2000; Siler & Martin, 1991). So far, there has been little evidence for these implications in non-rearfoot strikers (Jewell, Boyer, & Hamill, 2016). Furthermore, there have been no studies comparing the effect of fatigue on footfall patterns in highly and mid experienced habitual non-rearfoot strikers using minimalist footwear.
The purpose of this study was to compare kinematic characteristics of footfall patterns in two habitually non-rearfoot striking groups at different fitness levels during prolonged exhaustive run on a motorized treadmill.

METHODS: Twenty-eight habitually non-rearfoot runners (14 males, 6 females), who had no musculoskeletal injury history, participated in our study. All participants have been using minimalist shoes at least 1 year prior to the start of our study. Runners were divided into two performance groups according to their week mileage (High-mileage (HP) – 72,91 ± 14,92 km; Mid-mileage (MP) – 35,23 ± 7,08 km). Groups were paired by age and height of runners (HP: 28,2 ± 7,48 yrs, 179,07 ± 8,96 m; MP: 28 ± 7,73 yrs, 178,43 ± 8,73 m). All participants were informed of the experimental procedures and each provided written consent to participate. The study protocol was approved by the Ethics Committee of pedagogical faculty at the University of Ostrava.
Participants underwent two tests with a minimum of two weeks apart. At the first laboratory visit, participants performed a VO2max test to acquire their second ventilatory threshold (VT2) values. At the second visit, participants performed fatiguing run on a treadmill (Bertec, Bertec Corp., USA). Treadmill velocity was set at the value corresponding with VT2 – 5% velocity during VO2max test (HP: 15,15 ± 1,95 km*h^{-1}; MP: 11,79 ± 1,42 km*h^{-1}). Kinematic, physiological and biochemical data were captured at the beginning (BEG) and in the remaining

3 minutes of running protocol (END). All participants wore the same type of laboratory shoes (Inov8 F-lite 195) during their second laboratory visit.
Three-dimensional kinematic data of the pelvis, leg and foot were obtained by an optoelectronic stereophotogrammetry system consisting of eight cameras sampling at 240 Hz (Qualisys, Oqus, Sweden). Breath-by-breath system (Blue Cherry, Geratherm Medical AG, Germany) with a chest belt monitor (Polar Electro H9, Kempele, Finland) and portable lactate monitor (Lactate Pro 2, Cosmed, Rome) were used in the acquisition of physiological and biochemical data.
Trajectory data were processed using QTM (Qualisys track manager, Qualisys, Sweden) and Visual 3D software (C-motion, Rockville, MD, USA). The kinematic data were filtered using a low-pass Butterworth filter with a 10 Hz cut-off frequency. Angles in the lower limb joints were determined at the instant of initial contact (IC). All calculations were performed in the sagittal plane. Statistical analysis was performed using IBM SPSS software (IBM, Somers, NY). The primary outcome from the kinematic data was the foot angle (global inclination angle between the foot and the surface of the treadmill). After the test of variables normality (Shapiro-Wilk test) differences between each group (HP/MP - BEG/END) were tested by repeated measures two-way ANOVA. The level of significance was fixed at $P < 0.05$. Partial eta-squared (ηp^2) values were calculated as measures of effect size, and values <0.01, 0.01-0.06, 0.07-0.14, and >0.14 were considered to be trivial, small, medium, and large effect sizes, respectively (Cohen, 1990).
RESULTS: The results are shown in Table 1 and Figure1. The results from kinematic analysis showed significant effect of fatigue for Foot angle during IC ($P = 0,006$; $\eta p^2 = 0,260$). Blood lactate analysis used for indication of fatigued state of runners showed significant effect between groups ($P = 0,009$). The overall time for the second test was more than 40 minutes (t = 48,1 ± 3,6 min.).

Table 1: Kinematic and biochemical analysis

	High-mileage		Mid-mileage		Fatigue P	Group P	P [interaction
Variable	BEG	END	BEG	END	[condition]	[condition]	fatigue*group]
IC foot angle (°)	63,5 ± 4,7	64,9 ± 4,6	64,8 ± 7,3	69,5 ± 7,5	0,006*	0,175	0,106
Stride frequency	166,8 ± 9,6	170,8 ± 11,1	165,7 ± 9,1	170,2 ± 8	0,007*	0,800	0,887
Blood lactate (mmol/l)	-	8,1 ± 1,8	-	6,3 ± 1,3	0,009*	-	-
Fatigue run time (min)	48,1 ± 4,1		48,1 ± 3,3		0,875		
Treadmill velocity (m/s)	4,2 ± 0,54		3,28 ± 0,4		0,000*		

Displayed are group means ± SD, p-values for conditions and interaction.
* Significant group differences (P > 0.05)

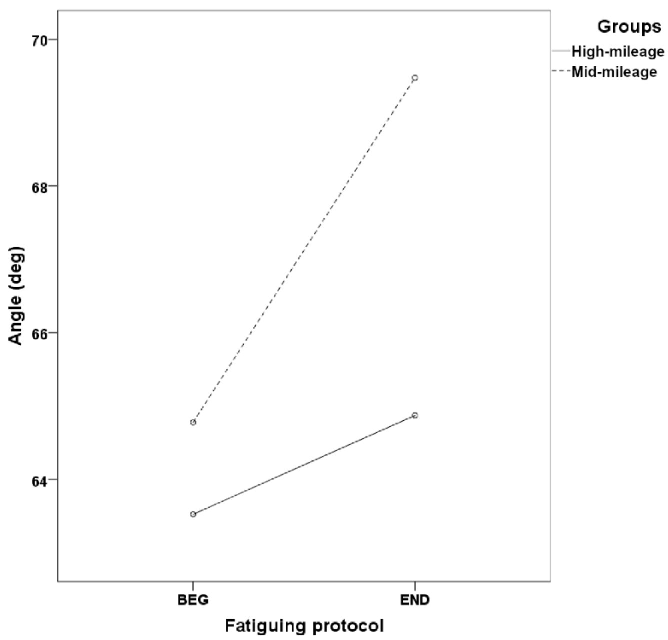

Figure 1: Foot angle at initial contact

DISCUSSION: The present study sought to determine the effect of running-induced fatigue on the footfall patterns of HP and MP group of habitually non-rearfoot strikers. Both groups were significantly affected by fatigue in a foot angle during initial contact (see Table 1.). There are no significant differences in this parameter between groups or in interaction. However, both conditions showed medium change (Group $\eta p^2 = 0{,}07$; Interaction $\eta p^2 = 0{,}098$). Figure 1 presents clearly visible different trends in reaction to fatigue by HP and MP. HP group shows only a small change in foot angle (63,5 ± 4,7 vs. 64,9 ± 4,6; es = 0,29), which refers to utilizing non-rearfoot pattern. MP group shows large change (64,8 ± 7,3 vs. 69,5 ± 7,5, es = 0,64) in foot angle, which refers to transitioning into landing more posteriorly (Altman & Davis, 2013; Breine et al., 2017). Blood lactate analysis has shown that all runners (HP: 8,1 ± 1,9; MP: 6,3 ± 1,3) were above normal values for the second ventilatory threshold (VT2) at the end of a fatiguing run (Hofmann & Tschakert, 2017).
The findings from an MP group are consistent with those of Jewell (Jewell et al., 2016). His study showed significant kinematic and kinetic changes in the group of recreational runners during treadmill run to volitional exhaustion (Jewell et al., 2016). The results from an HP group, on the other hand, contradicts with findings from previous studies, which confirmed significant kinematic changes in fatigued state regardless of the skill or fitness level of runners (Derrick, Dereu, & Mclean, 2002; Hasegawa et al., 2007). A possible explanation for only a small change in the footstrike patterns in an HP group in fatigue might be the use of minimalist shoes during the test. The aforementioned studies used cushioned shoes. Minimalist shoes do not absorb the impact of striking the ground in the same manner as cushioned shoes (Esculier, Dubois, Dionne, Leblond, & Roy, 2015). Consequently, it may be painful and economically inconvenient for the runner to maintain a rearfoot strike at high speed for a long time (Hamill, Russell, Gruber, & Miller, 2011; Squadrone, Rodano, Hamill, & Preatoni, 2015). Due to higher fitness level (larger blood lactate tolerance and mileage) participants from an HP group were probably able to maintain a non-rearfoot strike pattern to minimize metabolic cost despite increasing fatigue (Gruber, Umberger, Braun, & Hamill, 2013; Hunter & Smith, 2007).
One unanticipated finding was that stride frequency has not changed between groups in fatigue (P = 0,815). Furthermore, it was higher (HP: P = 0,127; MP: P = 0,012) during fatigued running in both groups which is contradictory to previous studies (Hausswirth, Bigard, & Guezennec, 1997; Hunter & Smith, 2007). This could occur as a result of different muscle adaption to fatigue based on fitness level (Fletcher & MacIntosh, 2018; Jewell et al., 2016; Ogueta-Alday, Rodríguez-Marroyo, & García-López, 2014).

CONCLUSION: The evidence from this study suggests that runners are not able to maintain consistent footstrike angle during prolonged exhaustive run. However, the high-mileage group increased their foot angle with only a small practical significance compared to the mid-mileage group during a prolonged exhaustive run. Further research should be done to investigate if there is a footstrike pattern change in habitually non-rearfoot runners after prolonged exhaustive run.

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