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Influence of Foot Strike Pattern and Local Fatigue of Plantar Flexors and Dorsiflexors on Plantar Pressure during Running

Der Einfluss von Fußaufsatztechnik und lokaler Muskelermüdung der Plantar- und Dorsalflexoren auf die plantare Druckverteilung beim Laufen

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Summary

- **Hintergrund:** Changes in foot strike pattern by local muscle fatigue can increase the rate of injury in running. The aim of this study was to investigate the influence of foot strike pattern and local muscle fatigue of the plantar flexors and dorsiflexors on plantar pressure distribution while running barefoot on a treadmill at three different speeds.
- **Methods:** The study included 52 male voluntary forefoot vs. rearfoot runners of similar age and body mass. Each group completed two tests, with an interval of 3-7 days. The fatigue protocol included the isometric maximum force test consisting of two sets with a maximum contraction and the isokinetic endurance test consisting of ten sets of six concentric contractions (10 s set break, ω=60°/s). Variance analysis with repeated measurements was used to check the differences.
- **Results:** The fatigue protocol reduces the efficiency of the plantar flexors and dorsiflexors, which perform different foot strike functions during running. As expected, the plantar pressure distribution under the foot was different depending on the foot strike pattern and local muscle fatigue. The pressure maxima was reduced under the exposed foot regions after fatigue, that means the maximum pressure is reduced after local muscle fatigue.
- **Conclusion:** For injury prevention, the foot strike pattern should be varied to relieve in particular the foot area under the heel and the forefoot. In the case of forefoot strikers, checks should be made as to whether they are habitual forefoot strikers.

Zusammenfassung

- **Hintergrund:** Eine Veränderung der Fußaufsatztechnik durch lokale Muskelermüdung kann zur Erhöhung der Verletzungsrate im Laufsport führen. Ziel der Studie war die Untersuchung des Einflusses der Fußaufsatztechnik und der lokalen Muskelermüdung der Plantar- und Dorsalflexoren auf die plantare Druckverteilung beim Barfußlaufen auf dem Laufband.
- **Methoden:** An der Studie nahmen 52 freiwillige Vor- und Rückfußläufer vergleichbaren Alters und Körpermasse teil. Jede Gruppe absolvierte zwei Testabläufe, mit einem zeitlichen Abstand von 3-7 Tagen. Das Ermüdungsprotokoll umfasste den isometrischen Maximalkrafttest, bestehend aus zwei Sätzen mit einer maximalen Kontraktion und einem isokinetischen Ausdauertest, der sich aus zehn Sätzen à sechs Wiederholungen konzentrischer Kontraktionen der Plantar- und Dorsalflexoren mit einer Winkelgeschwindigkeit von 60°/s zusammensetzte.
- **Ergebnisse:** Zur Überprüfung der Unterschiede wurde eine zweifaktorielle Varianzanalyse mit Messwiederholung berechnet. Das Ermüdungsprotokoll reduziert die Leistungsfähigkeit der Plantar- und Dorsalflexoren, die verschiedene Funktionen für den Fußaufsatz beim Laufen erfüllen. Wie erwartet, unterschied sich die plantare Druckverteilung unter dem Fuß in Abhängigkeit von der Fußaufsatztechnik und der lokalen Muskelermüdung. Nach Ermüdung reduzierten sich die Druckmaxima unter den exponiert belasteten Fußzonen, d. h., das Druckmaximum reduziert sich nach lokaler Muskelermüdung.
- **Fazit:** Zur Verletzungsprävention sollte die Fußaufsatztechnik variiert werden, um besonders den Fußbereich unter der Ferse bzw. dem Vorfuß zu entlasten. Bei Vorfußläufern sollte kontrolliert werden, ob Sie gewöhnliche Vorfußläufer sind.

KEY WORDS:
Forefoot, Rear Foot, Isometric Strength Test, Isokinetic Endurance Test

SCHLÜSSELWÖRTER:
Vorfußaufsatz, Rückfußaufsatz, isometrischer Krafttest, isokinetischer Ausdauertest

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Introduction

Nowadays, running can be considered one of the most important leisure activities (9). In recent years, many studies have addressed the various foot strike patterns in running (6,13,18,24,34).

Foot strike is defined by that part of the foot which makes first contact with the ground in running. Thus, differentiation can be made between landing on the heel (rearfoot strike), on the heel and ball of the foot (midfoot strike) and ball of the foot (forefoot strike) (6,10,14,17,31). Studies of the foot strike pattern concentrate on rearfoot and forefoot runners (1,19,30). Studies on the use of foot strike pattern have brought conflicting findings. Several studies determined that the majority of those examined were rearfoot runners, while other studies identified forefoot running as the natural mode.

Figure 1
Positioning of the Subject on the Isomed 2000-Dynamometer.

A biomechanical comparison of the foot strike pattern showed that the passive peak of ground reaction force and exercise intensity is lower in forefoot and midfoot runners than in rearfoot runners (6). More recent studies found that the landing and subsequent ground reaction forces are lower in forefoot runners (4, 29, 31). Forefoot runners are characterized by a weakened or missing initial passive force peak, but an elevated second active force peak (29, 31). In rearfoot runners, by contrast, greater passive ground reaction force with weakened active peak strength was found.

The results on plantar pressure distribution after fatiguing runs over various distances (10-km up to marathon or 30-min runs) vary. An increase in forefoot stress after running fatigue has been measured (3, 41, 42) and also after local fatigue of the plantar and dorsiflexors (35). The influence of running fatigue on the pressure distribution under the individual foot areas is not clear. Some studies found a decrease of pressure values under the heel (2, 3, 16, 42), while other studies reported a significant increase (40, 41). A significant reduction in pressure values under the toes, (14, 35, 41, 42), but no differences were found in two other studies (3, 40).

It is assumed that fatigue influences the foot strike pattern, whereby consistent findings on this are still missing (10,24). Fatigue can lead to a change in foot strike pattern during the run and increase the risk of injury to the lower extremities (18,28).

At present, an injury rate of ca. 30 % is assumed in runners (12). Hereby, more than 90 % of the running-associated complaints affect the lower extremities, with ca. one-third each for the knee, lower leg and foot (15, 21).

There is different stress in forefoot, midfoot and rearfoot running affecting the bones, joints, ligaments, tendons and musculature. If the foot strike pattern is unconsciously changed during the run, the stress areas are also changed. This may lead to overload reactions (Achilles tendon complaints, knee pain) and various injuries, such as torn ligaments, midfoot break, lateral ligament injury, meniscus injuries, internal ligament injuries, cruciate knee ligament injuries, lateral capsular ligament injuries).

In order to prevent these injuries, it is necessary to determine whether there is muscular dysbalance and how the foot strike pattern changes in fatigue (36). In running fatigue, however, it is only partially possible to differentiate how the pressure maximum under the individual foot zones changes. For precise analysis, there are standardized local fatigue protocols of the musculature of the knee and/or ankle prior to the run. In running at high intensity, the dorsiflexors and plantar flexors of the foot are active between 50-85 % of the running cycle and become fatigued (25).

Problem and Objective

The results of studies on the influence of fatigue on plantar pressure in running based on the various fatigue protocols (exhaustive running, jumping or local fatigue of the ankle and knee joint musculature) and examination of various foot zones are not unequivocally clear. The foot strike pattern has not been given much attention in the studies. Hypothetically, it is expected that the plantar pressure distribution under the foot differs in dependence on the foot strike pattern and local muscle fatigue. Rearfoot runners experience greater plantar pressure maxima under the heel and lower pressure maxima under the forefoot than forefoot runners. The plantar pressure maxima under the foot change depending on the foot strike pattern as a result of local fatigue of the dorsiflexors and plantar flexors.

Material and Methods

The study consisted of a training session and two test sessions, performed on different days. Since there were no important differences in the results of the two tests, only the findings of Test 2 are described below. The study was designed as a cross-sectional study of two voluntary groups of runners of comparable age and weight but different foot strike patterns (forefoot vs. rearfoot): forefoot group (N=26; age=26.9 (3.8) yrs; weight=79.6 (8.9) kg; height=182.3 (6.1) cm; rearfoot group (N=26; age=26.9 (3.8) yrs.; weight=79.0 (8.7) kg; height=180.6 (4.7) cm). On average, the subjects performed two to three runs per week. All subjects were healthy at the time of measurement. Prior to the start of the study, an ethics vote was obtained from the Medical Council Hamburg.

After warm-up and acclimatization to the treadmill (h/p/cosmos quasar-FDM-THQ-M, Zebris Medical GmbH, Germany) by 10-minute exercise at a speed of 9 km/h, the baseline was recorded for the three speeds (11, 13 and 15 km/h). The subjects ran barefoot for one minute at each speed. At the end of the minute, a running cycle of 30 s was recorded using the manufacturer's software (FDM-T Version 0.39, Zebris Medical GmbH).

During the acclimatization, the foot strike pattern was recorded and estimated using the measuring software. The subject was entered in the study as a rearfoot runner only when there was an initial passive strength maximum in the heel-to-toe behavior in both legs. If there was no initial passive strength maximum in the heel-to-toe behavior in both feet, the subject was entered as a forefoot runner.

Then the subjects performed the isometric maximum strength test and the isokinetic endurance test (fatigue protocol) in randomized sequence for the left and the right leg on the IsoMed 2000 Dynamometer, with application of the one-leg foot adapter (D&R FERSTL GmbH, Germany). To become accustomed to the test equipment and for warm-up of the target musculature, a submaximum contraction was set in the equipment prior to the isokinetic maximal strength test. The subjects were positioned as stipulated by the manufacturer (Fig. 1).

The subjects were seated, the thighs were fixed and a 90° angle set in the knee and in the ankle. The rotation axis of the upper ankle (thickest part of the Malleolus lateralis to the medial Malleolus) and of the Dynamometer were adjusted by laser. The foot was held on the plate by a belt. The backrest was tilted to 70° (Fig. 1).

The maximum strength test consisted of two sets with a 3-minute pause and one maximum contraction each. The strength was increased in slope reaching a maximum after 2-3s. The isokinetic endurance test consisted of 10 sets à six repeats of the plantar and dorsiflexors, at an angular velocity of 60°/s. The pause between sets was 10s. The extent of movement was set at maximal 55° for plantar flexion and 25° for dorsiflexion. The test began with plantar flexion. Immediately thereafter, the treadmill test was performed, followed by the fatigue protocol of the other leg and a treadmill test.

The data of the fatigue protocol were assessed using the manufacturer's software (IsoMed Analyse V.1.0.5), (Table 1, Fig. 2). The higher maximum torque of each set in the isometric maximum strength test was taken as the test value (M_x). The mean of the torque maxima of all 60 contractions (M_{60}) was determined for the isokinetic endurance test. The fatigue index was formed as a quotient of the two values in the equation: Fatigue index=M_{60}/M_x (32).

The reproduceability of the strength data was obtained for another sample and was good to excellent with intraclass correlation values (ICC (3.1)) for the plantar, resp. dorsiflexors in the isometric maximal strength test of 0.96-0.99, resp. 0.90-0.98, in the fatigue protocol of 0.89-0.97, resp. 0.87-0.97 and in the fatigue index of 0.84-0.96, resp. 0.76-0.94 (32).

The statistical assessment comprised description with arithmetic mean values and standard deviation. The data were checked for normal distribution and homogeneity of variance using the Kolmogorov-Smirnov and the Levene tests. To check the differences in strength and treadmill data, variance analyses with repeated measures in the customary linear model were used. For strength data, the intrasubject effect leg (left and right leg) and the intersubject effect foot strike (forefoot vs. rearfoot, Table 2) were calculated. To compare the fatigue index of the dorsiflexors and plantar flexors, a two-factor variance analysis with the intrasubject effects muscle (dorsiflexors and plantar flexors) and leg (left and right leg), and the intersubject effect foot strike (forefoot vs. rearfoot) were calculated.

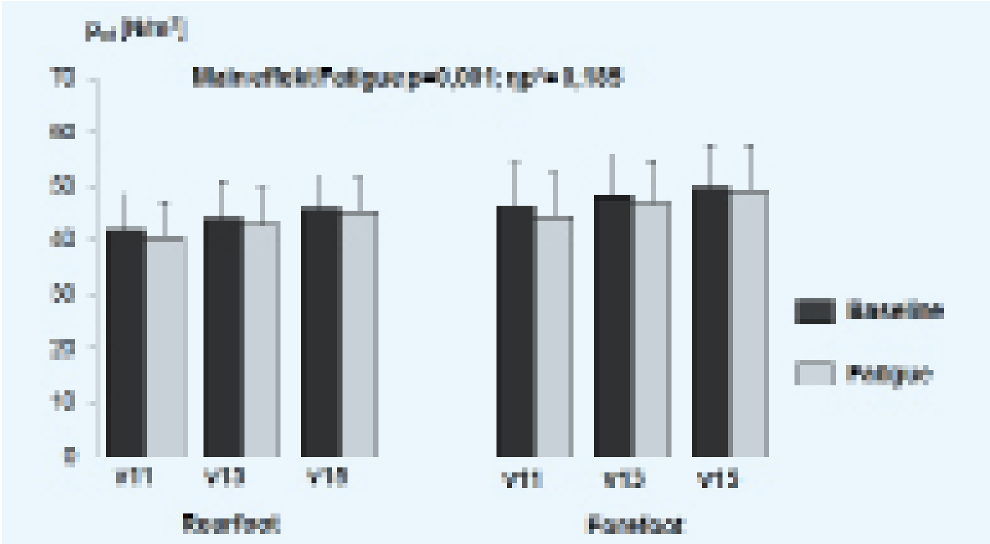

Figure 2

Comparison of the fatigue index of the dorsiflexors and plantar flexors of rearfoot and forefoot runners, itemized for the left and right leg (arithmetic mean and standard deviation), test values of the between-subjects effect (BE) foot strike and the interaction muscle*foot strike (p and ηp^2), N=52.

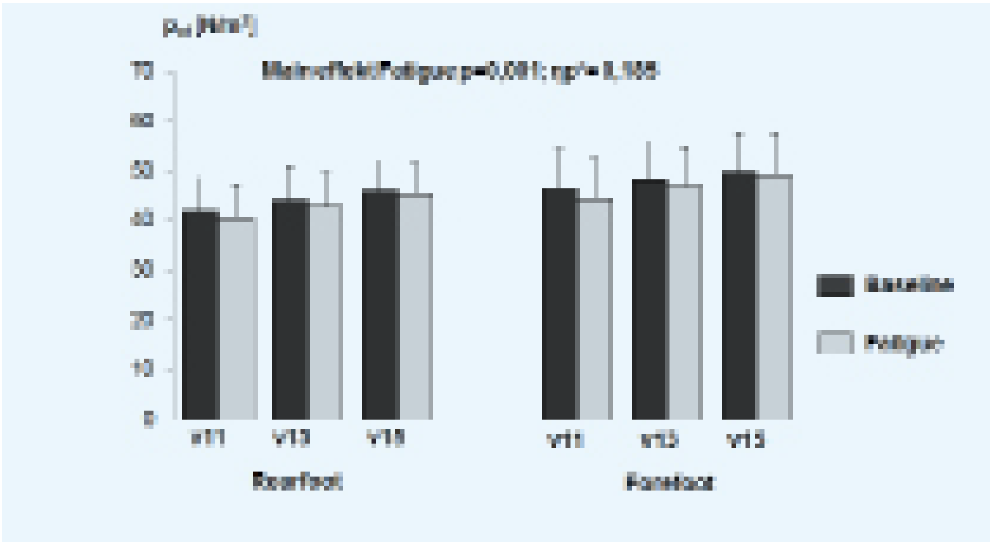

Figure 3

Fig. 3 Comparison of pressure maxima (forefoot, p_{xf}) as an example for the right leg of rearfoot and forefoot runners before and after fatigue itemized for the three running speeds (mean and standard deviation), main effect test values Fatigue Significance level (p) and partial eta square (ηp^2), N=52.

Table 1

Results of the strength test, arithmetic mean (standard deviation) as well as data of the variance analysis, maximum isometric torque (M_x), mean maximum torque in the endurance test (M_{60}), fatigue index (M_{60}/M_x), test values of the intersubject effect foot strike (IE), significance level (p) and partial etaquadrate, ηp^2; N=52.

MUSCLE	PARAMETER	LEG	FOOT STRIKE PATTERN		IE	
			FOREFOOT	REARFOOT	P	ηp^2
Plantar flexors	M_x [Nm]	left	161 (40)	183 (35)	0,421	0,013
		right	162 (30)	151 (32)		
	M_{60} [Nm]	left	48 (17)	97 (28)	0,000	0,554
		right	51 (18)	91 (30)		
	M_{60}/M_x	left	0,3 (0,11)	0,53 (0,14)	0,000	0,548
		right	0,32 (0,11)	0,6 (0,18)		
Dorsiflexors	M_x [Nm]	left	28,4 (12)	38,5 (7)	0,005	0,146
		right	32 (10,5)	35,3 (11,5)		
	M_{60} [Nm]	left	13,2 (4,7)	16 (4,3)	0,920	0,000
		right	14,3 (4,1)	11,7 (3,6)		
		left	0,5 (0,15)	0,42 (0,08)	0,002	0,180
		right	0,47 (0,11)	0,35 (0,13)		

Assessment of the treadmill data (Table 2) was made with the mentioned software. No analysis was made of the running strength data because the measuring system in the treadmill records plantar pressure as a strength/cross-sectional area and calculates the strength values from that. The treadmill data were checked using two-factorial analysis with the intrasubject effects fatigue (baseline vs. fatigue) and running speed (11, 13 and 15km/h) and the intersubject effect foot strike (forefoot vs. rearfoot, Table 2, Fig. 3). The partial eta-quadrate (ηp^2) served as a measure of effect power (small effect $\eta p^2 \geq 0.08$, moderate effect $\eta p^2 \geq 0.20$, large effect $\eta p^2 \geq 0.32$ (7,8). The significance level was set for all statistical tests at $p \leq 0.05$. Statistical calculations were made using IBM SPSS 20.0 (Chicago, IL, USA).

Results

In the strength test, rearfoot runners showed higher torque than forefoot runners. Significant differences were seen in plantar flexors for strength endurance (M_{60}) and for isometric maximum strength (M_x) for the dorsiflexors. The fatigue index (M_{60}/M_x) showed lower fatigue among rearfoot runners for the plantar flexors and greater fatigue for the dorsiflexors compared to the forefoot runners (Table 1).

In both groups, the relation plantar/dorsiflexors changed, whereby after fatigue compared to baseline there was greater relative muscular work capacity in the plantar over the dorsiflexors in the rearfoot runners. In the forefoot runners, the plantar flexors showed more fatigue than the dorsiflexors (Fig. 2).

The treadmill test was performed in both groups at the same running speed and comparable step length and step rate. Both groups showed differences in plantar pressure distribution both at baseline and after fatigue. Higher mean plantar pressure maxima under the heel accompanied by lower maximum pressure values under the midfoot was observed in rearfoot runners compared to forefoot runners (Tab. 2).

After muscular fatigue, the plantar pressure maxima under the forefoot were reduced in both groups (Fig. 3 and Tab. 2). The pressure maxima under the midfoot showed an interaction foot strike*fatigue ($p=0.04$; $\eta p^2=0.08$), whereby the values in the rearfoot runners increased (left by v11-15 and right by v11) and by contrast fell among forefoot runners (left and right by v11-15). After the fatigue protocol, however, the pressure maxima under the midfoot remained lower in the rearfoot runners than in the forefoot runners (Table 2).

The pressure maxima under the heel were also influenced by local muscle fatigue and there was an interaction foot-strike*fatigue ($p=0.002$; $\eta p^2=0.18$). In rearfoot runners, the plantar pressure maxima under the heel after the fatigue protocol fell at all three speeds, while the pressure maxima in this zone did not change significantly in forefoot runners (Table 2).

The step length and step rate, as well as the plantar pressure maxima under the midfoot and forefoot increased with running speed in both groups. In the pressure maxima under the heel, there was an interaction running speed*foot strike, whereby the rearfoot runners showed systematic increase of the pressure maxima in this foot zone and the forefoot runners comparable values at the three speeds (Table 2).

Discussion

In both groups, the fatigue protocol reduced work capacity in both the plantar and the dorsiflexors. In addition, marked fatigue of the dorsiflexors was seen in the rearfoot runners and the plantar flexors in the forefoot runners, so that the strength ratio plantar/dorsi-flexors changed compared to baseline (23, 33), however, differently in the two groups. The fatigue protocol was selected because the two muscle groups fulfill different functions in running, which are associated with the toe-to-heel behavior of the foot. The dorsiflexors raise the tip of the toes in the swing phase and pull the lower calf forward during the ground contact phase with fixed foot. The plantar flexors cushion the landing pressure at the start of ground contact, overcome the body weight in lifting the heels and are active in putting pressure on the forefoot at the end of the support phase. Running demands greater strength of the plantar flexors than of the dorsiflexors, the latter have less work capacity, have less muscle mass which presents as lower torque in the strength test.

The different local muscle fatigue is related to the foot strike pattern. In forefoot strike, higher maximum pressure values are measured under the forefoot and consequently the plantar flexors, which prevent heel splitting, are under more stress than in rearfoot strike. By contrast, in rearfoot strike, there is greater stress to the dorsiflexors since the tip of the toes must be raised by their activity prior to ground contact and, during the support phase with the foot in complete contact, the lower calf is drawn forward. Since the strength test, including the fatigue protocol, was performed after 10-minute warm-up and the baseline determined from one-minute runs at each of the three speeds,

Table 2

Results of the treadmill test, arithmetic mean (standard deviation) and data of the variance analysis, baseline (Base), Baseline left (Bli) and right (Bre), fatigue left (Fle) and right (Fre), step rate (f), step length (SL), pressure maximum under the heel (heel, pxh), mid-foot (midfoot, p_{xm}) and forefoot (forefoot, p_{xf}), Test values of the intersubject effect foot strike (IE) and main effect running speed (ME), significanc level (p) and partial etaquadrate ηp^2; N=52.

PARAMETER	TEST	FOOT STRIKE PATTERN						IE FOOT STRIKE		ME RUNNING SPEED	
		FOREFOOT			REARFOOT						
		V11	V13	V15	V11	V13	V15	P	ηp^2	P	ηp^2
f [1/min]	Base	176 (10,9)	185 (13,7)	194 (14,7)	175 (12,5)	184 (13,8)	193 (14,9)	0,550	0,01	0,00	0,81
	Eli	179 (14,6)	186 (16,3)	196 (18,3)	176 (13)	183 (13,4)	193 (15,8)				
	Ere	177 (13,1)	187 (18)	197 (19,6)	176 (13,6)	183 (13,4)	192 (16)				
s_L [cm]	Bli	105 (6,5)	118 (8,3)	129 (8,8)	105 (7)	118 (8,5)	130 (9,8)	0,530	0,01	0,00	0,95
	Eli	103 (7,2)	117 (9,1)	128 (10,6)	105 (7)	119 (7,9)	130 (10,4)				
	Bre	104 (6,2)	117 (8,1)	128 (9,6)	105 (6,9)	118 (8,2)	130 (9,8)	0,450	0,01		
	Ere	104 (7,2)	116 (9,8)	127 (11,4)	106 (10,6)	119 (8,1)	130 (10,2)				
p_{xh} [N/m²]	Bli	7,5 (3,8)	7,9 (4,3)	7,8 (3,9)	50,1 (12,3)	54,1 (12)	57,5 (13,1)	0,000	0,87	0,000	0,56
	Eli	7,6 (4,4)	8,9 (7,1)	9,3 (7)	47,4 (13,4)	51,3 (12,4)	54 (14,1)				
	Bre	7,1 (3,9)	7 (3,3)	8,1 (5,1)	48,5 (12,8)	51,7 (12)	56 (13,2)	0,000	0,86		
	Ere	8,4 (4,5)	7,2 (4,1)	7,6 (2,9)	45,8 (13)	50 (12,3)	52 (13,5)				
p_{xm} [N/m²]	Bli	31,1 (13,7)	32,2 (13,7)	33,6 (13,7)	22,3 (5,4)	23 (4,9)	25 (7,2)	0,000	0,17	0,000	0,20
	Eli	29,4 (11,6)	31,3 (12)	32,9 (10,4)	23,8 (6,1)	23,8 (5,3)	25,2 (5,1)				
	Bre	30,3 (11,5)	31,7 (11,9)	33,9 (11,7)	22,4 (4,4)	23,7 (4,8)	24,4 (5,6)	0,000	0,19		
	Ere	29,3 (12,6)	30,4 (12,2)	31,9 (13)	22,9 (5,1)	22,9 (4,8)	24,2 (5,4)				
p_{xf} [N/m²]	Bli	46,2 (7,9)	47,7 (8,4)	49,7 (9,1)	41 (8,6)	43,5 (9,1)	45,6 (9)	0,060	0,07	0,000	0,67
	Eli	44,9 (8,6)	46,8 (9,3)	48 (9,6)	39,4 (7,8)	42,6 (7,9)	45,2 (8,7)				
	Bre	46,4 (7,7)	48,0 (8)	49,7 (7,8)	41,8 (6,9)	44 (7)	45,9 (6,1)	0,060	0,07		
	Ere	44,4 (8)	46,7 (8,1)	49,1 (8,5)	40,5 (6,5)	43 (6,6)	45,3 (6)				

the different foot strike is already reflected in the fatigue index with greater fatigue in the plantar flexors in forefoot runners and in the dorsiflexors in rearfoot runners.

As hypothetically expected, the highest pressure maxima under the heel were found in the rearfoot runners, followed by forefoot and midfoot, while the sequence of decreasing values in the forefoot runners was forefoot, midfoot and rearfoot. These results agree with earlier studies (1, 6, 31, 39).

The local fatigue protocol reduced the pressure maxima in both groups and can be considered a stress relief of the fatigued musculature and bony foot structures. Stress reduction occurs in dependence on the foot strike pattern, especially for the particular stressed foot zones, i.e. under the heel in rearfoot runners and under the forefoot and midfoot in the forefoot runners. In both groups, a reduction of pressure maxima was measured under the forefoot, so that earlier findings of an increase in forefoot stress after running fatigue (3, 41, 42) and local fatigue of the plantar and dorsiflexors (35) were not confirmed. Rather the results support earlier findings of reduced pressure values under the toes (16, 35, 41, 42). The reduction of the plantar pressure maxima under the forefoot in both groups can be interpreted as an immediate result of the reduced work capacity of the plantar flexors due to local fatigue (3, 16, 35, 41, 42). The same applies to the lower maximal pressure under the midfoot in forefoot runners.

The reduced maximal pressure values under the heels in the rearfoot runners can be explained by the reduced work capacity of the dorsiflexors due to lower lifting of the tips of the toes prior to ground contact. The foot contact is flatter with less impact and - at least in some of the subjects - with higher pressure maxima under the midfoot.

Since the running speeds were predetermined and the step rate and length did not change, but there was reduction of the pressure maxima after local muscle fatigue, compensation mechanisms must be assumed. As a result of fatigue, a reduced vertical movement of the body's center of gravity could mean lower landing forces and greater flexion of the knee joint leading to better shock absorption (25). Moreover, the pressure values are distributed over several sensors, since the arch structures tire and the foot hits the ground flatter. In forefoot running, the knee is bent on ground contact more than in rearfoot running, which results in better shock absorption of the contact forces (31, 39). Due to the short test time, the question of the period over which these compensation mechanisms act without negative influence on running speed must remain open.

After local muscle fatigue, there were no changes in step length and step rate at the three running speeds, neither among forefoot runners nor rearfoot runners. These results agree with the findings which also determined no change in step rate (2). Other studies, on the other hand, assume a change in step length and step rate after fatigue (26). An increase in pressure maximum under the heel, midfoot and forefoot was found for both groups of runners, thus confirming earlier findings (5).

One limitation is seen in barefoot running on the treadmill. Conditions influence the foot strike pattern, step rate and step length (11, 16, 20, 22, 37). The advantages of treadmill examinations are seen in the control of disruptive factors and in the easier recording of data. After adequate adaptation, various authors see treadmill results as representative for running examinations (14, 37). Since there is trend to forefoot strike in barefoot running on the treadmill, it could not be ruled out that some subjects classified as forefoot runners do not use this foot strike pattern permanently when wearing running shoes.

Conclusions

Higher pressure peaks are induced in the forefoot and greater stress of the plantar flexors in forefoot strike. By contrast, rearfoot strike is associated with higher pressure maxima under the heels and greater stress of the dorsiflexors. The fatigue › protocol reduces the work capacity of the plantar and dorsiflexors, which fulfill different functions in landing during running. Warm-up (10min) prior to the fatigue protocol and recording of baseline by running with the corresponding foot strike pattern (3x1min) already results in varying local muscle fatigue of the plantar and dorsiflexors in forefoot and rearfoot runners who perform two to three training sessions per week. Due to local muscle fatigue, the pressure maxima under the corresponding stressed foot zone are reduced, that means under the forefoot in forefoot strike and under the heels in rearfoot strike. This reduction in pressure maxima indicates that various compensation mechanisms cope with local muscle fatigue, whereby running speed, step length and step rate are maintained, at least briefly. In order to be able to better judge the effect of the foot strike pattern, additional studies should examine longer time segments at various speed levels and examine the kinematics of the lower extremities in addition to plantar pressure.

As a preventive measure, the foot strike pattern should be varied under control in training to provoke different stress to the musculoskeletal structures. Targeted strength training of the plantar flexors prior to switching from the rearfoot to the forefoot strike is to be recommended.

Self-organization of the foot strike pattern can be learned by means of coordination training, more frequent barefoot running and a consciously-applied multiple alternating from "uphill" and "downhill" within a training session.

Prior to treadmill tests, the subject's actual foot strike pattern should be checked, preferably on the treadmill and with shoes, since barefoot running on the treadmill influences the foot strike pattern.

Conflict of Interest

The authors have no conflict of interest.

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