Foot Strike Pattern in Sport Shoes with Different Construction

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ABSTRACT

Shoe type and their hardness play an important role in the characteristics of gait cycle. Runners usually use a conventional running shoes (CRS) and also in the last years' minimalist running shoes (MRS) with a thin, flexible outsole or they run barefoot. The type of shoes reportedly affects the magnitude of the vertical ground reaction forces when running The aim of this study was to analyse foot strike pattern according to plantar pressure distribution and dynamic characteristics of running gait in a group of recreational runners (8 men and 7 women; mean±SD; age = 34.6±6.2 years, body height = 1.81±0.08 m, body weight = 68.10±8.9 kg) when using minimalist and conventional running shoes. The Pedar system (Pedar-X®, Novel, Munich, Germany) with measuring insoles was used to record plantar pressure distribution and vertical ground reaction forces under the foot, heel, midfoot and forefoot. For the same type of foot-strike pattern, impact forces are higher for MRS than for CRS, which is why runners using MRS modify their foot-strike pattern with the aim of reducing these impact forces. The foot- strike pattern changed in 5 runners when using minimalist shoes. The foot strike pattern shifted from middle-foot strike to forefoot strike or from rear-foot strike to middle-foot strike when running in MRS. Plantar pressure distribution was different when running in MRS and in CRS. When running in MRS the Peak pressure values under the foot were significantly higher than values when using CRS. Peak pressure values and vertical ground reaction forces under the heel were in MRS higher only in a group of rear-foot strikers. The values of Peak pressure and vertical ground reaction forces related to CRS were in the area of the midfoot and forefoot higher, but the differences were not statistically significant (p > 0.05; n = 15).

Keywords: *plantar pressure; ground reaction forces; minimalist running shoes.*

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Introduction

Running belongs to the oldest and, simultaneously, the most natural of human movement activities. It is widely applied in recreational and competitive forms. While human beings run, their joints may get overused, worn and torn due to the shock of repeated impacts. To eliminate these shocks, cushioned sports shoes were developed to absorb shocks and protect the runners' musculoskeletal system [1]. Footwear has undergone several developments; and in the context of new technologies still arising, it is constantly a widely-discussed topic.

The oldest surviving information on the use of shoes comes from the Old Stone Age. Hand-crafted footwear appeared as early as at the turn of the 11th and 12th centuries A.D., when shoes were used primarily for walking; their application for running took place only in the case of fighting and hunting. As late as in the 19th century, sports shoes began to be produced and in the modern history, the introduction of rubber is perceived as a turning point. Another milestone in the production of athletic shoes was the period of the 1950s and 1960s, when the main producers of sports shoes entered the market and started to play an important role, which has remained unchanged till today [2]. Currently, most runners use conventional running shoes, which provide them with protection.

Shoe type and their hardness play an important role in the characteristics of gait cycle. Running shoes and barefoot significantly influence a running gate [1].

Runners usually use a conventional running shoes (CRS) and also in the last years minimalist running shoes (MRS) with a thin, flexible outsole or they run barefoot (BF).

Barefoot footwear is designed to provide conditions closest to shoeless walking and running, as it has an ultra-thin sole (3–6 mm), which enables the runner to perceive the interaction of the sole with the surface. At the same time, this type of shoes has no arch support and there is a zero slope between the heel and forefoot. In contrast, MRS is more similar to CRS; it has a thicker sole than the barefoot one (7–11 mm) and is equipped with a slight slope between the heel and forefoot. The front part of the shoe is narrow to prevent spontaneous movement of toes. The arch is similar to that in CRS. The shocks under the heel are absorbed, which is not as significant as with the CRS.

Due to the popularity of barefoot running during marathon races researchers focussed on monitoring the movement patterns when running in CRS, in MRS, and barefoot [3-7].

The type of shoes reportedly affects the magnitude of the vertical ground reaction forces when running. For the same type of foot-strike pattern, impact forces are higher for MRS than for CRS, which is why runners using MRS modify their foot-strike pattern with the aim of reducing these impact forces.

The foot strike patterns can be identified by the use of visual inspection of the video sequence but it can also be identified by the use of plantar pressure distribution measurement. For a dynamic analysis of walking and running, the use of measuring insoles seems to be a very suitable method as it guarantees a very high accuracy of the measurement data [8-10].

According to previous studies [7,11,12] 75–90% of shod recreational runners strike with the heel at first impact and this foot strike pattern is called rearfoot strike (RFS). Runners who usually run with the first impact on the front part of the foot use so-called forefoot strike (FFS). In this case the lateral metatarsal heads touch the ground first. Alternatively, runners can strike the ground first with their midfoot. This is the so-called midfoot strike (MFS), when the ground is touched by both the heel and the ball of the big toe simultaneously. Nigg [1] found that the initially shod runners who were asked to run shoeless very often switched from the RFS to FFS, especially when running on hard surfaces.

The aims of this study was to analyse foot strike pattern according to plantar pressure distribution and dynamic characteristics of running gait in a group of recreational runners when using minimalist and conventional running shoes.

Methods

A group of 15 experienced recreational runners (8 men and 7 women; mean±SD; age = 34.6±6.2 years, body height = 1.81±0.08 m, body weight = 68.10±8.9 kg) volunteered for the study. They ran at least 30 km per week for more than 1 year and they self-reported using MRS and also CRS. Nobody was used to run barefoot.

Anthropometric data as body weight, height and age were recorded (portable Antropometr A 213, Trystom comp. Ltd and electronic scale medical Amboss ©) before 15 minutes long warming up including running and also stretching. The Pedar system (Pedar-X®, Novel, Munich, Germany) with measuring insoles was used to record plantar pressure distribution with the frequency of 100 Hz while running in CRS (all participants used the same shoe type: Asics GT-2000 in their correct size) and also in MRS (Nike Free 3.0). It was necessary to carry out a new calibration between the changing the shoe type. Measurements were made while the participants ran 800 m at their preferred training speed for long-distance running and with their habitual footfall pattern. The measurement was started when participants run 70 m on a straight piece of tract, 500 m after the start (Figure 1).

All experiments were performed with the approval granted by the institutional Review Board of the Charles University, Faculty of Sports Sciences. The experimental work conforms to the highest standards and safety and ethics, with respect to the Declaration of Helsinki and to the national laws. All participants completed an informed consent.

Figure 1: Running with Pedar measuring system

Data analysis

The Pedar-x software (Novel, Munich, Germany) was used to monitor the following variables: Peak Pressure under the foot [kPa], Peak pressure under the heel [kPa], Peak pressure under the midfoot [kPa], Peak pressure under the forefoot [kPa], ground reaction vertical force under the foot [N], ground reaction vertical force under the heel [N], ground reaction vertical force under the midfoot [N], and ground reaction vertical force under the forefoot [N].

The first contact with the ground was determined from the plantar pressure distribution on the measuring insoles. Insoles were divided into three parts (forefoot, midfoot and rearfoot) while using Pedar Masks function. It was assessed whether the runners applied the FFS, MFS, or RFS pattern.

Statistical analysis

Statistical analysis was performed by using a custom Matlab programme (Mathworks, Inc., Natick, MA, USA). A nonparametric sign test was used to verify the hypothesis. The values were considered significantly different when $p \leq 0.05$.

Results

Foot strike patterns

In a group of 15 participants were 4 runners with MFS forefoot strike pattern (FFS) when using CRS. In the same shoe type another 4 runners used midle foot strike pattern and 7 runners had the first contact with the surface in the rear part of their feet (RFS). The foot strike pattern changed in 5 runners when using minimalist shoes (Table 1). The foot strike pattern shifted from MFS to FFS or from RFS to MFS when running in MRS. Figure 2 shows an example of the differences in footstrike pattern when using FFS in minimalist shoes and when using MFS in conventional running shoes.

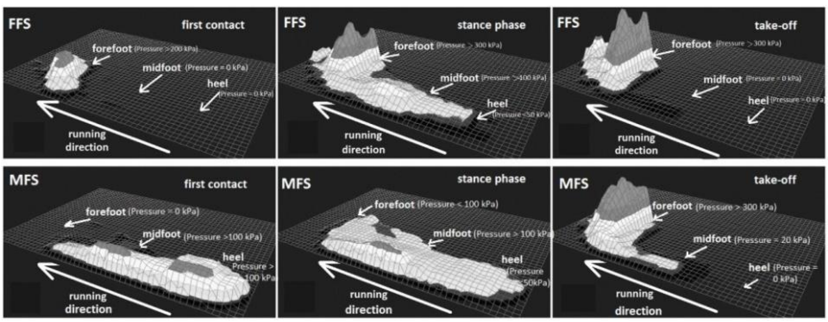

Figure 2: Plantar pressure distribution changes when using forefoot strike pattern (FFS) and middlefoot strike pattern (MFS)

Table 1 Footstrike pattern in conventional (CRS) and minimalist running shoes (MRS)

foot strike CRS/MRS	N = 15
RFS/RFS	4
MFS/MFS	2
FFS/FFS	4
RFS/MFS	3
MFS/FFS	2

Six out of 15 runners (40%) MRS used FFS, further 5 (33.3%) relied on MFS, and the remaining 4 (26.7%) utilized RFS, with the first contact with the ground in the heel area. Total of 3 runners using FFS when running in minimalist shoes demonstrated no contact of the heel with the ground throughout the gait cycle (Figure 2 above). This trend appeared in some participants exclusively in the case of using MRS. When using CRS, at least a brief contact (0.02–0.04 s) of the heel with the ground was always observed even in runners using FFS.

Plantar pressure distribution

Plantar pressure distribution was in a group of 15 recreational runners different when running in MRS and in CRS (Table 2). When analysing the peak pressure, which was monitored for the foot and also for its parts as a heel, midfoot and forefoot, differences were measured when running in MRS and in CRS.

When running in MRS the Peak pressure values under the feet were significantly higher ($P = 0.036$) than values when using CRS. Peak pressure values and vertical ground reaction forces under the heel were in MRS higher only in a group of rearfoot strikers. Other runners shifted the loading towards (they changed the footstrike pattern) and Peak pressure values and ground reaction forces were in MRS under the heel lower than in CRS. The values of Peak pressure and vertical ground reaction forces related to CRS were in the area of the midfoot and forefoot higher, but the differences were not statistically significant ($p > 0.05$; $n = 15$).

Table 2 Mean of differences and sign p-values for measured variables when running in minimal and sport shoes

Measured Variables		CRS	MRS	Mean of differences	Sign p-value
Relat. Peak Pressure	Feet	0,765	0,875	-108,57	**0,036**
	Heel	0,425	0,495	-68,54	0,400
	Midfeet	0,520	0,638	-95,01	0,078
	Forefeet	0,689	0,822	-130,36	0,126
Relat. F_{max}	Feet	2,560	2,734	-171,52	0,337
	Heel	0,783	0,919	-133,57	0,512
	Midfeet	1,233	1,366	-130,28	0,604
	Forefeet	1,482	1,554	-70,14	0,421

Discussions

The runners were categorized into 3 groups on the basis of the foot strike pattern applied when running both in minimalist and in conventional sports shoes. According to the preference for the foot part they used in the first contact with the ground, they were divided into these groups: those who landed on their forefoot (forefoot strikers with FFS pattern), middle foot (middlefoot strikers with MFS pattern) and rear foot (rearfoot strikers with RFS pattern). As initially hypothesised, the foot strike behavior among recreational runners was influenced by shoe type.

Among the 15 subjects, 4 runners (26.7%) employed FFS when running in conventional running shoes. They landed on their forefeet first. Gradually, the contact shifted towards the middle foot (mainly its outer part) and then backwards again, in the direction of the forefoot. The runners in this group had no contact of the heel with the ground. Another 4 runners (26.7%) applied the MFS pattern when running in CRS. They landed on the middle part of their feet first, most frequently on the outer part of their sole. Afterwards, the contact with the ground (or with the insoles of the shoes) remained in the middle part of the foot, spread in the mediolateral direction (inwardly), and then shifted towards the forefoot. The strike (the end of stance) was initiated in the forefoot area. While running in CRS, 7 runners (46.7%) landed on their heels. They used the RFS pattern. The first contact with the ground was under the heel, then the pressure moved further to the middle part of the foot, and the strike (end of stance) progressed from the metatarsal balls. The percentage was significantly lower than the one of RFS in shod runners studied previously in other investigations [7,11,12]. This situation can be explained by the fact that the studied group of recreational runners was selected to include individuals with previous experience of running in minimalist shoes. That could have influenced their foot strike pattern in the long term perspective.

Out of the 15 subjects, 6 runners (40%) used the FFS pattern when running in minimalist shoes. It is 2 runners more than in the case of running in conventional sports shoes. The representation of forefoot strikers is a little higher than in the study of Larson [13], where 33% minimal shod runners use forefoot strike. The dynamometric recording allowed them to observe, that in the 3 subjects, the first contact with the ground appeared in the area under the little toe edge. Lateral metatarsal heads contacted the ground first, which remains in accordance with other investigations [3,14,15]. When the runners used this little toe foot strike pattern, they did so when wearing both minimalist and sports footwear. Another 5 (33.3%) runners applied the MFS style, which means only 1 runner more than in the case of running in minimalist footwear. Yet, it is necessary to bear in mind that 2 runners were influenced by the minimalist shoes so that they transferred from MFS to FFS, and another 3 runners, under the same influence, shifted from RFS to MFS. During MFS, the heel and the ball of the big toe touch the ground simultaneously [3,14,15]. The remaining 4 runners (26.7%) landed first on their heels when using minimalist shoes. Thus, they used the RFS pattern. All of these runners landed on their heels in the minimalist and sports shoes, which is in accordance with another study [16]. The construction of sports shoes helps in absorption of shocks for the heel. In contrast, minimalist shoes absorb these impact peaks to a lesser degree. Therefore, we claim that some runners tend to change their foot strike patterns just as barefoot runners and minimalist shoes runners are likely to use FFS [7,11,13,16-19]. According to Nigg [1], the shift from RFS to FFS occurs mainly in running on hard surfaces. Our investigation took place on a surface used for athletic meetings; it is not as hard as e.g., tarmac, used for marathons or half-marathons.

Minimalist shoes made these 5 runners change the first interaction with the ground in the forward direction, always by one zone. Never did the minimalist shoes change the foot strike pattern from the landing on the heel all the way towards landing on the forefront of the foot. Based on the Nigg´s study [1] it can be hypothesised that running on the hard surface could influence the shift in the forward direction much more and the change might cover more than only one zone.

The changes of the foot strike pattern caused by minimalist footwear lead to considerations of what changes can be observed in the pressure distribution on the level of the foot in contact with the ground. Similarly to a previous study [19], it was identified that landing on the rear part of the foot significantly increased the vertical ground reaction force. The observations of the average values on both right and left feet proved that the peak pressure was lower with runners in conventional running shoes as compared with those in minimalist footwear. The values of the peak pressure are significantly greater in the minimalist shoe type, especially in the forefoot. This supports the findings observed in a recent study [18] of 50-km runners, where the peak pressures were significantly greater in the minimalist shoe type, especially in the medial forefoot. This confirms that the construction of CRS is designed to absorb strong impacts accompanying the initial stage of the stance in the area of the sole [20].

There are numerous theories that barefoot long-distance runners prefer the forefoot strike to eliminate painful impact forces under the heel. Conventional running shoes supress these impacts. Minimalist footwear is constructed to partially absorb the shocks, mainly under the heel, but the absorption is not as powerful as in the case of conventional running shoes [21]. This may predispose runners to an increased risk of metatarsal stress fractures if they participate in wrongly- designed training sessions [18]. Comparisons of the average values of F_{max} under the whole foot, in the area of the heel and midfoot, and under the forefoot also produced different results. The usage of CRS lead to lower absolute values as compared with minimalist shoes and the foot strike type influences vertical ground reaction forces [19]. Based on this measurement it can be recommended that recreational runners who suffer from some foot pains should use conventional running shoes, which absorb the main impact more than minimal shoes.

Conclusions

The study analysed both dynamic and stride characteristics of recreational runners in conventional running shoes, as well as in minimalist shoes through a collection of pressure data from the mobile pedographic system including measuring insoles. Some runners tend to change their foot strike patterns depending on shoes.

We found that the first contact with the ground is shifted more forward in a group of recreational runners when running in minimalist shoes, but only by one zone. Landing on the rearfoot increased the vertical ground reaction forces. Peak pressure turned out generally greater in the case of the minimalist shoe type.

Peak pressure values and vertical ground reaction forces under the heel were in MRS higher only in a group of rearfoot strikers. Other runners shifted the loading towards (they changed the footstrike pattern) and Peak pressure values and ground reaction forces were in MRS under the heel lower than in CRS. The values of Peak pressure and vertical ground reaction forces related to CRS were in the area of the midfoot and forefoot higher, but the differences were not statistically significant ($p > 0.05$; $n = 15$).

Our finding, together with the observed higher values of the peak pressure, support the conclusion that frequent usage of minimalist footwear must be preceded by a proper type of training to avoid metatarsal stress fractures. Running in minimalist shoes should be recommended to people who suffer from foot pain with caution. The COP trajectory is shorter in the anterior-posterior direction depending on the foot strike pattern, which probably influences the length of stance and thus the frequency of steps.

Due to the limited size of the study group, which consisted of 15 recreational runners, any generalisation of the findings to all runners must be done carefully. Additional studies are needed to evaluate the results even further, and also to discover changes appearing in the peak pressure and ground reaction vertical forces when runners wear minimalist shoes and CRS on surfaces with different degrees of hardness.

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