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RESEARCH

Is There a Relationship Between Strike Pattern and Injury During Running: A Review

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Object: Recently people have shown an interest in running barefoot or with minimalist shoes, which result in forefoot strike (FFS) patterns that are different from running in normal shod with the rearfoot strike (RFS). To date, there is a dispute whether runners' footfall pattern has an important impact on running injuries. Therefore, the purpose of this review is to investigate whether there is a relationship between different strike patterns and running injuries by reviewing the literature.
Materials and Methods: A database retrieval and reference search were carried out with PubMed, Scopus, Google Scholar, and ScienceDirect. In the final review, 10 papers were included by matching the inclusion criteria.
Results: Barefoot running exhibited smaller impact forces, short stride length, higher strike frequency, and shorter contact times compared to the standard shod condition. The forefoot strike pattern showed an increase in the plantarflexed foot, more ankle compliance during impact, smaller loading at the knee and lowered vertical loading rate in the FFS pattern than RFS.
Discussion: Although the running injury is driven by multi-factorial variables, our literature review did not show any scientific evidence to suggest that footfall patterns are directly related to running injury.

Keywords: barefoot; minimalist; running; injuries; footfall pattern; forefoot strike; rearfoot strike

Introduction

Recreational and competitive running has become very popular among amateur and elite athletes. Present figures report that 54 million people participate in running as a sport (Snipes & Pitts, 2015). Recently, research evidence suggests that the injury rate of runners' ranges from 3.2% for cross-country runners to 84.9% for novice runners (Kluitenberg et al., 2015). Over the last decade, with the rise in high injury risks associated with a running activity, researchers have expressed an interest in barefoot running (Hryvniak et al., 2014; Rothschild & Research, 2012). This is strengthened by anecdotal views that suggest the footfall pattern is related to injuries during running.

There are different styles of running that are classified by foot position and foot contact area during landing. These include "toe-heel-toe" running defined as forefoot strike (FFS), "flat-footed" running defined as a midfoot strike (MFS), and "heel-toe" running defined as a rearfoot strike (RFS) (Altman, Davis, & posture, 2012; Bobbert, Yeadon, & Nigg, 1992). Previous studies indicate that habitual barefoot runners are more likely to run with FFS or MFS, whereas the habitually shod runners run with an RFS (Hasegawa et al., 2007; Lieberman et al., 2010). Regarding the lower injuries' occurrence in both FFS and MFS runners, it is often classified both as an FFS running style with slight plantarflexion (Lieberman et al., 2015).

There are ongoing controversies about the impact runners' footfall patterns have on running injuries today. When compared with RFS, FFS runners showed lower loading rates and no impact peak during running (Squadrone and Gallozzi, 2009, Lieberman et al., 2015, Laughton et al., 2003). Larger loading rates and impact peaks in RFS still remain a prominent feature, this may be due to the development of the cushioned heel in running shoes (Lieberman, 2012). Over 95% of traditional shod runners' land with RFS on the modern hard surfaces during running. Thus, the cushioning design in modern running shoes probably could be the main reason for the runner developing an RFS pattern. Historically, our ancestors ran barefoot without any protection and likely ran supported by the balls of their feet with the aim to reduce the landing impact and increase energy storage released through the elastic structure of the legs and feet (Lieberman, 2012; Divert et al., 2008; Robbin et al., 1995). According to various footwear modalities, most runners can change from an RFS pattern to an FFS pattern or vice versa, even when they have a habitual running style.

Based on the investigation of gait kinematics between the FFS and RFS running, the results of strike length and stride frequency of both patterns have been indicated in very different conditions. The FFS runners run with higher stride frequencies and shorter stride lengths (De Wit, De Clercq, & Aerts, 2000; Divert et al., 2005). Converting from an RFS to an FFS pattern presents a beneficial impact on common injuries of running. For example, a case study consisting of 3 subjects who suffered longstanding patellofemoral pain, modified their landing pattern from RFS to FFS whilst running over a 2 weeks period. The outcome of this change showed their instantaneous load rates and vertical force were reduced on average by 24% and 19% respectively when compared to their baseline measurement (Cheung, Davis, & therapy, 2011). However, according to Heiderscheit the outcome of their investigations demonstrated that no differences in injury histories between the pattern of FFS and RFS were found (Heiderscheit, 2011). Unfortunately, there are only few studies to indicate the relationship between footfall patterns and injuries.

Therefore, the purpose of this review is to investigate whether there is a relationship between different strike patterns and running injuries by reviewing the literature. We will provide evidence to suggest that the strike pattern in barefoot condition or whilst wearing minimalist footwear will reduce the biomechanical attributes of one's natural running mechanics, which consequently may be an effective way to lower injury risks in runners.

Materials and Methods

Review method

The system database retrieval was carried out with PubMed online as the main database. In addition, the Scopus, Google Scholar, and ScienceDirect were searched as complementary databases. The procedure of this review followed the guidelines of the PRISMA statement (Moher et al., 2009). The keywords of minimalist, barefoot running shoes, foot strike pattern, forefoot strike, and rearfoot strike, and initial contact were conducted in the database. The literature search and screening of the paper were conducted by following the inclusion criteria; only eligible articles were selected and the relevant papers were fully reviewed in order to identify the following areas of interest: (1) the experiment involved a comparative study of two different strike patterns; (2) the subjects had running experience and their level of experience was clearly reported; (3) the study use of minimal shoes are based on the definition by (Esculier et al., 2015); (4) only full articles were selected; (5) only longitudinal prospective studies were involved in this review; (6) specifying the research purpose that evaluate the impacts of the footfall pattern of injuries were reported; (7) In order to conclude evidence from the main results of selected articles together with potential negative and positive outcomes of the two-strike patterns were reported. The definitions of quality of selected paper were conducted by Hall et al. (Hall et al., 2013). The number of high-quality studies that studied the same variable and found similar results were expressed as strong, $n \geq 3$; moderate, $n = 2$; limited, $n = 1$ while low-quality studies presented with limited ($n = 2$ + studies) and very limited ($n = 1$ + study). The risk of bias score by Downs and Black Quality Index to assess quality of evidence was divided into different grades based on score: Low-quality scores ranged from 0 to 6, moderate quality scores ranged from 7 to 13, and high-quality scores ranged from 14 to 20.

Statistical consideration

For the collected papers, the same research results were investigated by pooling and comparison methods. The subject data from which the same laboratory group conducted the same subject was only involved once in the pooling (Johnson et al., 2016; Ridge et al., 2013). The study of average values of subject data was excluded if the metric was not reported. A meta-analysis of the occurrence of injury occurs only when there is insufficient data to perform a meta-analysis of other variables. Most papers do not have a definition of injury. Therefore, the injury must be symptomatic for the purpose of meta-analysis.

Results

Search results

315 articles were selected from Google Scholar, and Scopus, and ScienceDirect and PubMed which also included the reference lists of seleced papers that were examined for any relevant articles not collected in the database. 185 articles were excluded by the inclusion criteria, 15 articles were removed by repetitive contents, and 20 conference articles were also deleted. 10 articles were selected in the final review after matching each paper based on the inclusion criteria (a flow chart of the study selection is showed in **Figure 1**). A summary of the eligible articles is provided in **Table 1**.

Biomechanical difference between FFS and FFS

Researchers have compared different biomechanical parameters between the barefoot running and shod running by using the treadmill with the outcome showing that barefoot running presented smaller impact forces, short stride length, higher strike frequency, and shorter contact times compared to the standard shod condition (Squadrone & Gallozzi, 2009). Divert et al. also indicated running in FFS pattern with the lower contact time, flight time, passive peak value, and higher braking/pushing impulses than RFS (Divert & Mornieux, 2005). Others conducted kinematic and kinetic analyses that found barefoot runners with FFE pattern produced an increased plantarflexed foot at the landing phase, more ankle compliance during impact, and generated smaller collision forces than RFS, even on hard surfaces (Lieberman et al., 2010). This was consistent with Brandon and colleagues who found that the plantar flexor moment of FFS was significantly larger during the first 50% of the stance phase (Brandon & Rooney, 2013). In order to investigate the impact of both strike patterns (FFS vs RFS) with respect to shock at the tibia during running; kinematic, acceleration of tibia, and ground reaction force (GRF) data on subjects were presented with the results showing that there was a significant increase in peak positive acceleration and a greater peak-to-peak acceleration in FFS than RFS pattern. In addition, the peak vertical ground reaction force (GRF) and the anteroposterior GRF load rates were significantly larger for the FFS pattern in contrast to RFS, furthermore, compared with RFS, FFS pattern reduced the ankle stiffness, increased knee and leg stiffness with associated smaller center mass excursion (De Wit et al., 2000; Laughton, Davis, & Hamill, 2003). Several articles also indicated the specific kinematic changes between the patterns of FFR and RFS, such as in the sagittal plane, the FFS presented a greater moment at the knee joint during the initial contact phase than RFS (Rooney & Derrick, 2013). Conversely, Dorsey and associates found that peak values for most parameters of kinematic and kinetic did not exhibit a statistically significant difference between FFS and RFS, apart from the larger peak vertical GRF and peak ankle plantarflexion moment found in FFS (Williams, McClay, & Manal, 2000). More recently, researchers have shown differences in joint power and noted that running with FFS pattern increased the plantarflexion, reduced negative knee power, and decreased total lower extremity joint power absorption when compared with the RFS pattern (Williams & Wurzinger, 2012).

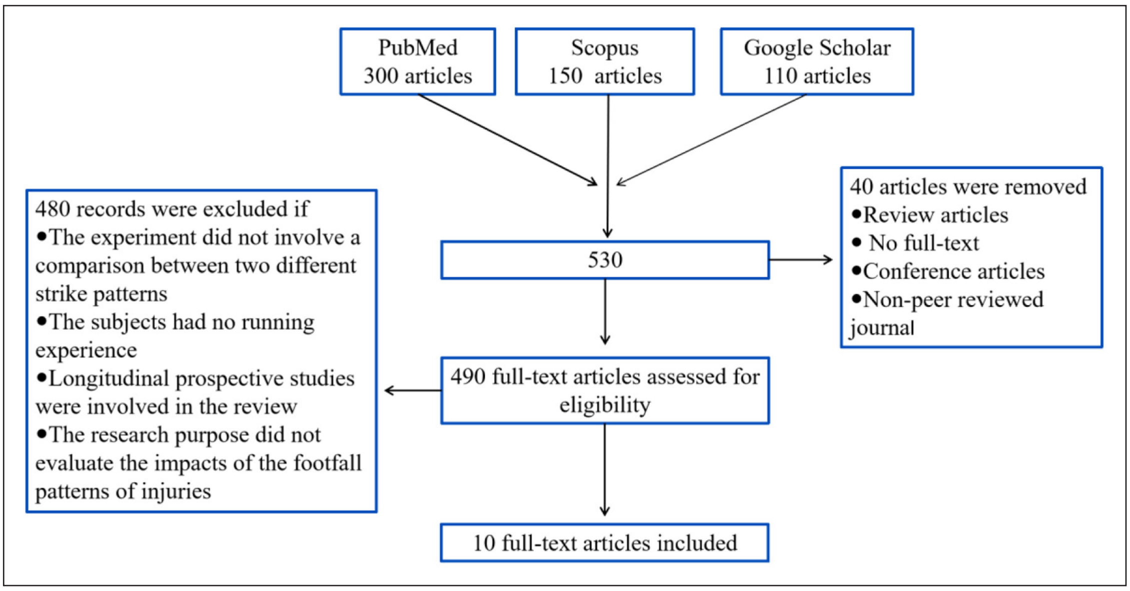

Figure 1: The search flowchart.

Table 1: Summary of main factors from the research papers included in this review.

Source	Participant's information and group size	Test parameter	Method	Main study outcomes
Altman et al., 2012	Forty recreational and highly trained runners	Kinematics of ankle and knee, force loading rates, and joint loading patterns	Subjects ran at four speeds with barefoot and shod on a treadmill respectively	Shod runners produced a lower stride frequency and larger stride length than all other runners. FFS pattern runners presented the greater plantarflexed ankles and more vertical lower legs at first contact compared to RFS runners.
Joel et al., 2002	26 trained runners, age range from 18 to 40 years, who ran with a rearfoot strike pattern and no experience running in minimalist shoes were recruited	Kinematic changes at the knee and ankle joints	Participants ran with different strike pattern, then captured by 8-cameras	Ankle angle at initial contact was less and strike index was greater when running FFS pattern compared with RFS
Soňa Jandová1 et al.	14 experienced recreational women runners, mean age is 31.92 ± 5.34 years	vertical force and plantar pressure	The subjects ran over a distance of 100 m with their different strike pattern	Greater plantar pressure in forefoot, higher foot loading at first contact in FFS when compared with RFS
Squadrone et al., 2009	8 healthy male runner, age 32 ± 5 years	Foot loading and lower limb kinematics	Subjects running on the treadmill with barefoot and conventional shoes respectively	More plantarflexion at the ankle joint, smaller impact forces, shorter strike length and contact time, higher strike frequency
Brandon et al., 2013	15 forefoot and 15 rearfoot strike runners (average age 22.46 ± 4 years)	internal loading of the joints	Using inverse dynamics to calculate the net joint moments and reaction forces	Larger net ankle joint moments, average contact forces at ankle and knee joint in FFS running than RFS
Divert et al., 2005	31 male runners (mean ± SD: age 28 ± 7 years)	Kinetic of lower extremity	Subjects ran two bouts of 4 minutes at 3.33 ms^{-1} on a treadmill with shod and barefoot running respectively	FFS presented significant lower contact and flight time, smaller passive peak, larger braking and pushing impulses
Dorsey et al., 2000	18 recreational runners	Kinematics and kinetics change of lower extremity	Subjects ran on a 25 m runway at a speed of 3.35 ms^{-1} with different strike pattern respectively	FFS showed lower peak vertical ground reaction force and lower peak ankle plantarflexion moment when compared with RES
Blaise et al.	10 male runners (mean ± SD age: 25.4 ± 2.01 years) and 10 female runners (24.1 ± 1.37 years)	Kinematics of ankle angle, knee angle and hip angle. kinetics of ankle power, knee power, and total power	8-cameras were used to collect kinematic data, and two forces plates recorded ground reaction forces when subjects ran whilst applying RFS and FFS conditions respectively at self-selected speed	Greater plantarflexion, smaller negative knee power, larger peak ankle power absorption and lower knee power absorption in FFS when compared to RFS

Source	Participant's information and group size	Test parameter	Method	Main study outcomes
Joseph Hamill et al.	5 male runners (mean ± SD age: 29.6 ± 2.9 years) and 5 female runners (mean ± SD age: 27.4 ± 2.9 years)	Kinematics and kinetics change of lower extremity	Kinematic data were attained form 8-camera, ground reaction force data were collected from AMTI force platform	Impact peak, ankle stiffness, and knee stiffness were differences between the shod and barefoot
Brigit et al.	9 male runners (mean ± SD age: 27.3 ± 9 years)	spatio-temporal variables, ground reaction forces and kinematics details in the sagittal and frontal plane	Subjects running in barefoot and shod condition at three different velocities (3.5, 4.5, 5.5 ms^{-1}), the data was captured by 3D camera and force platform	Greater external loading rate, higher leg stiffness during the stance phase in barefoot condition than shod

Discussion

The purpose of this review is to investigate whether there is a relationship between different strike patterns and running injuries by reviewing the literature. The main finding focused on the comparisons between FFS and RFS with respect to kinematics and kinetics.

Some studies indicated that running with normal shoes increase the risk of ankle sprains, due to the cushioned shoes heeled limit proprioception and somatosensory information (Robbins, Waked, & Rappel, 1995). Earlier research studies showed that FFS patterns led to a greater ankle plantar flexion and knee flexion in the sagittal plane (Lieberman et al., 2010). Despite these significant differences, no considerable differences were found in frontal and transverse planes when comparing FFS and RFS during running.

Several researchers have shown consistency in their results for the FFS pattern in terms of lower contact time, higher strike frequency, and smaller stride length than RFS (De Wit et al., 2000; Divert et al., 2005). These results were primarily due to the touch-down geometry changes (De Wit et al., 2000). These kinematic changes in FFS strike pattern could help to prevent the greater impact forces experienced during the barefoot running and the impact forces can be largely absorbed by the musculoskeletal system at each step. The study also showed that significantly lower values of peak vertical force were observed in running barefoot (Crowell & Davis, 2011).

As mentioned, a larger tibia acceleration was found in the FFS pattern along with greater peak vertical and anteroposterior GRF, as well as greater lower extremity stiffness at the leg and knee. The researcher also indicated that both peak and average values of anteroposterior GRF load rates were considerably larger in the FFS running pattern. In addition, there is a significantly correlated between peak positive acceleration and the shear load rates (Johnson et al., 2016; Kluitenberg et al., 2015). The larger peak acceleration in the FFS pattern may be also related to peak forces. These changes most likely led to the greater value of tibia acceleration in the FFS pattern. Furthermore, the stiffness of the lower extremity can be used to assess the larger tibia shock in the FFS pattern. In contrast to the RFS pattern, the FFS produced larger dorsiflexion excursion, resulting in lower ankle stiffness. A lower knee flexion excursion will lead to a greater knee stiffness, as well as greater leg stiffness in the FFS pattern. Those pieces of evidence suggest that the knee may be a powerful regulator of leg stiffness than the ankle.

Although running with barefoot or forefoot may reduce the risk of repetitive stress injuries in the lower extremity, such as the medial stress syndrome of the humerus; in theory, this increases the risk of injury associated with the Achilles tendon. Running barefoot and with minimal shoes, as well as the strike pattern of the forefoot and midfoot, are not a panacea for all running injuries. Some of his websites post individual case studies that running with minimalist shoes or barefoot may accelerate the development of other foot injuries such as fractures of metatarsal stress and sesamoiditis (Warburton, 2001). Thus, it is worth considering that the runners want to change their running strike patterns. And previous researches demonstrated that the injury risk more likely to increase when RFS pattern transitioning to the FFS during the initial period of change (Willson et al., 2014).

Conclusion

A comprehensive understanding of different footfall pattern is a necessary condition for the prevention and proper treatment of running-related injuries. In order to investigate the relationship between different footfall and running injury by collecting relevant researches, which indicated that the FFS pattern results in significantly different biochemical mechanics from the FFE, such as smaller the load of knee and lowered the vertical loading rate in FFS than RFS pattern. But despite these differences, there is no scientific evidence noted that footfall patterns directly related to running injury, since running injury are driven by multi-factorial variables.

Competing Interests

The authors have no competing interests to declare.

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