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# How Does Arch Height Factor Into Running-Related Injuries?

Taylor M. Brown

# HOW DOES ARCH HEIGHT FACTOR INTO RUNNING-RELATED INJURIES?

by

Taylor Brown

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The members of the Honors Committee appointed

To examine the thesis of Taylor Brown

Find it satisfactory and recommend that it be accepted.

____________________________________

Hanz Tao, DPT

Instructor, Department of Physical Therapy

Director of the Committee

____________________________________

Andrea Powell, M.A.

Instructor, Kinesiology and Sport Management

Member, University Honors Committee

____________________________________

Talin Louder, Ph.D.

Instructor, Department of Kinesiology and Health Science

Utah State University

# ABSTRACT

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Taylor Brown

Director: Hanz Tao, DPT

Running is popular and injuries associated with it are common. It is hypothesized that there are connections between running related injuries and their causes, some of which point to the biomechanics or arch type of the individual. The structure and function of the foot's arch is unique across individuals and different effects related to its function during running have been shown to be important. How all these aspects are related to one another have been compiled and discussed, in hopes that increased research will result. There are suspected patterns between the injuries runners sustain and their arch type. The purpose of compiling this data is to increase the population of runners' knowledge of this potential correlation and the injury risks that follow, while also aiming to decrease the injury rate across those affected by running-related injuries.


KEYWORDS: Running, Foot, Injuries, Arch

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*Why Running?*

Running is a form of exercise known to all and is a popular choice for many. It is estimated that 10-20% of Americans use running as their form of exercise regularly (Fields et al., 2010). Part of the growth in running popularity came after Frank Shorter won the Olympic marathon in 1972; marathon participation increased from fewer than 1,000 registrants in the 1960s, to over 30,000 in 2010 (Fields et al., 2010). Running is one of the most popular sports in the world due to its health benefits, ease of implementation, and low cost (Neumann, 2017; Saragiotto et al., 2014). Conditional evidence shows that running has several benefits in adult men and women, such as aerobic fitness, cardiovascular function, and metabolic fitness (Oja et al., 2015). While running has many health benefits, its relatively high injury risk should not be overlooked.

*What is a Running-Related Injury?*

Injuries are defined as acute or overuse (van der Worp et al., 2015). Acute injuries are less common among runners because they generally occur from a single traumatic event (Pulido, 2017). Some examples include dislocations, muscle or joint sprains, and blisters (Pulido, 2017; van der Worp et al., 2015). Acute injuries occur more commonly in contact sports due to the nature of the injury, but runners occasionally experience them as well (Pulido, 2017). Overuse injuries result from repeated exposure to forces that exceed a structure's fatigue threshold (Komi, 2000). In these situations, there is a "mismatch between the resilience of the connective and supporting tissue(s) and running" (van der Worp et al., 2015, p. 2). In general, overuse injuries cause 80% of all injuries in runners (van der Worp et al., 2015). This is likely due to the repetitive nature that running presents (Saragiotto et al., 2014; van der Worp et al., 2015; Williams III et al., 2001). One of the repeated forces that an individual becomes exposed to during running is ground reaction force (GRF) (Komi, 2000; McGinnis, 2013). GRF influences tissue resiliency because it is the cause of the increased stress on the ligaments and tendons that absorb the forces induced on the runner from the ground (Komi, 2000; McGinnis, 2013).

Overuse injuries that are associated with running are referred to as running-related injuries (RRI). RRI cause runners to alter their training program, often for one or more weeks (Fields et al., 2010; Pérez-Morcillo et al., 2019; van der Worp et al., 2015; Williams III et al., 2001). Some of these alterations include running speed, distance, duration, and frequency of activity (van der Worp et al., 2015). As the runner increases the duration of exercise their body fatigue increases, specifically the stretch shortening cycle process within the muscles (Komi, 2000). Fatigued skeletal muscle loses its ability to absorb GRF over time, and therefore puts the runner at an increased risk for injury because of it (Komi, 2000). Some of the most common injuries sustained by long distance runners are Achilles tendinopathy, illiotibial band friction syndrome (ITBS), medial tibial stress syndrome (MTSS), patellofemoral pain syndrome (PFP), plantar fasciitis, and lower extremity stress fractures (Fields et al., 2010; Powell et al., 2016; Tonoli et al., 2010; Williams III et al., 2001).

*What is the Prevalence and Impact of Running-Related Injuries?*

The overall incidence of RRI varies between 18% and 92%, with the wide range derived from the amount of people considered in the population and the definition of injury (Fields et al., 2010; Pérez-Morcillo et al., 2019; Sargiotto et al., 2014; van der Worp et al., 2015). RRI could be detrimental to a runner's well-being due to the high socioeconomic costs of seeking professional rehabilitation services (Pérez-Morcillo et al., 2019; Tonoli et al., 2010). Severe RRI may also force runners to stop running for a long period of time, which significantly impacts their day-to-day lives (Pérez-Morcillo et al., 2019; Tonoli et al., 2010). Therefore, preventing RRI and gaining knowledge of their potential risks may help runners maintain a recreational or competitive lifestyle without incurring high socioeconomic costs. Research investigating why and how runners get injured should continue to be developed, due to both prevalence and incidence of RRI.

While many individuals among the current population of runners get injured, the causes and effects of injuries are uniquely represented. One professional athlete, Gwen Jorgensen the 2016 Triathlon Olympic gold medalist and now professional marathon runner for the Nike Bowerman Track Club, was forced to undergo heel surgery in order to fix a RRI that was caused by Haglund's deformity (Middlebrook, 2019). A stiff Achilles tendon and high arches have been linked as risk factors for this condition (Middlebrook, 2019). Jorgensen had both factors. According to reports, it could take three to four months to return to full-time training (Middlebrook, 2019). Another professional runner, Evan Jager, was pulled out of racing for nine months due to a misdiagnosed stress fracture in his left talus (Gault, 2019). Jager believed that a previous injury was the cause of the talus injury due to the biomechanical changes his body experienced when racing the steeplechase with altered form (Gault, 2019). Both individuals experienced RRI differently, but similarly experienced lasting effects on their careers because of them.

*What are Risk Factors for Running-Related Injuries?*

Running-related injuries have been linked to intrinsic and extrinsic risk factors (Fields et al., 2010; Saragiotto et al., 2014; Tonoli et al., 2010; van der Worp et al., 2015; Williams III et al., 2001). When characterizing RRI into these two categories, intrinsic risk factors include those that are related to personal characteristics of the individual. Common intrinsic risk factors that lead to RRI include age, previous injury, muscle weakness, biomechanical patterns, and foot posture (Fields et al., 2010; Saragiotto et al., 2014; Tonoli et al., 2010; van der Worp et al., 2015; Williams III et al., 2001). In contrast, extrinsic risk factors refer to those related to the training environment of the individual. Common extrinsic factors that have been associated with RRI are running surface and training errors, such as training volume and frequency (Fields et al., 2010; Saragiotto et al., 2014; van der Worp et al., 2015). It is important to keep in mind that these potential risk factors impact individuals differently. Therefore, individual variability should be taken into consideration when discussing risk factors of RRI (van der Worp et al., 2015).

As noted, previous injury has been strongly associated with RRI (Saragiotto et al., 2014; van der Worp et al., 2015). More specifically, previous injury in the last 12 months is a primary intrinsic risk factor (Fields et al., 2010; Saragiotto et al., 2015). When attempting to understand how a RRI developed, a previous injury can make it hard to distinguish the specific cause. For example, following a previous injury, a subsequent injury could develop due to incomplete healing, uncorrected biomechanical patterns, or recall bias (Saragiotto et al., 2014; van der Worp, 2015).

The runner's biomechanical pattern during running is another risk factor. Prior research suggests that runners who are injured develop biomechanical changes to their form in an attempt to protect their body from an overuse injury, which can put them at risk for developing a whole new series of injuries (Saragiotto et al., 2014). Two examples of biomechanical patterns are alignment of the knee joint (Floyd, 2017; McGinnis, 2013; Powell et al., 2016) and arch height (Butler et al., 2008; Fields et al., 2010; Tonoli et al., 2010; van der Worp et al., 2015; Williams III et al., 2001). Throughout the rest of the paper, the research behind one specific risk factor for RRI, foot posture, including arch height, will be analyzed with an aim to increase awareness and potentially prevent future injuries.

### *What is Foot Structure?*

The foot's structure is formed by multiple bones, ligaments, and muscles (McGinnis, 2013; Neumann, 2017). Foot structure is often expressed by the shape of three arches: the medial longitudinal arch (MLA), transverse arch, and lateral longitudinal arch (McGinnis 2013). The lateral longitudinal arch aids in balance and the transverse arch helps the foot adapt to the ground (Floyd, 2017). The MLA is the most important of the three arches due to its functions in shock absorbtion and load bearing (Adhikari et al., 2014; Floyd, 2017; Neumann, 2017). In most research cases, the MLA type is classified as high, medium ("normal"), or low (Floyd, 2017).

The medial longitudinal arch is a primary support system for the foot. Changes in MLA height alter the foot's ability to absorb shock from high GRFs produced during running (Adhikari et al., 2014; Butler et al. 2008; Neumann, 2017; Powell et al., 2016). A foot with a high MLA often suggests a more rigid structure, where the shock is transferred to proximal lower extremity segments (McGinnis, 2013; Williams III et al., 2001). In contrast, a foot with a low MLA is often more mobile, where the shock is absorbed by soft tissue structures around the foot (McGinnis, 2013; Neumann, 2017; Williams III et al., 2001).

*What is Foot Posture and How Does it Contribute to Running?*

Foot posture describes the structure of the foot under weightbearing (WB) conditions (Neumann, 2017; Redmond et al., 2016). The foot often changes its structure in response to load (Adhikari et al., 2014; Neumann, 2017). Foot posture can be described as static, the foot's structure under standardized WB load, or dynamic, the foot's degree of structural change under varying degrees of non-weightbearing (NWB) to WB loads such as throughout a gait cycle (Neumann, 2017; Redmond et al., 2016). Changes in foot posture during a gait cycle may play a role in the body's ability to absorb shock (GRF) during initial contact, while generating force during push off (Komi, 2000; Neumann, 2017).

The primary joint of interest during running is the subtalar joint, which is part of the rearfoot (Neumann, 2017). The subtalar joint consists of the interaction between two bones: the talus and calcaneus (Neumann, 2017). Subtalar joint motion contributes to complex, three-dimensional movements known as pronation and supination (Neumann, 2017). For the simplicity of this paper, subtalar pronation involves MLA collapse (dropping) and foot widening, while subtalar supination involves MLA rising and foot narrowing (Neumann, 2017). Under normal conditions, a small degree of subtalar pronation occurs when the foot is subjected to the weight of the body (Adhikari et al., 2014; Neumann, 2017). In extreme cases however, this is not normal; a lack of pronation indicates a supinated foot, while excessive pronation indicates an overpronated foot (Adhikari et al., 2014; Neumann, 2017; van der Worp et al, 2015).

Running consists of a series of phases that presents the runner's gait, including stance and flight (McGinnis, 2013; Neumann, 2017). The stance phase includes the entire duration of foot-ground contact, from initial contact to push off (McGinnis, 2013; Neumann, 2017; Powell et al., 2016). Different foot loading patterns create different effects (McGinnis, 2013; Neumann, 2017). The most common foot strike pattern during running is a heel strike pattern (McGinnis, 2013). When the heel strikes the ground at initial contact, the rearfoot briefly supinates, quickly pronates during midstance, and then supinates again during push off (McGinnis, 2013; Neumann, 2017). Pronation allows the foot to adapt to the surface and absorb shock, while supination stabilizes the foot and becomes a rigid lever that aids in the propulsion out of the stance phase (McGinnis, 2013; Neumann, 2017).

The foot is subjected to high GRF during the stance phase because the runner's downward motion is stopped, and then propelled up and forward into the next phase (McGinnis, 2013). During this stage, the foot must absorb GRFs up to three times the runner's body weight (Butler, et al., 2008). All of this must be performed during single-leg support and is first absorbed by the foot (McGinnis, 2013). Due to the repetitive nature of running, each foot makes ground contact 1000 to 1900 times per mile, thus subjecting the foot to high cumulative forces during a single bout of running (Hoeger et al., 2008; Neumann, 2017). Therefore, small changes to foot posture during running may impact the body's ability to absorb and transfer forces.

### *How is Foot Posture Measured?*

The type of measurement system used to characterize the arch, the type of WB condition used, and navicular drop (ND), play important roles in measuring a runner's foot posture (Adhikari et al., 2014; Butler et al., 2008; Pérez-Morcillo et al., 2019; Williams & McClay, 2000; Zuil-Escobar et al., 2018). Three common clinical tests include Arch Height Index, Foot Posture Index, and Navicular Drop Test. Each of these clinical tests measure slightly different constructs of foot posture. The reliability and validity of these tests are explored below.

The Arch Height Index (AHI), also known as arch ratio, measures static foot posture, specifically the shape of the MLA (Butler et al, 2008; Powell et al., 2016). The AHI value is represented by measuring the vertical height of the dorsum (from foot to floor) at 50% of the total foot length, divided by the truncated foot length (foot length without toes) (Butler et al., 2008; Powell et al, 2016; Williams & McClay, 2000; Williams III et al., 2001). This measurement is tested under 10% and 90% WB conditions. After measuring the participants weight, 10% and 90% were calculated and the individual's AHI was measured under each condition (Williams & McClay, 2000). Weight distribution under the two categories were created by holding onto a countertop and standing on a scale with one foot to replicate the different condition's WB percentages (Williams & McClay, 2000). The AHI of the foot on the ground was then measured while the individual was standing for each condition (Williams & McClay, 2000). The AHI is both reliable and valid (Butler et al., 2008; Powell et al., 2016; Williams & McClay, 2000; Williams III et al., 2001). Under both 10% and 90% WB, interclass correlation coefficient (ICC) values were 0.939-0.975 for intertester reliability, 0.811-0.848 for interrater reliability, and 0.844-0.851 for concurrent validity (Williams & McClay, 2000; Williams III et al., 2001).

A further development, the Arch Height Index Measurement System (AHIMS), was developed to standardize the measurement procedures for the AHI (Adhikari et al., 2014; Butler et al., 2008). Standardization included consistent use of bony landmarks and using a WB condition, while measuring with sliding calipers that aid in finding all of the required measurements for the AHI calculation from one foot position (Butler et al., 2008). ICC values were 0.96-0.99 for intrarater reliability and 0.98-0.99 for interrater reliability (Butler et al., 2008). It should be noted that measurements using the AHIMS had higher interrater and intrarater reliabilities than the standard AHI measurements, most likely due to the consistency of the AHIMS device (Butler et al., 2008; Williams & McClay, 2000).

Butler et al. (2008) also used the AHIMS to compare arch height between sitting and standing to determine the impact of bearing weight. The mean arch height was 6.6 cm in sitting and 6.3 cm in standing (Butler et al., 2008). This finding suggests that WB decreases the AHI value, suggesting the dynamic nature of foot posture (Butler et al., 2008). While this may create a concern for accuracy of the arch measurement, WB during testing has also been viewed as a more accurate measurement of the arch and how it functions when running, when compared with NWB (Butler et al., 2008). There are three categories for foot type: high arch (AHI >0.356 or .377), normal arch (AHI <.356 or .377 and >.275 or .290) and low arch (AHI <0.275 or 0.290) (Powell et al., 2016; Williams III et al., 2001).

A second clinical test, the Foot Posture Index (FPI), is one of the most commonly used methods to measure foot posture (Pérez-Morcillo et al., 2019). The FPI-6 quantifies foot posture while observing 6 specific rearfoot and forefoot postures during standing (Pérez-Morcillo et al., 2019; Redmond et al., 2006). Each of the 6 observations are scored between -2 and +2 (Pérez-Morcillo et al., 2019; Redmond et al., 2006). Each foot is then given a total score between -12 (excessively supinated) and +12 (excessively pronated) (Pérez-Morcillo et al., 2019; Redmond et al., 2006). ICC values for the FPI-6 were 0.62–0.91 (Redmond et al., 2006). FPI is only a measurement of static foot posture and should not replace a person's foot posture during a gait cycle. Nonetheless, it can provide key insight into how the foot might function (Pérez-Morcillo et al., 2019; Redmond et al., 2006).

A third clinical test, one that measures the dynamic posture of the foot, is the navicular drop test (NDT) (Adhikari et al., 2014). This test measures the vertical distance that the navicular tuberosity drops from a NWB (seated) to WB (standing) position (Adhikari et al., 2014; Zuil-Escobar et al., 2018). The navicular tuberosity is relevant to the rearfoot because the navicular tuberosity directly interacts with the talus and further contributes to the structure of the MLA (Neumann, 2017). As the talus pronates at the subtalar joint, the navicular tuberosity drops, thus lowering the MLA (Neumann, 2017). Measuring the distance the navicular tuberosity drops upon WB, provides us with more insight into how the dynamic foot functions during a running gait cycle (Neumann, 2017).

The NDT begins with the individual sitting with hips and knees flexed at 90 degrees and ankles in neutral position. The navicular tuberosity is marked, and an index card is placed next to the foot to also be marked at that height (Adhikari et al., 2014). The subject is then asked to stand with equal weight on both feet, and the new position of the navicular tuberosity is marked on the note card by the examiner (Adhikari et al., 2014). The difference between the two marks on the note card is measured in millimeters, equaling the total ND (Adhikari et al., 2014).

Research has determined that a high ND is associated with a low MLA and subtalar pronation, while a low ND is associated with a high MLA and subtalar supination (Zuil-Escobar et al., 2018). When evaluating the ICC values for ND Test, research has revealed that this form of testing is reliable and valid (Zuil-Escobar et al., 2018). The average ND is approximately 7-10 mm for an adult male (Adhikari et al., 2014; Neumann, 2017). A ND of 5-9 mm is considered by some to be normal, with the mean ND value being 6.7 ± 2.9 mm (Zuil-Escobar et al., 2018). While some consider individuals with a ND of greater than 15 mm to have an abnormal ND (Adhikari et al., 2014), others consider a ND greater than 10 mm to be abnormal (van der Worp et al., 2015). Interrater reliability values for this test measured 0.914-0.939 and intrarater reliability values measured 0.922-0.945 (Zuil-Escobar et al., 2018). An emphasis on experience as a requirement for this form of testing to repeat similar ICC values is noted in addition to the results (Zuil-Escobar et al., 2018).

In some cases, a large ND has been linked to overpronation of the foot and a risk of developing an overuse injury (Adhikari et al., 2014; Tonoli et al., 2010; van der Worp et al., 2015). ND can provide insight into the true function of the arch during the WB stages of running, by representing dynamic foot posture, and should be considered when measuring foot posture (Adhikari et al., 2014; van der Worp et al., 2015). Findings from the NDT further validate the hypothesis, made by Butler et al. (2008), that arch height is affected by the quantity of load that the foot is subjected to (Adhikari et al., 2014; Williams & McClay, 2000).

*What Role Does Foot Posture Have on a Runner Experiencing Other Biomechanical Changes?*

In some cases, individuals with abnormal foot posture and/or abnormal running biomechanics are at an increased risk for injury (McGinnis, 2013; Neumann, 2017; Pérez-Morcillo et al., 2019; Powell et al., 2016; Saragiotto et al., 2014; Tonoli et al., 2010; Williams III et al., 2001). Other than the foot, biomechanical changes at the knee are also linked to RRI (McGinnis, 2013; Powell et al., 2016; Williams III et al., 2001). During the stance phase of running, the knee joint becomes exposed to high stresses imposed by the GRFs generated up the leg where the muscles crossing over the joint experience an increased amount of tension (McGinnis, 2013). Incorrect tracking over an extended period of time can lead to excessive stress on the patella. This mechanism is hypothesized to cause running-related knee pain, such as PFP (Floyd, 2017; McGinnis, 2013; Neumann, 2017; Powell et al., 2016; Saragiotto et al., 2014; Williams III et al., 2001). Specifically, individuals who experience PFP have increased knee abduction moments (KAMs) during closed chain movements like running (Powell et al., 2016).

Powell et al. (2016), set out to research the connection between KAMs and foot type. They included 20 females in their study, 10 with high MLA's (HA) and 10 with low MLA's (LA); their arches were measured using AHIMS and were characterized into MLA type groups using the values previously mentioned in this review. The researchers observed the participants and calculated their KAMs using Visual 3D; their analysis found that, since the foot is the contact point with the ground during the stance phase, dynamic foot posture may influence the development of KAMs (Powell et al., 2016). Specifically, excessive foot pronation during running causes tibial internal rotation, which is linked to increased KAMs (McGinnis, 2013; Neumann, 2017; Williams III et al., 2001). Therefore, overpronation can contribute to developing PFP when experienced in a repetitive process like running (Powell et al., 2016). Individuals with LA were found to experience greater KAMs than those with HA (Powell et al., 2016; Williams III et al., 2001). Other examples of patterns of RRI for different MLA types will be discussed in the following section.

*How Has Foot Posture Been Linked to Running-Related Injuries & What Are Suspected Injury Patterns of High and Low Medial Longitudinal Arch Runners?*

Different measurement techniques, such as AHI, FPI, and NDT show how abnormal foot postures have been associated with RRI. In the article previously mentioned by Pérez-Morcillo et al. (2019), highly supinated feet, determined by FPI, were associated with 76.8 times higher odds for injury, over that of an individual with a neutral FPI. Highly pronated feet had 20.0 times higher odds of injury than individuals with a neutral FPI (Pérez-Morcillo et al., 2019). A p-value < 0.001 were found for both variables (Pérez-Morcillo et al., 2019). In other studies, excessive ND has been linked to MTSS and stress fractures, though these studies had limitations (Tonoli et al., 2010; van der Worp et al., 2015).

Research by Williams III et al. (2001) determined the different injury patterns that HA and LA runners experience. Subjects for the study were screened for placement in the HA or LA category using arch ratio (Williams III et al., 2001). They included 20 HA and 20 LA runners, between the ages of 18 and 50, that had a RRI, in the study (Williams III et al., 2001). HA runners reported more lateral and bony injuries, while LA runners demonstrated more medial and soft tissue injuries (Williams III et al., 2001). HA runners suffered injuries like lateral ankle sprains and ITBS, while LA runners suffered from PFP and medial knee injuries (Powell et al., 2016; Williams III et al., 2001).

### *What Limitations Does This Research Present?*

It is important to note that the patterns of injuries discussed within this review for arch types are not directly correlated for all individuals within the respective categories of arches. Each individual presents unique factors and should be analyzed on their own in order to come to any conclusions. Additionally, individuals with more moderate deviations of the arch should take more caution when applying the patterns of injuries discussed within this review to themselves (Williams III et al., 2001).

Limitations exist in the research utilized for this review and are important to consider when drawing conclusions from this information. Recall bias is represented as a limitation in some studies due to the utilization techniques of collecting data on injury history (Pérez-Morcillo et al., 2019; Williams III et al., 2001). Participation bias is specific to the research by Powell et al. (2016), as the study only included healthy recreational female athletes. The shoe type, foot orthotics, and even the absence of shoes present potential limitations when attempting to analyze the foot in the most accurate way of how it functions while running (Powell et al., 2016; Williams III et al., 2001). A low number of subjects involved in some of the studies and the preceding limitations should be considered when attempting to apply these study's results to a larger population (Powell et al., 2016; Williams III et al., 2001; Zuil-Escobar et al., 2018).

*Why Are These Findings and Ideas Important?*

The majority of this information is not completely conclusive. Therefore, there is a need for more research to investigate specific causes of RRI. Because there are so many different biomechanical factors and predisposed body abnormalities that could contribute to RRI, research should shift in the direction of analyzing an individual's risk factors in hopes of preventing injuries. Another avenue of additional research should seek to find a way to measure the MLA that is most similar to dynamic foot posture.

While the findings and patterns discussed within this review do not create a cause effect relationship between RRI and arch height, the current evidence reported in this thesis may help runners learn about how their foot type may contribute to risk of developing a RRI (Pérez-Morcillo et al., 2019; van der Worp et al., 2015; Williams III et al., 2001). With this knowledge, runners can seek appropriate avenues to reduce their risk, such as physical therapy, orthotics, correct shoe selection for their foot type, and/or finding their appropriate training load.

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