A Theoretical Perspective on Running-Related Injuries

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The etiology of running-related injuries remains unknown; however, an implicit theory underlies much of the conventional research and practice in the prevention of these injuries. This theory posits that the cause of running-related injuries lies in the high-impact forces experienced when the foot contacts the ground and the subsequent abnormal movement of the subtalar joint. The application of this theory is seen in the design of the modern running shoe, with cushioning, support, and motion control. However, a new theory is emerging that suggests that it is the use of these modern running shoes that has caused a maladaptive running style, which contributes to a high incidence of injury among runners. The suggested application of this theory is to cease use of the modern running shoe and transition to barefoot or minimalist running. This new running paradigm, which is at present inadequately defined, is proposed to avoid the adverse biomechanical effects of the modern running shoe. Future research should rigorously define and then test both theories regarding their ability to discover the etiology of running-related injury. Once discovered, the putative cause of running-related injury will then provide an evidence-based rationale for clinical prevention and treatment. (J Am Podiatr Med Assoc 104(2): 211-220, 2014)

Running is one of the most popular forms of exercise in North America, and its benefits to health and wellness are well-known. Despite evidence to suggest that running is one of the most effective ways to achieve fitness, recent statistics suggest that it also involves a relatively high risk of injury. The results of several studies have found that 11% to 85% of recreational runners experience a running-related injury (RRI) every year and that 30% to 90% of injuries result in a reduction or stoppage of training. The wide ranges in these statistics are largely due to varied definitions of the words runner and injury. For the purposes of this paper, a runner is defined as anyone who self-identifies as such and runs a minimum distance per week on a regular basis for the purpose of physical fitness. An RRI is defined as any musculoskeletal ailment of the lower extremities that is attributed to running and results in a reduction or stoppage in running mileage for at least 1 day. Considering the well-known health benefits of physical activity, any factor that causes a reduction or stoppage in physical activity should be viewed as a barrier to the health and wellness of North Americans. In this context, the etiology of RRIs must be well-defined to develop effective modes of prevention and treatment and, consequently, to improve the overall health status of North Americans.

The etiology of RRIs has been a source of debate for many years. An RRI may occur as a result of any number of combinations of different factors, often unique to each individual. This multifactorial nature makes the prevention of RRIs challenging and a simple, customizable system of prevention appealing. One of the most common methods of prevention is the prescription of running shoes based on foot type. This is a widely accepted practice, and the design of the modern running shoe now seems to be technologically advanced to address the problem of RRIs. However, despite each popular brand’s claims of cushioning, support, and motion control, a recent systematic review found that these shoes have never been tested in controlled clinical trials, and so their effect on injury rates remains unknown. In fact, a review of the literature on injury incidence has shown that RRIs have actually increased alongside the development of the modern running shoe during the past 40 years. Because there remains no real consensus on what causes these injuries or how best to prevent them, the modern running shoe remains the gold standard and is consistently recommended to footwear prescrib-
A new theory is emerging that supports the use of shoes made with the Running Shoe Theory in footwear for the prevention of RRIs, this perspective is referred to as the "Running Shoe Theory" for the purposes of this paper.

Based on the high injury rates associated with the use of shoes made with the Running Shoe Theory in mind, many in the running community are now questioning where this thinking came from and how helpful it really is to the health and wellness of those who run for exercise. It has recently been challenged by a variety of researchers, clinicians, and runners alike, who suggest that there may be an alternative way of thinking about the foot's function during running and the role that footwear plays in RRI. A new theory is emerging that supports the barefoot running movement as a more natural and potentially less injurious way to run. Despite having only a small amount of scientific evidence to support this new way of thinking, many runners have taken off their shoes and joined the movement based solely on the experiences of other runners who have done the same. They claim to experience fewer injuries and better performance, but many skeptics still hold to the traditional way of thinking and are waiting on solid evidence before changing their views. This emerging theory on the causes and prevention of RRIs is referred to as the "Barefoot Running Theory" for the purposes of this paper.

As research progresses and the running community reconsiders the etiology of RRIs, it is critical that these opposing theories be well-defined and fully developed. Theory plays an important role in clinical decision making and in the development of new research programs, especially when there is a need for stronger evidence. This paper outlines both theories on the contributing factors to RRIs and summarizes the available evidence to confirm or contradict their claims.

The objectives of this paper were to describe and discuss the theories behind RRI and footwear choice from the two opposing views. We first describe the Running Shoe Theory of RRI, which supports the use of cushioned, supportive, motion control shoes. We then summarize the evidence behind the application of this theory and the lack of evidence that has led many to question its usefulness. Principles and existing research of the emerging Barefoot Running Theory are then discussed, including the ways in which this theory addresses the problems of the opposing theory. Finally, the areas in which future research is needed and the challenges specific to this kind of research are outlined.

Running Shoe Theory on the Cause of RRIs

Theory Development

Theory may be defined as a set of tested propositions to explain an observed phenomenon. When developing modes of prevention and treatment of injury where the ultimate cause is unknown, theory is critical for informing research and practice. This means that a theory should be thoughtfully developed and subject to continual testing against the latest evidence. Unfortunately, this does not always happen, as theory may develop alongside practice based predominantly on the most prevalent way of thinking. Eventually, theories may become widely accepted without ever undergoing scientific testing. This seems to be the case when considering the ultimate cause of RRIs.

A recent systematic review by Richards et al found no studies that evaluated the effects of running shoes on injury or performance. They suggest that running shoes have, therefore, been prescribed as the gold standard for the prevention and treatment of RRIs without scientifically proven benefit. If not based on evidence, it can be said that this practice, along with the design of the modern running shoe, is based on a perspective that is only theoretical in nature. The following sections define and describe this theory to help us better understand the paradigm that exists between current research and practice.

According to Robbins and Hanna, the assumptions underlying the design of modern running shoes contend that feet are evolutionarily unsuccessful and inherently fragile; therefore, the only way to prevent RRIs is to protect the foot by packaging it in footwear that provides cushioning, support, and pronation control. For the purposes of this paper, these assumptions are referred to as the Running Shoe Theory. Application of the Running...
Shoe Theory can be seen in a typical modern running shoe that has thick heel cushioning, firm arch support, and a rigid heel counter to control motion at the subtalar joint. These shoes as a group are termed “pronation control, elevated cushioned heel” (PCECH) shoes to reflect the different types of running shoes that are often prescribed after classifying an individual by foot type and arch structure. These shoes are designed to address the supposed causes of RRIs and, therefore, work to prevent injury. However, there is a lack of evidence that supports the use of PCECH shoes to prevent injury, and, therefore, it is important to reexamine our theories on what causes RRIs. The following discussion defines and describes the two most common causes of injury as held by the Running Shoe Theory of RRIs.

**High-Impact Forces (Kinetics)**

The Running Shoe Theory on the cause of RRIs asserts that high-impact forces experienced while running are a major cause of injury. This assumption is founded in logic and has been held for many years. In fact, 25 years ago, Robbins and Hanna described a general consensus that existed among sports medicine practitioners as to the ultimate cause of RRIs. It was understood that while running, the high rate and magnitude of loading (impact force) on contact with the ground was the cause of RRIs. From a biomechanical perspective, Hreljac describes the stress-frequency curve, which applies to all tissues of the body. Based on its physiology, each tissue has a different injury threshold, which may be reached with either a high frequency or high stress (magnitude) of impact forces. From this standpoint, it is understandable that excessive force will inevitably result in injury; however, this curve may be modified by many factors, making the relationship between impact and injury more complex.

Only recently have several observational studies actually linked these high-impact forces to RRIs. As Hreljac summarizes, when comparing injured and noninjured runners, at least four published studies have found that injured runners had greater vertical impact forces than noninjured runners. In addition, one prospective study followed 240 female runners over 2 years and reported greater impact loading in the group of runners who sustained an injury during that time. From these results, it is suggested that high-impact loading may increase the risk of RRIs.

It has also been argued that running on hard surfaces increases impact forces and, subsequently, risk of injury. However, the evidence to support this assumption is weak. In fact, Ferris et al report that when running on hard surfaces, humans tend to land with less leg stiffness and, therefore, maintain the same peak ground reaction force despite a change in surface stiffness. Nigg and Wakeling agree and suggest that the mechanism behind this adjustment involves muscle tuning in the locomotor system, which occurs shortly before ground contact to prepare the body for landing. These findings put the Running Shoe Theory into question because it seems that the body is capable of attenuating the high-impact forces experienced on hard surfaces and, therefore, may not need any additional protection to avoid injury.

Although an association between high-impact forces and RRIs is supported by the research, it is clear that hard surfaces do not directly increase these forces. More research is, therefore, needed to determine the cause of high-impact forces and the best ways to attenuate them.

**Abnormal Subtalar Motion (Kinematics)**

A second factor that is often implicated as injury causing by the Running Shoe Theory is based on what is considered to be abnormal motion at the subtalar joint. Also known as the talocalcaneal joint, the subtalar joint occurs at the articulation between the talus and calcaneus bones and allows for pronation and supination of the foot during gait. Abnormal motion at the subtalar joint is proposed to consist of either overpronation or oversupination.

Pronation at the subtalar joint allows for the attenuation of impact forces over a longer period, preventing overloading of the lower extremity. It typically occurs during the first 25% of the stance phase and allows the foot to become flexible and adaptable to different types of terrain. Normally, pronation ends as the foot approaches midstance and supination occurs to allow the foot to act as a rigid lever and propel the body forward. When pronation continues throughout this period, it may stretch the plantar ligaments and prolong the internal rotation of the leg, both of which may lead to pain and injury. This extended period of pronation is considered by supporters of the Running Shoe Theory to be abnormal and potentially injury causing.

The idea that overpronation leads to injury has been tested, and the results are conflicting. When measuring maximum pronation angles and max-
imum pronation velocities, Hreljac\textsuperscript{9} summarizes that injured runners have been reported in different studies to exhibit more pronation,\textsuperscript{18,19} less pronation,\textsuperscript{12} and no difference in pronation\textsuperscript{13} compared with noninjured runners. Some researchers have even suggested that more pronation is favorable during running, as long as it ends at midstance.\textsuperscript{12} Based on these reports, it is clear that no consistent association exists between overpronation and RRI s. 

Oversupination, or underpronation, at the subtalar joint is less commonly mentioned in the literature because it seems to be less prevalent in the general population. However, it is another classification of foot type that is often prescribed specific shoes to prevent supination that exceeds the normal range.\textsuperscript{4} This range, similar to that of overpronation, remains relatively undefined, and we did not locate any controlled clinical trials that examined the relationship between oversupination and RRI s.

Despite being commonly implicated as a major cause of injury in runners, no consistent association has been made between subtalar motion and RRI s. This finding, along with the lack of data on effectively attenuating high-impact forces, brings into question the Running Shoe Theory on the cause of RRI s, and with it the design of the modern running shoe. The following discussion addresses the application of this traditional theory and considers the elements of PCECH shoes that are commonly believed to reduce the risk of injury despite a lack of support in the scientific literature.

Application of the Running Shoe Theory

According to Stewart,\textsuperscript{20} the first shoes were worn primarily to protect the sole. Until the development of the modern running shoe in the 1970s, everyone ran either barefoot or in minimal shoes with little cushion and minimal heel lift.\textsuperscript{8} The PCECH shoe was developed as a natural application of what was thought to be the cause of RRI s. If injuries were thought to occur as a result of high-impact forces and abnormal subtalar motion, then, logically, a shoe that could attenuate these forces and prevent abnormal motion at the subtalar joint should prevent injuries. Although both of these proposed causes lack support in the scientific literature, PCECH shoes continue to be prescribed for the prevention of RRI s. In addition, the assumption that a shoe might effectively attenuate high-impact forces and prevent abnormal subtalar motion remains unproved.\textsuperscript{5}

Richards et al\textsuperscript{5} reviewed the evidence for the prescription of PCECH shoes and listed cushioning, an elevated heel, and motion control systems as the three major features that have been typically incorporated to prevent injury. The following discussion considers the two features of the PCECH shoe that have been designed to address the previously mentioned proposed causes of RRI s: cushioning features to address high-impact forces and motion control systems to address abnormal subtalar motion. The lack of evidence for these strategies to effectively reduce the risk of RRI s is then reviewed.

Cushioning

A typical PCECH shoe uses cushioning as a strategy to attenuate the high-impact forces experienced while running. The Running Shoe Theory of RRI s behind this strategy views the foot as an inflexible lever, meaning that it is, therefore, incapable of attenuating the high magnitude and rate of forces believed to be experienced when running on hard surfaces. The role of footwear, from this perspective, is to provide shock absorption through the use of cushioning in the midsole. Most commonly, ethylene vinyl acetate foam is used, but other technologies include air, gel, rubber, altered ethylene vinyl acetate, and even springs.\textsuperscript{21} However, the evidence is poor that supports the assertion that decreasing the stiffness of the interface between the foot and the ground reduces impact forces or injury rates.\textsuperscript{15} This is largely due to the observation that depending on the stiffness of the surface, muscle tuning seems to alter the stiffness of the leg just as the foot makes contact with the ground.\textsuperscript{22} In addition, a study by Kong et al\textsuperscript{21} compared the kinetics and kinematics of running in new cushioned shoes versus worn shoes with degraded cushioning. They report no difference in maximum vertical active force or loading rate between new and worn shoes but an increase in stance time in worn shoes. From these results, they suggest that runners maintain constant impact loading by modifying their running form according to the amount of shoe cushioning.\textsuperscript{21}

The theoretical assumption that a cushioned shoe can lessen impact forces and reduce injuries seems to be contrary to the findings of the aforementioned studies. In addition, as Richards et al\textsuperscript{5} suggest, cushioning itself may cause more harm than good by diminishing proprioception and providing the runner with a false sense of security against high-impact forces. The proposed negative effects of
PCECH shoes are further discussed as applicable to the emerging Barefoot Running Theory of RRIs.

**Motion Controlling**

Based on the theoretical assumption that abnormal motion at the subtalar joint contributes to RRIs, a typical PCECH running shoe includes features that are designed to prevent the subtalar joint from motion that exceeds the so-called normal range. This most commonly refers to the prevention of overpronation but may also include features to prevent oversupination. Features that are often advertised as being motion controlling include a wedging or heel flare counter and the use of materials with different deformation rates in the lateral and medial midsoles. These features are designed to control motion by either restricting the subtalar joint’s range of motion to that considered to be normal or directing motion from supination to pronation and back to supination.

Reports on the effectiveness of motion control shoes on subtalar motion are conflicting. Some studies report that these shoes are capable of only small, subject-specific changes in running kinematics. In contrast, a recent systematic review concluded that “motion control footwear is effective at reducing the amount of foot pronation and the vertical impact peak during running.” However, this review did not find any evidence to suggest that motion control footwear is effective at controlling rotation at proximal segments, such as the tibia and femur. As they explain, it is the rotation at the knee that is most often cited as the site of injury. Although PCECH shoes may reduce foot pronation, it is unknown what impact this has on the risk of experiencing an RRI.

The theoretical assumption that motion control footwear is effective at altering subtalar motion is meaningless if abnormal subtalar motion does not contribute to RRIs. As previously mentioned, there has been no consistent link made between subtalar motion and injury rates. More research is needed to examine the effects of pronation and supination on the incidence of RRIs. Specifically, longitudinal trials that compare injury rates between runners wearing shoes with and without motion control systems are required to test this assumption.

Although PCECH shoes are a common clinical application for the prevention of RRIs, there is a lack of support for this practice in the scientific literature. The design of a typical PCECH shoe relies on two theoretical assumptions that remain unproved: that cushioning may effectively reduce high-impact forces and, therefore, reduce injuries and that reducing the amount of abnormal subtalar motion while running will reduce injuries. Without support for these assumptions on its application, the validity of the Running Shoe Theory on the cause of RRIs must be called into question. It is here, in the shortcomings of its predecessor, that a new theory is emerging to explain the etiology behind RRIs and suggest new strategies for their prevention and treatment.

**Barefoot Running Theory on the Cause of RRIs**

**Theory Development**

In the larger North American running community, there is a growing movement of barefoot runners. Although supporters of the practice have always been around, it is only in the past decade that it has substantially grown, in large part due to the publicity from scientific and nonscientific sources. Beginning with the trailblazing work of Robbins and Hanna in the late 1980s and gaining more public attention with the 2010 study by Lieberman et al., a scientific basis for the practice of barefoot running is now growing. Many attribute the recent surge in popularity of barefoot running to the publication of Christopher McDougall’s book *Born to Run.* The best-selling book promotes the practice while telling the story of the author’s own journey in learning to run long distances without injury. Throughout both the book and the scientific literature, a new way of thinking about what does and does not cause RRIs is presented, and a new theory on their prevention is steadily being built.

The emerging theory behind the barefoot running movement is based on what are considered to be the reasons for the large incidence of RRIs with the use of PCECH shoes. Several researchers have implicated these shoes as the cause of detrimental adverse effects that may contribute to RRIs. According to the Barefoot Running Theory, the foot is a dynamic, flexible system that attenuates high impacts with the downward deflection of the medial longitudinal arch. It is capable of rehabilitation and avoids injury when allowed to function according to its physiologic design. Running-related injuries occur when the foot is forced to function unnaturally, that is, confined within a PCECH shoe, and the body maladapts to this condition. These maladaptations, or adverse effects, of the PCECH shoe have been proposed to cause injury, often based more on a lack of support for the Running...
Shoe Theory than on experimental evidence showing their detriment. Considering the limited body of evidence in support of this emerging theory, the following discussion concentrates on the three most commonly cited adverse effects of PCECH shoes: atrophy of the intrinsic foot musculature, diminished somatosensation, and an abnormal gait. Although other factors, such as running economy, are mentioned in the literature, these three have been chosen based on the amount of currently available evidence.

Atrophy of Intrinsic Foot Musculature

As early as 1972, Stewart proposed that the solution to foot ailments lies in using them in a more natural physiologic way. His observations of the Army Shoe Board led him to believe that the foot’s arch is maintained not only by bones and ligaments but also by strong intrinsic musculature. To maintain the arch, these intrinsic foot muscles must be strong, and to be strong they must be used. The Running Shoe Theory of RRIs assumes that the typical rigid foot with its relatively unyielding arch is beyond rehabilitation. It is, therefore, packaged into a shoe with a large amount of shock-absorbing material surrounding it. This tightly packed shoe does not require much, if any, muscular support to maintain the medial longitudinal arch because it is firmly supported. The Barefoot Running Theory of RRIs hypothesizes that intrinsic foot musculature may atrophy as a result of the use of tightly packed, cushioned shoes, which may cause many of the common foot ailments seen today.

As a result of the PCECH shoe’s tight fit, little intrinsic muscle activation is required for locomotion. It is, therefore, proposed that runners who wear PCECH shoes may develop weak intrinsic foot musculature, which may lead to a decrease in medial longitudinal arch height and subsequent injuries. These injuries may include plantar fasciitis, one of the most commonly experienced conditions in sports involving running and jumping. Although a PCECH shoe treats the symptoms of plantar fasciitis by providing support for the medial longitudinal arch, it does nothing to treat the cause and, therefore, nothing to alleviate the symptoms of plantar fasciitis experienced when not wearing PCECH shoes. For example, a person who experiences plantar fasciitis may find that a new pair of PCECH shoes alleviates the pain normally felt while shod, but they still experience pain and discomfort while at home and unshod. Robbins and Hanna propose that strengthening intrinsic foot musculature may spare the fascia by giving it support during impact. More research is required to compare intrinsic muscle strength between habitually shod and habitually barefoot runners. Based on Davis’ Law, it is reasonable to suppose that the use of a PCECH shoe that provides enough support to the medial longitudinal arch without much muscular support may lead to atrophy of these muscles. This adverse effect is, therefore, proposed to contribute to an increased risk of injury.

Diminished Somatosensation

The Barefoot Running Theory of RRIs proposes that sensory feedback between the peripheral and central nervous systems is critical in the avoidance of injury. Somatosensation from the foot is provided in large part by proprioception and touch. Proprioception in this context refers to a kinesthetic sense of foot position. McCloskey defines kinesthetic sensations as those perceived about the “static position or velocity of movement of those parts of the body moved by skeletal muscles and perceived sensations about the forces generated.” Touch refers to the information provided by mechanoreceptors on the plantar surface of the foot. Robbins and Waked proposed that footwear attenuates plantar tactile events, thus preventing normal stimulation of the foot’s mechanoreceptors. It is these plantar surface mechanoreceptors that respond to plantar deformations and provide the body with directional sensibility to allow for rapid changes in foot position to avoid injury. Although sensory information is provided by proprioceptive muscle receptors in the foot and plantar mechanoreceptors on the skin’s surface, the results of a study by Robbins et al suggest that plantar mechanoreceptors provide a more precise sense of foot position because they are not influenced by previous muscle contractions. According to this finding, exposure of the plantar skin’s mechanoreceptors to the ground surface is critical to provide the body with accurate feedback to function optimally and avoid injury.

Based on one study of young men in barefoot and shod conditions, errors in foot position sense increased by more than 4° when in the shod condition. In addition, a similar study conducted in older men found an increase in foot position sense errors in conditions with firmer, thinner soles compared with firmer, thicker soles. The danger in these errors in foot position sense lies in their correlation to ankle injuries when running. According to Robbins and Waked, impaired propriocep-
tion results in inadequate use of anticipatory muscular movements during dynamic situations. These anticipatory muscular movements are what the body relies on to prevent injury when there is not enough time to respond to a loading event, such as when landing on an uneven surface.

Robbins and Hanna suggest that the modern running shoe has placed the runner in a vulnerable state by diminishing sensory feedback without diminishing the injury-causing impact. Injuries occur because of the lack of protective actions normally stimulated by sensory feedback and the appearance of protection provided by a heavily cushioned running shoe. This is referred to as the “discomfort-impact illusion,” whereby injury is inevitable as a result of footwear that provides the wearer with plantar comfort despite the large vertical impact on landing. On account of the perceived impact being, therefore, lower than the actual impact, the body responds with inadequate anticipatory muscular movements to moderate the impact, and subsequent injury occurs. According to the Barefoot Running Theory of RRIs, PCECH shoe wearers believe that the cushioning in their shoes decreases their risk of injury by attenuating the impact experienced at heel strike, but in reality it has diminished only their somatosensation of the impact. This adverse effect is, therefore, proposed to contribute to an increased risk of injury.

**Unnatural Running Form**

In addition to weakened foot musculature and diminished sensory feedback, the Barefoot Running Theory of RRIs proposes that PCECH shoes may contribute to injury by facilitating an unnatural running form while running. This concept has developed in large part from the work of Harvard physical anthropologist Dr. Daniel Lieberman. Lieberman suggests that running in shoes with elevated heels promotes a landing that is characterized by a heel (or rearfoot) strike. From an evolutionary perspective, this landing is unnatural because the foot is a product of eons of adaptations to different conditions and environments, all experienced, until recently, completely barefoot.

The Barefoot Running Theory of RRIs proposes that our feet and bodies have maladapted to wearing shoes that offer a cushioned, elevated heel. Previous work has found that runners who rearfoot strike produce a spike in the magnitude and rate of loading on a vertical ground reaction force–time curve that is not present in runners who forefoot strike. This spike is frequently referred to as the “impact transient” and has been commonly implicated as injury causing. Lieberman suggests that our feet have maladapted to wearing shoes and that this injury-causing impact transient is a result. In fact, he suggests that the pain experienced when landing with a rearfoot strike while running barefoot may serve as a warning signal that we are running in a way that may lead to chronic overloading of tissues and subsequent injury. The pain would, therefore, force our bodies to find a running form that generates a smaller impact peak, such as that of a forefoot or midfoot strike. By wearing a PCECH shoe, the Barefoot Running Theory proposes that the wearer is ignoring the body’s natural adaptive processes and is instead adapting to a running form that increases the impact forces experienced at foot-ground contact. More research is required to support this relatively new concept; however, it is reasonable to propose that running with a form that results in higher impact peaks may lead to an increased risk of injury.

In summary, the Barefoot Running Theory of RRIs proposes that RRIs are the result of adverse effects experienced from the use of PCECH shoes. These adverse effects include weakened intrinsic foot musculature, leading to a decrease in medial longitudinal arch height; decreased somatosensation, leading to more foot position sense errors; and an altered running form, resulting in large impact peaks on contact with the ground. To avoid RRIs, this theory must be applied and practical steps must be outlined to prevent or reverse the adverse effects of PCECH shoes.

**Application of the Barefoot Running Theory**

Based on the proposed injury-causing adverse effects associated with PCECH shoes, the Barefoot Running Theory of RRIs suggests that barefoot running avoids the negative effects of running while wearing PCECH shoes. Many authors and clinicians familiar with podiatric medicine report that the foot ailments commonly seen in the shod population are absent in barefoot populations. Therefore, it is proposed that running barefoot allows for several positive changes to occur and that these changes may reduce the risk of certain RRIs.

By transitioning to barefoot running or even incorporating it into a runner’s training schedule, it is proposed that the risk of RRIs may be decreased through three specific changes: an increase in the strength of the intrinsic foot musculature, an improvement in somatosensation,
and a shift to a lower-impact running form. Current evidence in support of these hypotheses is presented in the following sections.

**Improve Intrinsic Foot Muscle Action**

Much anecdotal evidence from clinicians and researchers reports a rare incidence of flat feet in barefoot populations.\(^{20,35}\) This has led to the hypothesis that barefoot activity may improve the action of the intrinsic foot musculature, especially that required to maintain the medial longitudinal arch.

A study by Robbins and Hanna\(^7\) was one of the first to analyze changes in the medial longitudinal arch as a result of increased barefoot activity. Using foot imprints and radiographs, they measured changes in the medial longitudinal arch span of 17 recreational runners. The experimental group was told to increase their barefoot weightbearing activity over approximately 4 months and was encouraged to walk or run barefoot when possible. They found a mean change (representing either shortening [+] or lengthening [–] of the medial longitudinal arch) of +4.7 mm in the experimental group and –4.9 mm in the control group, suggesting that an increase in barefoot activity activates the normally inactive musculature while weightbearing.\(^7\) Although this study demonstrated significant change between the two groups, it faces criticism because of its small sample size and lack of dosage regulation.

No published studies have yet reported a reduction in RRIs as a result of increased intrinsic muscle action. Although it would be reasonable to suppose that a stronger foot may provide protection and support against injuries of the bones and joints of the foot, more research is required to investigate the effect of increased intrinsic muscle action on the incidence of RRIs.

**Facilitate Somatosensation**

By running barefoot, the foot is able to make direct contact with the ground surface. Consequently, this allows the mechanoreceptors on the foot’s plantar surface to directly receive sensory feedback. This information is used to properly position the foot, minimize forces, and command muscular support, all while preventing overloading to the ligaments.\(^{32}\) As Lieberman\(^8\) hypothesizes, barefoot runners are more likely to adjust their gait or muscular support accordingly as they sense damaging rates and magnitudes of loading. This is especially important in the prevention of ankle sprains, which are reported to have a lower incidence in barefoot populations.\(^{32}\)

A recent study by Squadrone and Gallozzi\(^36\) had participants estimate treadmill surface slope while in either a minimalist shoe or a standard cushioned running shoe. A minimalist shoe is meant to provide the benefits of barefoot running while still offering some plantar protection. They report that while running, treadmill surface slope was significantly better estimated by runners when wearing a minimalist shoe than when wearing a standard cushioned running shoe.\(^36\) In this case, treadmill surface slope is an outcome measure of proprioception, and the results suggest that a minimalist shoe facilitates better proprioception than a PCECH shoe. The main limitation to this study is that its generalizability to barefoot running is poor. As Jenkins and Cauthon\(^6\) explain, minimalist shoes may provide the runner with a false sense of security, allowing them to run at an intensity that the natural bare foot would not allow. In addition, many varieties of minimalist shoes are becoming available with unique characteristics that, therefore, need to be tested individually to determine their effectiveness. This study provides promising results for an improvement in somatosensation with the practice of barefoot running, as sound reasoning would suggest that the results might be amplified as closer contact between the sensory tactile sensors and the ground surface is made.

Sufficient somatosensation allows the body to carefully monitor and limit the intensity of a run to prevent chronic overloading of the tissues. This means that injuries are prevented by paying attention to pain and limiting intensity accordingly, possibly leading to less running overall. Considering that training intensity is one of the only modifiable factors with a strong association to injury,\(^{24}\) barefoot running could result in fewer RRIs simply because it limits the intensity that a person can run at. More research is needed to determine exactly what effect barefoot running has on somatosensation and the impact that this may have on the incidence of RRIs.

**Promote Better Running Form**

The Running Shoe Theory on the cause of RRIs proposes that the impacts experienced during running should be minimized using a cushioned heel. In contrast, the Barefoot Running Theory suggests that these impacts can be minimized or even avoided by running with a different form,
specifically, by landing on either the forefoot or the midfoot rather than the rearfoot.\textsuperscript{25} This form is distinguished by several characteristics, including a shorter stride, a high cadence (\textgreater 170 steps per min), a landing on the ball of the foot below the fourth and fifth metatarsal heads, and a loose, aligned upper body.\textsuperscript{8} In fact, the Barefoot Running Theory proposes that this running form is a result of the body’s adaptation to the painful impacts experienced during running with a heel strike.

A recent retrospective study compared injury rates and severities of collegiate-level distance runners based on foot strike.\textsuperscript{37} They found that runners who habitually ran with a rearfoot strike had approximately twice the rate of repetitive stress injuries as those who habitually ran with a forefoot strike. There were several limitations to this study, including a lack of measurement of footwear type and a relatively small, homogenous sample. Although the results of this study provide some support for the theory that a runner’s form may contribute to the incidence of RRI, more well-designed, prospective studies are needed to investigate the link between foot strike and injury incidence.

**Future Research Directions**

This review summarized several studies that suggest that running barefoot may increase intrinsic musculature, improve somatosensation, and promote better running form.\textsuperscript{7,25,36} One study explored the differences in injury rates between forefoot- and rearfoot-striking runners,\textsuperscript{37} but more prospective research is needed. Specifically, future research should address the effectiveness of barefoot running on somatosensation and intrinsic muscle action. In addition, the links between better somatosensation and RRI and between increased muscle action and RRI need to be investigated.

Ideally, a prospective study comparing injury rates and severities between habitually barefoot and habitually shod runners is needed to test the merits of this emerging theory and provide evidence for both research and practice.

Many methodological challenges exist when designing a study to measure harm.\textsuperscript{38} Despite yearly injury rates as high as 85\%,\textsuperscript{2} the occurrence of an injury is still a rare event that would require a large sample size and an extensive follow-up period to effectively capture.\textsuperscript{38} Another difficulty becomes apparent when attempting to eliminate confounding variables. Running-related injuries are multifactorial\textsuperscript{9} and, therefore, could be the result of a variety of unique combinations of factors, which could be different for each individual. When comparing barefoot and shod running, more specific challenges arise owing to the practical differences between the two footwear conditions. To ensure equal treatment,\textsuperscript{38} adjustments must be made to correct for differences in shoe mass. Also, it is difficult to maintain equal dosages when the nature of barefoot running prevents novice runners from training at the same intensity and durations that are possible when shod. To further develop a theory behind the cause and prevention of RRI, it is critical that future research studies find ways to address these challenges.

**Conclusions**

The high incidence of injuries in the running population is a barrier to physical activity, and effective modes of treatment and prevention are essential for the health and wellness of runners everywhere. In the development of treatment and prevention modalities, both theories on the cause of RRI should be examined and considered. The Running Shoe Theory proposes high-impact forces and abnormal subtalar motion to be the cause of RRI. Therefore, to prevent RRI, it is recommended that runners use shoes that provide cushioning, support, and motion control. There is little research to support this practice, and even some to suggest that these shoes may do more harm than good. The Barefoot Running Theory proposes that RRI are a result of atrophy of the intrinsic foot musculature, diminished somatosensation, and altered gait. Therefore, it is recommended that runners transition to barefoot running to improve intrinsic foot muscle action, facilitate somatosensation, and promote better running form.

To fully develop and define both theories, more research is needed to provide support for the assumptions made by both opposing views. Considering the lack of success in lowering the rate of RRI with application of the Running Shoe Theory, it may be beneficial to focus future trials on the development and testing of new ways of thinking, such as that around barefoot running. Some promising evidence has been published to support the reduction of RRI with barefoot running, but many questions are yet to be answered.

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