Running shoes and running injuries: mythbusting and a proposal for two new paradigms: 'preferred movement path' and 'comfort filter'

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ABSTRACT

In the past 100 years, running shoes experienced dramatic changes. The question then arises whether or not running shoes (or sport shoes in general) influence the frequency of running injuries at all. This paper addresses five aspects related to running injuries and shoe selection, including (1) the changes in running injuries over the past 40 years, (2) the relationship between sport shoes, sport inserts and running injuries, (3) previously researched mechanisms of injury related to footwear and two new paradigms for injury prevention including (4) the 'preferred movement path' and (5) the 'comfort filter'. Specifically, the data regarding the relationship between impact characteristics and ankle pronation to the risk of developing a running-related injury is reviewed. Based on the lack of conclusive evidence for these two variables, which were once thought to be the prime predictors of running injuries, two new paradigms are suggested to elucidate the association between footwear and injury. These two paradigms, 'the preferred movement path' and 'the comfort filter', suggest that a runner intuitively selects a comfortable product using their own comfort filter that allows them to remain in the preferred movement path. This may automatically reduce the injury risk and may explain why there does not seem to be a secular trend in running injury rates.

INTRODUCTION

In the past 100 years, running shoe designs have experienced dramatic changes. The running shoes in 1912 were shoes that would be considered dress shoes today (figure 1). The current running shoes are technical and engineering masterpieces and have descriptions such as support, cushioning, light weight, minimalist and barefoot. There is no question that a 2015 runner would not use the 1912 'running shoes' for running activities. The question is, however, whether or not the shoes in 2015 are associated with fewer running-related injuries than the running shoes used in 1970 or in 1912. The more general question is whether or not running shoes (or sport shoes in general) influence the running injury rates at all.

This paper will address five aspects related to running injuries and shoe selection, specifically:

1. The changes of running injuries in the past 40 years.
2. The relationship between sport shoes, sport inserts and primary running injury prevention.
3. The factors that influence the frequency of running injuries, including the importance of 'cushioning' and 'pronation control'.
4. The preferred movement path.
5. The comfort filter.

CHANGES IN RUNNING INJURIES OVER THE PAST 40 YEARS

Running started to become very popular in the 1970s.[1] Parallel to this development, runners started to get injured and scientific studies were published discussing the prevalence of running injuries. These studies showed a wide variety of results with relative running injury frequencies varying between about 15% and 85% of runners (figure 2).[2–18] However, there seems to be no apparent secular trend (over time) for the frequency of injuries.

Several reasons could explain this phenomenon. One is a change in the running population and the second is the definition of a running injury.

Possible differences in running population

The runners in the 1970s and 1980s were different than the runners in the third millennium. The runners in the 70s were dedicated runners, aiming to win, skinny and primarily ran; 75% were male. The runners in the current millennium are primarily recreational runners who run a marathon to finish, some are overweight and most are involved in cross-training activities. Now a slight majority of runners are female (54%). Furthermore, the populations studied in various epidemiological studies were not the same. Some authors studied new runners while others studied competitive runners.[8 13 14]

Definition of running injuries

Definitions of running injuries varied widely in older studies. Some used a definition that required medical attention to be included as an injury.[19] Other authors used a definition that used a defined time where the running activity could not be performed and the duration was not consistently the same.[12] Other authors defined a running injury if there was any symptom about pain or discomfort.[8] It is obvious that the injury frequencies for such different injury definitions could not be the same.[20]

Based on these considerations (running population and definition of injury) the numbers of these studies can and should not be compared and conclusions about changes in running injuries over time or the effects of running shoes based on these data seem inappropriate.[21]

Figure 1 Examples of running shoes in 1912, the Spalding running shoes (left) (adapted from[69] with permission from the author) and modern running shoes in 2014 (right) (with permission from New Balance Athletic Shoe, Inc and Mizuno Corporation).

SPORT SHOES AND SPORT INJURIES

The relationship between injury incidence and sport shoes has been at the centre of attention for several studies (table 1).

The publications summarised in table 1 illustrate several interesting points:

1. The direct effect of running shoes on running injuries was not addressed until 2012.[22] The earlier studies compared baseball, basketball, soccer and military shoes.
2. The only two studies that addressed cushioning as an injury prevention strategy[23 24] did not show a significant decrease of the injury frequency when changing the midsole hardness.
3. Only one study compared two different running shoes with respect to running injuries.[25] The difference in injury frequency between the two running shoes was about 200%. Thus, based on this study,[25] one can conclude that running shoes can affect injury frequencies substantially.

SPORT INSERTS/ORTHOTICS AND SPORT INJURIES

Several studies addressed the association between injuries and shoe inserts or orthotics.[26–30] Details from selected studies that showed significant differences between two insole conditions are summarised in table 2.

These studies suggest two major comments concerning the effect of orthotics/insoles on injuries, one related to the hardness and one related to comfort.

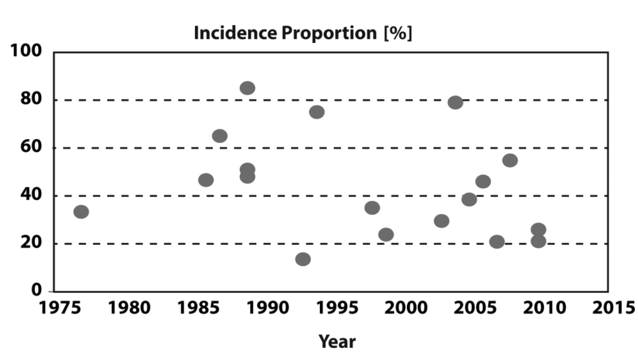

Figure 2 Summary for the frequency of running injuries based on studies from.[2–18]

Hardness

Contrary to the shoe sole results, where the studies analysing the effect of soft shoe soles did not show any significant differences, the insole studies came to a different conclusion: a softer shoe insole seems to reduce injuries in military shoes and (we speculate) probably also in running shoes.

Comfort

The study of Muendermann *et al.*[29] contains information that seems important for the understanding of injury aetiology. They provided six different insoles (different with respect to arch, heel shape, material and elasticity) to a test group of 106 soldiers and asked them to assess the insoles with respect to

Table 1 Summary of the publications found discussing the association between injury frequencies and sport shoes.[22–25 64–68]

Author	Year	Shoe feature	Activity	Significant	Comments
Cameron	1973	Swivel	Football	Yes	Idea disappeared
Milgrom	1992	Comfort	Basketball	Yes	Military vs basketball shoe
Barret	1993	High vs low cut	Basketball	No	
Lambson	1996	Cleat position	Soccer	Yes	ACL injuries
Meeuwisse	1998	Shoe construction	Basketball	Yes	Feet you wear vs rest
Curtis	2008	Cushioning	Basketball	No	Questionnaire (n=230)
Knapik	2010	Plantar shape	Military	No	Basic training (n=2676)
Goss	2012	Barefoot vs minimalist	Running	Yes	Self-reported (n=2157)
Theisen	2014	Cushioning	Running	No	Double blind (n=247)
Ryan	2014	Neutral vs minimalist	Running	Yes	Nike Pegasus vs Nike Free (n=99)

The shoe feature column represents the shoe feature that varied between studied footwear conditions.
ACL, anterior cruciate ligament.

Table 2 Summary of selected studies addressing the association between insoles and injuries.[26–30]

Author	Year	Injury	Sign	Comments
Milgrom *et al*	1985	Femoral stress fractures	Yes	Military. Military stress 'orthotic' insole
Schwellnus *et al*	1990	All stress fractures N_{rel}(test)=22.8% N_{rel}(control)=31.9%	Yes	Military. Running shoes with 'flat' insoles for physical training
Finestone *et al*	1999	Tibial stress fractures N_{rel}(test/soft)=10.7% N_{rel}(control)=27.0%	Yes	Military. Soft 'biomechanical' orthoses
Muendermann *et al*	2001	Foot injuries spec reduction 1.5–13.4% General reduction 53%	Yes	Military. Self-selected insoles. Comfort assessment important for lower extremity injuries
Larsen *et al*	2002	Tibial stress fractures Risk Ratio RR RR=0.7 shin splints	Yes	Military. Custom made 'biomechanical' insoles

comfort. After this assessment, the members of the test group received their most comfortable insole and used it for the next 4 months. Injury frequencies were determined for the test group (n=106) and a control group (n=106) both exposed to the same military training. There were two very important results from this study:

1. From the six different insoles, five were selected as the most preferred (most comfortable) insole with about the same frequency.
2. The test group had 53% fewer lower-extremity injuries than the control group.

The only selection criterion for the insoles was the individual comfort. Thus it seems that comfort of insoles is an important factor for injuries. We propose that *comfort is important for all movement-related injuries to the lower extremities*.

PREDICTORS OF RUNNING INJURIES

Past studies have assessed extrinsic and intrinsic risk factors for running injuries. Extrinsic risk factors, or risk factors external to the runner, include weekly mileage and training, subject injury history and the training environment.[2 5 31 32] A variety of intrinsic risk factors that are inherent to the runner have also been identified for running injury. The two most commonly studied variables that were thought to be associated with the development of running injuries were foot pronation and impact forces during heel–toe landing.

Foot pronation: Shoe inserts and orthotics had been used for many decades before the running boom in the 1970s. Foot pronation was one of the major variables discussed in the early professional literature of podiatrists.[33] Consequently, when biomechanical research on running and running-related injuries started, pronation (or foot eversion) was considered an important variable for running shoe construction. Based on the existing (prerunning boom) literature it was assumed, without any epidemiological evidence, that foot pronation was one of the variables responsible for the development of running injuries.

Impact forces: Impact forces during sport activities were first discussed in the mid and late 1970s.[34–39] Without any epidemiological evidence, it was assumed that impact forces during running promote the running injury. Thus, it seems logical, that the running injury-related literature should be analysed with respect to the injury epidemiology of these variables.

Impact forces appear to be unrelated to running injuries

A review of the publications that attempted to assess the association between vertical impact force peaks (figure 3, top) and vertical impact loading rate and running injuries (figure 3, bottom) shows that there is no conclusive evidence that vertical impact forces are associated with running injury. The major reason for the fact that the results are not conclusive is the small sample sizes used in the cited studies. Among 15 studies, seven had a sample size below 25,[40–45] seven had a sample size between 25 and 100,[46–52] and one had a sample size between 100 and 150.[53] While it is difficult to draw a conclusion regarding the influence of vertical loading rate on running injury frequency, it is interesting to note that as the study participant sample size increased, the relative frequency of running injuries decreased.

In addition to the lack of epidemiological support for impact as an important determinant of running injury there is also a functional concern. If higher impact peaks or loading rates were associated with running injuries one would expect runners who run faster have more impact-related injuries. However, there is no study or even anecdotal evidence that this is the case. Consequently, there is no supporting evidence that vertical impact peaks and/or vertical loading rates are variables that contribute to running injuries.

Foot pronation (or foot eversion)

One finds a similar phenomenon when critically examining the variable foot pronation or foot eversion. Most studies have a rather small sample size and, consequently, the results for these studies are not conclusive. However, one study that has a large sample size.[54] In this study, the foot position (foot inversion to eversion) was quantified for novice runners at the start of the data collection and running injuries were tracked for 1 year. The results are interesting result in that the injury frequency was lowest for the foot position between 7 and 10° pronated (everted; figure 4). This group had significantly less injuries than all other groups. This result shows that a pronated (everted) foot position is, if anything, an advantage with respect to running injuries. Consequently, it is difficult to find supporting evidence that foot pronation (eversion) is a strong predictor of running injuries.

Consequently, there is no evidence that foot pronation (eversion) is a variable responsible for running injuries. This indicates that two variables that were thought to be the prime predictors of running injuries are not valid.

THE PREFERRED MOVEMENT PATH

One of the most important running-related research projects of our University of Calgary research group was quantifying the

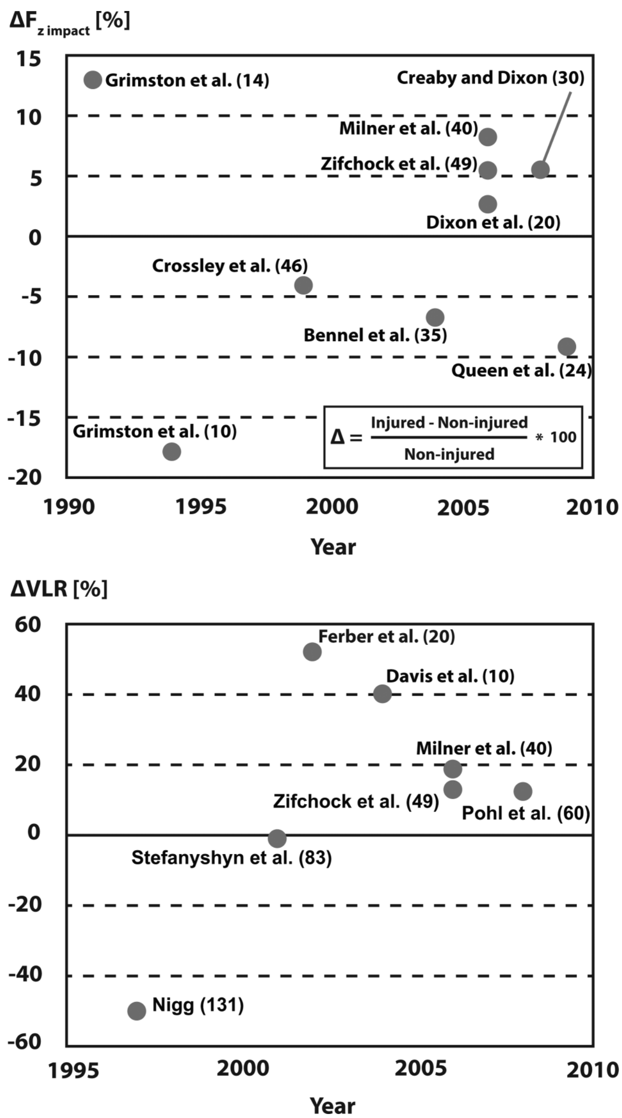

Figure 3 Illustration for the difference in vertical impact force peaks and injury frequencies (top) and vertical loading rates and running injury frequencies (bottom) based on studies addressing this question. The numbers beside the points indicate the number of subjects in these studies. The vertical loading rate results for Nigg 1997 were based on data of the unpublished Doctoral Thesis of A Bahlsen 1988 'The aetiology of running injuries: a longitudinal prospective study'.

actual movement of the *skeleton* of the lower extremities and its changes as a result of footwear interventions.[55–59] Prior studies (1975–1995) had addressed shoe/orthotic intervention questions used skin or shoe mounted markers. Our skeleton movement study used markers on bone pins screwed into the calcaneus, the tibia and the femur. Out of the many questions that were answered with this study, the two most importance in this context are:

1. What effect does changes in shoe or insert construction have on the skeletal movement during running?
2. What is the difference in skeletal movement between shod and barefoot running?

The results of the bone pin study were rather surprising. With changes in shoes and/or insoles, the changes in the actual path of movement of the calcaneus and the tibia were small and not systematic. Changes occurred primarily in the range of movement but not in the **path of movement**. These bone pin

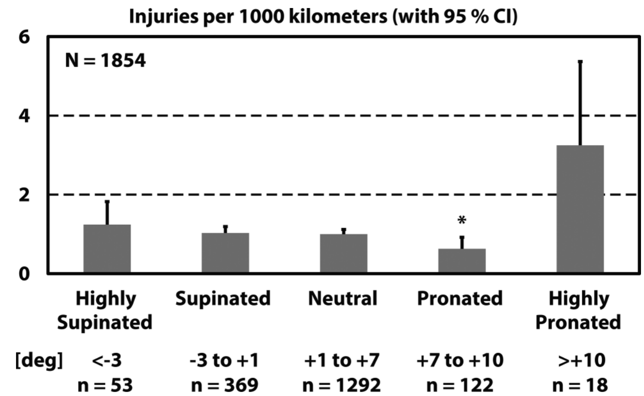

Figure 4 Static foot position and running injuries per 1000 km based on a prospective study with 1854 subjects grouped arbitrarily into highly supinated, supinated, neutral, pronated and highly pronated runners (adapted from[54] with permission from the author).

results and the general results of many skin mounted marker studies[59–61] that showed similar effects when changing the shoe conditions were the basis for a new paradigm, the paradigm of the 'preferred movement path'.

We proposed:[59 62] The skeleton of an individual athlete attempts for a given task (eg, heel–toe running) to stay in the same movement path, the 'preferred movement path'.

Muscle activity is used to ensure that the skeleton stays in this path. It may be, however, that the amplitude of this path varies. For instance, when running barefoot, the initial dorsiflexion of the ankle joint is reduced. However, the actual movement path stays the same. (Note: The term 'preferred movement path' is a working term and may/should be improved). If this paradigm is correct, the definition of a 'good' running shoe may have to change. A 'good' running shoe would be a shoe that allows the skeleton to move in the 'preferred movement path'. A 'good' running shoe would, therefore, demand less muscle activity than a 'bad' running shoe to ensure that the skeleton moves in the correct path.

The assessment of whether or not a shoe supports the preferred movement path may be difficult. Since the paradigm states that the movement does not change, assessment of movement does not help in the assessment of this question. Any assessment of a shoe with respect to the preferred movement path paradigm using movement assessment is, therefore, per definition inappropriate. It is proposed that other indirect ways should be chosen to make such an assessment (eg, muscle activity, energy demand or others).

It is proposed that the 'preferred movement path' may be one paradigm that could replace the inappropriate paradigms of cushioning and pronation for the primary prevention of running injuries.

COMFORT

Studies assessing comfort of shoe/insert conditions have shown that:[29 59 63]

1. Different subjects select different shoe conditions as the most comfortable. There are different functional groups of athletes that need different construction features to feel comfortable in a shoe (eg, some subjects like a medial support, some like no medial support).

2. Shoe conditions that are more comfortable are associated with a lower movement-related injury frequency than shoe conditions that are less comfortable.
3. Shoe conditions that are comfortable are associated with less oxygen consumption than shoe conditions that are less comfortable.

Comfort is difficult to define and to quantify. However, it seems that shoe comfort is important for running injuries as well as running performance.

We propose a new paradigm, the **comfort filter paradigm** as follows: When selecting a running shoe, an athlete selects a comfortable product using his/her own comfort filter. This automatically reduces the injury risk and may be a possible explanation for the fact that there does not seem to have been a trend in running injury frequencies over time.

Stated differently, it is not that footwear could not have an influence on running injuries. On the contrary, footwear does appear to influence the frequency of injuries since we already choose the most comfortable shoe and avoid uncomfortable and potentially harmful footwear.

FINAL COMMENTS

We propose that the previous paradigms of 'cushioning' and 'pronation' should be replaced with the two new paradigms of 'preferred movement path' and 'comfort filter'. Both proposed paradigms need substantial new research with respect to definition, verification and quantification. However, it is suggested that they may improve insight into the mechanisms of running performance and running injuries.

Summary

- The frequency of running injuries has not changed over the past 40 years.
- Little evidence for pronation and impact forces as risk factors despite being considered primary predictors of running injuries.
- Two new suggested paradigms for predicting running injury are the 'preferred movement path' and the 'comfort filter'.

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