

U.S. Army Center for Health Promotion
and Preventive Medicine

**Epidemiological Consultation Number:
12-MA-6558-01**

**Evaluation of Injury Rates During
Implementation of the Fort Drum
Running Shoe Injury Prevention Program**



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Readiness Thru Health

U.S. Army Center for Health Promotion and Preventive Medicine

The lineage of the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) can be traced back over 50 years. This organization began as the U.S. Army Industrial Hygiene Laboratory, established during the industrial buildup for World War II, under the direct supervision of the Army Surgeon General. Its original location was at the Johns Hopkins School of Hygiene and Public Health. Its mission was to conduct occupational health surveys and investigations within the Department of Defense's (DOD's) industrial production base. It was staffed with three personnel and had a limited annual operating budget of three thousand dollars.

Most recently, it became internationally known as the U.S. Army Environmental Hygiene Agency (AEHA). Its mission expanded to support worldwide preventive medicine programs of the Army, DOD, and other Federal agencies as directed by the Army Medical Command or the Office of The Surgeon General, through consultations, support services, investigations, on-site visits, and training.

On 1 August 1994, AEHA was redesignated the U.S. Army Center for Health Promotion and Preventive Medicine with a provisional status and a commanding general officer. On 1 October 1995, the nonprovisional status was approved with a mission of providing preventive medicine and health promotion leadership, direction, and services for America's Army.

The organization's quest has always been one of excellence and the provision of quality service. Today, its goal is to be an established world-class center of excellence for achieving and maintaining a fit, healthy, and ready force. To achieve that end, the CHPPM holds firmly to its values which are steeped in rich military heritage:

★ Integrity is the foundation

★ Excellence is the standard

★ Customer satisfaction is the focus

★ Its people are the most valued resource

★ Continuous quality improvement is the pathway

This organization stands on the threshold of even greater challenges and responsibilities. It has been reorganized and reengineered to support the Army of the future. The CHPPM now has three direct support activities located in Fort Meade, Maryland; Fort McPherson, Georgia; and Fitzsimons Army Medical Center, Aurora, Colorado; to provide responsive regional health promotion and preventive medicine support across the U.S. There are also two CHPPM overseas commands in Landstuhl, Germany and Camp Zama, Japan who contribute to the success of CHPPM's increasing global mission. As CHPPM moves into the 21st Century, new programs relating to fitness, health promotion, wellness, and disease surveillance are being added. As always, CHPPM stands firm in its commitment to Army readiness. It is an organization proud of its fine history, yet equally excited about its challenging future.

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13. ABSTRACT <i>(Maximum 200 words)</i> The Ft Drum Running Shoe Injury Prevention Program was initiated in November 1999 and consists of three parts: 1) a foot evaluation where medical personnel determined the soldier's foot arch height, ankle flexibility, and body weight, 2) a running shoe recommendation based on the foot evaluation, and 3) the actual shoe purchase by the soldier. This epidemiological consultation (EPICON) examined the effectiveness of the program by examining injury rates before and during the program. A historical cohort design was used. International Classification of Diseases, Version 9 (ICD-9) codes representing overuse-related injuries in the lower extremity or low back regions were downloaded from the local Ambulatory Data System (ADS). All visits to the Physical Therapy Clinic between 1 August 1998 and 31 January 2001 by active duty soldiers were considered in the analysis. Denominator data (soldiers on post) were obtained from the 10th Mountain Division S-1 Office (Personnel Section). Average \pm standard deviation total injury rates were 36.8 ± 7.1 cases/1000 soldiers/month in the Pre-Intervention period (August 1998 through October 1999) and 18.6 ± 4.4 cases/1000 soldiers/month in the Intervention period (July 2000 through January 2001) (relative risk=2.0, $p < 0.01$). Thus, a decline in injury rates corresponded in time to the implementation of the program suggesting an association between this program and the lower injury rates. However, a major potential confounder was the switch from the use of the Ambulatory Data System (ADS) to the KG-ADS system during February to March 2000. KG-ADS required medical care providers to scroll through a list of diagnoses on their computer screens and was considered cumbersome and time-consuming, possibly resulting in provider impatience and miscoding. A number of other potential temporal confounders (paving of the shoulders of the roads at Ft Drum, the Pool Therapy Program, physical therapist turnover, recorder bias, a deployment to Bosnia and seasonal variations) were considered and discounted. Overall, the data tentatively support the effectiveness of the Ft Drum Running Shoe Injury Prevention Program, but it is imperative that the program be tested in a randomized prospective cohort study before a full				
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Table of Contents

	Page
Executive Summary.....	4
1. REFERENCES.....	7
2. INTRODUCTION.....	7
3. BACKGROUND LITERATURE.....	7
a. Running Shoe Characteristics.....	7
b. Injuries and Footwear.....	14
c. Foot Morphology.....	16
d. Injuries and Foot Morphology.....	18
e. Foot Arch Indices and Validity of Indices.....	19
4. METHODS.....	23
a. Fort Drum Running Shoe Injury Prevention Program.....	23
b. Injury Data.....	25
c. Soldiers on Post (Denominator Data).....	26
d. Running Shoe Program Survey.....	26
e. Data Analysis.....	27
5. RESULTS.....	28
a. ICD-9 Data.....	28
b. Running Shoe Program Survey.....	32
6. DISCUSSION.....	33
a. General Findings.....	33
b. Changes in Temporal Factors (Potential Confounders).....	33
c. Running Shoe Program Survey.....	37
d. Injury Reduction Mechanism.....	38
e. Fit-The-Foot Program.....	39
7. CONCLUSION.....	39
Appendix A. References.....	40
Appendix B. Acknowledgements.....	46

Executive Summary

Epidemiological Consultation Number 12-MA-6558-01 Evaluation of Injury Rates During Implementation of The Fort Drum Running Shoe Injury Prevention Program

1. Introduction. In November 1999, the US Army Medical Department Activity (MEDDAC) at Ft Drum, New York, initiated the "Running Shoe Injury Prevention Program". This program was an effort to reduce injuries by matching running shoes to particular characteristics of individual soldier's feet. In March 2001, the MEDDAC Commander requested the assistance of the US Army Center for Health Promotion and Preventive Medicine (USACHPPM) to determine the effectiveness of the program. This epidemiological consultation (EPICON) examined injury rates before and during implementation of the program.

2. Methods. The Running Shoe Injury Prevention Program consisted of three parts. The first part was a foot evaluation provided to soldiers as they inprocessed at Ft Drum. Based on a visual examination, a physical therapist or physical therapy assistant classified the soldier's foot arch height as low, normal, or high. Ankle flexibility was graded as either rigid, flexible, or hypermobile. Body weight was obtained. The second part of the program was a recommendation to the soldier to purchase a particular type of shoe based on the results of the foot evaluation. If the soldier had a low arch with a hypermobile foot, a "motion control" shoe was recommended. If the soldier had a high or normal arch with a rigid foot, a "cushion" shoe was recommended. If the soldier had a high or normal arch with a flexible foot, a "stability" shoe was recommended. Men over 180 lb and women over 150 lb were directed to specific shoes within each category. The third part of the Running Shoe Injury Prevention Program was the soldier's shoe purchase.

a. To evaluate the effectiveness of the program, a historical cohort design was used. International Classification of Diseases, Version 9 (ICD-9) codes representing overuse-related events involving primarily the lower extremity or low back regions were downloaded from the local Ambulatory Data System (ADS). All visits from 1 August 1998 through 31 January 2001 were obtained. Seven injury categories were developed using specific ICD-9 codes: total injury, low back injury, hip/thigh injury, knee injury, lower leg injury, ankle injury, and other injury. Only primary visits (defined as the first incidence of a particular ICD-9 code for a particular individual in a 6-month period) to the Physical Therapy Clinic were considered in the analysis. Denominator data (soldiers on post) were obtained from the 10th Mountain Division S-1 Office (Personnel Section).

b. Monthly data (injury cases/total on-post troop strength) were separated into three "periods" for analysis. The Pre-Intervention period included the months August 1998 through October 1999. The Transition period (when the first groups of soldiers were receiving the foot screening) included the months November

1999 through June 2000. The Intervention period included the months July 2000 through January 2001.

3. Results. Average±standard deviation total injury rates were 36.8±7.1 cases/1000 soldiers/month in the Pre-Intervention period and 18.6±4.4 cases/1000 soldiers/month in the Intervention period (relative risk=2.0, p<0.01). Rates were also lower in the Intervention period (compared to the Pre-Intervention period) for the low back (11.5±2.8 vs. 5.8±1.7 cases/1000 soldiers/month, p<0.01), hip/thigh (2.5±1.0 vs. 0.6±0.02 cases/1000 soldiers/month, p<0.01), knee (6.7±1.9 vs. 3.3±1.2 cases/1000 soldiers/month, p<0.01), lower leg (6.8±1.8 vs. 0.2±0.2 cases/1000 soldiers/month, p<0.01), and ankle (6.5±1.5 vs. 3.5±0.6 cases/1000 soldiers/month, p<0.01). In the "other injury" category, the pattern was reversed: rates were lower in the Pre-Intervention period than in the Intervention period (2.5±0.9 vs. 4.8±1.4 cases/1000 soldiers/month, p<0.01).

4. Discussion. The overall risk of an overuse-related lower extremity/low back injury sick call visit to the Physical Therapy Clinic at Ft Drum decreased in the July 2000 to January 2001 period when compared to the August 1998 to October 1999 period. The decline corresponded to the implementation of the Running Shoe Injury Prevention Program suggesting this program was associated with the lower injury rates. Total injuries and all other injury categories except "other injuries" showed decreases in the Intervention period compared to the Pre-Intervention period. The "other injury" category represented injuries with non-specific or multiple sites and the injury rate in this category was small relative to the total injury rate.

a. Great caution must be taken in assuming that the shoe program was the major factor involved in the decline in injury rates. It is possible that the shoe-fitting program had the effect of encouraging soldiers to buy new shoes and this alone may have reduced injury rates. Changes in temporal factors unrelated to the shoe program may have changed during the study period and these could have influenced injury rates.

b. The major potential temporal confounder was the switch from the use of the Ambulatory Data System (ADS) to KG-ADS. The ADS system used bubble sheets that contained the most common diagnosis for the clinic and allowed therapists to shade in the appropriate diagnosis. The sheets were scanned into a computer at a later time. KG-ADS was a system available to therapists on their computer screens and required scrolling through a list of diagnoses to find the appropriate one. Therapists considered the KG-ADS system cumbersome and time-consuming, at times resulting in impatience and possible miscoding.

c. Another potential confounder was that the shoulders of the roads at Ft Drum were blacktop paved during the summer of 2000. The roads had been rough gravel before this. This change in surface could have reduced running or

road marching injuries if the assumption is made that surfaces influence injury rates. However, epidemiological studies have generally shown no association between self-reported injury risk and self-reported running surface. Further, there were no changes in injury rates before and after the road paving.

d. Another potential confounder was an expanded Pool Therapy Program put in place in September 1999. This program may have given injured soldiers alternatives to unit physical training and assisted in decreasing reinjury. However, an analysis before and after the Pool Therapy Program showed no difference in reinjury rates.

e. There was staff turnover in the Physical Therapy Clinic during the course of the study and some therapists may have used different ICD-9 codes for similar diagnoses. However, matching therapists' arrival and departures showed no differences in rates compared to those historically seen. Also, the individuals who worked the shoe fit program were many of the same physical therapists that reported the diagnoses, but little evidence of systematic bias was found. A deployment of Ft Drum troops to Bosnia could not be shown to influence injury rates. Finally, seasonal variations in injury rates have been reported in some military training environments but few systematic seasonal variations were noted in the data gathered here.

f. It is difficult to explain the mechanism whereby the Ft Drum Running Shoe Injury Prevention Program could have reduced injuries. Although running shoes may protect the foot from adverse road conditions, the assumption that they reduce overuse injuries is based on conjecture from clinical opinion and biomechanical analysis and a few case studies. Running shoes can reduce pronation after foot strike but there is no evidence that reducing pronation will influence injury rates. Running shoes can also provide cushioning but with the exception of one case study, there is no direct evidence that this factor is related to injury. Randomized cohort studies are needed that specifically look at injuries among individuals with specific foot types and wearing running shoes with specific characteristics.

5. Conclusions. Shortly after initiation of the Running Shoe Injury Prevention Program at Ft Drum, New York, recorded visits for lower-extremity/low back injuries in the Physical Therapy Clinic decreased. There were a number of temporal changes at Ft Drum that occurred concurrent with the decline in injury rates. Temporal changes that can be discounted include paving of the shoulders of the roads at Ft Drum, the Pool Therapy Program, physical therapist turnover, seasonal variations, and a deployment to Bosnia. The change from ADS to KG-ADS cannot be discounted since it corresponded closely in time to the reduction in injury rates. Overall, the data tentatively support the effectiveness of the Ft Drum Running Shoe Injury Prevention Program. However, it is imperative that the program be tested in a randomized prospective cohort study before a full determination can be made on the program effectiveness.

**Epidemiological Consultation Number 12-MA-6558-01
Evaluation of Injury Rates During Implementation
of the Ft Drum Running Shoe Injury Prevention Program**

1. REFERENCES. Appendix A contains the references used in this report.

2. INTRODUCTION. In November 1999, the Army Medical Department Activity (MEDDAC) at Ft Drum, New York, initiated the "Running Shoe Injury Prevention Program". This program was designed to examine soldier's feet and recommend specific running shoes based on characteristics of the soldiers' feet. Preliminary data collected and analyzed by the Physical Therapy Clinic at Guthrie Army Clinic (Ft Drum, NY) suggested that injury rates had declined shortly after the program was initiated. In March 2001, the US Army Center for Health Promotion and Preventive Medicine (USACHPPM) was contacted and an epidemiological consultation (EPICON) was initiated at the request of the hospital commander. This paper describes the results of a historical cohort study examining lower extremity/low back injury rates before and after the shoe program was implemented.

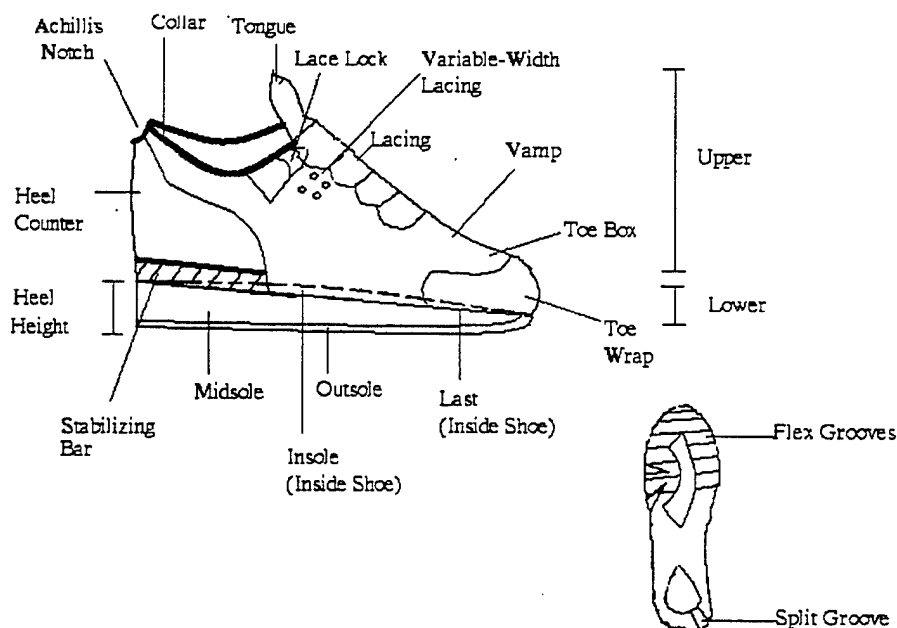
3. BACKGROUND LITERATURE. This review focuses on several aspects of the study. First, we reviewed running shoe characteristics to understand the purposes of running shoes and how these characteristics may influence injury rates. Next, we critically examined the limited data specifically addressing associations between injuries and running shoes. Because the Ft Drum running shoe program was based on an assumed relationship between foot type and injuries, we then critically reviewed the literature on foot morphology and injuries. Finally, we examined the literature on objective foot arch height measurement.

a. Running Shoe Characteristics.

(1) Shoe Components. In order to discuss running shoe characteristics it necessary to understand the various components of the shoe. Figure 1 shows these components. The shoe can be divided into an upper and lower portion. The vamp of the upper portion is usually composed of a synthetic, breathable, and fast drying material like nylon. A strip of leather or some other sturdy material (toe wrap) is placed over the front of the toebox to provide durability and to protect the toes from potential impacts. The toebox allows room for the toes and maintains the shape of the anterior portion of the shoe. The heel counter in the rear of the shoe maintains the shape of the posterior portion, increases cushioning, and stabilizes the hindfoot by "locking" the heel into the shoe. A rearfoot stabilizing bar is included on many running shoes, presumably to decrease pronation. The collar maintains an opening so the foot can be placed into the shoe and the collar must be wide enough to allow for ankle plantar flexion and dorsiflexion during running. An Achilles tendon notch is

designed to prevent irritation of the Achilles tendon. Variable width lacing allows the user to more comfortably position the shoelaces and the lace lock holds the laces in the position desired by the user (80, 81).

Figure 1. Running Shoe Components



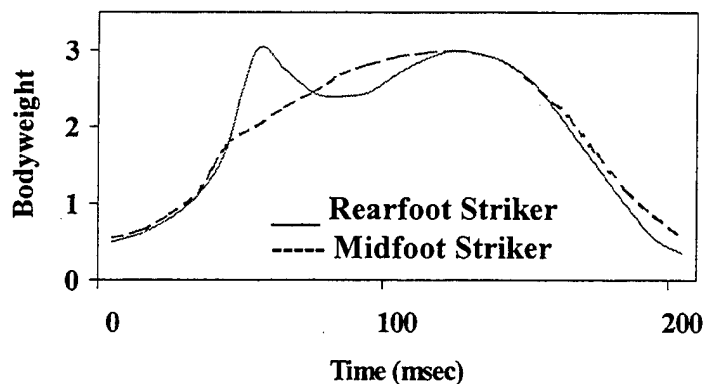
(2) The lower portion of the running shoe consists of the outsole, midsole, insole, and the last (Figure 1). The outsole is the very bottom of the shoe. It provides traction and wear resistance and is typically composed of carbon rubber, blown rubber, and/or styrene butadiene. Non-uniform outsoles have different types of materials in high wear areas or areas where more traction is necessary. Flex grooves (running medially and laterally) and split grooves (running anterior-posterior) contribute to shoe flexibility (Figure 1). The midsole presumably provides cushioning and stability. The most common materials used in the midsole are ethyl vinyl acetate (EVA) or polyurethane. EVA is lighter and softer but also less durable and less resistant to compaction than polyurethane. Polyurethane has better resistance to compaction and is more durable but also provides less cushioning. Besides EVA and polyurethane, some manufacturers use additional midsole materials like encapsulated air, gel, and water in an attempt to further increase cushioning. Another component of the shoe is the insole, which is inside the shoe and in contact with the plantar surface of the foot. The insole provides additional cushioning and may increase support along the longitudinal foot arch. The insole can be composed of a very wide variety of material and may be removable or permanently attached to the shoe. Finally, the last sits on top on the midsole and under the insole. The last is the template on which the shoe is constructed and it can be curved, semicurved, or straight (80, 81, 91).

(3) Shoe Functions. The literature suggests that running shoes should have four major functions: a) protect the foot from the external environment, b) provide traction by increasing friction, c) attenuate the shock of footstrike, and d) provide motion control during the stance phase of the running cycle (80, 81, 87, 107). A fifth function not discussed in the literature is minimizing the energy cost of running since this would be advantageous for long-distance running. Each of these is discussed below.

(4) Protection of the Foot. Protection of the foot from the external environment is an obvious shoe characteristic. Running surfaces can be hot, cold, rocky, and/or uneven. The running shoe protects the plantar surface of the foot by providing a barrier to the external environment and by providing a relatively even surface to bridge uneven ground. The running shoe thus protects the foot from thermal contact injury, abrasions, lacerations, and contusions.

(5) Traction. One function of the outsole is to increase traction. The composition of the outsole of most running shoes provides a high coefficient of friction with concrete and asphalt surfaces (24). Better traction may reduce the probability of traumatic injuries from slips and falls. Greater traction may also improve running efficiency by preventing slipping and more effectively directing muscular effort in positioning the foot during the stance phase of running. Greater traction would provide more effective forward movement during the toe-off phase of running.

Figure 2. Influence of Different Types of Foot Strikes on the Vertical Component of Ground Reaction Forces



(6) Attenuation of Shock on Foot Strike. In running, the foot strikes the ground with a force two to three times body weight, although forces between individuals can vary by as much as 30% (12, 28, 31). There appear to be two fundamentally different types of foot strikes: rearfoot and midfoot. Rearfoot strikers (70% of all runners) initially contact the ground with the posterior-lateral portion of the shoe. The vertical component of the ground reaction forces show an initial peak, followed by a decrease in force, and finally a second peak (Figure 2). The initial peak appears to be due to the initial foot strike, the trough is the movement of the center of pressure across the longitudinal arch, and the second peak is the forefoot strike. Midfoot strikers contact the ground near the center of the medial portion of the shoe and peak force occurs as the forefoot strikes the ground (Figure 2) (12, 28).

(a) It has been suggested that the high impact forces repetitively experienced during running may be associated with certain types of overuse injuries like stress fractures, shin splints, and damage to the knee meniscus (8, 20) but there is no direct evidence for this idea. If repetitive impact forces causes a higher rate of overuse injuries, a more rapid onset and/or a higher incidence of osteoarthritis may be expected among runners. However, this does not appear to be the case. In cross-sectional studies comparing runners to swimmers, elite shooters, community controls, sedentary controls, or patients referred for abdominal X-rays there is no radiographic (i.e., sclerosis, joint space narrowing, spur formation) or clinical evidence (e.g., crepitation, joint stability) of a higher incidence of osteoarthritis among runners nor is there a higher incidence of osteoarthritic risk factors (58, 59, 62, 89, 99). One study did find that running more than 20 miles a week was significantly associated with osteoarthritis in young men (20-49 years) after controlling for age, body mass index, smoking history, alcohol and caffeine intake; however, no association was found in older men (50 years of age or more) or among women of any age (14). A case-control longitudinal investigation reported on a cohort of 41 runners and 57 community controls (about 58 years old at baseline) in follow-up periods of 0, 2, 5, and 9 years (61, 62, 64, 65). The study found a progressive age-related increase in osteoarthritis of the knees and hips, but there were no differences between runners and the controls. One major problem with this longitudinal study was that the community controls were not totally sedentary since some control subjects exercised; however, the difference in running mileage between the groups was relatively large, 26 vs 3 miles/week on average. One study (63) compared 498 runners to 365 community controls and made considerable efforts to control for runner self-selection. The authors found that older runners were considerably healthier on standard disability measures including osteoarthritic risk factors. Thus, the majority of the literature supports the concept that long term running does not increase the likelihood of osteoarthritis.

(b) Compared to bare feet, using running shoes generally result in a decrease in the force of the initial impact spike and a slower initial rate of force development (12, 26-28, 79). It might be argued that the similar rates of

osteoarthritis among runners and nonrunners indicate that running shoes have successfully performed their function in absorbing impact forces. However, to test this hypothesis what would be necessary are long-term comparisons of runners wearing shoes with little shock absorption versus runners wearing shoes with great shock absorption.

(c) Studies using accelerometers, force platforms, and X-rays have all demonstrated that the heel counter of the running shoe increases shock absorbance. Confinement of the heel in the heel counter reduces lateral compression of the anatomical fat pad. Reducing lateral compression appears to increase vertical cushioning making the fat pad a more effective shock absorber (26, 50, 51).

(d) If shock absorbency is important for reducing injuries in runners, then changes due to shoe wear might be expected to increase the likelihood of injury. Cook et al. (21) tested 25 models of shoes for initial shock absorbency and changes in shock absorbency. A prosthetic foot and mechanical piston was used to apply forces equivalent to those of running. Table 1 shows the loss of initial shock absorbency for all shoes averaged. There was no trend or differences among shoes based on price or manufacturer. Interestingly, when runners tested the shoes the loss of shock absorbency was less: the shoes tested by the runners retained 80% of initial shock absorbency at 150 miles and 70% at 500 miles. It should be noted that this study was published almost 20 years ago and some of the new midsole materials (e.g., encapsulated air, gel) have not been tested (74).

Table 1. Loss of Initial Shock Absorbency of Running Shoes (Machine Testing)

Estimated Distance (miles)	Loss of Initial Value (%)
50	27
100	32
200	38
300	43
500	47

(e) Robbins and Gouw (93) have challenged the assumption that shock absorption should be a characteristic of running shoes. They hypothesize that normal plantar tactile stimuli during running results in behaviors that reduce impact forces and presumably reduce the likelihood of injury. These impact-moderating behaviors include greater use of intrinsic foot shock absorption, greater knee and hip flexion, and a decrease in the height of the leg drop just prior to the stance phase of running. Robbins and Gouw (93) propose that plantar feedback is optimal between bare feet and natural surfaces but the cushioning in athletic shoes attenuates plantar feedback. They showed that sufficient vertical and horizontal impact forces ($>0.4 \text{ kg/cm}^2$) evoked higher subjective discomfort; an irregular surface further increased this discomfort.

However, they did not specifically measure their hypothesized impact moderating behavior. Further, testing was not conducted while running but rather while subjects were seated with impact loads applied by pistons to the thigh and Achilles tendon regions. Their subjects were not runners.

(f) Many studies using force platforms have shown no differences in external impact forces for different types of midsole hardnesses (60, 79, 85). This is surprising since smaller impact forces might be expected for softer, more compliant insoles (i.e., EVA vs polyurethane) and different hypotheses have been advanced to explain this phenomenon. Lake (60) argued this lack of difference among midsole hardnesses may not be surprising since the force platform measures the vertical ground reaction forces, and these forces reflect the acceleration of the total body's center of mass. Average measures may mask large changes occurring in the legs. Nigg et al. (85) argues that changes in midsole hardness may result in a redistribution of loads across the foot. They found that with harder midsoles subjects landed on more lateral portions of the shoe and ankle pronation velocities were greater. With greater velocity and more deceleration distance there was a decrease in the initial impact force. Thus, with different midsole hardnesses subjects adjusted their footstrike to achieve similar external impact forces. One study (79) compared mean accelerations and times to peak accelerations of shoes with different midsoles. In mechanical drop tests there were significant differences among midsoles; however, when runners performed with these same midsoles there were no differences in tibial mean accelerations or peak accelerations. Although the authors could not find midsole-related differences in the angular displacement of the knee or ankle, these results still support the idea that runners subjectively adjust their footstrike to achieve similar mean accelerations and time to peak accelerations regardless of the type of midsole.

(7) Shoes and Motion Control. Running is a complex series of repetitive movements that consist of support (foot on the ground) and nonsupport (foot airborne) movements. The support phase can be divided into the heel strike, midstance, and toe-off. At heel strike, the foot is supinated and tibia externally rotated. Going into the midstance, there is rapid hip and knee flexion, while the ankle dorsiflexes and the foot pronates. As the foot takes on the weight of the body, the tibia internally rotates and the subtalar joint everts to accomplish foot pronation. Pronation of the foot along with the flexion of the hip, knee, and ankle helps dissipate the forces of impact. The midtarsal joint tightens the arch to support the body weight. As the airborne leg passes across the stance leg the body center of gravity moves over the stance foot. At toe off, the tibia externally rotates, and the subtalar joint inverts. The foot supinates, while hip extension, knee extension, and plantar flexion occur (8, 20, 45, 78).

(a) An excessive amount or excessive rate of foot pronation during the early stance phase of running has been hypothesized to be associated with a higher incidence of running injuries because of the increase in leg internal

rotation and resultant stress on bone and soft tissue (37, 45, 103). It has been suggested that excessive pronation on foot strike may be related to shin splints, compartment syndromes, Achilles tendinitis and plantar fasciitis (8, 20, 78) but there is no direct evidence of this.

(b) There has been a good deal of research on "rearfoot control" which can be defined as the ability of running shoes to limit the amount of foot pronation after footstrike (17). For example, one early study compared two shoes: 1) a training shoe that had a multidensity midsole (EVA and polyurethane), a stiff heel counter, and a wide heel base, and 2) a racing flat that had a midsole of uniform density EVA, a softer heel counter, and a much narrower heel base. The training shoe had about 20% less total rearfoot motion (39). While studies of this type are suggestive, they do not allow isolation of specific factors that may influence rearfoot control. Fortunately, other studies have systematically manipulated shoe characteristics and specific factors that limit foot pronation have been identified. Characteristics that have been investigated include midsole hardness, heel flare, and heel lift.

(c) Midsoles constructed of softer material resulted in greater and more rapid foot pronation than harder material (17, 38). Softer midsoles resulted in a resupination of the foot while the knee was still flexing. It was suggested that this could set up an antagonistic relationship: the resupinating foot caused an external rotation torque on the tibia while the flexing knee imposed an internal rotation torque. Repeated cycles of these opposing torques during running could result in overuse injury of the knee (38).

(d) The influence of heel flare (the angular distance that the midsole in the heel area protrudes from the lateral and/or medial portions of the shoe) is not clear but the inconsistent results suggest that heel flare has no systematic influence on rearfoot motion. One study found the lack of heel flare resulted in greater and more rapid total pronation (17) while other studies showed no effect (86, 102). Heel flares of 0 to 30 degrees were tested. In one study, initial joint pronation (first tenth of foot contact time) and initial pronation velocity was less with a negative (more rounded) heel flare but total amount of pronation was not affected. Greater heel flare did not change the vertical impact forces but did result in a later occurrence of the impact force after heel strike (86).

(e) Heel lift (a greater height in the rear of the shoe than in the front of the shoe, see Figure 1) has been hypothesized to reduce the incidence of Achilles tendonitis by reducing forces on the Achilles tendon (18, 20, 92). However, the magnitude and time of occurrence of the maximal plantar flexion moments (a surrogate for Achilles tendon loading) were not altered by heel lifts ranging from 5 to 9.5 degrees (92). On the other hand, as heel height was increased, the angular acceleration of pronation decreased (17).

(8) Energy Cost. Heel counters reduce the energy cost of running (50), possibly by increasing mechanical stability so less muscular force is necessary to stabilize the lower extremity. Lighter shoes also allow individuals to run at a lower energy cost. For each 1 kg added to the foot, the increase in energy expenditure is 7% to 10% (11, 48, 49, 67, 100). This may be because during running, the lower extremities are moved through a greater range of motion than other parts of the body resulting in more mechanical work. The additional mass on these extremities calls for greater muscular force and consequently more energy expenditure.

(9) Summary. Running shoes are generally designed to protect the foot, provide traction, attenuate the impact of foot strike, control foot pronation, and lower the energy cost of locomotion. The repetitive high impact forces of foot strike (two to three times body weight) are assumed to be associated with injury but this has not been directly demonstrated. In fact, cross-sectional and longitudinal studies comparing osteoarthritis incidence among runners and nonrunners have generally shown no difference. Running in shoes does reduce the vertical ground reaction forces (shock absorbency) compared to running barefooted, and firm heel counters appear to be key shoe characteristics for this effect. Running shoes lose some of their shock absorbency with use. Midsole hardness does not appear to influence shock absorbency, possibly because of gait adjustments runners make in response to changes in hardness. Much research has focused on the control of foot pronation during the stance phase of running because of an assumption that excessive pronation may be related to injury. Softer midsoles result in greater and more rapid pronation than harder midsoles. Greater heel lift decreases pronation velocity. Studies on heel flare are not consistent with regard to pronation. Lighter running shoes and firm heel counters reduce the energy cost of running.

b. Injuries and Footwear.

(1) Despite the relatively large number of studies on the biomechanics of running shoes and the hypothesized effects on injury reduction cited above, the data linking running shoes to actual cases of injuries is very sparse. There are two case studies and several epidemiological investigations providing some evidence that ill-fitting and older shoes may result in higher injury rates.

(2) Wilk et al. (105) reported a case study of a 40-year old male triathlete who presented with symptoms of right foot plantar fasciitis after a triathlon. Examination of the patient's racing shoes (which differed from the training shoe) showed that the heel counter on the right shoe had a pronounced medial tilt when compared to the left shoe. This was because the heel counter had been glued onto the shoes at an incorrect angle. The investigators hypothesized that the medial tilt resulted in excessive pronation creating a torsional force that repeatedly overstretched the plantar fascia leading to the

fasciitis. However, the authors only established an association between the injury and the shoe. They did not actually measure the amount of pronation on the foot with and without the defective heel counter. Further, plantar fasciitis is a common running injury (8, 43, 45) and the problem in this case could have been caused by factors other than the shoe.

(3) Burgess and Ryan (10) reported a case study of a 26-year old man who lost one of his running shoes and ran a 14-km race in a borrowed pair of older "tennis" shoes. He was examined 2-weeks later and had slight edema and marked tenderness over the lateral aspect of both shins with radiographic evidence of bilateral fibular stress fractures. Eight weeks later there was no edema or tenderness, and radiographs showed healing stress fractures with new bone formation. Compression loading tests showed that his usual running shoe absorbed twice as much energy and deformed five times as much as the "tennis" shoe.

(4) Gardner et al. (32) found that Marine recruits who reported to basic training with older running shoes were more likely to experience stress fractures than those reporting with newer shoes. Recruits that indicated that their shoes were 6 months to 1 year old were 2.3 times more likely to experience a stress fracture in training than those who indicated that their shoes were less than one month old.

(5) Injuries were compared in groups of Israeli recruits training in either 1) modified high-topped basketball shoes with soles of EVA or 2) regular combat boots with soles of molded double density polyurethane. Tibial accelerations while walking on concrete were 19% lower in the basketball shoes. The group with the basketball shoes had a lower incidence of metatarsal stress fractures and overuse injuries of the foot (metatarsalgia, heel pain, arch pain). However, the overall incidence of stress fractures or all injuries was not different between groups (femoral stress fractures were slightly higher in the basketball shoe group) (82).

(6) An observational study of injuries in basketball found that players using shoes with air cells had 4.3 times the odds of ankle injury compared to players wearing other types of shoes (77).

(7) These studies present a confusing picture and are difficult to summarize because of their diverse nature. There is some suggestion that older running shoes are associated with a higher likelihood of stress fractures. This was shown in Marine recruit training; one of the case studies suggested an association between lower shock absorbency and stress fractures, and there is a known mileage-related loss of shock absorbency in running shoes (21). However, in the Israeli recruit study, overall stress fracture rates were the same in the boot vs the more shock absorbent basketball shoe. In the Marine recruit study, recruits wore their running shoes only for morning physical training while in

the Israeli recruit study, recruits wore the basketball shoes in all training. Perhaps shock absorbency is more important for stress fracture reduction during more intense physical activity like running where impact forces are likely to be greater.

c. Foot Morphology.

(1) The Ft Drum Running Shoe Injury Prevention Program involves a determination of the height of the longitudinal arch and a general classification of the arch into one of three categories (low, normal, and high). Thus, a review of the literature on low arches (pes planus) and high arches (pes cavus) was conducted.

(2) Usually, the determination of pes planus and pes cavus are on the basis of clinical opinion and experience. There are no widely established objective criteria that define these conditions and clinicians show little agreement when asked to judge them (23). It would seem that the linear measurement of the arch height with a caliper would be the most accurate. Norms and techniques are available (22) but have not been widely applied.

(3) An appreciation of the biomechanics of the foot is central to understanding the importance of the longitudinal arch during locomotion. During passive standing by the normal foot, ligaments and bony articulations hold the foot structure together and none of the intrinsic muscles of the foot are active (4). During level walking, there is no muscular activity in the intrinsic foot muscles until about 20% of the stance phase, whereupon muscular activity progressively increases until toe off (70). Muscular activity has not been studied in the muscles of the foot during running. From data obtained during walking it is reasonable to assume that during the early stance phase, the normal foot serves as a flexible organ that adapts to the conditions of the ground. Later in the stance phase (as intrinsic muscular activity begins and bony articulations begin to bear the weight of the body), the foot transitions to a more rigid platform that allows for push-off and propulsion of the body forward (70). The condition of the longitudinal arch appears to affect this sequence of events. In general, the flatfoot never changes from a flexible platform to become a rigid one, the cavus foot is not flexible early in the stance phase (6, 88).

(4) Pes Planus.

(a) Flat feet are normal in children, but by age 10 most (but not all) have transitioned to normal arches (3). In adulthood, flat feet may be congenital or acquired, and if acquired can have an insidious onset (71, 72). About 20% of adults appear to have low arches (34, 40, 57, 88), although only a small proportion of these may be symptomatic (40).

(b) The flexible flatfoot on clinical examination shows a normal arch in a non-weight-bearing condition. On weight bearing, the arch disappears, there is a protrusion on the medial side of the foot and there may be moderate valgus angulation of the heel. The flattening of the arch appears to be due to the talus subluxating and depressing medially as it loses a portion of its base of support on the calcaneus. The medial protrusion seen on weight bearing is the talus bone. The Achilles tendon may exacerbate this problem by pulling the calcaneus laterally (further out from underneath the talus). As the talus subluxates, the bones on the medial side of the foot separate and those on the lateral side compress altering the normal relationship between the bones and the muscles and probably leading to the problems associated with flat feet in some individuals. There is often a limited range of dorsiflexion because of shortening of the Achilles tendon. There are varying degrees of this condition characterized by different degrees of hypermobility and symptoms (19, 40).

(c) Models have been derived from scans (computer-assisted tomography) of patients with symptomatic flatfeet, presumably due to rupture of the tibialis posterior tendon. These models showed that 68% and 51% of the posterior and anterior facets of the calcaneus, respectively, were in contact with the talus; individuals with normal arches had 92% and 95% of the posterior and anterior facets of the calcaneus, respectively, in contact with the talus (2). The findings are consistent with analysis of cadaver specimens and X-rays that reveal less contact between the calcaneus and talus in individuals with flat feet (40).

(d) Risk factors for flexible flatfeet include ligamentous laxity, obesity, arthritis, rupture of the posterior tibial tendon, ligamentous tears, neuropathy, ankle equinus, rotational abnormalities (toeing-in or toeing-out), tibial varum, and tibial valgus (3, 7, 72, 83).

(e) A very small proportion of flat feet can be of the "rigid" type. One paper estimated this proportion at 2% but the authors did not present the basis of this estimate (19). Rigid flatfeet present as lack of an arch under both weight bearing and non-weight-bearing conditions. Rigid flat feet are usually due to bony alterations in the foot. In congenital vertical talus the navicular bone is displaced superiorly (dorsally) and the talus is forced to the plantar surface. In congenital tarsal coalition there is fusion of one or more of the tarsal bones, most frequently the talus and calcaneus, or navicular and calcaneus. (19, 83).

(5) Pes Cavus.

(a) Pes cavus is characterized by an abnormally high longitudinal arch due to plantar flexion of the forefoot relative to the hindfoot (90, 95). Multiple parts of the foot structure can be elevated and this has led to multiple sub-classifications of the cavus foot. In forefoot cavus, the metatarsals

are more plantar-flexed and adducted in relation to the hindfoot. In midfoot and hindfoot cavus, the calcaneus is tilted more superiorly. Some authors state that when a cavus foot is compensated for by a flexible ankle it is asymptomatic (44, 95). About 5 to 10% of the population have self-reported pes cavus (34, 57).

(b) The elevation of the arch may be caused by a muscular imbalance of neurological origin (e.g., Charcot-Marie-Tooth Disease), although infection and trauma (e.g., tendon laceration) can be involved in some cases (76, 90, 95). Some cases appear idiopathic (95). Because of the high arch, walking and running results in pressure concentrated on the first and fifth metatarsal where callus formation and lesions may appear (44, 76).

(6) Running Shoes and Longitudinal Arch Height.

(a) Planus feet tend to be hypermobile and do not become rigid for toe-off during locomotion (6). A shoe design that minimizes mobility and provides a rigid platform for toe-off would thus be desirable. Shoes with hard midsoles (polyurethane) and higher heel lifts can limit foot pronation (17, 38). The harder midsole material might also provide a more rigid platform for toe off.

(b) Cavus feet appear to lack flexibility on foot strike and thus do not adapt well to the conditions of the ground. Further, the body weight is distributed over a smaller surface area resulting in pressure points on the feet (44, 76). Shoes with soft insoles and midsoles (EVA) may be desirable. As the foot accepts the weight of the body in the stance phase of running, softer insole material would allow the cavus foot to distribute the body load over a greater surface area as it compresses into the softer material. The softer midsole will also allow the cavus foot more pronation (17, 38).

d. Injuries and Foot Morphology.

(1) Several studies have shown an association between foot type and injury. Most of these studies were conducted in basic training environments where trainees were wearing standard issue military boots the majority of time. During physical training sessions, a variety of running shoes were likely to be worn but physical training took up a relatively small proportion of the day (about 1 hour).

(2) Benseal (5) studied the distribution of injuries by foot type among individuals during Marine recruit training. Compared to recruits with normal arches, those with pes cavus tended to have a lower blister incidence but a higher incidence of stress fractures, heel contusions, and retrocalcaneal bursitis. Recruits with pes planus had a lower incidence of ankle sprains but more synovitis. Galidi et al. (33) found that Israeli Army recruits in basic training who had pes planus were less likely to suffer stress fractures than those with normal arches. Those with higher arches tended to have higher overall injury

incidence than those with normal arches. Neither of these two studies (5, 33) specified how arch height was measured.

(3) Cowan et al. (22) measured arch height and then tracked injuries among trainees during U.S. Army infantry basic training. Arch height was measured using a number of different methods, all of which involved measurements from the floor to either soft-tissue sites or to bony landmarks. All arch height measures gave similar results with regard to injuries. Compared to normal arch height, the risk of a lower extremity musculoskeletal injury was lower among those with low arches and higher among those with high arches.

(4) Simkin et al. (98) studied injuries and arch height in Israeli Army recruits. They used calcaneal angle, forefoot angle, and foot length to arch height ratio (talar head) to define arch height. Individuals were separated into only two groups. They found that those with higher arches had a higher incidence of femoral and tibial stress fractures, but those with lower arches had more metatarsal stress fractures.

(5) Kaufman et al. (52) examined foot arch height and injuries among Navy Sea, Air, Land (SEAL) candidates during their 25-week training program. Foot arch height was measured statically (while standing) as the ratio of navicular height to foot length and dynamically (while walking) as the ratio of midfoot contact area to the total foot contact area. Individuals with both high and low arches tended to have a higher likelihood of stress fractures, Achilles tendonitis, and iliotibial band syndrome when compared to those of normal arch height.

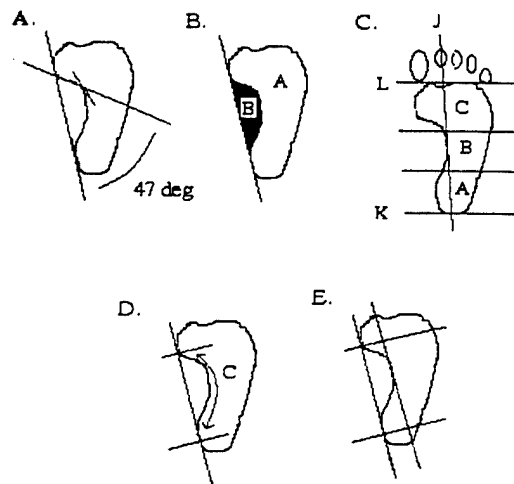
(6) Knapik et al. (57) reported that during a single 20-km road march in cadet basic training at the U.S. Military Academy (West Point, New York), individuals with self-reported pes planus had a higher incidence of foot blisters compared to those with self-reported normal arches.

(7) In summary, many of the differences among these studies may be attributed to different ways of measuring arch height, different definitions of injuries, differences in the physical activities producing the injuries, and differences in subject populations. The above literature is consistent in showing a higher injury risk among individuals with high arches, especially for stress fractures and overall musculoskeletal injury (5, 22, 33, 52, 98). The literature on low arch feet is conflicting with some studies showing a protective effect for ankle sprains, stress fractures, and overall musculoskeletal injuries (5, 22, 33) but other studies showing a higher likelihood of blisters, metatarsal stress fractures, overall stress fractures, and specific overuse injuries (52, 57, 98).

e. Foot Arch Indices and Validity of Indices. Several objective methods have been developed to classify arch height based on indices calculated from impressions of the foot. These methods assume that there is a relationship

between the index and the height of the medial longitudinal arch. However, biological variability in the soft tissue (e.g., amount of subcutaneous fat, muscle mass, and fascia) may mask the true architecture of the foot. To validate the foot impression indices, each must be examined along with actual anthropometric measures of foot arch height. This section first describes each of the foot arch indices and their reliability, then it examines studies on the validity of these measures. Note that reliability (in this context) is the extent to which measures can be replicated and validity is the extent to which a measure relates to the factor it purports to measure (75).

Figure 3. Calculation of Various Foot Arch Indices



(1) Foot Arch Indices.

(a) The footprint angle (16) is calculated by drawing three lines (Figure 3A). The first line connects the two most medial portions of the feet. The second line represents the slope of the inner segment of the longitudinal arch at the junction with the metatarsal border of the arch. The third line connects the most lateral point on the medial side (point of greatest indentation) to the most medial point of the metatarsal area (point of greatest protrusion on upper lateral side). The angle formed by the first and third line is the footprint angle. The assumption is that as the arch becomes higher the footprint angle should become larger. Between and within rater reliability were both 0.97 on samples of 75 and 135 footprints, respectively.

(b) The footprint index (42) is calculated by connecting the most medial portions of the footprint, then calculating the ratio of non-contact area (Section B in Figure 3B) to the contact area (Section A in Figure 3B). The higher the footprint index the higher the arch is assumed to be. One problem with this method is that the index cannot be calculated for an individual with very high arches where the rearfoot and forefoot are not connected on the footprint. Between and within rater reliabilities were both 0.98 on samples of 100 and 50 footprints, respectively.

(c) The arch index (13) shown in Figure 3c can be calculated statically or dynamically. The static index uses a footprint obtained as the subjects stands on paper with $\frac{1}{2}$ the body weight on the measured foot. The dynamic index uses a footprint obtained as the subject walks over the paper. For both types of indices, a line is drawn from the center of the heel to the second toe (Line J in Figure 3C). Two other lines are then drawn perpendicular to this one: one is tangential to the metatarsal heads (most protruding part of the main footprint minus the toes), the other tangential to the heel (Lines L and K in Figure 3C). The main part of the footprint is then divided up into three equal parts and their areas are calculated. The arch index is the ratio of the center portion to the entire area. Referring to Figure 3C, the arch index is calculated as $B/(A+B+C)$. Arch indices calculated from 10 subjects taken on the same day and on two successive days demonstrated within rater reliabilities of 0.96 and 0.94, respectively.

(d) The arch length index (Figure 3D) (41) is calculated as the linear distance between the most medial portions of the footprint divided by the actual distance along the arch. The truncated arch index (Figure 3E) is calculated by first drawing a line tangent to and connecting the most medial portions of the footprint. Perpendicular lines are then drawn to the first line at the most medial portions of the footprint. The non-contact area enclosed by the lines is then divided by the contact area enclosed by the lines. For the arch length index, between and within rater reliabilities were 0.96 and 0.70, respectively; for the truncated arch index these were 0.96 and 0.91, respectively (n=15).

(e) The "wet test" has been widely advocated as a method of estimating arch height for running shoe selection (1, 74, 91). In this test, individuals wet the bottom of their feet and make footprints on a piece of paper. The paper imprints are compared to a template (91) to determine whether the individual has a high normal or flat foot arch. The reliability or validity of this method has not been reported.

(2) Validity of Foot Arch Indices.

(a) It can be seen that all of these foot arch indices appear to be highly reliable. Three studies have examined validity by determining the relationship between the actual height of the longitudinal arch and these indices.

(b) Cureton (25) took foot impressions in sand and measured the arch height by slicing a triangle through the mound made by the arch and down to the lowest point made by the heel and the first metatarsal joint at the proximal end of the big toe. The correlation between this arch height measure and the footprint angle was 0.86 and 0.96 (two separate sets of data).

(c) Hawes et al (41) measured arch height as the vertical distance from the ground to the soft tissue margin of the medial plantar curvature of the right foot in full weight bearing. They calculated the footprint angle, footprint index, arch index, arch height index, and truncated arch index. Correlations between measured arch height and these indices were 0.39, 0.20, -0.39, -0.36 and 0.35, respectively.

(d) Chu et al. (15) measured foot arch height from the floor to the navicular tuberosity. They also carefully obtained footprints from a force platform and measured the arch index from digitized foot images. The correlation between the measured arch height and the arch index was 0.70.

(e) Thus, the data on the validity of footprint indices as a measure of arch height is conflicting. The lower correlation obtained by Hawes et al. (41) is not related to their use of the soft tissue (which may require some degree of subjectivity) because they reported a reliability coefficient of 0.99 on repeat measures of 15 subjects. The differences between studies are not apparent.

(3) Relationship of Arch Height from Anthropometry and Radiography. An important question in determining the validity of measures of the medial longitudinal arch is how well noninvasive anthropometric measurements of the foot actually reflect the bony structure. Saltzman et al. (94) selected patients presenting at a university orthopedic foot and ankle clinic and took lateral x-rays of the foot. They also obtained anthropometric measures from the ground to the navicular, ground to talus and ground to soft tissue. Correlations with radiographically obtained floor to talar heights (corrected for foot length) were 0.86, 0.81, and 0.81, respectively. Williams and McClay (106) performed a similar study and correlated 12 radiographic arch height measurements with similar anthropometric measures. Correlations ranged from 0.70 to 0.94 with most measures >0.80 . Thus, the relationship between anthropometrically measured arch heights and radiographically determined heights appears to be reasonably high.

(4) Subjective Evaluations of Foot Arch Height. Cowan et al. (23) examined agreement among clinicians (3 orthopedic surgeons and 2 podiatrists) when they viewed foot photos of 246 Army recruits. They rated arch height on a 5-point scale. Photos had clearly marked anatomical locations and marks indicating soft tissue arch height. The median probability of agreement was only

0.57 for flat feet and 0.17 for high- arched feet. These data suggest that clinical assessments of arch height differ widely among individual raters.

4. METHODS

a. Fort Drum Running Shoe Injury Prevention Program. The Ft Drum Running Shoe Injury Prevention Program consisted of three parts. The first part was the foot evaluation in which the soldier's weight, arch height, and ankle flexibility were determined. The second part was the shoe recommendation, which is based on information collected during foot evaluation. The third part was the actual shoe purchase.

(1) Foot Evaluation.

(a) The foot evaluation was performed as part of the normal soldier medical inprocessing conducted by Guthrie Army Medical Clinic. A physical therapy assistant or physical therapist performed the evaluation, which lasted about 30 seconds.

(b) When the soldier arrived for screening, he or she was asked to remove his or her boots or shoes and he or she was weighed on a scale. Body weight was recorded.

(c) The soldier was then evaluated for arch height. The soldier stood with full weight on the bare foot and the evaluator determined arch height by visual examination. Arches were classified as normal, flat, or high. In general, a flat foot was assessed as one with minimal or no space between the medial plantar arch and the floor as the soldier stood on a level tile surface. A normal arch was determined to be one that matched an intermediate arch height. A high arch was determined to be one that displayed an abnormally great distance between the medial plantar arch and the floor. All of these determinations were based on the clinical experience of the evaluator.

(d) Next, flexibility/mobility was determined. The soldier was asked to lift his or her foot and move through supination and pronation. Flexibility was classified as either rigid, flexible, or hypermobile. A rigid arch generally had a small range of motion, a flexible arch a larger range of motion, and a hypermobile arch a very wide range of motion. If flexibility/mobility could not be readily categorized, the evaluator would ask the soldier to walk and the evaluator would observe for the amount of motion that occurred throughout the gait cycle.

(2) Shoe Recommendations. After the foot evaluation, the soldier was then provided the hand-out (Shoe Recommendation Form) shown in Figures 4a (front side) and 4b (back side). The handout recommended a specific group of shoes for a specific foot type. If the soldier had a low arch with a hypermobile foot, a "motion control" shoe was recommended to help limit excessive pronation.

(3) Shoe Purchase. The soldier could go to the Post Exchange (PX) with the shoe recommendation sheet in hand. Once there, he or she would find the display shown in Figure 5 that matched the handout sheet. The soldier could then select a shoe in the appropriate group. Soldiers were free to purchase shoes elsewhere.

Figure 5. Running Shoe Display



b. Injury Data.

(1) In order to evaluate injuries before and after initiation of the shoe recommendation program, this investigation used a historical cohort design. The study population consisted of all activity duty soldiers at Ft Drum, NY. Injury visits by active duty soldiers from 1 August 1998 through 31 January 2001 were downloaded from the Guthrie Army Medical Clinic Ambulatory Data System (ADS) located in the Patient Administration Division. Conversations with hospital staff indicated that most visits to the main clinic and the two outlying Troop Medical Clinics (TMCs) were included in this database but Battalion Aid Station (BAS) data was not. Many battalions did not have a BAS. The chief of one of the TMCs estimated that that only 15% of soldiers were initially seen at the BASs with the remainder reporting directly to one of the TMCs.

(2) International Classification of Diseases, Version 9 (ICD-9) codes that were selected for downloading were those representing overuse-related events and anatomical locations generally involving the lower extremity or low back. Some commonly used non-specific and multiple site codes were also selected since lower extremity or low back events could be coded here. The ICD-9 codes selected were 715.00-719.89 (osteoarthritis, osteopathies, internal derangements of knee and lower extremity, unspecified disorders of lower extremity), 722.0-722.9 (intervertebral disc disorders), 724.0-724.9 (other disorders of the back), 726.0-727.8 (enthesopathies, disorders of synovium, tendon, and bursa), 728.7 (plantar fasciitis), 729.5 (pain in limb), 732.7 (osteochondritis), 733.1 (pathologic fractures), 734 (flat feet), and 843-848.9 (sprains and strains of lower extremity and back).

(3) Seven injury categories were developed based on examination of the descriptions in the ICD-9 codebook (96) and with reference to specific anatomical locations. These indices and the ICD-9 codes which comprised them included: Total Injury – All ICD-9 codes downloaded; Hip/Thigh Injury – 719.45, 726.50, 843.80; Knee Injury – 717.10-717.90, 726.60, 836.20, 836.30, 844.00-844.90; Lower Leg – 719.46; Ankle Injury – 718.87, 719.47, 726.70-726.79, 845.00-845.09; Low Back Injury – 722.10, 722.52, 724.20, 724.50, 846.00-846.90, 847.20, 847.90; Other Injury – 715.90, 715.98, 716.90, 719.40, 719.48, 722.20, 722.60, 726.90, 729.50, 732.70, 733.10, – 727.10, 728.71, 734.00, 845.10-845.19

(4) Only visits to the Physical Therapy Clinic were included in the analysis because conversations with providers in this and other clinics suggested that the former were the most consistent in their application of the ICD-9 codes.

(5) Primary visits were defined as the first incidence of a particular ICD-9 code in the 30 month period for a particular individual. An individual with a particular ICD-9 code was not counted again as a primary visit unless a 6-month period had elapsed and that code appeared again for that individual. An individual could be counted more than once if another ICD-9 code appeared for that individual.

c. Soldiers on Post (Denominator Data). The number of active duty soldiers on post on a monthly basis was obtained from the S-1 Office (Personnel Section) of the 10th Mountain Division Headquarters. Personnel in the S-1 calculate weekly troop strength for all units on post as part of the Commanding General's Weekly Summary. The last weekly report of each month was used to represent the denominator for the entire month.

d. Running Shoe Program Survey. We surveyed a convenience sample of 122 soldiers with regard to the shoe program. All of these soldiers were from the 210th Forward Support Battalion (FSB) and were involved in Soldier

Readiness Checks at the time of the survey. Surveys were conducted on four groups of soldiers and four questions were asked each group. After each question soldiers were asked to raise their hands for an affirmative response. The four questions were as follows. Did you go through medical inprocessing when you arrived at Ft Drum? Did you go through the running shoe fitting portion of the medical inprocessing? Did you buy new shoes while here at Ft Drum? Did you buy new running shoes based on information provided as a result of the shoe-fitting program at medical inprocessing?

e. Data Analysis.

(1) Injury rates were calculated as the number of primary injury visits (numerator) divided by the number of soldiers on post (denominator). Monthly rates were plotted to graphically show the trends in the data.

(2) For further analysis, the data were broken down into three periods. Period 1 represented the "Pre-Intervention" interval and included all months between August 1998 and October 1999. Period 2 represented the "Transition" period (when the first groups of soldiers were receiving the foot screening) and included all months between November 1999 and June 2000. Period 3 represented the "Intervention" period and comprised all months between July 2000 and January 2001. The Transition period involved a time when about 1/3 of the troop population would have been medically inprocessed (about 370 soldiers per month for an average troop population of 9101 in this time period).

(3) A one-way analysis of variance (ANOVA) was used to compare the three periods within each injury category. Where the hypothesis of no difference was rejected, the Tukey test was used to identify between-period differences. Statistical Package for the Social Sciences, Version 10.1.0 was used for this analysis.

(4) Further analysis was performed using linear regression. Since the dependent variable (cases/soldiers on post) was a proportion, an arcsin transformation was performed to stabilize the variance (84). Periods were recoded to "dummy" variables (yes/no). Linear regression analysis was performed with the arcsin-transformed numbers as the dependent variable and the recoded periods as the independent variables. The t-statistic was used to test the hypothesis that the regression coefficients were different from zero. STATA Version 6 (College Station TX) was used for the analysis.

5. RESULTS. There were a total of 58,101 visits for the specified ICD-9 codes in the 30-month study period. Of these, 58% (33,538) were visits to the Physical Therapy Clinic. Primary visits to the Physical Therapy Clinic were 25% (8484).

a. ICD-9 Data.

(1) Figures 6 through 12 graphically display the monthly injury rates in each of the seven injury categories. Injury rates in most of the injury categories appear to be lower after March or April 2000 compared to previous time periods. An exception is "other injuries" (Figure 12) where the injury rate appears to have increased after March 2000.

(2) Table 2 shows the injury rates in each of the seven injury categories for each of the three periods. For all injury categories, ANOVA indicated a significant difference among the three periods. The Tukey test indicated that in all injury categories except for "other injuries", the injury rate was lower in the Intervention period than in the Pre-intervention period. For "other injuries" the pattern was reversed: a higher injury rate was found in the Intervention Period compared to the Pre-intervention period. The average±standard deviation numbers of soldiers on post during the Pre-Intervention, Transition, and Intervention periods were 9366±825, 9101±1397, and 9752±840, respectively.

Table 2. Comparison of Injury Rates (cases/1000/month) in the Three Periods (values are means ± standard deviation)

	All Injury	Low Back	Hip/Thigh	Knee	Lower Leg	Ankle	Other
Pre-Int ^a	36.8±7.1 ¹	11.5±2.8 ¹	2.5±1.0 ¹	6.7±1.9 ¹	6.8±1.8 ¹	6.5±1.5 ¹	2.5±0.9 ¹
Transition	31.2±10.8 ¹	10.9±4.2 ¹	1.7±1.2 ¹	4.8±1.9 ²	3.5±3.3 ²	5.8±2.7 ¹	3.9±2.2 ¹
Intervention	18.6±4.4 ²	5.8±1.7 ²	0.6±0.2 ²	3.3±1.2 ²	0.2±0.2 ³	3.5±0.6 ²	4.8±1.4 ²
F-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

^aPre-Intervention

¹²³Different subscripted numbers indicate a significant difference between periods for that column

Figure 6. Total Injury Rate

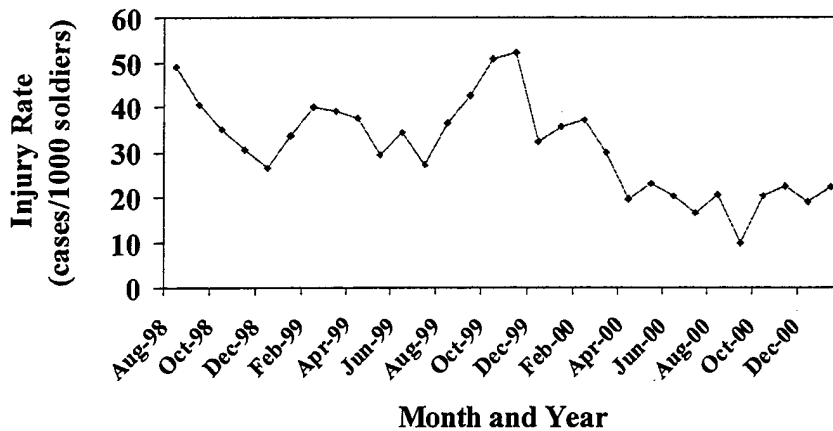


Figure 7. Low Back Injury Rate

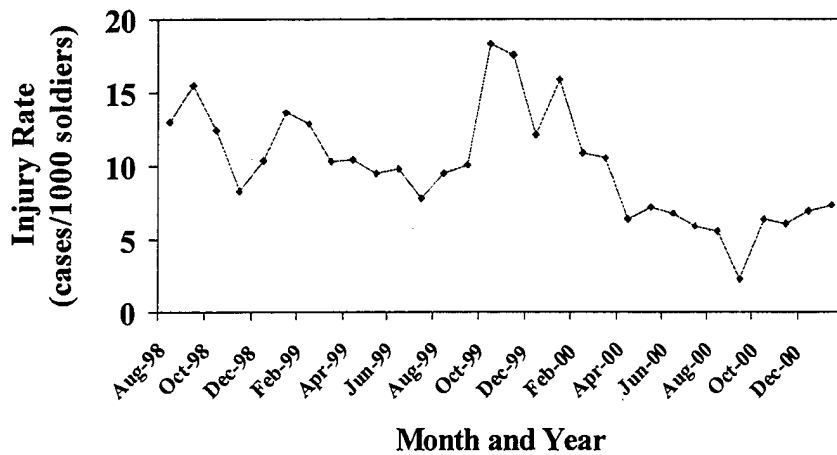


Figure 8. Hip/Thigh Injury Rate

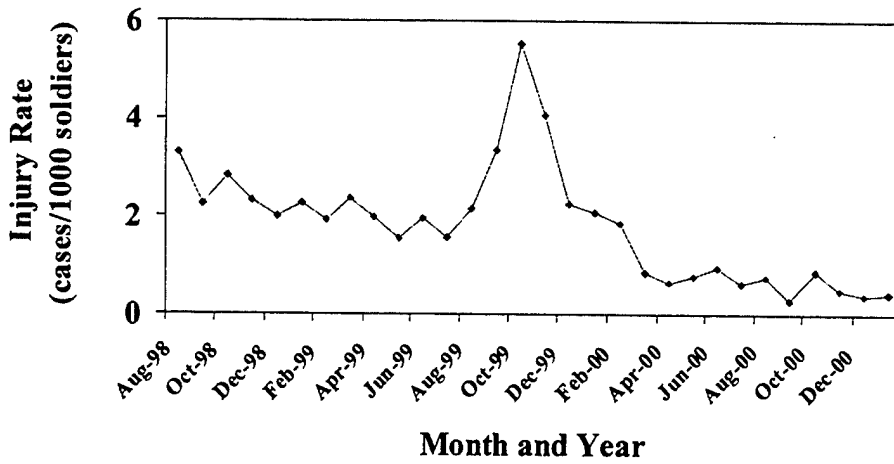


Figure 9. Knee Injury Rate

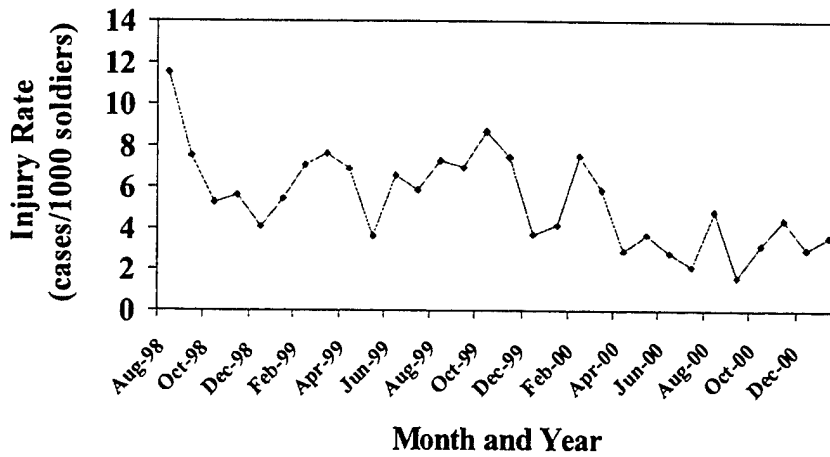


Figure 10. Lower Leg Injury Rates

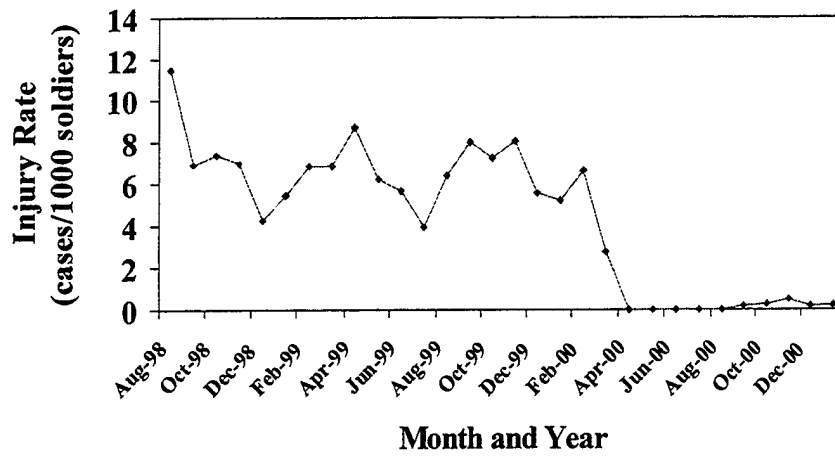


Figure 11. Ankle Injury Rates

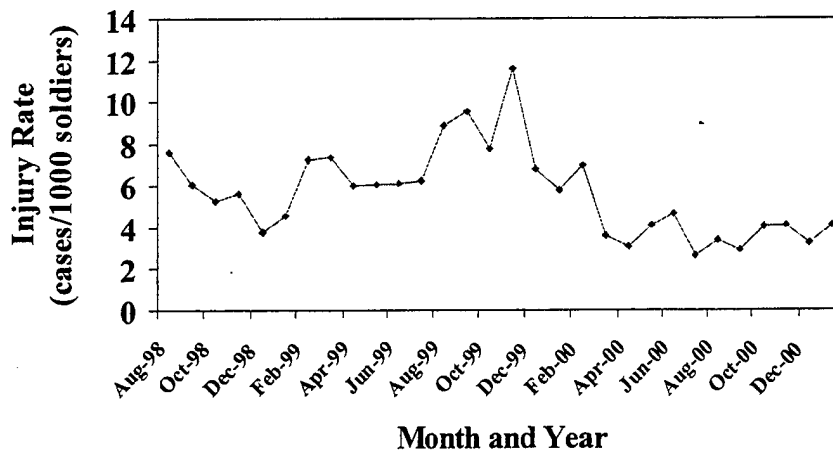
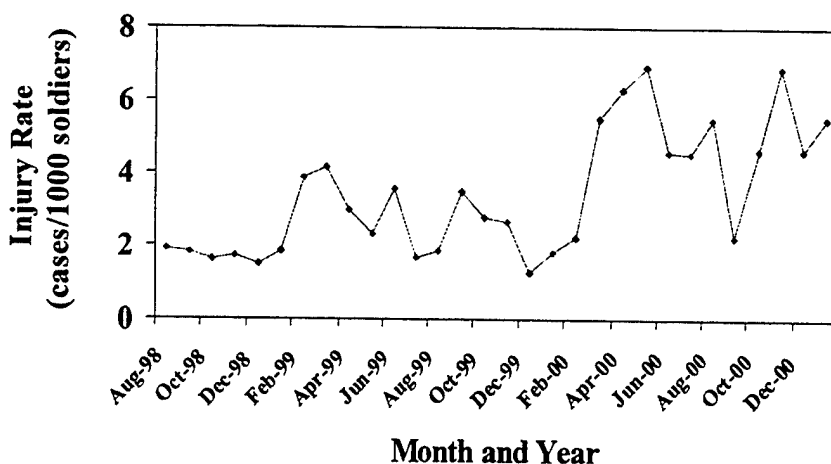


Figure 12. Other Injury Rate



(3) Table 3 shows the relative risk and p-values for the arcsin transformed regression coefficients comparing the Pre-Intervention period to the Transition and Intervention periods. All of the regression coefficients in the Pre-Intervention vs the Intervention period were significantly different from zero ($p < 0.01$) indicating different injury rates in the two periods for all seven injury categories.

Table 3. Relative Risk and p-values for Transformed Regression Coefficients in Pre-Intervention Period Compared to Transition and Intervention Periods

Type of Injury	Pre-Intervention/Transition		Pre-Intervention/Intervention	
	Relative Risk	p-value	Relative Risk	p-value
All Injury	1.2	0.01	2.0	<0.01
Lower Back	1.1	0.59	2.0	<0.01
Hip/Thigh	1.5	0.07	4.1	<0.01
Knee	1.4	0.02	2.0	<0.01
Lower Leg	1.9	<0.01	34.0	<0.01
Ankle	1.1	0.26	1.9	<0.01
Other	0.6	0.05	0.5	<0.01

b. Running Shoe Program Survey. The questions asked of the soldiers in the 210th Forward Support Battalion (FSB) and the proportions responding affirmatively are shown in Table 4. About half of the soldiers went through the foot evaluation portion of the medical inprocessing. Of those, 23% (14/60) said they bought new shoes based on the advice given. However, only 11% of the total sample said they bought a new shoe based on the shoe recommendation.

Table 4. Results of Interviews Regarding the Shoe Fitting Program (Convenience Sample of 122 Soldiers from the 210th Forward Support Battalion)

Question	Yes (n)	Yes (%)
Did you go through medical inprocessing (MIP) on arrival at Ft Drum?	111	91
Did you go through the running shoe fitting portion of the MIP?	60	49
Did you buy new shoes while here at Ft Drum?	87	71
Did you buy new running shoes based on information provided as a result of the shoe-fitting program at MIP?	14	11

6. DISCUSSION.

a. General Findings.

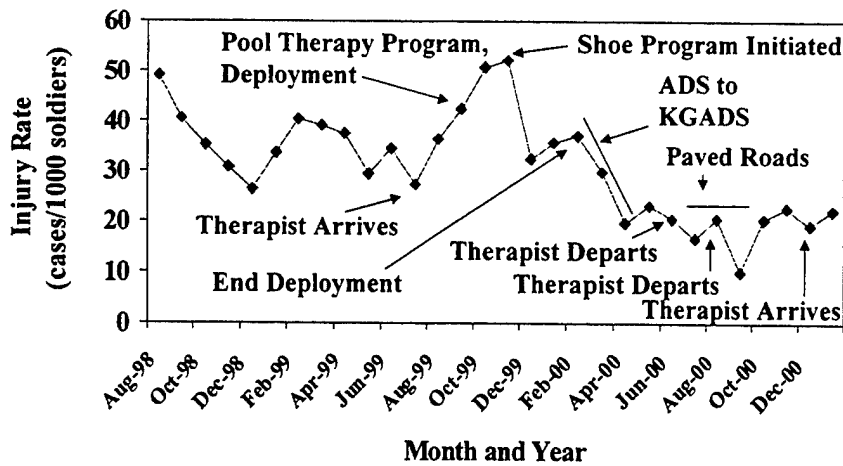
(1) This study indicated that lower extremity/low back injury sick call visits to the Physical Therapy Clinic at Ft Drum decreased in the July 2000 to January 2001 period when compared to the August 1998 to October 1999 period. The decline in injury rates corresponded to the implementation of the Running Shoe Injury Prevention Program, suggesting this program may have influenced the decline in injuries. All injury categories showed decreases in the Intervention period with the exception of the "other injury" category. The "other" injury category was for those ICD-9 codes that had non-specific or multiple anatomic sites.

(2) Great caution must be taken in assuming that the shoe program alone was responsible for the decline in injury rates. It is possible that the Running Shoe Injury Prevention Program had the effect of encouraging soldiers to buy new shoes and that new shoes alone (rather than the specific shoes selected based on foot type) reduced injury rates. A study of Marine recruits showed that those who arrived at training with newer running shoes had fewer stress fractures during their 12-week training program (32). About 70% of soldiers in the convenience sample survey in the present study said they had bought new shoes while at Ft Drum but only 11% said they had used the shoe recommendation advise provided.

b. Changes in Temporal Factors (Potential Confounders).

(1) It is also possible that other factors may have changed in the environment at Ft Drum during the study period and these changes could have influenced injury rates. We identified a number of these potential confounders and their temporal relationship to the study is shown in Figure 13. Each factor is discussed below.

**Figure 13. Total Injury Rates
With Potential Confounders**



(2) The major potential confounder in this study was the switch from the use of the ADS to the KG-ADS* system. The ADS system used scannable sheets of paper, which contained the most commonly used codes in a particular clinic. After seeing a patient, the provider filled in a bubble on this sheet that indicated the diagnosis for a particular case. These sheets were then scanned and the diagnoses placed into the database that was kept locally at the PAD. The KG-ADS was available to providers on their computer screens. Providers scrolled through a list of diagnosis to find the appropriate one, then sent that diagnosis forward on the network. Several users of this system told us that it was cumbersome and often required spending considerable time to find a particular diagnosis. Providers could become impatient and possibly miscode a case, especially when the number of clinic visits was large. If miscoding occurred, it was possible that the ICD-9 code used after the switch may have been one other than those examined in this study (i.e., not an overuse-related code). The first clinic switched from ADS to KG-ADS in February 2000. By April 2000 all clinics had completed the switch. Note in Figure 13 that the decline in injuries corresponded with the switch from ADS to KG-ADS.

(3) Another potential confounder was that the shoulders of the roads at Ft Drum were blacktop paved during the summer 2000 (see Figure 13). Previously, the roads had been rough gravel. This change in surface could have reduced injuries due to running or road marching if the assumption is made that surfaces influence injury rates. However, epidemiological studies have generally shown no association between self-reported injury risk and self-reported running surface (9, 43, 69, 73, 104). One investigation (69) showed that women who

* KG-ADS – The “K” refers to the Tripler Army Medical Center Identifier and “G” to government.

generally ran on concrete had a higher odds of injury than those who did not; however, this same study did not find this in men and other studies addressing concrete vs other surfaces found no difference (9, 104). A study of U.S. Navy Sea, Air, and Land (SEAL) recruits found that those who had trained on soft surfaces in the 6 months before training were more likely to be injured during SEAL training (97). Overall, there is no strong evidence that a change in running surface is associated with the decline in injuries. Further, the decline in injury rates in the present study occurred before the summer 2000. Thus, it is not likely that the road paving influenced the injury rates.

(4) The reasons that running surfaces may have little effect on injury rates may be related to adjustments subjects make to accommodate to different surfaces. One study looked at leg stiffness (peak vertical ground reaction force/maximal leg compression) during transitions from hard to soft running surfaces. The two surfaces differed in compliance by a factor of 25. Runners completely adjusted their leg stiffness within the first step of running on a different surface. Peak vertical ground reaction forces were similar for both surfaces. Thus, subjects adjusted their gait such that the leg became a better shock absorber on the hard surface and less of a shock absorber on the soft surface. Despite this, there was a reduction in the *initial spike* of the vertical ground reaction force (see Figure 2) with the softer surface (29). Also, one study using accelerometers attached to the medial malleolus found that peak shank decelerations were about 10% greater on concrete than on grass (66). Thus, there may still be some biomechanical differences between hard and soft surfaces that require more research.

(5) Another potential confounder in the present study was an expanded Pool Therapy Program put in place in September 1999 (see Figure 13). Soldiers in this program performed a combination of swimming, shallow water running and walking, and other water aerobics activities five times per week in lieu of regular unit fitness training. This may have given injured soldiers alternatives to unit physical training and thereby contributed to a decline in reinjury rates. To determine if the Pool Therapy Program influenced reinjury rates, we compared the number of repeat codes in two periods before and after the Pool Therapy Program. In performing this analysis it must be remembered that only the first occurrence of an injury was considered in the present study; 6-months would have to elapse before an injury was considered again in the data analysis. Thus, in the pre-pool therapy time, we examined ICD-9 codes in the 6-month period September 1998 to February 1999 and looked to see how many were repeated in the 6 month period from March to August 1999. In the post-pool therapy time we examined ICD-9 codes in the 6-month period from September 1999 to February 2000 and looked to see how many were repeated in the period March to August 2000. The results are shown in Table 5. There were no differences in the two periods in the proportion of subjects with repeated ICD-9 codes. Thus, the Pool Therapy Program did not appear to influence reinjury rates.

Table 5. Number of Individuals with Repeat ICD-9 Codes in Two Timeframes

	Repeated Codes (n)	No Repeated Codes (n)	Proportion with Repeated Codes (%)	p-value ^a	Risk Ratio (2000/1999)	95% Confidence Interval
Mar-Aug 1999	53	1977	2.6	0.45	1.2	0.8-1.8
Mar-Aug 2000	33	1058	3.1			

^aFrom chi-square test comparing 1999 and 2000

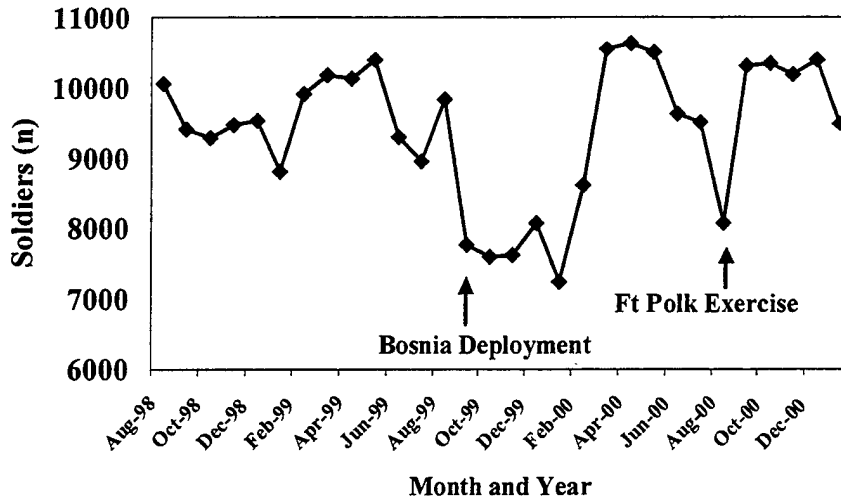
(6) As in any military medical facility, there was staff turnover during the course of the study. Different therapists may have used different ICD-9 codes for similar diagnoses. Figure 13 shows when new therapists arrived and departed. Injury rates increased with the arrival of a new therapist in July 1999 but the rates were not outside historical levels seen the previous year. The arrival and departure of three other therapists in the June to September 2000 timeframe occurred after the shoe program was in place and appeared to have had little influence on injury rates.

(7) Physical therapists both initiated the Running Shoe Injury Prevention Program and evaluated injuries among soldiers who took part in the program. It is possible that during the Intervention period some unintentional bias may have been present such that lower extremity injuries were classified into some other injury category. The increase in the "other" injuries in the Intervention period may support such a hypothesis. However, the overall lower extremity/low back injury rate (which included the "other" category) still declined in the Intervention period. It is unlikely that therapists placed lower extremity injuries into upper extremity ICD-9 codes. Conversations with providers revealed no conscious systematic bias.

(8) A large number of Ft Drum soldiers were deployed to Bosnia in September 1999 and most had returned by March 2000. Figure 14 shows the lower troop strength during this period. Injury rates went up in the September to November 1999 timeframe as seen in Figure 13. Soldiers not deployed were likely to be those less healthy and thus a larger proportion may have reported to the clinic with injury problems. However, the increase during the September to November 1999 timeframe was not greater than historical levels from the previous year. The end of the deployment corresponded with a decline in injury rates to below historical levels. Returning soldiers may have been those more healthy and less likely to report to the clinic with injury problems. However, many of these same soldiers would have been present prior to the deployment and would have been equally likely to have injury problems in this pre-deployment period. Also, soldiers returning from Bosnia were likely to have taken leave and injuries would have been less likely because these soldiers would have been less exposed to the physical hazards of their occupations. However, these same soldiers would eventually come back from leave and generated injuries as they resumed running and other training. Figure 13 does not suggest this pattern.

Thus, the overall decline in injury rates during the intervention period cannot be explained by the deployment.

Figure 14. Total On-Post Troop Strength at Ft Drum in Study Period



(9) Seasonal variations in injury rates have been reported in some military training environments (53). In the present study, injury rates tended to be lower in December; this may reflect lower levels of physical activity (and consequently less exposure to injury producing events) due to vacation (leave) associated with the holiday season. However, there is no other evidence of seasonal patterns in these data (Figures 6 and 13).

(10) The amount and type of physical training is known to influence injury incidence in military populations (46, 47, 54-56). It is possible that less active training regimes were followed by units at Ft Drum during the Intervention period but no data were available that could test this hypothesis.

c. Running Shoe Program Survey.

(1) The Running Shoe Program survey was taken on a convenience sample of 122 soldiers in a single unit and represented 1.3% of the average troop population during the Intervention period (n=9752 soldiers). This sample was far from a random one and represented only a small part of a single unit. Further, the soldiers' time at Ft Drum was not queried; thus, some soldiers may have been on post prior to initiation of the shoe program. Twenty-three percent of those who said they had their feet screened (14/60) reported using that advice to buy a running shoe. Non-compliance with prescribed health regimens is a common problem often cited in the literature (30, 35, 36).

Compliance can be defined as the extent to which an individual's behavior coincides with medical advice (36, 68). Compliance rates vary widely, probably depending on the numerous factors that can influence the decision to comply. Overall compliance rates are about 50%, with a range of 20% to 80% (35, 36, 68). Most of these studies involve taking prescribed medications, and the purchase of a running shoe is a much more complex behavior. Purchase of a shoe requires the soldier to go to a store that carries the running shoe, examine the shoes available at the time of the visit, decide on the shoe, and purchase the shoe. Thus, a much greater number of actions and decisions are required compared to the taking of medication, possibly accounting for a portion of the lower compliance rate.

(2) Only 11% of the overall surveyed population said they had taken the running shoe advice (only about ½ of the survey sample received the foot screen). Extrapolated to all of Ft Drum, this 11% represented 1072 soldiers out of the average 9752 soldiers on post during the Intervention period. There was an average of 345 primary injury visits/month to the Physical Therapy Clinic in the Pre-Intervention period and 182 primary injury visits/month in the Intervention period. The difference (163 primary visits/month) extrapolated to 6 months (during which time an ICD-9 code for a particular individual was not repeated in the analysis) was 978 primary visits. Thus, it is possible that the small percentage of subjects who reported taking the shoe advice could have played a role in the injury reduction seen in the Intervention period.

d. Injury Reduction Mechanism.

(1) It is difficult to explain how the Ft Drum Running Shoe Injury Prevention Program reduced injuries based on our review of the literature. There is little agreement among clinicians on what constitutes a high vs low arch (23). A number of different individuals at Ft Drum evaluated foot arch height and foot flexibility during the Transition and Intervention periods, and it is likely that they used different criteria to determine arch height.

(2) Although running shoes may protect the foot from adverse road conditions (81), the assumption that they reduce overuse injuries is based on conjecture from clinical opinion (8, 18, 20, 45) and biomechanical analyses (50, 86, 101). One case study suggests an improperly aligned heel counter was associated with plantar fasciitis (105). Running shoes can reduce pronation after foot strike (17, 38, 39, 86, 102), but there is no direct evidence that reducing pronation will influence injury rates. Running shoes can also provide cushioning (12, 26-28, 79) but with the exception of one case study (10), there is no direct evidence that this factor is related to injury. Randomized cohort studies that specifically look at injuries among individuals with specific foot types and wearing running shoes with specific characteristics are needed.

e. Fit-The-Foot Program.

(1) All Army, Air Force Exchange Service (AAFES) stores now have a "Fit-The-Foot" Program. This program involves a display similar to the one in Figure 5. The shoes for each category are selected by a designated TRADOC individual based on catalogs from running shoe companies, running magazines, and shoe samples. The shoe selection is reviewed by a physical therapist who provides his/her expert opinion. Tags are placed on the shoes indicating their type (cushioned, stability, or motion control). It should be noted that most individuals who see the display may select a shoe on the basis of self-selected arch height alone and will not perform the same evaluation as the Ft Drum program provides.

(2) At Ft Jackson South Carolina, all new recruits have their foot arch height evaluated by drill sergeants based on the foot impression made while the trainee stands on a Plexiglas platform. The trainee is given a sheet of paper showing their foot type (normal, flat, high arch) and a recommendation for a shoe type in one of three categories (cushioned, stability, or motion control). They are then taken to the AAFES where they can select and purchase a running shoe. There is a current initiative to add a running shoe to the initial issue clothing bag of trainees. Cost will be offset by removing one of the two field jackets issued now.

7. CONCLUSIONS.

a. During the time period that the Ft Drum Running Shoe Injury Prevention Program was in place there was a decrease in recorded visits for lower-extremity/low back injuries in the Ft Drum Physical Therapy Clinic.

b. There were a number of temporal changes at Ft Drum that occurred concurrent with the decline in injury rates. Temporal changes that can be discounted include paving of the shoulders of the roads at Ft Drum, the Pool Therapy Program, physical therapist turnover, and a deployment to Bosnia. One temporal change that cannot be totally discounted is the change from ADS to KG-ADS since providers stated this new system could have resulted in ICD-9 miscoding and since the change corresponded closely in time to the reduction in injury rates.

c. Since overall lower extremity injury rates declined shortly after the introduction of the Running Shoe Injury Prevention Program, the data tentatively support the effectiveness of this program. However, it is imperative that the program be tested in a randomized prospective cohort study before a full determination can be made regarding the program's effectiveness.

APPENDIX A

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