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

USACHPPM

USACHPPM REPORT NO. 12-MA-05SB-08

INJURY REDUCTION EFFECTIVENESS OF PRESCRIBING RUNNING SHOES BASED ON FOOT SHAPE IN BASIC COMBAT TRAINING

U.S. Army Center for Health Promotion and Preventive Medicine
Aberdeen Proving Ground, MD

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14. ABSTRACT

In Basic Combat Training (BCT), running shoes are prescribed based on plantar foot shape (reflecting longitudinal arch height). In response to a request from the Military Training Task Force of the Defense Safety Oversight Council, this study examined whether or not this prescription technique influenced injury risk. After foot examinations, BCT recruits in an experimental group (E, n=1,079 men, 456 women) were prescribed motion control, stability, or cushioned shoes for foot shapes judged to represent low, medium, or high arches, respectively. A control group (C, n=1,068 men, 464 women) received a stability shoe regardless of plantar foot shape. Injuries during BCT were determined from outpatient visits provided by the Army Medical Surveillance Activity. Other previously known injury risk factors (e.g., age, fitness, smoking) were obtained from a questionnaire and existing databases. Multivariate Cox regression controlling for other injury risk factors showed little difference between the E and C groups among men (risk ratio (C/E) = 1.11, 95% confidence interval = 0.91–1.34) or women (risk ratio (C/E)=1.14, 95% confidence interval = 0.91–1.44). This prospective study demonstrated that prescribing shoes on the basis of the shape of the plantar foot surface had little influence on injury risk even after control of known injury risk factors.

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US ARMY CENTER FOR HEALTH PROMOTION AND PREVENTIVE MEDICINE
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EXECUTIVE SUMMARY
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1. PURPOSE.

a. In 2003 the Secretary of Defense directed the Department of Defense to reduce preventable mishaps or injuries. The Under Secretary of Defense for Personnel & Readiness responded by establishing the Defense Safety Oversight Council which chartered nine task forces to develop recommendations to reduce preventable injuries. One of these task forces was the Military Training Task Force (MTTF), which worked to decrease injuries during military training activities. Each year the MTTF prioritized a number of projects directed at training-related injury reduction. In 2005, the MTTF ranked military physical training footwear prescription and trainee fitness five out of 21 projects.

b. In the US Army, recruits entering Basic Combat Training (BCT) are prescribed running shoes based on the shape of the underside of the foot (i.e., plantar foot surface), the shape of which is assumed to indicate foot arch height. Shoe manufacturers market three types of running shoes designed for feet with high, normal, and low arches: cushion, stability, and motion control shoes, respectively. There is currently insufficient evidence to determine whether injury rates are affected by matching these three types of running shoes to the corresponding arch heights. The major purpose of this study was to examine whether or not injury risk can be reduced by prescribing running shoes based on the shape of the plantar foot surface (presumed to reflect foot arch height). Additional purposes were to 1) examine the association between the shape of the plantar foot surface and actual foot arch height, 2) examine the relationship between foot arch height and injuries, 3) compare current injury rates in BCT to those of past investigations, and 4) examine risk factors for injuries in BCT.

c. Participants for this study were male and female volunteers arriving for BCT. Volunteers filled out a questionnaire regarding age and lifestyle characteristics, including physical activity, smoking status, prior injury, and (for women) menstrual history. The shape of each subject's plantar foot surface was examined and categorized as either low, normal, or high based on a template indicating the amount of contact between the foot and the floor. The template was such that more area in the middle third of the plantar surface indicated a low arch, and less area indicated a high arch. Actual foot arch height was measured with a custom-designed caliper (floor to navicular bone). Subjects were randomized to either an experimental (E) group or a control (C) group. E subjects were prescribed a shoe based on foot shape: a subject with a low arch received a motion control shoe, a subject with a high arch received a cushion shoe, and a subject with a normal arch received a stability shoe. C subjects received a stability shoe (New Balance 767ST) regardless of plantar surface type.

d. The outcome measure was injury during BCT determined from outpatient visits recorded in the Standard Ambulatory Data Record. Attrition (discharge or recycled to another unit) was determined from two Armywide databases, the Resident Individual Training Management system and the Automated Instructional Management System-Personal Computer. Height and weight on entry to service were obtained from the Reception Battalion Automated Support System. The Defense Manpower Data Center provided race, sex, marital status, educational level, and component. The training units provided Army Physical Fitness Test scores. To account for differential follow-up time (subjects who attrited from training), Cox regression (univariate and multivariate) was the major statistical technique used in analyses to obtain risk ratios (RR) and 95% confidence intervals (95%CI).

2. CONCLUSIONS.

a. Volunteers for the study included 2,689 men and 1,263 women. Subjects were excluded from analysis if 1) they did not, or could not, obtain the prescribed shoe in the post exchange, or 2) if they did not wear the prescribed shoe for all physical training sessions in BCT. The final sample with complete injury data for the C group was 1,068 men and 464 women, and for the E group, 1,079 men and 456 women. There were no significant group differences in attrition from BCT among the men (C=7%, E=7%, p=0.37) or women (C=20%, E=19%, p=0.68).

b. Overall, the cumulative injury incidence was 37% for men and 67% for women. Injury rates did not differ between those in the C and E groups among either men (C=6.0 injuries/1000 person days, E=6.0 injuries/1000 person days, p=0.85) or women (C=10.9 injuries/1000 person days, E=11.4 injuries/1000 person days, p=0.58). Univariate Cox regression confirmed that there was little difference between the C and E groups among men (RR (C/E)=1.02, 95% CI=0.89–1.17) or women (RR (C/E)=1.06, 95%CI=0.90-1.24). Factors significantly associated with injury risk in both men and women included older age; lower performance on push-ups, sit-ups, or the 2–mile run; active Army status (versus Army Reserve or National Guard); cigarette smoking prior to BCT; beginning smoking at a younger age; less non-smoking time (among those who had quit smoking); less physical activity prior to BCT; and “other” marital status (mostly divorced and widowed). Among women only, prior lower limb injury, menstrual dysfunctions, and prior pregnancy were injury risk factors. When multivariate analysis was performed controlling for the other injury risk factors, there was still little difference between the C and E groups among men (RR (C/E)=1.11, 95% CI=0.91–1.34) or women (RR (C/E)=1.14, 95%CI=0.91–1.44).

c. Measured arch heights corresponded to plantar surface determination for both men and women when evaluated on an average basis (p< 0.01 for all comparisons). When individual cases were examined, over 75% of individuals in the middle distribution of measured arch heights were classified as having normal arches by plantar foot surface evaluation. However, many of those in the lowest and highest distributions of measured arch height were also classified as having normal arches by plantar surface evaluation. Only 29% to 44% of those classified as low arch by plantar surface evaluation were in the lowest distribution of measured arch heights; only 24% to 34% of those classified as high arches by plantar surface evaluation were in the highest distribution of measured arch heights. Overall, arch height was correctly classified 66% of the time for both men and women.

d. To examine associations between arch height and injury risk, comparisons were made among the measured foot arch heights for the lowest 20% of values, the middle 60% of values, and the highest 20% of values. For the men, there tended to be slightly higher injury risk associated with a lower arch on the left foot (RR (low/middle) =1.17, 95%CI=0.98–1.39) or the right foot (RR (low/middle)=1.10, 95%CI=0.92-1.31). For women, there was little difference in injury risk regardless of the arch height.

e. The current study is not in accord with a previous investigation that showed a decrease in injuries after initiation of a running shoe prescription program. However, there were many methodological differences between the current study and the past one. The current study only involved a prescription on the basis of shape of the plantar foot surface while the previous study involved a prescription based on a visual evaluation of foot arch height and foot flexibility. The current study involved a population of recruits where it could be ascertained that the prescribed shoe was obtained and worn during the entire course of the study. The previous study involved Soldiers who were given the shoe prescription, but there was little follow-up to determine whether they actually purchased the prescribed shoe and no knowledge of when or how often the shoes were used for training. The current study was prospective, involving two groups training side by side with follow-up for all injuries. The previous study involved a retrospective cohort design and examination of medical visits to a physical therapy clinic before and after the shoe program was initiated. The current study controlled for known injury risk factors. In the past study, a number of temporal factors were potential confounders, especially a change in the injury surveillance system which occurred at the exact point when injuries began to decrease.

f. Many of the BCT risk factors identified in the present study have been documented previously. These include older age, lower physical fitness, less physical activity, cigarette smoking, and menstrual dysfunction. The present study expanded the data on cigarette smoking to show that 1) injury risk progressively increased with younger age of smoking onset and 2) that injury risk progressively decreased the longer subjects had quite smoking. The mechanisms accounting for the higher injury risk in smokers may have more time to develop in individuals who have smoked for a longer period of time and these mechanisms may have more time to dissipate the longer it has been since the subject ceased smoking.

g. Subjects in the active Army tended to have a higher injury rate than National Guard or Reserve Soldiers. This may be associated with the guard and reserve Recruit Sustainment Program, which provides recruits with physical training and administrative support prior to BCT entry.

h. In past surveys of BCT cumulative injury incidence ranged from 17% to 31% for men and 41% to 67% for women. In this study the cumulative injury incidence was 37% for men and 67% for women, making these injury rates historically high. These higher injury rates may be associated with changes in the BCT program of instruction or in recruiting policies. In response to experiences in Iraq and Afghanistan the BCT program of instruction now involves “weapons immersion” (in which recruits constantly carry their weapons), convoy operations live-fire, reflex firing, and close-quarters marksmanship. Recruits wear body armor much of the day and there are more drills on urban warfare techniques, dismounting and assaulting from vehicles, and dealing with improvised explosive devices. The field training exercise in which Soldiers live and operate continuously in the field has been extended from 3 days to 5 days and recruits now spend a total of 21 days in the field. Recruiting policies have also changed to allow older (up to age 42), less educated, and less fit individuals to enter the service and these are known injury risk factors.

i. This prospective study demonstrated that prescribing shoes based on the shape of the static weight-bearing plantar foot surface had little influence on injury risk in BCT even after controlling for known injury risk factors. There was no consistent association between arch height and injury risk, although men with low measured arches tended to have higher injury risk. Plantar foot shapes judged as high, normal, or low corresponded to measured arch heights on an average, group basis; however, there was considerable individual misclassification, with only 66% correspondence. Injury incidence in this study was historically high, possibly as a result of changes in the BCT program of instruction, changes in recruiting policies allowing older, less fit, and less educated recruits enter the Army, and/or a continuing temporal trend of lower physical fitness on entry. In consonance with previous investigations, factors that increased injury risk included older age, lower physical fitness, less physical activity prior to entry, cigarette smoking, and menstrual dysfunction. Findings related to cigarette smoking were expanded by showing that injury risk progressively increased with a younger onset of smoking and decreased the longer it had been since the individual had quit smoking. Active Army recruits were at higher injury risk than guard or reserve recruits, possibly due to better pre-BCT preparation, especially emphasis on pre-BCT physical training.

3. RECOMMENDATION. It is not necessary to prescribe running shoes to BCT recruits on the basis of the shape of the plantar surface of the foot as it does not protect against injury any more than prescribing a single shoe regardless of plantar foot shape. The current practice of prescribing shoes in this manner in BCT can be discontinued. It is still recommended that recruits receive a new shoe on entry to BCT since older running shoes have previously been shown to increase injury risk.

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

2. INTRODUCTION AND PURPOSE.

a. In 2003, the Secretary of Defense directed the Department of Defense to reduce preventable mishaps or injuries by 50%. In 2006, the goal became to reduce preventable mishaps or injuries by 75% and the new Secretary of Defense remained committed to this goal for 2008 (1). The Under Secretary of Defense for Personnel & Readiness responded to the initial (2003) Secretary of Defense request by establishing the Defense Safety Oversight Council (DSOC), which chartered nine task forces to develop recommendations for policies, programs, and investments to reduce preventable injuries and accidents. One of these task forces was the Military Training Task Force (MTTF) which was chaired by the Army Deputy Chief of Staff, G-3. The MTTF sought to validate solutions to reduce the risk of injury during military training activities. Each year the MTTF prioritized a number of projects directed at training-related injury reduction. In 2005, the MTTF ranked military physical training footwear prescription and trainee fitness number five out of 21 projects.

b. Current practice in the United State (US) Army is to prescribe running shoes to recruits entering Basic Combat Training (BCT) based on the amount of foot surface contacting the floor (i.e., the shape of the plantar foot surface created by static weight-bearing on an acrylic surface). The plantar foot shape during weight-bearing is presumed to reflect foot arch height. Shoe manufacturers market three classes of running shoes designed for individuals with high, normal, and low arches individuals: cushion, stability, and motion control, respectively. These shoes presumably reduce injuries by compensating for presumed differences in running mechanics. However, there is insufficient evidence in the scientific literature to determine whether this strategy reduces injury rates (2). Further, any investigation testing the efficacy of shoe prescription for injury reduction must control for the fitness and lifestyle factors that are already known to increase injury risk in BCT (3). Also, as noted above, the shape of the plantar foot surface is assumed to indicate foot arch height, but this assumption has not been examined. A few studies have suggested that a relationship may exist between injuries and foot arch height (4, 5) and the current study presents an opportunity to further explore whether or not this relationship exists. Finally, this study also presents the opportunity to continue exploring the fitness and lifestyle factors that are known to increase injury risk in BCT (3).

c. Thus, the major purposes of this study were to 1) determine whether or not injury risk can be reduced by prescribing running shoes based on the static weight-bearing plantar foot shape,

2) examine the association between the shape of the plantar foot surface and arch height, 3) examine the relationship between arch height and injuries, 4) compare current injury rates in BCT to those of past investigations, and 5) more fully examine risk factors for injuries in BCT.

3. AUTHORITY.

a. Under Army Regulation 40-5 (6), the US Army Center for Health Promotion and Preventive Medicine (USACHPPM) is responsible for providing epidemiological consultation services upon request. This project was initiated by the MTTF of the DSOC. USACHPPM agreed to the project. The letter of request is in Appendix B.

b. It was determined that this project constituted research. Under Army Regulation 70-25 (7), all research must be reviewed and approved by a human subjects review board and potential participants must be briefed on the risks involved in the study. This study was approved by the institutional review board at the Army Medical Research and Material Command. The approval is in Appendix C.

4. BACKGROUND. Popular running magazines and other publications (8-11) suggest that the shape of the plantar surface of the foot can be used as an indication of the height of the longitudinal foot arch and that this can be used to select certain types of running shoes. Individuals with low arches are presumed to have disproportionate foot flexibility that allows the foot to pronate excessively during the stance phase of running. Motion control shoes are prescribed for those with low arches because they presumably control this excessive pronation. Individuals with high arches are presumed to have rigid or inflexible feet that underpronate and impact the ground with high force. Cushioned shoes are designed for those with high arches to presumably allow more pronation and provide cushioning to reduce ground impact forces. Individuals with average arch heights are assumed to impact the ground with less force and have an appropriate amount of pronation during the stance phase of running. Stability shoes are designed for those with average arches and these shoes have moderate cushioning and motion control characteristics (8).

a. <u>Gait Mechanics and Characteristics of Running Shoes.</u>

(1) The categorization of running shoes into motion control, stability, and cushioning shoes rests on two assumptions: 1) that individuals with high and low foot arch heights have the gait mechanics described above, and 2) that particular shoe characteristics can adjust or compensate for these gait differences to more closely conform to those of individuals with more average arch heights. With regard to the first assumption, when previously injured or symptomatic runners with low and high arches were tested using the same shoes, there were differences in running kinematics. Runners with low arches tended to demonstrate more inversion/eversion and less internal tibial rotation on the talus during the stance phase of running. Runners with high arches had less inversion/eversion, more internal tibial rotation on the talus, more leg stiffness, higher initial ground impact forces, and a higher rate of initial force development on ground impact (12-14). On the other hand, when nonsymptomatic high- and low-arched runners or walkers were examined, there were few arch-related differences in rearfoot motion or impact forces (15-18). Thus, gait differences associated with foot type may

be more applicable to symptomatic and previously injured individuals but less applicable to those who are not experiencing symptoms or who had not been previously injured.

(2) The second assumption is that particular shoe characteristics can adjust the gait mechanics of high- and low-arched individuals to more closely conform to that of individuals with average arch heights. Motion control shoes attempt to attenuate excessive rearfoot motion; cushioned shoes attempt to alleviate higher impact forces while allowing more rearfoot motion. However, when high-arched or low-arched individuals ran in motion control or cushioned shoes, there was little difference in kinematics between these two foot types even during prolonged running (19, 20). The only variable to differ was the instantaneous loading rate (maximal instantaneous slope of initial force development on ground impact), which, contrary to expectation, was actually higher in the cushioned shoe (compared with the motion control shoe) when worn by the low-arched individuals. This occurred despite the fact that motion control shoes (regardless of arch type) attenuated rearfoot motion better than cushioned shoes and that cushioned shoes generally attenuated shock better than the motion control shoes (19, 20). Thus, while the shoes performed as expected, there were no differences in mechanics (other than instantaneous loading rate) between low- and high-arched individuals running in these shoes.

b. Running 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 foot strike, d) provide motion control during the stance phase of the running cycle (21-24). The shoes should be as light as possible to minimize the energy cost of the additional weight they impose on the body (25).

(1) Protection of the Foot. Protection of the foot from the external environment is an obvious shoe characteristic. Surfaces can be hot, cold, rocky, and/or uneven. The shoe protects the plantar surface of the foot by providing a barrier to the external environment and a relatively even surface to bridge uneven ground. The shoe thus protects the foot from extremes of temperature and physical trauma such as abrasions, lacerations, and contusions.

(2) Traction. One function of the shoe outsole is to increase traction. The composition of the outsole of most shoes provides a high coefficient of friction with concrete and asphalt surfaces (26). Better traction may reduce the probability of traumatic injuries from slips and falls. It may also improve running efficiency by preventing slipping and by directing muscular effort more effectively in positioning the foot during the stance phase of running. Greater traction also provides more effective forward movement during the toe-off phase of running.

(3) Attenuation of Shock.

(a) Compared with bare feet, running shoes generally result in a decrease in the force of the initial impact spike and a slower initial rate of force development (27-31). Certain shoe characteristics may attenuate shock. Heel counters on shoes appear to reduce the lateral compression of the anatomical heel pad, making it a more effective shock absorber (29, 32, 33).

(b) The effect of shock-absorbing materials in the shoe is not clear. In studies where materials are placed on benches and durometers are used to measure material hardness (34), investigators find (as would be expected) that impact forces decrease as material hardness decreases (30, 35, 36). On the other hand, studies involving subjects running across force platforms have shown little difference in external impact forces for different types of midsole hardnesses (30, 37-39). This is surprising since, as with bench studies, lower impact forces might be expected for softer, more compliant insoles (i.e., ethyl vinyl acetate (EVA) versus polyurethane). Several hypotheses have been advanced to explain this finding. Lake (37) suggested that this lack of difference in impact forces among midsoles of various 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. (38) suggested 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, the initial impact force decreased. Thus, with different midsole hardnesses subjects adjusted their foot strike to achieve similar external impact forces. Studies performed on different types of running surfaces show that runners increase their leg stiffness when running on soft, compliant surfaces and decrease their leg stiffness when running on harder surfaces (40, 41). Yet a recent study examining two-dimensional sagittal plane kinematics showed no differences in leg stiffness between the two shoes with different cushioning properties (impact forces were not reported) (42). Thus, the effects of midsole hardness on impact forces are not clear at this point. Studies using shoes with different midsole hardnesses and employing three-dimensional kinematics with force platforms are necessary.

(c) Robbins and Gouw (43) have challenged the assumption that shock absorption should be a characteristic of running shoes. They hypothesize that normal plantar tactile stimulus during running results in adaptations 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. They propose that plantar feedback is optimal between bare feet and natural surfaces and that the cushioning in running shoes attenuates plantar feedback. They showed that sufficient vertical and horizontal impact forces (> 0.4 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. Also, their subjects were not runners.

(4) Motion Control.

(a) There has been a good deal of research on "rearfoot control," which can be defined as the ability of shoes to limit the amount of foot pronation after foot strike (44). 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 (45). 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.

(b) Midsoles constructed of softer material resulted in greater and more rapid foot pronation than harder material (44, 46). 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 rotational torque on the tibia, while the flexing knee imposed an internal rotational torque. Repeated cycles of these opposing torques during running could result in an overuse injury to the knee (46).

(c) 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 (44), while other studies showed no effect (47, 48). 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 (47).

(d) Heel lift (a greater height in the rear of the shoe than in the front of the shoe) has been hypothesized to reduce the incidence of Achilles tendonitis by reducing forces on the Achilles tendon (49-51). 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 (51). On the other hand, as heel height increased, the angular acceleration of pronation decreased (44).

(e) Medial (varus) and lateral (valgus) wedging have also been compared. Varus wedging is achieved by placing a wedged-shaped pad under the medial aspect of the heel, thus causing the calcaneus to tilt away from the midline of the body. Conversely, the same wedge placed under the lateral aspect of the heel causes the calcaneus to tilt toward the midline of the body. A 5-degree varus wedge was found to decrease foot pronation, but it also increased peak impact, rate of force development, and tibial shock (52). Thus, there are tradeoffs with wedging.

(5) Energy Cost. Heel counters are firm cups surrounding the calcaneus. They reduce the energy cost of running (32), possibly by increasing mechanical stability so that 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% (53-57). This may be because, during running, the lower extremities move through a greater range of motion than other parts of the body, resulting in more mechanical work. The additional mass on the extremities calls for greater muscular force and consequently more energy expenditure.

(6) Summary of Running Shoe Functions. 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. Running in shoes reduces vertical ground reaction forces (shock absorbency), compared with running barefoot, and firm heel counters appear to be key shoe characteristics for this effect. The effect of midsole hardness is not clear, but it may be that hardness does not influence shock absorbency since runners adjust their gait to achieve a similar impact force regardless of shoe hardness. Softer midsoles result in greater and more rapid pronation than harder midsoles. Studies of heel flare are not consistent with regard to pronation. Greater heel lift decreases pronation velocity. Heel wedges trade off stability for greater ground reaction forces. Lighter running shoes and firm heel counters reduce the energy cost of running.

c. <u>Foot Arch Height and Injuries.</u>

(1) Measuring arch height is often considered useful, quantifiable information regarding foot structure, shock absorption capabilities, and movement function. However, arch height measurement can be confounded by both bone and soft-tissue variation between individuals. Static arch height measurements alone do not take into account dynamic foot flexibility, which may be related to injury (16). Nonetheless, prospective studies specifically examining arch height and injuries during military training suggest that either high foot arches (4) or both high and low foot arches (5) increase injury risk.

(2) One civilian study (58) selected 20 individuals with high arches and 20 with extremely low arches who had previous injuries but no current injuries. Selection was based on 1.5 standard deviations above and below the mean arch height ratio. The arch height ratio was defined as the height from the floor to the dorsum (50% of foot length) divided by the foot length from the posterior calcaneus to the first metatarsal phalangeal joint. Subjects reported their previous injuries on a questionnaire. High-arched individuals were found to have more injuries to lateral parts of the lower extremities, more bony injuries (stress fractures and stress reactions), and more foot and ankle injuries. Low-arched runners had more medial lower extremity injuries, more soft tissue injuries, and more knee injuries. The researchers hypothesized that the "pronated position of the foot often associated with a planus foot places increased stress on the medial structures of the lower extremity." They demonstrated that in high-arched individuals there was increased lateral loading of the foot compared with low-arched individuals, possibly placing more stress on this area and possibly leading to more injuries. The higher incidence of knee injuries in the high-arched group was related to a greater range of knee external rotation, possibly resulting in misalignment of the patellofemoral joint and thus higher stress in this area.

(3) Clinical classification of foot arch height may be problematic. One study measured the level of agreement among six clinicians on the classification of foot types into flat, normal, or highly arched, based on observations of photographs of different angles of the feet (59). The authors concluded that there was unacceptable interclinician variability and stressed the need for more objective standards in evaluating foot arch height. The validity of clinically diagnosed arch-height measurement has also been questioned by other authors (2, 60). There can be significant discrepancies between the radiographic appearance of the foot and the external clinical measurement. One study observed several feet that appeared clinically flat, but when lateral radiographs were obtained and standard radiographic indices applied, the feet could be classified as highly arched. It may be that simple observation of arch height alone is of little predictive clinical value and is therefore best used as a minor piece of clinical information (2).

However, no study has specifically examined how closely the clinical observation of the foot conforms to the actual arch height.

d. Injuries and Footwear.

(1) As noted above, there are a large number of biomechanical studies involving running shoes (e.g., 21-24, 29, 32, 33) and these studies frequently hypothesize that specific changes in body mechanics induced by running shoes can influence injury rates. However, the data linking shoes to actual cases of injuries are 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. These studies are reviewed below.

(2) Wilk et al. (61) 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 with 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 foot pronation with and without the defective heel counter. Further, plantar fasciitis is a common running injury (62-64) and the problem in this case could have been caused by factors other than the shoe.

(3) Burgess and Ryan (65) 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 two 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. (66) found that Marine Corps recruits who reported to basic training with older running shoes were more likely to experience stress fractures than those reporting with newer shoes. Recruits who 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 Defense Force 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. Experiments showed that 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) (67).

(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 with players wearing other types of shoes (68).

(7) These studies present a confusing picture. There is some suggestion that older running shoes are associated with a higher likelihood of stress fractures. This was shown in Marine Corps recruit training; one of the case studies suggested an association between lower shock absorbency and stress fractures, and there is a mileage-related loss of shock absorbency in running shoes (50). However, in the Israeli recruit study, overall stress fracture rates were the same in those wearing the boot versus the more shock-absorbent basketball shoe. In the Marine Corps recruit study, recruits wore their running shoes only for morning physical training, while in the Israeli recruit study, recruits wore the basketball shoes for 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.

(8) A retrospective cohort study (25) tested the effectiveness of a running shoe prescription program for reducing injuries. At Fort Drum, New York, newly arriving Soldiers had their feet examined by a physical therapist and feet were classified on the basis of observed arch height (high, medium, or low) and flexibility (normal or rigid). A category of running shoes (motion control, stability, or cushion) was then recommended on the basis of the foot examination. 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). Denominator data were obtained from the Fort Drum (10th Mountain Division) S-1 Office (Personnel Section). Injury rates were 36.8 cases/1000 soldiers-months) before the program began and 18.6 cases/1000 soldiers-months 5–14 months after the program began (relative risk (after/before)=0.5, $p < 0.01$). Thus, the decline in injury rates corresponded in time to the implementation of the program. However, a major potential confounder was the switch in how medical surveillance data was recorded. The hospital switched from the use of the Ambulatory Data System (ADS) to another system called KG-ADS (intended as an automated upgrade to ADS). Providers considered the KG-ADS 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 Fort Drum, the Pool Therapy Program, physical therapist turnover, recorder bias, a deployment to Bosnia, and seasonal variations) were considered and discounted. It was considered imperative that the program be tested in a randomized prospective cohort study.

e. Injury Incidence and Injury Risk Factors in Basic Training.

(1) Cumulative injury incidences (proportion of trainees with one or more injuries) and injury rates (injured trainees per month) have been examined in the basic training units of the Army, Navy, Marine Corps, and Air Force (66, 69-81). Army data are shown in Table 1. US Army BCT was extended from 8 to 9 weeks in October 1998 and thus studies performed before and after this time are separated in Table 1 to reflect the increased time at risk in the latter investigations. Two studies are included of US Army infantry basic training, which is 12 weeks long.

(2) With regard to data collection methods, most studies used medical records screening (74, 75, 81-85), but other studies used a medical surveillance system (86) or questionnaires (76). With regard to injury definitions, most studies have looked at cases where trainees reported to a medical care provider for any type of physical damage to the body (75, 77, 81, 84, 85), but other studies have included only musculoskeletal injuries (74), or lower extremity overuse injuries (74, 83). One study used a self-report and included any injury regardless of whether or not the trainees sought medical care (76).

Table 1. Cumulative Incidence of Injury and Injury Incidence Rates during US Army Basic Combat Training

Service	Length of Training (Weeks)	Study (Reference Number)	Year Data Collected	Recruits (n)		Cumulative Injury Incidence (%)		Injury Incidence Rate (% / month)	
				Men	Women	Men	Women	Men	Women
Army	8 weeks	76[a]	1978	347	770	26.2	62.0	13.1	31.0
		75	1980	1840	644	20.7	41.2	10.4	20.6
		74	1984	124	186	27.4	50.5	13.7	25.3
		82	1988	509	352	27.0	57.0	13.5	28.5
		81	1994	ND[b]	165	ND[b]	66.7	ND[b]	33.3
		83	1996	159	84	41.5	65.5	20.8	32.8
		77	1998	604	305	30.8	58.0	15.4	29.0
	9 weeks	84	1998	655	498	29.9	65.3	13.3	29.0
		85[c]	2000	682/441	579/554	13.5/16.9	36.1/46.8	6.0/7.5	16.0/20.8
		86[c,d]	2003	518/656	416/465	21.8/31.2	45.9/53.9	9.7/13.9	20.4/23.9
	12 weeks (Infantry)	73	1988	303	ND[b]	45.9	ND[b]	15.3	ND[b]
		[e]	1996	768	ND[b]	48.0	ND[b]	16.0	ND[b]

[a]Injury data from self-report questionnaire
[b]ND=No data collected on this gender
[c]Cohort study with two groups
[d]Injury data from surveillance system
[e]Previously unpublished data

(3) Several injury risk factors have been identified in US Army BCT. Intrinsic risk factors (those that relate to characteristics of the individual) include female gender (71-79), low aerobic fitness (71, 72, 74, 77, 81, 87), low muscular endurance (73, 77), cigarette smoking prior to BCT (73, 77, 87, 88), and low physical activity prior to BCT (66, 72, 74, 77, 89). Extrinsic risk factors (those related to the external environment) have included training in the summer compared with the fall (90), training company (73, 87), and longer running mileage during basic training (89). Multivariate analyses have shown that cigarette smoking prior to BCT, low levels of aerobic fitness, and low levels of physical activity prior to BCT were independent injury risk factors (73, 77, 91).

5. METHODS.

a. Subjects and Study Design.

(1) Subjects were men and women involved in BCT at Fort Jackson, South Carolina. They were briefed on the purposes and risks of the study and provided their voluntary agreement

to participate by signing an informed consent statement. The study protocol was approved the institutional review committee of the Army Medical Research and Development Command. All enrolled volunteers were followed until graduation or separation from their original BCT unit.

(2) This prospective study randomized the trainees into two groups. The experimental (E) group was prescribed a running shoe based on the shape of the plantar surface of their feet. The control (C) group received a standard stability running shoe, which was a New Balance 767ST.

b. Initial Testing Procedures.

(1) All initial testing was performed in the reception station at Fort Jackson South Carolina between 5 March 2007 and 4 May 2007. Subjects were new recruits who had just arrived to be processed into BCT. Immediately after the informed consent briefing, volunteers were administered a questionnaire that asked about tobacco use, physical activity, injury history, and (for women) menstrual history. This questionnaire is in Appendix D. Whenever possible, questionnaires were checked while subjects were still available to assure that all questions were answered. This was not possible on all occasions because subjects needed to move to the next location in the reception station to continue their processing schedule.

(2) After completing the questionnaire, subjects removed their shoes and socks and wiped their feet with an anti-bacterial cloth (active ingredient: benzethonium chloride 0.15%). To determine the shape of the plantar surface of the foot (plantar surface evaluation), the barefoot volunteer mounted the acrylic platform of the light box device shown in Figure 1. The device contained a mirror that reflected the underside of the trainee's foot, thus providing a visual representation of the footprint indicating the amount of foot contact with the surface. The subjects were instructed to stand with equal weight on each foot. The area encompassed by the footprint was examined by two testers who were side by side. The testers made independent (though side-by-side) determinations of the plantar surface as either high arched, normal arched or low arched based on a template (8). On the templates, more area in the middle third of the plantar surface indicated a low arch and less area a high arch. If the assessments of the two raters differed, they discussed the assessment and reached a consensus. Both independent determinations and the final consensus were recorded.

Figure 1a.High-Arched Feet

Figure 1b. Normal Arched Feet

Figure 1. Plantar Foot Shape Device

(3) After the plantar foot shape determinations, subjects' foot lengths and foot arch heights were measured with the device shown in Figures 2 and 3. Total foot length and medial metatarsal phalangeal joint (MPJ) length were determined using a measuring tape built into the device. Total foot length was measured as the distance from the most distal aspect of the first toe to the most posterior part of the heel. MPJ length was measured as the distance from the first MPJ to the most posterior part of the heel. Foot arch height was measured with a caliper (Figure 3) as the distance from standing surface to the inferior medial border of the navicular tuberosity. The three measures were obtained on both the right and left foot while the subject was standing with weight equally distributed on both feet.

Figure 2. Device Used to Measure Foot Arch Height

Figure 3. Foot Length and Arch Height Measurements Being Taken on a Subject

c. <u>Running Shoe Prescription and Fitting.</u>

(1) After completing the questionnaire and prior to the foot evaluations, subjects were randomized into the two groups in sequential order. That is, as the subjects lined up for the plantar shape determinations, the first subject was placed in the E group, the second in the C group, the third in the E group, and so on. Subjects in the C group had their feet evaluated but received a New Balance 767ST shoe regardless of plantar surface shape. Trainees in the E group received a shoe based on the determined shape of the plantar surface of their foot. If the subject in the E group was classified as having a low foot arch (based on plantar shape), a motion control shoe was prescribed. If the subject in the E group was classified as having a high foot arch (based on plantar shape), a cushion shoe was prescribed. If the subject in the E group was classified as having a normal foot arch, a stability shoe was prescribed. For subjects in the E group, if the arch determination was different for a subject's right foot and left foot based on the plantar surfaces visualized with the light box, the raters determined the degree of difference and prescribed a shoe appropriate for the "average." For example, a subject with a moderately high left foot arch and a normal right foot arch would be assigned a stability shoe since the left foot arch was not extremely high.

(2) The day after the foot measurements were obtained, subjects were escorted by a drill sergeant to the post exchange (PX) where they purchased their prescribed running shoes. An individual that was part of the study team assured that each person obtained the proper shoe type and was fitted with the proper shoe size. E subjects could select any shoe in their assigned types. There were 19 shoe models available for purchase at the PX. Table 2 lists the specific shoe models along with the shoe types. Shoe types in the PX were determined by the Army and Air Force Exchange System (AAFES) (who informed us that the shoe types were provided by the shoe vendors) and passed along to the respective PXs. To verify the Army shoe types we also examined the Runner's World magazine shoe ratings (9-11) and the Runner's World Running

Shoe Finder (www.runnersworld.com/channel/0,7119,s6-240-0-0-0,00.html). We also examined websites for the various shoe manufactures and, in some cases, called the company representatives to verify the shoe types. For two shoes the Army classification differed from those of the Runner's World and the manufacturer. One was the New Balance 857, which the Army classification listed as a motion control shoe but Runner's World and the manufacturer listed as a stability shoe; the other was the Nike Air Max Moto listed in the Army classification as a stability shoe but by Runner's World and the manufacture as a cushioned shoe. Two shoes, the New Balance 644 and the New Balance 717, could not be found in the Runner's World sources.

Table 2. Classification of Shoes by Type

<table>
<tr><th>AAFES Classification</th><th>Manufacturer Classification</th><th>Runner's World Classification</th><th>Shoe (Brand and Model)</th></tr>
<tr><td rowspan="4">Motion Control</td><td rowspan="3">Motion Control</td><td rowspan="3">Motion Control</td><td>Asics Gel Foundation 7</td></tr>
<tr><td>Brooks Addiction 7</td></tr>
<tr><td>Saucony Grid Stabil 6</td></tr>
<tr><td rowspan="9">Stability</td><td rowspan="8">Stability</td><td>New Balance 857</td></tr>
<tr><td rowspan="9">Stability</td><td>New Balance 767</td></tr>
<tr><td>Asics Gel 1120</td></tr>
<tr><td>Asics Gel 2120</td></tr>
<tr><td>Brooks Adrenaline GTS6</td></tr>
<tr><td>Brooks Adrenaline GTS7</td></tr>
<tr><td>Nike Structure Triax</td></tr>
<tr><td>Saucony Grid Omni 5</td></tr>
<tr><td>Not Rated</td><td>New Balance 717</td></tr>
<tr><td rowspan="7">Cushion</td><td rowspan="6">Cushion</td><td>Nike Air Max Moto</td></tr>
<tr><td rowspan="6">Cushion</td><td>New Balance 755</td></tr>
<tr><td>Asics Gel Cumulus</td></tr>
<tr><td>Brooks Radius 6</td></tr>
<tr><td>Nike Air Pegasus</td></tr>
<tr><td>Saucony Grid Trigon 4</td></tr>
<tr><td>Not Rated</td><td>New Balance 644</td></tr>
</table>

(3) A member of the study team fit the shoe to the subject's foot. Subjects donned both running shoes with a standard issue sock, fully laced the shoe, and then tapped the back of shoe on the floor twice while flexing the forefoot off the ground. They then stood with their body weight on that shoe. A member of the study team pressed with a thumb on the toe box near the distal aspect of the great toe (first phalanx) of the participant. If the thumb fit between the distal end of the subject's toe and the front edge of the shoe the size was considered correct, the procedure was repeated for the other foot. If the thumb did not fit in this manner, the subject obtained another size and the procedure was repeated. Subjects were given the same size of running shoe for both the right and left foot based on the larger of the two feet if they differed in size. This procedure was used because it is the usual way that shoes are fit for BCT Soldiers at Fort Jackson.

d. Basic Combat Training.

(1) After the subjects received their shoes they continued nprocessing at the Reception Station for 3 to 7 days. During this time they completed paperwork (finance, legal, personnel, insurance), obtained uniforms, received vaccinations and medical examinations, obtained dog tags, and performed other activities. After inprocessing was completed, they relocated from the Reception Station to their training companies where they began BCT. BCT took 9 weeks to complete. Training was very similar within each training company, as described in Army Training and Doctrine Command Regulation 350-6 (92). The training day began at about 0530 with a wake-up call by the drill sergeant. The trainees dressed in their physical training (PT) uniform, which included the shoes prescribed for the study. Daily PT sessions were performed for 1–1.5 hours, 4–6 days per week except during the week of the 5-day field training exercise when PT was conducted only once or twice. PT sessions generally alternated between “cardiorespiratory days” and “muscle strength days.” Cardiorespiratory days involved distance running (0.5–3 miles) and/or sprinting with some push-ups and sit-ups. Four running “ability groups” were formed in each company on the basis of the distribution of run scores on the first fitness test (25% in each group). Muscle strength days involved different types of push-ups and sit-ups, in addition to a wide variety of calisthenic exercises, as described in Army training manuals (93, 94).

(2) After PT, trainees returned to the barracks, performed hygiene, changed into their Army Combat Uniform, assembled in formation, and filed into the mess hall for breakfast. After breakfast, the military training events of the day were conducted. Often these involved classroom instruction in the battalion area or nontactical road marches or motorized transport to a training site. Classroom instruction included lessons in the uniform code of military justice, personal hygiene, uniform wear, equal opportunity, responsibilities and heritage, Geneva Convention, military customs and courtesies, Army values, first aid, communication, and other instruction. Physical activities included tasks like barracks maintenance, bayonet training, inspections, drill and ceremony, tactical foot marches, obstacle courses, basic rifle marksman, convoy operations, live fire exercises, grenade throwing, rifle maintenance, weapons training (M60 machine gun, M203 grenade launcher, M18 Claymore mines), nuclear/biological/chemical training, high tower operations (rappelling, use of ropes and ladders), urban warfare, land navigation, team tactical training, combatives (hand-to-hand combat), counterinsurgency operations, checkpoint operations, and other activities. Lunch was generally served at 1200, either in the battalion mess hall or at the training site in the field. Training continued in the afternoon with dinner at about 1700. Generally, training continued until about 2030. Trainees had personal time until about 2130 when lights went out. Generally, subjects did not wear their prescribed shoes during military operational training. On Sundays, there was no formal military training and subjects were at liberty to wear their prescribed shoes much of the day. No effort was made to restrict wear of running shoes to PT and no system was in place to account for the amount of time subjects wore their running shoes during discretionary time.

e. Shoe Changes during BCT. It was important to determine whether subjects wore the prescribed shoe during the entire course of BCT. In the final week of BCT, subjects were assembled in their BCT company formations. Individuals who had changed their running shoes during the course of BCT were asked to fill out the questionnaire in Appendix E. This asked participants to 1) list the new shoe they changed into, 2) the size of that shoe, 3) the proportion of the time they wore the newly purchased shoe, 4) why they changed shoes, and 5) whether the shoes were replaced more than once.

f. Attrition from Training.

(1) Some subjects did not complete the entire 9-week BCT cycle but their data were included for the time they remained in training, as described below. Reasons for attrition included 1) discharge from the Army, 2) reassignment to a new unit (recycle), 3) return to National Guard Unit and release from active duty (REFRAD), and 4) absent without leave (AWOL). Discharges and recycles were obtained from a local data system maintained at Fort Jackson and these were cross-checked with two Armywide databases called the Resident Individual Training Management system and the Automated Instructional Management System-Personal Computer. REFRADs were obtained from the senior Army Reserve/National Guard liaison at Fort Jackson, who maintains a database of these cases. AWOLs were obtained from a local list maintained by the Trainee/Student Work Division at Fort Jackson.

(2) Discharges were subjects who were not suitable for service in the Army and were formally released from their service commitment during the course of BCT. There were numerous reasons for which a subject could have been discharged but most fell into two categories: medical conditions that existed prior to service or poor entry-level performance. The latter category is often called an entry-level separation or Chapter 11 discharge. These are most often the result of inability to adapt to the military environment because of lack of ability (cannot adequately perform critical military tasks) or for psychosocial reasons (motivation, inability to follow orders, personality problems, etc.). The date of discharge and reason were recorded.

(3) Recycles were subjects leaving their original training company and entering another BCT company before the end of the 9-week BCT cycle. New Soldiers are generally recycled because they could not complete mandatory requirements for reasons such as low motivation, serious injury, emergency leave, or inability to meet specific training standards with their peers (e.g., difficulty developing specific skills like basic rifle marksmanship or passing the APFT, etc.). The date the subject was recycled was recorded.

(4) A special category of recycles were individuals who were injured or became ill during BCT to the extent that they could not continue training. These individuals were sent to the Physical Training and Rehabilitation Program (PTRP) to recover from their injury or illness. After recovery, the individual returned to BCT. The PTRP unit maintained a separate list of these individuals and this list was obtained to cross check the recycle information for Soldiers assigned to the PTRP. The date the subject was assigned to the PTRP was obtained.

(5) A number of subjects were training to be part of their state National Guard. If the unit was recalled, this was a REFRAD. Often, this occurred when the participant was injured or ill and could not complete training on time (because of school or job scheduling). It also occurred if the participant was having trouble with particular military tasks. The date the subject was considered REFRAD was recorded.

(6) Subjects who left BCT without specific authorization were considered AWOL and recorded as such. The date of the AWOL was obtained.

g. Physical Characteristics and Training Unit. Height and weight on entry to service were obtained from an automated data system called the Reception Battalion Automated Support System. Heights and weights in this system were obtained shortly before entry into service at the military entrance processing station (MEPS). Training company and training battalion were obtained from records in the reception station.

h. Physical Fitness Test Scores.

(1) Within 1 to 4 days of entering their training companies, subjects took the Army physical fitness test (APFT) (95). APFT scores were obtained from the basic training companies. The APFT consisted of three events: a 2-minute maximal effort push-up event, a 2-minute maximal effort sit-up event, and a 2-mile run for time, administered in that order. Some companies performed a 1-minute test for sit-ups and push-ups and a 1-mile run. Subjects in these latter companies were considered separately.

(2) The three fitness test events were administered by drill sergeants using standardized procedures (95). For the push-up, the subject lowered his or her body in a generally straight line to a point where the upper arms were parallel to the ground, and then returned to the starting point with elbows fully extended. For the sit-up, the subject's knees were bent at a 90° angle, fingers were interlocked behind the head, and a second person held the subject's ankles, keeping the heels firmly on the ground. The subject raised the upper body to a vertical position so that the base of the neck was anterior to the base of the spine and then returned to the starting position. Scores were the number of push-ups or sit-ups successfully completed within a 2-minute (or 1-minute) time period. The performance measure for the run was the time taken to complete the 2-mile (or 1-mile) distance. Time between events was no less than 10 minutes (95).

i. Defense Manpower Data Center Demographic Data. The Army medical surveillance activity provided demographic data for study subjects from the Defense Medical Surveillance System (DMSS). The DMSS regularly and systematically incorporates demographic data from the Defense Manpower Data Center (DMDC) and the Military Entrance Process Command. Information provided from DMSS for study subjects included component (active, reserve, National Guard), educational level, marital status, and race.

j. Injury Outcome Measures.

(1) The DMSS regularly incorporates data on ambulatory (outpatient) encounters that occur within military treatment facilities (MTFs) or that occurs outside of the MTF but is paid for by the DOD. The DMSS provided visit dates and ICD-9 codes for all outpatient medical visits within the BCT timeframe of each subject. The first four diagnoses for each visit were considered, although a single visit usually included only one diagnosis. Five injury indices were calculated: the Installation Injury Index (III), the Modified Installation Injury Index (MIII), the Training Injury Index (TII), the Comprehensive Injury Index (CII), and the Overuse Injury Index

(OII). All indices include specific ICD-9 codes (in any of the four diagnoses areas), as described previously (79).

(2) The III and TII were developed by personnel at the DMSS. The III has been used to compare injury rates among military posts and is reported on a monthly basis at the Army Medical Surveillance Activity (AMSA) website (http://amsa.army.mil). The TII is limited to lower extremity overuse injuries and has been used to compare injury rates among basic training posts. The TII is reported on a monthly basis to the Army Training and Doctrine Command surgeon.

(3) The MIII, CII, and OII were developed by personnel in the Injury Prevention Program at the USACHPPM. The MIII captures a greater number of injuries than the III, including more overuse type injuries. The CII captures all ICD-9 codes related to injuries. The OII captures the subset of musculoskeletal injuries presumably resulting from cumulative microtrauma (overuse-type injuries). The OII includes such diagnoses as stress fractures, stress reactions, tendonitis, bursitis, fasciitis, arthralgia, neuropathy, radiculopathy, shin splints, synovitis, strains, and musculoskeletal pain (not otherwise specified).

k. Data Analysis.

(1) Age was calculated from the date of birth on the questionnaire to the date of the informed consent briefing. Body mass index (BMI) was calculated as weight/height^2 (96). Two foot arch indices were calculated using total foot length, MPJ length, and arch height. The arch index was defined as the arch height divided by the total foot length. The bony arch index was defined as the arch height divided by the MPJ length. The arch index and bony arch index were developed because it might be assumed that an individual with a greater foot length might have a higher foot arch.

(2) The C and E groups were compared on attrition, age, physical characteristics, physical fitness, demographic characteristics, questionnaire variables, and foot measurement and indices. For discrete, nominal, and ordinal variables comparisons were made using the chi-square statistic; for continuous measures, C and E group comparisons were performed using an independent sample t-test. Between-rater reliability of plantar foot shape determination was made with the kappa coefficient.

(3) For all injury indices, person-time injury incidence rates (injured subjects/1000 person-days) were calculated as:

$$(\text{Subjects with} \geq 1 \text{ injury}) \div (\text{total time in BCT} \times 1000)$$

The total time in BCT was 63 days for subjects who completed BCT and less for those who attrited from training. Comparisons between the E and C groups were made using a chi-square for person-time (97).

(4) Cox regression was used to examine the associations between covariates (including group membership) and time to first CII injury. For each analysis, once a subject had an injury

his or her contribution to time in BCT was terminated. Those who attrited from training had their time terminated (censored) at the day they left the unit. All covariates were entered into the regression model as categorical variables. Some interval and ordinal variables were combined to increase statistical power. Most continuous variables were converted to four equal-sized groups based on the distribution of the scores. Age was partitioned into 4 groups (17–19, 20–24, 25–30, and ≥ 30 years). Arch height measures and arch indices were separated into 1) groups comprising the highest 20% and lowest 20% of values (leaving 60% in the central distribution), 2) groups comprising the highest 10% and lowest 10% of values (leaving 80% in the central distribution). Univariate Cox regressions established the association between time to first injury and each covariate in isolation. Multivariate Cox regressions established the effect of multiple covariates (including group membership) on injury risk. Covariates were included in the multivariate model if they achieved $p< 0.10$ in the univariate analyses (98).

(5) Measures of arch height and arch indices were compared to plantar surface determinations in three ways. The distribution (%) of those classified with low, normal and high plantar shapes were compared with the same distributions (%) of measured arch height and arch indices. Those classified with low, normal, and high plantar shapes were compared with arch height and arch indices separated into groups comprising the highest 20% and lowest 20% of values (leaving 60% in the central distribution). Finally, those classified with low, normal, and high plantar shapes were compared with arch heights and arch indices separated into tertiles (three groups of approximately equal size, 33% of values in each of the groups).

6. RESULTS.

a. Participants and Study Exclusions.

(1) There were 2,689 men and 1,263 women who volunteered for the study. When they entered BCT they were distributed throughout 38 BCT companies in all 9 battalions at Fort Jackson. The first group began training on 9 March 2007 and graduated on 11 May 2007. The last group began training on 18 May 2007 and graduated on 13 July 2007.

(2) Subjects were excluded from analysis if 1) they did not, or could not, obtain the prescribed shoe in the PX, or 2) if they did not wear the prescribed shoe for all physical training while in BCT. Thus, the cohort for the study was defined as those volunteers who had obtained the prescribed shoe and wore it throughout BCT. The major reason for not obtaining the prescribed shoe in the PX was that it was not available at the time of purchase. The number of new Soldiers processing through the PX daily made it difficult to keep all the shoe types and sizes in stock. Some subjects voluntarily dropped from the study because they found the prescribed shoe uncomfortable during the fitting process or because they did not like the shoe style.

(3) Table 3 shows the primary reasons subjects reported for changing their shoes while they were in BCT. Most subjects (80% of men and 80% of women) responded in the two categories listed directly on the questionnaire, indicating that the shoes caused pain or discomfort. Shoe wear and “lack of support” in the prescribed shoe were also cited frequently.

Table 3. Reasons for Changing Shoes during BCT

	Men		Women	
	C (n)	E (n)	C (n)	E (n)
Shoes Hurt Feet/Caused Pain	79	74	59	75
Shoes Uncomfortable	17	32	20	22
Wear	14	9	9	5
Lack of Support	5	5	4	7
Lack of Shock Absorption	0	1	1	0
Size Too Big	1	4	5	1
Size Too Small	1	1	1	1
Too Heavy	2	2	3	0
Shoe Width	0	0	1	0
Medical Recommendation	0	0	3	3
Lost	2	0	0	0
Appearance	2	2	0	0
No Response	1	0	0	0

(4) Table 4 shows the number and proportion (%) of volunteers included and excluded. For men in the C and E groups, 20% and 19%, respectively, of the initial sample were excluded; for the C and E women, 23% and 27%, respectively, of the initial sample were excluded. The rest of the analysis considered only the subjects who were retained.

Table 4. Volunteers Excluded and Retained in Study

	Volunteers (n)				Proportion of Volunteers (%)			
	Men		Women		Men		Women	
	C	E	C	E	C	E	C	E
Screened	1343	1346	630	633	100	100	100	100
Prescription Not Obtained in PX	140	127	41	51	10	9	7	8
Changed Shoes during BCT	124	130	106	114	9	10	17	18
Total Retained[a]	1079	1089	483	468	80	81	77	74
Total Excluded[b]	264	257	147	165	20	19	23	26
p-value (Retained/Excluded)	0.34		0.13					

[a]Retained = Screened – (Prescription Not Obtained in PX + Changed Shoes during BCT)
[b]Excluded = Prescription Not Obtained in PX + Changed Shoes during BCT

b. Types of Shoes Worn. All subjects in the C group wore the New Balance 767ST. Table 5 shows the various types of shoes worn by the subjects in the E group. The shoe purchased by the largest proportion of E men (30%) and E women (31%) was the New Balance 767ST. The second and third most purchased shoe for the men were the Nike Structure and Asics 2120, both of which were purchased by 11% of the men (22% total for the two shoes). The second and third most purchased shoes for the women were the Asics 2120 and Brooks GTS7, purchased by 14% and 10% of the women, respectively.

Table 5. Distribution of Shoes by Type

AAFES Classification	Manufacturer Classification	Runner's World Classification	Shoe (Brand and Model)	Men (n)	Women (n)
Motion Control	Motion Control	Motion Control	Asics Gel Foundation 7	21	13
			Brooks Addiction 7	29	9
			Saucony Grid Stabil 6	33	21
	Stability	Stability	New Balance 857	37	1
Stability			New Balance 767ST	328	143
			Asics Gel 1120	3	0
			Asics Gel 2120	118	65
			Brooks Adrenaline GTS6	42	16
			Brooks Adrenaline GTS7	108	46
			Nike Structure Triax	124	3
			Saucony Grid Omni 5	43	21
		Not Rated	New Balance 717G4	2	1
	Cushion	Cushion	Nike Air Max Moto	22	43
Cushion			New Balance 755	24	1
			Asics Gel Cumulus	30	22
			Brooks Radius 6	45	28
			Nike Air Pegasus	70	26
			Saucony Grid Trigon 4	8	9
		Not Rated	New Balance 644	2	0

c. <u>Attrition From Training.</u>

(1) Table 6 shows a group comparison of training attrition by category. There were only small differences between E and C groups among either the men or women. When all training attrition was considered together, the C men had slightly more attrition than the E men (C=9%, E=7%, p=0.08) but there was no significant group differences among the C and E women (C=22%, E=23%, chi-square p=0.26).

Table 6. Subjects Not Completing Training with Original Unit

Type of Attrition	Men					Women				
	C (n)		E (n)		p-value	C (n)		E (n)		p-value
	No	Yes	No	Yes		No	Yes	No	Yes	
Discharges	1030	49	1038	51	0.37	416	67	405	63	0.85
Recycles	1052	27	1072	17	0.12	455	28	443	25	0.76
PTRP	1064	15	1081	8	0.14	467	16	449	19	0.54
AWOL	1072	7	1084	5	0.55	482	1	467	1	0.98
REFRAD	1079	0	1089	0	---	481	2	467	1	0.58

(2) Table 7 shows the reasons for discharge. For the men, 80% of discharges were for medical reasons and 11% were entry level separations. For the women, 77% of discharges were for medical reasons and 5% were entry level separations. Overall, 5% (100/2168) of the male subjects were discharged and 14% (130/951) of the female subjects.

Table 7. Reasons for Discharge

Reason	Men		Women	
	n	Proportion of all Discharges (%)	n	Proportion of all Discharges (%)
Medical	80	80	100	77
Entry Level Separation	11	11	7	5
Erroneous Enlistment	2	2	4	3
Hardship	0	0	2	2
APFT Failure	2	2	0	0
Homosexuality	0	0	1	1
Misconduct	3	3	0	0
Pregnancy	0	0	4	3
Other	0	0	10	8
Unknown	2	2	2	2
Total	100	100	130	100

(3) Table 8 shows the diagnoses for subjects who were assigned to the PTRP. There were 61% of the men and 83% of the women who had stress fractures. Thus, serious stress fractures (those that resulted in a PTRP assignment) occurred in 0.6% of the men (14/2168) and 3.0% (29/951) of women. The clinical criteria for assigning stress fracture cases to the PTRP is explained in Appendix F.

Table 8. PTRP Diagnoses

Diagnoses	Men		Women	
	n	Proportion of all Diagnoses (%)	n	Proportion of all Diagnoses (%)
Stress Fracture	14	61	29	83
Knee Trauma	2	9	0	0
Ankle Trauma	1	4	2	6
Shin Trauma	0	0	2	6
Shoulder Trauma	1	4	0	0
Foot Trauma	1	4	0	0
Fracture (wrist, fibula, scaphoid)	3	13	0	0
Lower Body Overuse	1	4	0	0
Impingement	0	0	1	3
Unknown	0	0	1	3
Total	23	100	35	100

d. <u>Comparisons of C and E Groups.</u> Not all subjects had complete measurements on all variables. This occurred primarily because the data were not available in the DMSS databases, subjects did not provide a response on the questionnaire, or the training unit did not have the information. In a few cases, reception station personnel imposed time constraints so that a few subjects could not complete the entire initial testing battery. Sample sizes are shown in all tables below.

(1) Age, Physical Characteristics, and Fitness Test Scores. Of the 38 companies with recruits in this study, 11 did not retain the initial fitness test scores and these scores could not be recovered. The total number of subjects with fitness test scores was 2165 (69% of the sample). Table 9 compares group differences in age, physical characteristics, and fitness scores for men and women. Among the men, the E group had lower body weight, lower BMI, and higher performance on the fitness tests. However, the mean group differences were small, amounting to 3 lb in weight, 0.5 BMI units, 2 push-ups, and 0.4 minutes on the run. Among the women, there were only very small group differences in age, physical characteristics, and the fitness test scores.

Table 9. Group Comparisons for Age, Physical Characteristics, and Fitness Scores

	Men					Women				
	C		E			C		E		
	n	Mean ±SD	n	Mean ±SD	p-value	n	Mean ±SD	n	Mean ±SD	p-value
Age (yr)	1077	22.8 ± 4.7	1088	23.0 ± 4.8	0.51	483	23.2 ± 5.7	467	23.2 ± 5.4	0.87
Height (in)	1078	69 ± 3	1089	69 ± 3	0.78	483	64 ± 3	468	64 ± 3	0.63
Weight (lb)	1078	175 ± 32	1089	172 ± 32	0.02	483	139 ± 23	468	138 ± 23	0.66
BMI (kg/m^2)	1078	25.7 ± 4.3	1089	25.2 ± 4.2	0.01	483	23.7 ± 3.2	468	23.7 ± 3.3	0.89
1-min Push-ups (reps)	104	26 ± 12	120	27 ± 12	0.69	40	14 ± 11	53	13 ± 11	0.79
1-min Sit-ups (reps)	104	28 ± 11	120	30 ± 9	0.22	40	18 ± 12	53	16 ± 11	0.31
1-mile Run (min)	104	9.0 ± 1.7	120	8.8 ± 1.4	0.53	35	10.6 ± 1.5	53	11.1 ± 1.9	0.22
2-min Push-ups (reps)	667	34 ± 15	663	36 ± 15	0.02	269	14 ± 12	248	15 ± 13	0.54
2-min Sit-ups (reps)	666	40 ± 15	664	41 ± 14	0.23	270	32 ± 17	247	34 ± 18	0.18
2-mile Run (min)	626	18.5 ± 3.1	618	18.1 ± 3.0	0.04	246	22.2 ± 3.7	222	21.9 ± 3.3	0.37

(2) Demographic Characteristics. Table 10 shows the group comparisons for the demographic variables. The distribution of subjects was similar within the two groups for component, race, and martial status for both men and women. The distribution for education was also similar between the two groups of women; however, the C group of men had fewer high school graduates and more individuals who had some college, who were college graduates, or whose educational status was unknown.

(3) Questionnaire. Table 11 compares the groups on the ordinal and nominal questionnaire variables. For most questions, the distribution of C and E subjects across the response categories was very similar. One exception was that more C than E women had gone ≥ 6 months without a menstrual cycle in the last 12 months. A number of subjects who indicated they had trained < 2 times per week on Question 17 answered inappropriately on Question 18 by responding in a category other than "did not train > 2 times per week". Table 12 examines differences in the continuous questionnaire variables. Here again, differences between groups were small.

Table 10. Group Comparisons on Demographic Characteristics

Variable	Level of Variable	Men			Women		
		C (n)	E (n)	p-value[a]	C (n)	E (n)	p-value[a]
Component	Active Army National Guard Army Reserve	533 407 126	554 404 123	0.84	241 175 61	225 167 66	0.76
Educational Level	< High School Graduate High School Graduate Some College College Graduate Unknown	56 809 74 59 97	42 860 61 39 79	0.03	24 346 39 31 37	13 346 38 19 42	0.19
Race	American Indian Asian/Pacific Island Black Hispanic White Unknown	10 29 180 113 727 7	11 37 184 153 691 5	0.15	4 19 145 51 254 4	8 13 124 47 265 1	0.32
Marital Status	Single Married Other Unknown	820 203 37 6	819 225 32 5	0.69	338 107 32 0	322 108 28 0	0.87

[a]Chi-square statistic

Table 11. Group Comparisons on Ordinal/Nominal Questionnaire Variables

Question	Response Category	Men			Women		
		C (n)	E (n)	p-value[a]	C (n)	E (n)	p-value[a]
Q7. Shoe Type	Boots Dress Running Heels ≤ 1 inch[b] Heels ≥ 1 inch[b] Sandals Other Unsure	195 52 623 0 0 26 144 39	211 45 635 0 0 23 135 40	0.84	33 18 234 17 53 56 61 11	33 15 251 13 30 63 51 12	0.26
Q8. Smoked 100 Cigarettes in Lifetime	No Yes	515 564	497 592	0.33	276 207	246 222	0.16
Q13. Self Rating of Physical Activity	Much Less Than Average Somewhat Less Than Average About the Same Somewhat More Active Much More Active	98 281 347 269 83	96 252 371 293 75	0.44	84 165 118 102 14	75 134 137 103 19	0.23
Q14. Frequency of Exercise or Sports Last 2 Months	Never < 1 time/week 1 time/week 2 times/week 3 times/week 4 times/week 5 times/week 6 times/week ≥ 7 times/week	45 116 121 213 234 143 112 39 55	46 125 146 221 206 160 102 42 39	0.36	36 60 75 98 88 56 43 13 14	33 71 76 89 93 46 37 15 8	0.80

Table 11. (continued)

Question	Response Category	Men C (n)	Men E (n)	Men p-value[a]	Women C (n)	Women E (n)	Women p-value[a]
Q15. Frequency of Running or Jogging Last 2 Months	Never	83	77	0.30	54	44	0.13
	< 1 time/week	225	228		101	118	
	1 time/week	173	212		89	73	
	2 times/week	240	23		92	102	
	3 times/week	179	175		73	65	
	4 times/week	92	73		35	33	
	5 times/week	67	81		30	31	
	6 times/week	0	0		0	0	
	≥ 7 times/week	19	19		9	1	
Q16. Length of Time Ran or Jogged Prior to BCT	Did Not Run or Jog	157	158	0.86	86	88	0.76
	≤ 1 month	459	431		197	179	
	2 months	201	215		88	76	
	3 months	97	109		35	46	
	4–6 months	77	78		34	38	
	7–11 months	18	22		13	11	
	≥ 12 months	69	74		30	30	
Q17. Frequency of Exercise with Weights Prior to BCT	Never	374	367	0.42	266	255	0.37
	< 1 time/week	166	184		65	78	
	1 time/week	122	103		51	33	
	2 times/week	161	148		46	39	
	3 times/week	119	131		32	30	
	4 times/week	58	81		15	21	
	5 times/week	44	45		6	8	
	6 times/week	15	11		2	4	
	≥ 7 times/week	20	19		0	0	
Q18. Consistency of Performing Weight Training ≥ 2 Times/Week	Did Not Train ≥ 2 Times/Week	556	525	0.55	341	339	0.25
	≤ 1 month	148	172		58	47	
	2 months	118	112		37	22	
	3 months	72	86		10	17	
	4–6 months	72	76		13	18	
	7–11 months	31	26		4	6	
	≥ 12 months	82	90		20	18	
Q19. Had a Lower Limb Injury	No	924	923	0.53	416	407	0.71
	Yes	154	166		67	61	
Q20. Did Lower Limb Injury Prevent You from Doing Normal Physical Activity	No Injury	924	923	0.68	416	407	0.88
	No	108	125		47	46	
	Yes	40	36		18	13	
	No Response	6	5		2	2	
Q21. Returned to Normal Physical Activity Since Injury	No Injury	924	923	0.48	416	407	0.88
	Yes	130	148		57	49	
	No	12	7		6	7	
	No Response	12	11		4	5	
Q24. Gone ≥ 6 Months without Menstrual Cycle	No	[b]			419	433	< 0.01
	Yes				64	35	
Q25. Used Birth Control in Past 12 Months	No				335	329	0.63
	Yes				146	135	
	No Response				2	4	

[a]Chi-square statistic
[b]Not considered in the analysis for men

Table 12. Group Comparisons on Continuous Questionnaire Variables

Question	Men					Women				
	C		E			C		E		
	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value[a]
Q9. Age Started Smoking (years)	723	16 ± 3	729	16 ± 3	0.85	272	15 ± 3	277	16 ± 3	0.17
Q10. Smoked Cigarettes in Last 30 Days (# days)	543	20 ± 11	524	21 ± 11	0.11	201	21 ± 11	205	22 ± 10	0.09
Q11. Cigarettes Over Last 30 Days (cigarettes/day)	543	9 ± 7	524	10 ± 8	0.09	197	8 ± 6	205	8 ± 6	0.65
Q12. Quit Smoking (months)	155	20 ± 26	184	20 ± 26	0.92	60	16 ± 24	70	20 ± 25	0.31
Q22. Age at Menarche (years)						196	12 ± 2	202	13 ± 2	0.83
Q23 Menstrual Cycles (n/year)	b					196	11 ± 4	204	10 ± 4	0.23
Q26. Time Since Last Pregnancy (months)						164	38 ± 39	161	44 ± 4	0.17

[a]Independent sample t-test
[b]Not considered in the analysis for men

(4) Foot Measurements and Arch Indices.

(a) The kappa coefficient between the two raters on the plantar surface evaluations was 0.98 for both the right foot and the left foot. Table 13 shows the distribution of subjects by foot type, determined from the plantar surface evaluation. The distribution of C and E subjects did not differ by foot type for either the men or the women.

Table 13. Distribution of Subjects by Foot Type

Foot	Plantar Shape	Men					Women				
		C		E			C		E		
		n	%	n	%	p-value	n	%	n	%	p-value
Right Foot	Low	128	11.9	114	10.5	0.29	34	7.0	36	7.7	0.81
	Normal	807	74.8	808	74.2		367	76.0	347	74.1	
	High	144	13.3	167	15.3		82	17.0	85	18.2	
Left Foot	Low	122	11.3	111	10.2	0.57	34	7.0	38	8.1	0.76
	Normal	785	72.8	791	72.6		361	74.7	341	72.9	
	High	172	15.9	187	17.2		88	18.2	89	19.0	
Final	Low	138	12.8	120	11.0	0.37	39	8.1	40	8.5	0.84
	Normal	776	71.9	790	72.5		357	73.9	338	72.2	
	High	165	15.3	179	16.4		87	18.0	90	19.2	

(b) Table 14 compares group differences in the foot measurements and calculated arch indices. All measures are very similar for the groups. The men in the C group had a slightly higher left foot arch height, but the difference was < 1 mm.

Table 14. Group Comparisons on the Foot Measures

	Men					Women				
	C		E			C		E		
Foot Measures	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Left Foot Total Length (cm)	1075	26.8 ± 1.4	1088	26.8 ± 1.4	0.26	482	24.3 ± 1.3	468	24.3 ± 1.2	0.95
Right Foot Total Length (cm)	1075	26.8 ± 1.3	1088	26.8 ± 1.3	0.34	482	24.4 ± 1.4	468	24.3 ± 1.2	0.57
Left Foot MPJ Length (cm)	1075	19.8 ± 1.1	1088	19.7 ± 1.1	0.94	481	18.0 ± 1.2	468	17.9 ± 0.9	0.48
Right Foot MPJ Length (cm)	1075	19.7 ± 1.1	1088	19.7 ± 1.1	0.76	482	17.9 ± 1.1	468	17.9 ± 1.0	0.86
Left Foot Arch Height (mm)	1075	39.9 ± 8.2	1088	39.2 ± 8.2	0.07	482	36.4 ± 7.3	468	36.2 ± 7.0	0.72
Right Foot Arch Height (mm)	1075	41.6 ± 7.7	1088	41.1 ± 7.6	0.14	482	37.7 ± 6.8	468	37.3 ± 6.9	0.34
Left Arch Index	1075	0.1490 ± 0.0320	1088	0.1470 ± 0.0320	0.14	482	0.1500 ± 0.0313	468	0.1492 ± 0.0301	0.69
Right Arch Index	1075	0.1556 ± 0.0304	1088	0.1541 ± 0.0301	0.26	482	0.1555 ± 0.0298	468	0.1538 ± 0.0294	0.39
Left Bony Arch Index	1075	0.2028 ± 0.0450	1088	0.1995 ± 0.0442	0.09	481	0.2033 ± 0.0437	468	0.2025 ± 0.0410	0.77
Right Bony Arch Index	1075	0.2122 ± 0.0428	1088	0.2099 ± 0.0420	0.20	482	0.2119 ± 0.0418	468	0.2092 ± 0.0405	0.33

e. <u>Injury Rates and Risk Factors.</u> The AMSS returned data on 98% of those requested. The numbers of subjects requested and returned are displayed in Table 15.

Table 15. Medical Information Requested and Returned from the Army Medical Surveillance Activity

Men						Women					
C			E			C			E		
Requested	Returned		Requested	Returned		Requested	Returned		Requested	Returned	
n	n	%	n	n	%	n	n	%	n	n	%
1079	1068	99.0	1089	1079	99.1	483	464	95.9	468	451	96.4

(1) **Injury Main Analyses.**

(a) Table 16 shows the person-time injury incidence rates for the various injury indices and compares the rates in the C and E groups. The group differences in rates are very small.

Table 16. Comparison of Injury Incidence Rates for Groups C and E for the Injury Indices

Index	Men				Women			
	Injury Incidence Rate (Injuries/ 1000 person-days) C	Injury Incidence Rate (Injuries/ 1000 person-days) E	Risk Ratio-C/E (95% Confidence Interval)	p-value[a]	Injury Incidence Rate (Injuries/ 1000 person-days) C	Injury Incidence Rate (Injuries/ 1000 person-days) E	Risk Ratio-C/E (95% Confidence Interval)	p-value[a]
Installation Injury Index	5.49	5.48	1.00 (0.86–1.16)	0.99	10.30	10.67	0.97 (0.82–1.14)	0.67
Modified Installation Injury Index	5.89	5.87	1.00 (0.87–1.15)	0.96	10.86	10.93	0.96 (0.82–1.12)	0.61
Overuse Injury Index	4.37	4.55	0.96 (0.82–1.13)	0.63	8.87	9.16	0.94 (0.79–1.11)	0.45
Training-Related Injury Index	3.99	4.38	0.91 (0.77–1.08)	0.13	8.80	8.59	0.99 (0.83–1.18)	0.90
Comprehensive Injury Index	5.95	6.04	0.99 (0.86–1.13)	0.85	10.87	11.37	0.96 (0.82–1.12)	0.58

(b) Table 17 shows the univariate Cox regression examining the association of time to first injury with group, age, physical characteristics, and the fitness test scores. Differences in injury risk between the C and E groups were small. For both men and women, time to first injury was associated with older age, and lower performance on the 2-minute push-up, the 2-minute sit-up, the 2-mile run, and the 1-minute sit-up.

Table 17. Injury Hazard Ratios by Group, Age, Physical Characteristics, and Fitness Test Scores (Univariate Cox Regression)

Variable	Men				Women			
	Level of Variable	n	Hazard Ratio (95%CI)	p-value	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Group	C	1068	1.00	---	C	464	1.00	---
	E	1079	1.02 (0.89–1.17)	0.80	E	451	1.06 (0.90–1.24)	0.48
Age	17.0–19.9 years	692	1.00	---	17.0–19.9 years	328	1.00	---
	20.0–24.9 years	945	1.07 (0.90–1.26)	0.45	20.0–24.9 years	355	1.02 (0.85–1.23)	0.84
	25.0–29.9 years	305	1.36 (1.10–1.68)	< 0.01	25.0–29.9 years	118	1.30 (1.01–1.66)	0.04
	≥ 30 years	205	1.37 (1.06–1.73)	0.02	≥ 30 years	114	1.43 (1.12–1.84)	< 0.01
Height	60–67 inches	605	0.96 (0.77–1.19)	0.70	56–62 inches	267	0.97 (0.76–1.24)	0.80
	68–69 inches	610	1.12 (0.91–1.37)	0.31	63–64 inches	280	1.22 (0.96–1.54)	0.11
	70–71 inches	544	1.07 (0.86–1.33)	0.54	65–66 inches	209	1.05 (0.81–1.36)	0.70
	72–79 inches	388	1.00	---	67–73 inches	159	1.00	---
Weight	96–149 pounds	545	1.00	---	85–121 pounds	229	1.00	---
	150–169 pounds	531	0.98 (0.80–1.18)	0.76	122–137 pounds	237	1.06 (0.85–1.32)	0.59
	170–195 pounds	550	1.08 (0.89–1.31)	0.45	138–153 pounds	221	1.01 (0.80–1.26)	0.96
	196–308 pounds	521	1.00 (0.82–1.22)	0.98	154–237 pounds	228	0.85 (0.67–1.06)	0.15
Body Mass Index	15.20–22.12 kg/m^2	538	1.00	---	14.15–21.29 kg/m^2	230	1.00	---
	22.13–25.06 kg/m^2	542	0.89 (0.73–1.08)	0.23	21.30–23.80 kg/m^2	228	0.89 (0.71–1.11)	0.30
	25.07–28.36 kg/m^2	534	1.06 (0.87–1.28)	0.56	23.81–25.97 kg/m^2	228	0.91 (0.73–1.13)	0.40
	28.37–39.56 kg/m^2	533	0.97 (0.79–1.18)	0.74	25.98–34.02 kg/m^2	229	0.89 (0.71–1.11)	0.28
Push-Ups (2-minute)	0–25 reps/2 min	359	1.38 (1.08–1.78)	0.01	0–4 reps/2 min	132	1.92 (1.41–2.59)	< 0.01
	26–34 reps/2 min	309	1.19 (0.91–1.54)	0.21	5–13 reps/2 min	134	1.36 (0.99–1.86)	0.06
	25–44 reps/2 min	331	1.01 (0.77–1.32)	0.95	14–22 reps/2 min	128	1.20 (0.87–1.65)	0.27
	45–83 reps/2 min	331	1.00	---	23–62 reps/2 min	122	1.00	---

Table 17. (continued)

Variable	Men				Women			
	Level of Variable	n	Level of Variable	n	Level of Variable	n	Level of Variable	n
Sit-Ups (2-minute)	0–33 reps/2 min	333	1.24 (0.96–1.61)	0.10	0–20 reps/2 min	139	1.75 (1.29–2.37)	< 0.01
	31–40 reps/2 min	336	1.19 (0.92–1.32)	0.19	21–33 reps/2 min	130	1.34 (0.98–1.83)	0.07
	41–51 reps/2 min	349	1.01 (0.78–1.32)	0.92	34–46 reps/2 min	127	1.10 (0.79–1.51)	0.58
	52–92 reps/2 min	312	1.00	---	47–89 reps/2 min	120	1.00	---
2-Mile Run	11.7–16.0 minutes	310	1.00	---	12.3–19.4 minutes	118	1.00	---
	16.1–17.4 minutes	315	1.11 (0.84–1.47)	0.46	19.5–22.1 minutes	116	0.99 (0.71–1.38)	0.94
	17.5–20.2 minutes	305	1.24 (0.94–1.64)	0.13	22.2–24.7 minutes	117	1.14 (0.82–1.59)	0.43
	20.3–32.2 minutes	310	1.52 (1.16–1.99)	< 0.01	24.8–31.3 minutes	116	2.18 (1.60–2.98)	< 0.01
Push-Ups (1-minute)	0–21 reps/1 min	76	0.86 (0.48–1.54)	0.62	0–4 reps/1 min	31	0.98 (0.54–1.81)	0.97
	22–30 reps/1 min	76	1.19 (0.69–2.06)	0.54	5–19 reps/1 min	33	0.75 (0.40–1.38)	0.35
	31–70 reps/1 min	72	1.00	---	20–42 reps/1 min	29	1.00	---
Sit-Ups (1-minute)	0–26 reps/1 min	79	2.10 (1.15–3.86)	0.02	0–11 reps/1 min	33	1.77 (0.96–3.25)	0.07
	27–34 reps/1 min	81	1.37 (0.72–2.61)	0.33	12–22 reps/1 min	30	1.40 (0.74–2.68)	0.31
	35–62 reps/1 min	64	1.00	---	23–47 reps/1 min	30	1.00	---
1-Mile Run	6.0–8.1 minutes	75	1.00	---	6.9–10.0 minutes	29	1.00	---
	8.2–9.2 minutes	74	0.93 (0.52–1.64)	0.79	10.1–11.6 minutes	30	0.54 (0.27–1.06)	0.08
	9.3–18.6 minutes	73	1.14 (0.66–1.98)	0.64	11.7–15.7 minutes	29	1.21 (0.67–2.21)	0.53

(c) Table 18 shows the univariate Cox regression examining the association of time to first injury with the demographic characteristics. For both men and women, Active Army subjects tended to have higher injury risk than subjects in the National Guard or Army Reserve. Educational level was not associated with injury risk. Among both men and women, subjects of Asian descent were at lower risk of injury than those of white descent; black women were also at

Table 18. Injury Hazard Ratios by Demographic Characteristics (Univariate Cox Regression)

Variable	Men				Women			
	Level of Variable	n	Hazard Ratio (95%CI)	p-value	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Component	Active Army	1075	1.00	---	Active Army	454	1.00	---
	National Guard	807	0.87 (0.75–1.01)	0.06	National Guard	326	0.85 (0.71–1.01)	0.06
	Reserve	245	0.81 (0.64–1.03)	0.08	Reserve	122	0.78 (0.61–1.00)	0.05
Educational Level	< HS Graduate	98	1.00	---	< HS Graduate	37	1.00	---
	HS Graduate	1653	0.99 (0.71–1.36)	0.94	HS Graduate	664	0.91 (0.63–1.33)	0.63
	Some College	135	1.05 (0.70–1.59)	0.81	Some College	74	0.83 (0.52–1.31)	0.42
	College Graduate	69	0.65 (0.38–1.13)	0.13	College Graduate	49	0.77 (0.46–1.26)	0.29
	Unknown	172	0.71 (0.47–1.08)	0.11	Unknown	78	0.81 (0.51–1.28)	0.36
Race	White	1401	1.00	---	White	494	1.00	---
	Black	364	0.95 (0.78–1.15)	0.58	Black	263	0.75 (0.62–0.90)	< 0.01
	Hispanic	266	1.01 (0.81–1.24)	0.97	Hispanic	96	0.82 (0.64–1.07)	0.15
	Asian	66	0.63 (0.39–1.02)	0.06	Asian	32	0.59 (0.37–0.94)	0.03
	American Indian	21	0.67 (0.30–1.50)	0.33	American Indian	12	0.95 (0.47–1.92)	0.89
	Unknown	9	1.11 (0.42–2.98)	0.83	Unknown	5	0.40 (0.10–1.59)	0.19
Marital Status	Single, Never Married	1628	1.00	---	Single, Never Married	639	1.00	---
	Married	423	1.09 (0.92–1.30)	0.33	Married	203	1.28 (1.07–1.55)	< 0.01
	Other	68	1.47 (1.03–2.10)	0.03	Other	60	1.97 (1.39–2.53)	< 0.01
	Unknown	8	1.36 (0.51–3.64)	0.54	Unknown			

lower risk of injury compared with white women. For marital status, both men and women who were classified as "other" (primarily those divorced or widowed) were at higher risk of injury than those who had never been married; among women, those who were married were also at higher risk of injury.

(d) Table 19 shows the association between time to first injury and the questionnaire variables. The reference group for Question 12 ("If you quit smoking cigarettes, how many months has it been since you quit") was "never/seldom" smokers, who had never smoked or had smoked on fewer than 20 of the last 30 days before BCT. Smokers were those who had smoked on at least 20 of the 30 days before BCT.

(e) Men and women had many similar findings in the univariate Cox regression on the questionnaire variables shown in Table 19. For both men and women, higher injury risk was associated with wearing boots (relative to running shoes) before BCT, smoking 100 cigarettes during the subject's lifetime, starting smoking at a younger age, more days smoking or more cigarettes smoked in the 30 days prior to BCT, being a current smoker or having only recently quit smoking (compared with those who never/seldom smoked), performing less physical activity prior to BCT (including less exercise or sports and/or less running or jogging).

Table 19. Injury Hazard Ratios for Questionnaire Variables (Univariate Cox Regression)

		Men			Women		
Variable[a]	**Response Category**	**n**	**Hazard Ratio (95%CI)**	**p-value**	**n**	**Hazard Ratio (95%CI)**	**p-value**
Q7. Shoe Type Worn Before BCT	Running	1246	1.00	---	462	1.00	---
	Boots	404	1.20 (1.00–1.43)	0.05	65	1.42 (1.06–1.92)	0.02
	Dress	97	1.08 (0.77–1.52)	0.65	33	0.81 (0.52–1.28)	0.37
	Heels ≤ 1 inch[b]	0	---	---	28	0.52 (0.30–0.91)	0.02
	Heels >1 inch[b]	0	---	---	83	1.14 (0.85–1.51)	0.39
	Sandals	48	0.66 (0.37–1.18)	0.16	115	1.22 (0.96–1.56)	0.11
	Other	274	1.23 (1.00–1.51)	0.05	106	0.95 (0.73–1.24)	0.71
	Unsure	78	1.28 (0.90–1.83)	0.19	23	1.01 (0.61–1.66)	0.98
Q8. Smoked 100 Cigarettes in Life	No	1007	1.00	---	508	1.00	---
	Yes	1140	1.36 (1.18–1.57)	< 0.01	407	1.59 (1.36–1.86)	< 0.01
Q9. Age Started Smoking	Never Smoked	705	1.00	---	389	1.00	---
	6–9 years old	57	2.11 (1.44–3.10)	< 0.01	12	2.00 (1.06–3.76)	0.03
	10–14 years old	447	1.71 (1.41–2.07)	< 0.01	206	1.59 (1.30–1.95)	< 0.01
	15–19 years old	814	1.31 (1.10–1.56)	< 0.01	272	1.30 (1.07–1.57)	< 0.01
	≥ 20 years old	124	1.04 (0.74–1.47)	0.83	36	1.28 (0.85–1.92)	0.24
Q10. Days Smoked Cigarettes| in Last 30 Days	None	1092	1.00	---	531	1.00	---
	1–9 days	217	0.97 (0.76–1.25)	0.83	79	1.21 (0.91–1.61)	0.18
	10–19 days	167	1.14 (0.87–1.50)	0.34	51	1.57 (1.12–2.20)	< 0.01
	≥ 20 days	671	1.42 (1.22–1.65)	< 0.01	254	1.58 (1.32–1.88)	< 0.01
Q11. Cigarettes per Day in Last 30 Days	None	1095	1.00	---	533	1.00	---
	1–9 cigarettes/day	559	1.20 (1.01–1.42)	0.04	224	1.44 (1.19–1.73)	< 0.01
	10–19 cigarettes/day	333	1.24 (1.01–1.42)	0.04	114	1.49 (1.17–1.89)	< 0.01
	≥ 20 cigarettes/day	160	1.67 (1.31–2.13)	< 0.01	44	1.90 (1.34–268)	< 0.01
Q12. Smokers and Quitters	Never/Seldom	1157	1.00	---	546	1.00	---
	Smoker	671	1.49 (1.28–1.74)	< 0.01	254	1.57 (1.32–1.88)	< 0.01
	Quit 1–12 months ago	190	1.35 (1.06–1.72)	0.02	67	1.52 (1.14–2.04)	< 0.01
	Quit > 12 months ago	129	1.28 (0.95–1.71)	0.10	48	1.14 (0.79–1.65)	0.48

Table 19. (continued)

Variable[a]	Response Category	Men n	Men Hazard Ratio (95%CI)	Men p-value	Women n	Women Hazard Ratio (95%CI)	Women p-value
Q13. Self Rating of Physical Activity	Much Less Active	191	1.72 (1.23–2.41)	< 0.01	152	1.47 (0.92–2.34)	0.11
	Somewhat Less Active	528	1.18 (0.87–1.59)	0.28	285	1.47 (0.94–2.03)	0.09
	About the Same	709	1.11 (0.84–1.49)	0.47	245	1.16 (0.73–1.82)	0.54
	Somewhat More Active	559	0.96 (0.71–1.30)	0.78	200	1.06 (0.67–1.69)	0.80
	Much More Active	157	1.00	---	33	1.00	---
Q14. Frequency of Exercise or Sports Before BCT	≤ 1 time/week	591	1.26 (1.02–1.55)	0.03	336	1.41 (1.09–1.82)	< 0.01
	2–4 times/week	1167	1.04 (0.86–1.27)	0.66	455	1.11 (0.86–1.43)	0.42
	≥ 5 times/week	386	1.00	---	124	1.00	---
Q15. Frequency of Running/Jogging Before BCT	≤ 1 time/week	988	1.28 (0.98–1.68)	0.07	459	1.62 (1.16–2.27)	< 0.01
	2–4 times/week	973	1.03 (0.78–1.34)	0.86	385	1.32 (0.94–1.86)	0.11
	≥ 5 times/week	184	1.00	---	70	1.00	---
Q16. Length of Time Running/Jogging Before BCT	Did Not Run or Jog	310	1.58 (1.17–2.14)	< 0.01	167	1.34 (0.96–1.85)	0.08
	≤ 1 month	885	1.11 (0.84–1.47)	0.45	310	1.18 (0.87–1.59)	0.29
	2–3 months	612	1.13 (0.85–1.51)	0.39	239	0.92 (0.67–1.26)	0.61
	4–6 months	154	1.24 (0.87–1.78)	0.24	69	1.10 (0.74–1.63)	0.66
	≥ 7 months	183	1.00	---	80	1.00	---
Q17. Frequency of Exercise with Weights, Last 2 Months	≤ 1 time/week	1303	1.09 (0.83–1.43)	0.55	717	1.19 (0.67–2.11)	0.55
	2–4 times/week	692	0.92 (0.69–1.23)	0.56	178	0.93 (0.51–1.69)	0.80
	≥ 5 times/week	152	1.00	---	20	1.00	---
Q18. Consistency of Performing Weight Training ≥ 2 Times/Week	Did Not Weight Train	1070	1.37 (1.07–1.76)	0.01	651	1.29 (0.88–1.88)	0.20
	≤ 1 month	313	1.24 (0.92–1.66)	0.16	101	1.12 (0.72–1.75)	0.62
	2–3 months	387	1.12 (0.84–1.49)	0.45	86	1.09 (0.69–1.72)	0.73
	4–6 months	148	1.42 (1.01–2.01)	0.05	30	0.58 (0.30–1.14)	0.11
	≥ 7 months	227	1.00	---	46	1.00	---
Q19. Prior Lower Limb Injury	No	1830	1.00	---	793	1.00	---
	Yes	316	1.01 (0.60–1.22)	0.95	122	1.41 (1.13–1.75)	< 0.01
Q20. Did Lower Limb Injury Prevent Activity	No	75	1.00	---	29	1.00	---
	Yes	230	0.91 (0.60–1.38)	0.64	90	0.91 (0.57–1.45)	0.68
Q21. After Recovery, Returned to 100%	No	19	2.09 (1.12–3.90)	0.02	12	0.62 (0.30–1.29)	0.20
	Yes	274	1.00	---	102	1.00	---
Q22. Age at Menarche	8–10 years				83	1.05 (0.80–1.38)	0.72
	11–14 years				715	1.00	---
	15–26 years				117	1.11 (0.88–1.41)	0.37
Q23. Menstrual Periods in Last Year	0				30	1.83 (1.22–2.76)	< 0.01
	1–3				28	1.05 (0.66–1.68)	0.84
	4–6				36	1.25 (0.85–1.86)	0.26
	7–9				39	1.23 (0.84–1.80)	0.29
	10–12				750	1.00	---
	≥ 13				28	1.05 (0.65–1.68)	0.85
Q24. 6 Months without Cycles, in Last Year	No		b		769	1.00	---
	Yes				91	1.15 (0.881.50)	0.30
Q25. Taken Birth Control Pills, Last 12 Months	No				641	1.00	---
	Yes				268	1.02 (0.86–1.22)	0.76
Q26. Months Since Last Pregnancy	Never				599	1.00	---
	1–6 months				24	0.83 (0.48–1.44)	0.52
	7–12 months				55	1.58 (1.15–2.18)	< 0.01
	≥ 12 months				237	1.61 (1.35–1.93)	< 0.01

[a]"Q" followed by a number indicated the question number (see Appendix D)
[b]Not considered in the analysis for men

Interestingly, these associations showed dose-response relationships with injury risk progressively decreasing as 1) the age when the subject started smoking increased, 2) days of smoking in the 30 days before BCT decreased, or 3) the number of cigarettes smoked per day in the 30 days before BCT decreased. Also, individuals who had quit smoking had progressively lower risk as their time since quitting increased.

(f) Men and women differed on some findings in the univariate Cox regressions on the questionnaire variables in Table 19. Men reporting that they did not train with weights in the 2 months before BCT were at higher injury likelihood; women showed a similar tendency, but it was much weaker. Women reporting a prior lower limb injury had higher likelihood of injury during BCT, but men reporting a prior lower limb injury did not. The few men who reported that they did not return to 100% of their normal physical activity after the lower limb injury had higher likelihood of injury during BCT, while this was not true for the women.

(g) Among the questions asked only of the women, those having no menstrual periods in the last year and those who had been pregnant > 7 months previously had higher likelihood of injury.

(h) Table 20 shows the association between injury risk and the plantar surface determinations. There were no differences in injury risk between the various plantar surface determinations for either foot, in either men or women.

Table 20. Injury Hazard Ratios for Plantar Surface Evaluations (Univariate Cox Regression)

Foot	Plantar Surface Determination	Men			Women		
		n	Risk Ratio (95%CI)	p-value	n	Risk Ratio (95%CI)	p-value
Left	Low	232	1.08 (0.87–1.35)	0.49	70	0.90 (0.66–1.23)	0.51
	Normal	1561	1.00	---	678	1.00	---
	High	354	1.15 (0.96–1.38)	0.14	167	1.07 (0.88–1.31)	0.50
Right	Low	241	1.01 (0.83–1.29)	0.76	68	0.89 (0.65–1.22)	0.48
	Normal	1598	1.00	---	689	1.00	---
	High	308	1.11 (0.92–1.35)	0.29	158	1.01 (0.82–1.25)	0.91

(i) Table 21 shows the association between the time to the first injury and arch height, arch index, and bony arch index. The first six rows of data show subjects grouped in the lowest 20% of values, middle 60% of values, and highest 20% of values. The last six rows show the subjects grouped in the lowest 10% of values, middle 80% of values, and lowest 10% of values. For the men, higher injury risk tends to be associated with a lower arch on the left foot, with a similar but much reduced tendency on the right foot. As might be expected since the arch indices are calculated from arch height, a lower arch index or bony arch index on the left side also tends to be associated with higher injury risk, and a similar but much reduced tendency is evident on the right side. For women, there is little difference in injury risk regardless of the arch height or arch index grouping.

Table 21. Injury Hazard Ratios for Arch Height and Arch Indices (Univariate Cox Regression)

Grouping	Variable	Men				Women			
		Level of Variable	n	Hazard Ratio (95%CI)	p-value	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Highest and Lowest 20%	Arch Height Left	9.3–32.7 mm	433	1.17 (0.98–1.39)	0.08	15.3–30.0 mm	186	1.11 (0.91–1.36)	0.31
		32.8–46.1 mm	1282	1.00	---	30.1–42.2 mm	548	1.00	---
		46.2–69.0 mm	432	1.01 (0.85–1.22)	0.87	42.2–59.4 mm	181	1.04 (0.84–1.27)	0.74
	Arch Height Right	13.8–34.9 mm	433	1.10 (0.92–1.31)	0.30	16.6–31.8 mm	183	0.99 (0.81–1.22)	0.94
		35.0–47.7 mm	1282	1.00	---	31.9–42.9 mm	551	1.00	---
		47.8–69.0 mm	432	1.02 (0.86–1.22)	0.81	43.0–63.5 mm	181	1.05 (0.86–1.29)	0.64
	Arch Index Left	0.0347–0.1222	431	1.16 (0.97–1.38)	0.11	0.0590–0.1233	186	0.95 (0.77–1.16)	0.61
		0.1223–0.1746	1282	1.00	---	0.1234–0.1758	547	1.00	---
		0.1747–0.2659	434	1.01 (0.83–1.19)	0.91	0.1759–0.2517	182	0.98 (0.80–1.21)	0.88
	Arch Index Right	0.0515–0.1301	431	1.14 (0.96–1.36)	0.14	0.0687–0.1288	181	0.96 (0.78–1.19)	0.20
		0.1302–0.1792	1282	1.00	---	0.1289–0.1791	551	1.00	---
		0.1793–0.2640	434	1.02 (0.85–1.22)	0.85	0.1792–0.2669	183	1.14 (0.93–1.39)	0.72
	Bony Arch Index Left	0.0456–0.1650	429	1.18 (0.99–1.41)	0.06	0.0778–0.1662	185	1.02 (0.83–1.25)	0.88
		0.1651–0.2377	1286	1.00	---	0.1663–0.2387	546	1.00	---
		0.2378–0.3901	432	1.03 (0.86–1.23)	0.76	0.2388–0.3529	184	1.06 (0.86–1.30)	0.58
	Bony Arch Index Right	0.0678–0.1756	430	1.13 (0.95–1.35)	0.17	0.0905–0.1753	182	1.02 (0.83–1.26)	0.83
		0.1757–0.2450	1282	1.00	---	0.1754–0.2461	551	1.00	---
		0.2451–0.3939	435	1.01 (0.85–1.21)	0.89	0.2462–0.3671	182	1.16 (0.95–1.41)	0.16
Highest and Lowest 10%	Arch Height Left	9.3–29.2 mm	217	1.23 (0.99–1.54)	0.06	15.3–27.4 mm	92	0.91 (0.69–1.19)	0.48
		29.3–49.0 mm	1710	1.00	---	27.5–45.6 mm	730	1.00	---
		49.1–69.0 mm	215	1.10 (0.88–1.38)	0.41	45.7–59.4 mm	93	0.98 (0.75–1.28)	0.88
	Arch Height Right	13.8–31.6 mm	216	1.18 (0.95–1.47)	0.14	16.6–29.0 mm	94	1.01 (0.78–1.32)	0.92
		31.7–51.4 mm	1710	1.00	---	29.1–46.6 mm	726	1.00	---
		51.5–69.0 mm	216	1.03 (0.82–1.30)	0.76	46.7–63.5 mm	95	1.09 (0.84–1.40)	0.53
	Arch Index Left	0.0347–0.1074	216	1.24 (0.99–1.54)	0.06	0.0590–0.1117	92	0.93 (0.71–1.22)	0.59
		0.1075–0.1888	1711	1.00	---	0.1118–0.1896	731	1.00	---
		0.1889–0.2659	215	1.19 (0.95–1.48)	0.13	0.1897–0.2517	92	0.89 (0.68–1.16)	0.39
	Arch Index Right	0.0515–0.1163	216	1.12 (0.89–1.40)	0.32	0.0687–0.1174	92	0.98 (0.75–1.27)	0.86
		0.1164–0.1945	1711	1.00	---	0.1175–0.1941	732	1.00	---
		0.1946–0.2640	215	1.06 (0.85–1.34)	0.59	0.1942–0.2669	91	1.11 (0.85–1.43)	0.45
	Bony Arch Index Left	0.0456–0.1459	214	1.12 (0.89–1.40)	0.35	0.0778–0.1515	92	0.97 (0.74–1.27)	0.83
		0.1460–0.2582	1713	1.00	---	0.1516–0.2594	731	1.00	---
		0.2583–0.3901	215	1.19 (0.96–1.49)	0.12	0.2595–0.3529	92	1.07 (0.82–1.39)	0.64
	Bony Arch Index Right	0.0678–0.1587	216	1.12 (0.89–1.40)	0.34	0.0905–0.1588	92	1.02 (0.78–1.33)	0.89
		0.1588–0.2666	1711	1.00	---	0.1589–0.2498	731	1.00	---
		0.2667–0.3939	215	1.06 (0.85–1.34)	0.61	0.2499–0.3671	92	1.13 (0.87–1.46)	0.37

[a]In each cell, the first number is the lowest

(j) Because so much of the APFT data were missing, two multivariate Cox regression models were run for both men and women. The first model included the APFT variables that met the inclusion criteria (i.e., p< 0.10 in the univariate Cox regression), the second model did not include the APFT variables. Table 22 shows the multivariate Cox regression model including the fitness variables and with the group membership (C or E) forced into the model. Those with complete data included 1239 men (58% of the entire male sample) and 461 women (50% of the entire female sample). For both men and women, group differences in time to first injury were small. Slower 2-mile run times, less physical activity prior to BCT, and starting smoking at a younger age were associated with time to first injury. For women, slower 2-mile run time, smoking in the last 30 days, quitting smoking, prior lower limb injury, and marital status were associated with higher injury risk.

Table 22. Injury Hazard Ratios for Study Variables Including Fitness (Multivariate Cox Regression)

Variable	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Men				
Group	C E	623 616	1.00 1.11 (0.91–1.34)	--- 0.31
2-Mile Run	11.7–16.0 minutes 16.1–17.4 minutes 17.5–20.2 minutes 20.3–32.2 minutes	310 315 305 309	1.00 1.08 (0.81–1.43) 1.22 (0.92–1.62) 1.47 (1.11–1.95)	--- 0.62 0.18 < 0.01
Physical Activity Before BCT	Much Less Active Somewhat Less Active About the Same Somewhat more Active Much More Active	109 292 414 334 90	1.65 (1.05–2.62) 1.02 (0.67–1.55) 0.99 (0.66–1.49) 0.93 (0.62–1.41) 1.00	0.03 0.94 0.96 0.73 ---
How Old First Time Smoked Whole Cigarette	Never 6–9 years 10–14 years 15–19 years ≥ 20 years	414 30 252 479 64	1.00 2.63 (1.57–4.43) 1.99 (1.53–2.58) 1.27 (1.00–1.62) 1.02 (0.61–1.69)	--- < 0.01 < 0.01 0.05 0.96
Women				
Group	C E	242 219	1.00 1.14 (0.91–1.44)	--- 0.26
2-Mile Run	12.3–19.4 minutes 19.5–22.1 minutes 22.2–24.7 minutes 24.8–31.3 minutes	117 114 115 115	1.00 0.89 (0.64–1.26) 1.10 (0.79–1.53) 2.13 (1.55–2.91)	--- 0.52 0.57 < 0.01
Smoking in Last 30 Days	None 1–9 days 10–19 days ≥ 20 days	266 47 23 125	1.00 1.36 (0.93–2.00) 1.70 (1.05–2.75) 1.52 (1.16–1.99)	--- 0.12 0.03 <0.01
Quit Smoking	Seldom/Never Smoker 1–12 months > 12 months	275 125 40 21	1.00 [a] 1.83 (1.25–2.67) 1.05 (059–1.87)	--- [a] < 0.01 0.87
Marital Status	Single Married Other	328 107 26	1.00 1.29 (0.99–1.69) 1.68 (1.05–2.71)	--- 0.06 0.03
Lower Limb Injury	No Yes	393 68	1.00 1.57 (1.16–2.13)	--- < 0.01

[a]Linearly codependent with ≥ 20 days in "Smoking in Last 30 days" variable (same subjects)

(k) Table 23 shows the results of the multivariate Cox regression that excluded the APFT variables so that more subjects could be included in the analysis. Those with complete data included 2124 men (98% of the male sample) and 901 women (95% of the female sample). Among the men, group membership was not associated with injury risk, but injury risk was higher among men who were less physically active before BCT, were in the active Army (versus the National Guard), smoked their first cigarette at a younger age, or were older. Among the women, group membership was not associated with injury risk, but injury risk was higher among those performing less running/jogging before BCT, those in the active Army, those smoking more cigarettes per day prior to BCT, those who had recently quit smoking, those who were married or of "other" marital status (compared with those who were single), and those with a prior lower limb injury.

Table 23. Injury Hazard Ratios for Study Variables with Fitness Variable Excluded (Multivariate Cox Regression)

Variable	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Men				
Group	C	1054	1.00	---
	E	1070	1.01 (0.88–1.16)	0.87
Physical Activity Before BCT	Much Less Active	189	1.63 (1.16–2.28)	< 0.01
	Somewhat Less Active	523	1.18 (0.87–1.60)	0.28
	About the Same	705	1.12 (0.83–1.50)	0.47
	Somewhat more Active	552	0.98 (0.72–1.33)	0.88
	Much More Active	155	1.00	---
Component	Active Army	1074	1.00	---
	National Guard	806	0.85 (0.73–0.98)	0.03
	Army Reserve	244	0.85 (0.67–1.08)	0.85
How Old First Time Smoked Whole Cigarette	Never	698	1.00	---
	6–9 years	56	2.15 (1.46–3.16)	< 0.01
	10–14 years	441	1.69 (1.39–2.05)	< 0.01
	15–19 years	807	1.30 (1.09–1.55)	< 0.01
	≥ 20 years	122	0.90 (0.64–1.28)	0.56
Age	17.0–19.9 years	679	1.00	---
	20.0–24.9 years	940	1.07 (0.91–1.26)	0.43
	25.0–29.9 years	301	1.48 (1.19–1.83)	< 0.01
	≥ 30 years	204	1.56 (1.21–2.01)	< 0.01
Women				
Group	C	457	1.00	---
	E	444	1.04 (0.88–1.22)	0.65
Frequency of Running/Jogging Before BCT	≤ 1 time/week	452	1.68 (1.19–2.36)	< 0.01
	2–4 times/week	379	1.40 (0.99–1.97)	< 0.01
	≥ 5 times/week	70	1.00	---
Component	Active Army	453	1.00	---
	National Guard	326	0.82 (0.69–0.98)	0.03
	Army Reserve	122	0.78 (0.61–1.01)	0.05
Cigarettes per Day in Last 30 Days	None	526	1.00	---
	1–9 cig/day	220	1.39 (1.10–1.76)	< 0.01
	10–19 cig/day	111	1.39 (0.98–1.97)	0.07
	≥ 20 cig/day	44	1.85 (1.20–2.85)	< 0.01
Quit Smoking	Seldom/Never	537	1.00	---
	Smoker	251	1.11 (0.83–1.47)	0.49
	1–12 months	66	1.54 (1.15–2.07)	< 0.01
	> 12 months	47	1.00 (0.69–1.47)	0.98
Marital Status	Single	638	1.00	---
	Married	203	1.22 (1.01–1.48)	0.04
	Other	60	2.01 (1.48–2.72)	< 0.01
Lower Limb Injury	No	780	1.00	---
	Yes	121	1.48 (1.19–1.85)	< 0.01

(2) Injury Subgroup Analyses.

(a) Within the C and E groups, injury risk was examined for the three plantar foot shapes. Table 24 shows the univariate Cox regression. Among the C subjects (all whom wore the stability shoe), there were very minor differences in injury risk by plantar foot shape. When compared with normal arch E subjects who wore stability shoes, high arch E men who wore the cushioned shoe were at higher risk of injury; this elevated injury risk was not seen among the E women who wore cushioned shoes.

Table 24. Injury Hazard Ratios by Group and Plantar Foot Shape (Univariate Cox Regression)

Subjects	Shoe Type	Plantar Foot Shape	Men n	Men Hazard Ratio (95%CI)	Men p-value	Women n	Women Hazard Ratio (95%CI)	Women p-value
C Subjects Only	Stability	Normal	768	1.00	---	345	1.00	---
	Stability	Low	137	1.02 (0.76–1.24)	0.88	38	0.74 (0.47–1.18)	0.21
	Stability	High	162	0.93 (0.70–1.24)	0.63	81	1.05 (0.78–1.41)	0.75
E Subjects Only	Stability	Normal	784	1.00	---	327	1.00	---
	Motion Control	Low	119	1.17 (0.86–1.58)	0.33	43	1.18 (0.81–1.71)	0.39
	Cushion	High	176	1.34 (1.04–1.72)	0.02	81	1.02 (0.76–1.36)	0.90

(b) Injury risk for the C and E groups was compared within plantar foot types. Table 25 shows the results of the univariate Cox regression. There was little difference between the C and E groups of individuals with normal plantar shapes who wore the stability shoe. High-arched men wearing the cushioned shoe tended to have higher injury risk than high-arched men wearing the stability shoe. Although sample sizes were small, low-arched women wearing the motion control shoe tended to have higher risk than low-arched women wearing the stability shoe.

Table 25. Injury Hazard Ratios Comparing C and E Groups within Each Plantar Foot Shape (Univariate Cox Regression)

Plantar Foot Shape	Group	Shoe	Men n	Men Hazard Ratio (95% CI)	Men p-value	Women n	Women Hazard Ratio (95% CI)	Women p-value
Normal	C	Stability	768	---	---	345	---	----
	E	Stability	784	0.94 (0.80–1.12)	0.52	327	1.02 (0.85–1.23)	0.81
Low	C	Stability	137	---	---	38	---	---
	E	Motion Control	119	1.08 (0.73–1.60)	0.69	39	1.48 (0.83–2.63)	0.18
High	C	Stability	162	---	---	81	---	---
	E	Cushion	176	1.36 (0.97–1.91)	0.08	85	1.04 (0.72–1.49)	0.85

(c) A separate analysis was also performed comparing injury risk in only high- and low-arched individuals in the E and C groups. Table 26 shows that injury risk was slightly higher in the E group for both men and women.

Table 26. Injury Hazard Ratios by Group with Only High/Low-Arched Individuals by Plantar Surface Evaluation (Univariate Cox Regressions)

Group	Men n	Men Hazard Ratio (95%CI)	Men p-value	Women n	Women Hazard Ratio (95%CI)	Women p-value
C	299	1.00	---	119	1.00	---
E	295	1.23 (0.96–1.59)	0.11	124	1.16 (0.85–1.58)	0.35

(d) Because two of the shoes (New Balance 857 and Nike Air Max Moto) worn by subjects were classified differently in the AAFES versus the Runner's World and manufacturer's ratings, E subjects wearing these two shoe models were analyzed separately. Two analyses were performed and these are shown in Table 27. The first analysis compared the C group to the subjects in the E group who wore the New Balance 857 and Nike Air Max Moto. Injury risk was similar in these two groups. The second analysis removed the subjects wearing the New Balance 857 or Nike Air Max Moto from the E group and compared the remaining E group subjects to the C group. Differences in injury risk were small between C and E subjects without the shoes in question.

Table 27. Injury Hazard Ratios by Group with and without Particular Shoes (Univariate Cox Regression)

Group	Men			Women		
	n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
C E (Nike Air Max Moto and New Balance 857 Only)	1068 58	1.00 1.08 (0.71–1.64)	--- 0.72	464 43	1.00 1.04 (0.71–1.52)	--- 0.85
C E (Without Nike Air Max Moto or New Balance 857)	1068 1021	1.00 1.02 (0.88–1.34)	--- 0.84	464 408	1.00 1.06 (0.90–1.26)	--- 0.48

f. <u>Comparison of Plantar Surface Determination with Arch Height and Arch Indices.</u>

(1) Table 28 shows the plantar surface determinations with average±SD arch heights and arch indices. A higher plantar surface determination had a correspondingly higher arch height, arch index, or bony arch index. Differences between all the plantar surface determinations, for all three measures were significant by the Tukey test ($p < 0.01$). There were larger differences between the low and normal plantar surfaces than between the normal and high plantar surfaces.

Table 28. Plantar Surface Determination and Corresponding Arch Height and Arch Indices

Gender, Foot	Plantar Surface Determination	n	Arch Height (mm) (mean ±SD)	p-value	Arch Index (mean ±SD)	p-value	Bony Arch Index (mean ±SD)	p-value
Men, Left	Low	233	31.3 ± 7.9	< 0.01	0.114 ± 0.029	< 0.01	0.154 ± 0.040	< 0.01
	Normal	1573	40.0 ± 7.6		0.150 ± 0.029		0.204 ± 0.041	
	High	357	42.9 ± 7.7		0.162 ± 0.030		0.221 ± 0.042	
Men, Right	Low	241	34.0 ± 7.1	< 0.01	0.125 ± 0.027	< 0.01	0.168 ± 0.037	< 0.01
	Normal	1612	41.8 ± 7.1		0.157 ± 0.028		0.214 ± 0.039	
	High	310	44.6 ± 7.4		0.169 ± 0.029		0.231 ± 0.041	
Women, Left	Low	71	29.4 ± 5.7	< 0.01	0.119 ± 0.022	< 0.01	0.160 ± 0.031	< 0.01
	Normal	702	36.4 ± 6.7		0.149 ± 0.028		0.203 ± 0.039	
	High	177	38.6 ± 7.5		0.162 ± 0.033		0.220 ± 0.046	
Women, Right	Low	69	30.6 ± 6.0	< 0.01	0.122 ± 0.024	< 0.01	0.166 ± 0.032	< 0.01
	Normal	714	37.4 ± 6.5		0.154 ± 0.028		0.210 ± 0.039	
	High	167	40.8 ± 6.4		0.171 ± 0.028		0.233 ± 0.039	

(2) Figure 4 graphically displays the plantar surface determinations plotted against the measured arch height. Even though mean values differ (Table 28), there is considerable overlap in measured arch heights among the 3 plantar surface determinations.

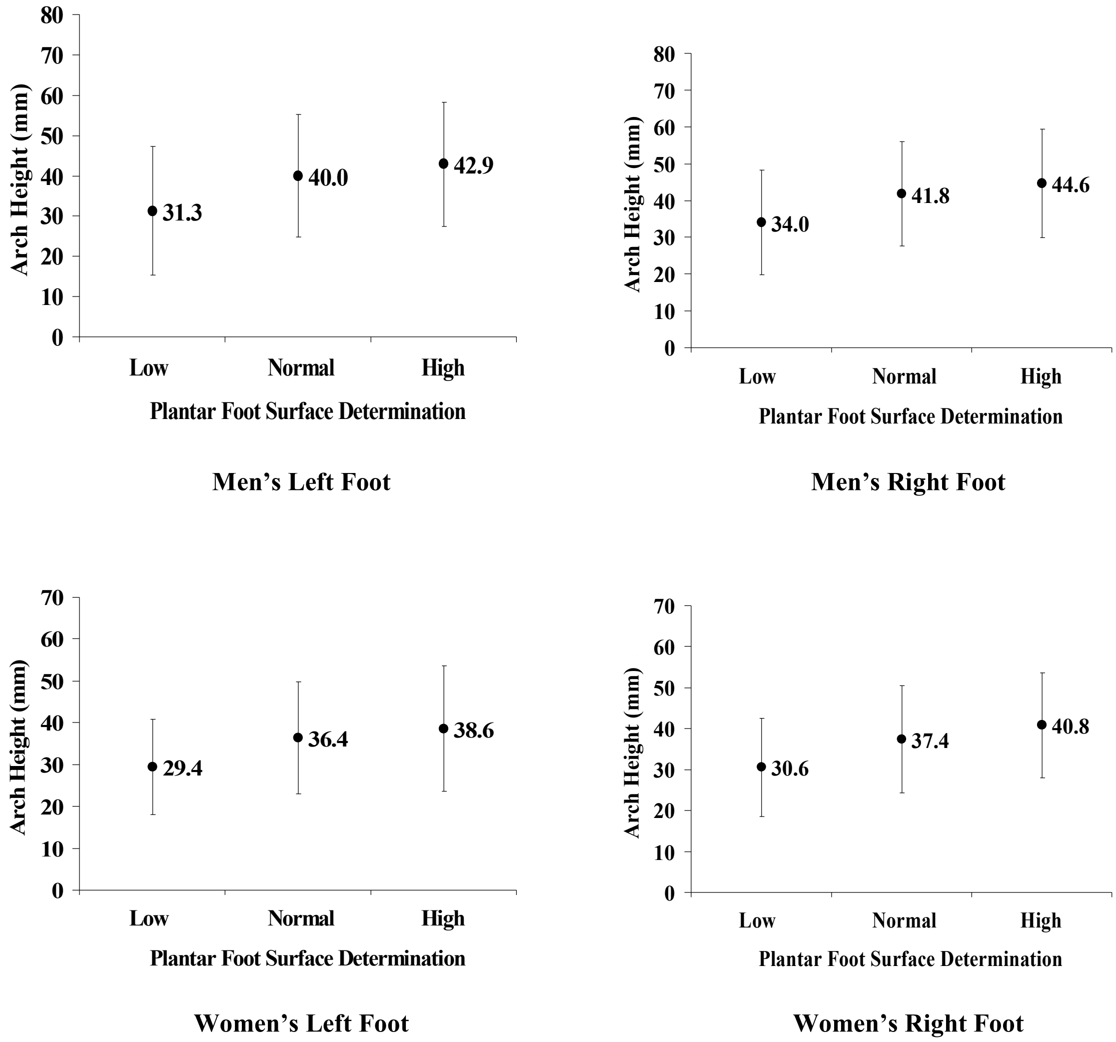

Figure 4. Comparison of Measured Arch Height with Plantar Foot Surface Determinations. Mean values are displayed and vertical bars are 2SD.

(3) Table 29 shows subjects cross-classified by plantar surface determination and measured arch height and arch indices. Arch height and the arch indices are separated into the percentile distributions found in the plantar surface determinations. Among the men, the low plantar surface matched with the lowest distributions of arch heights, arch indices, or bony arch indices in 38% to 44% of the cases; the normal plantar surface matched with the middle distributions of arch heights, arch indices, or bony arch indices in 76% to 78% of the cases; the high plantar surface matched with the highest distributions of arch heights, arch indices, or bony arch indices in 24% to 31% of the cases. Among the women, the low plantar surface matched with the lowest distributions of arch heights, arch indices, or bony arch indices in 29% to 43% of the cases; the normal plantar surface matched with the middle distribution of arch heights, arch indices, or bony arch indices in 77% to 78% of the cases; the high plantar surface matched with

the highest distributions of arch heights, arch indices, or bony arch indices in 27% to 34% of the cases. For both men and women, the highest and lowest distributions of arch heights or arch indices were more likely to be classified as a normal plantar surface (55% to 71% of cases) than a high or low plantar surface. The lowest distributions were much less likely to be classified as a high plantar surface (2% to 7% of cases) and the distributions were much less likely to be classified as low (1% to 4% of cases). Overall, arch height was correctly classified by plantar surface 66% of the time for both men and women.

Table 29. Classification of Subjects by Plantar Surface Determination and Measured Arch Height and Arch Indices[a]

Variable	Percentiles of Arch Heights and Arch Indices (Based on Plantar Surface Distributions)	Low Plantar Surface		Normal Plantar Surface		High Plantar Surface	
		n	%	n	%	n	%
Men							
Arch Height Left	0.1–10.7%	**100**	**42.9**	128	54.9	5	2.1
	10.8–83.4%	119	7.6	**1199**	**76.1**	258	16.4
	83.5–100.0%	13	3.6	245	68.2	**101**	**28.1**
Arch Height Right	0.1–11.1%	**93**	**38.4**	144	59.5	5	2.1
	11.2–74.5%	133	8.2	**1244**	**77.0**	238	14.7
	74.6–100.0%	15	4.8	221	71.1	**75**	**24.1**
Arch Index Left	0.1–10.7%	**101**	**43.3**	130	55.8	2	0.9
	10.8–83.4%	119	7.6	**1202**	**76.3**	254	16.1
	83.5–100.0%	11	3.1	241	67.1	**107**	**29.8**
Arch Index Right	0.1–11.1%	**96**	**39.7**	143	59.1	3	1.2
	11.2–74.5%	133	8.2	**1253**	**77.6**	228	14.1
	74.6–100.0%	11	3.5	215	69.1	**85**	**27.3**
Bony Arch Index Left	0.1–10.7%	**103**	**44.2**	128	54.9	2	0.9
	10.8–83.4%	117	7.4	**1208**	**76.7**	250	15.9
	83.5–100.0%	11	3.1	238	66.3	**110**	**30.6**
Bony Arch Index Right	0.1–11.1%	**98**	**40.5**	142	58.7	2	0.8
	11.2–74.5%	132	8.2	**1257**	**77.8**	226	14.0
	74.6–100.0%	11	3.5	212	68.2	**88**	**28.3**
Women							
Arch Height Left	0.1–7.7%	**22**	**30.6**	47	65.3	3	4.2
	7.8–81.1%	39	5.6	**545**	**77.6**	118	16.8
	81.2–100.0%	12	6.8	105	59.3	**60**	**33.9**
Arch Height Right	0.1–7.4%	**21**	**30.0**	47	67.1	2	2.9
	7.5–82.2%	47	6.6	**551**	**77.2**	116	16.2
	82.3–100.0%	4	2.4	113	67.7	**50**	**29.9**
Arch Index Left	0.1–7.7%	**20**	**27.8**	51	70.8	1	1.4
	7.8–81.1%	41	5.8	**543**	**77.4**	118	16.8
	81.2–100.0%	10	5.7	107	60.8	**59**	**33.5**
Arch Index Right	0.1–7.4%	**24**	**43.3**	44	62.9	2	2.9
	7.5–82.2%	42	5.9	**557**	**78.1**	114	16.0
	82.3–100.0%	3	1.8	112	67.1	**512**	**31.1**

Table 29. (continued

Variable	Percentiles of Arch Heights and Arch Indices (Based on Plantar Surface Distributions)	Low Plantar Surface		Normal Plantar Surface		High Plantar Surface	
		n	%	n	%	n	%
Bony Arch Index Left	0.1–7.7%	**21**	**29.2**	4	66.7	3	4.2
	7.8–81.1%	40	5.7	**544**	**77.6**	117	16.7
	81.2–100.0%	10	5.7	107	60.8	**59**	**33.5**
Bony Arch Index Right	0.1–7.4%	**29**	**41.4**	40	57.1	1	1.4
	7.5–82.2%	74	10.4	**554**	**77.6**	86	12.0
	82.3–100.0%	5	3.0	117	70.1	**45**	**26.9**

[a]Highlighted cells are where the largest agreement might be expected. Arch height and arch height indices are separated into percentiles represented by plantar surface distributions

(4) Table 30 shows subjects cross-classified by plantar surface determination and measured arch height and arch indices. Arch height and arch indices are separated into the highest and lowest 20% and the middle 60%. Among the men, the low plantar surface matched with the lowest 20% of arch heights, arch indices, or bony arch indices in 31% to 35% of the cases; the normal plantar surface matched with the middle 60% arch heights, arch indices or bony arch indices in 75% to 78% of the cases; the high plantar surface matched with the highest

Table 30. Classification of Subjects by Plantar Surface Determination and Measured Arch Height and Arch Indices[a]

Variable	Measured	Men						Women					
		Low Plantar Surface		Normal Plantar Surface		High Plantar Surface		Low Plantar Surface		Normal Plantar Surface		High Plantar Surface	
		n	%	n	%	n	%	n	%	n	%	n	%
Arch Height Left	Lowest 20%	**148**	**34**	259	59	29	7	**47**	**25**	122	64	21	11
	Middle 60%	98	8	**995**	**77**	203	16	30	5	**445**	**78**	96	17
	Highest 20%	12	3	312	72	**111**	**26**	2	1	128	67	**60**	**32**
Arch Height Right	Lowest 20%	**134**	**31**	268	62	32	7	**48**	**25**	126	66	17	9
	Middle 60%	115	9	**985**	**75**	199	15	29	5	**437**	**77**	103	18
	Highest 20%	9	2	313	72	**112**	**26**	2	1	132	69	**57**	**30**
Arch Index Left	Lowest 20%	**149**	**35**	257	59	26	6	**51**	**27**	123	65	16	8
	Middle 60%	202	16	**995**	**77**	101	8	26	5	**447**	**78**	97	17
	Highest 20%	8	2	314	72	**115**	**26**	2	1	125	65	**64**	**34**
Arch Index Right	Lowest 20%	**140**	**32**	264	61	28	7	**51**	**27**	124	65	15	8
	Middle 60%	110	9	**983**	**76**	205	16	26	5	**442**	**78**	102	18
	Highest 20%	8	2	319	73	**110**	**25**	2	1	129	68	**60**	**31**
Bony Arch Index Left	Lowest 20%	**150**	**35**	255	59	27	6	**51**	**27**	123	65	15	8
	Middle 60%	99	8	**1000**	**78**	199	15	26	5	**442**	**78**	102	18
	Highest 20%	9	2	311	71	**117**	**27**	2	1	130	68	**60**	**31**
Bony Arch Index Right	Lowest 20%	**140**	**32**	264	61	28	7	**51**	**27**	123	65	15	8
	Middle 60%	110	9	**987**	**76**	201	16	26	5	**441**	**78**	102	18
	Highest 20%	8	2	315	72	**114**	**26**	2	1	129	68	**60**	**31**

[a]Highlighted cells are where the largest agreement might be expected. Arch height and arch height indices separated into highest and lowest 20% and middle 60%.

20% arch heights, arch indices, or bony arch indices in 25% to 27% of the cases. Among the women, the low plantar surface matched with the lowest 20% of arch heights, arch indices, or bony arch indices in 25% to 27% of the cases; the normal plantar surface matched with the middle 60% of arch heights, arch indices, or bony arch indices in 77% to 78% of the cases; the high plantar surface matched with the highest 20% of arch heights, arch indices, or bony arch indices in 30% to 34% of the cases. For both men and women, the highest and lowest 20% of arch heights or arch indices were more likely to be classified as a normal plantar surface (59% to 73% of cases) than a high or low surface. The lowest 20% were much less likely to be classified as high (6% to 11% of cases) and the highest 20% were much less likely to be classified as low (1% to 3% of cases). Overall, arch height was correctly classified by plantar surface 57% and 58% of the time for men and women, respectively.

(5) Table 31 shows subjects cross-classified by both plantar surface and measured arch height and arch indices. Arch height and arch indices are separated into tertiles. Among the men, the low plantar surface matched with the lowest tertiles of arch heights, arch index, or bony arch index in 25% to 26% of the cases; the normal plantar surface matched with the middle tertiles of arch height, arch indices, or bony arch indices in 77% to 78% of the cases; the high plantar surface matched with the highest tertiles of arch height, arch index, or boney arch index in 23% to 25% of the cases. Among the women, the low plantar surface matched with the lowest

Table 31. Classification of Subjects by Plantar Surface Determination and Measured Arch Height and Arch Indices

Variable	Range of Measured Variable	Men						Women					
		Low Plantar Surface		Normal Plantar Surface		High Plantar Surface		Low Plantar Surface		Normal Plantar Surface		High Plantar Surface	
		n	%	n	%	n	%	n	%	n	%	n	%
Arch Height Left	Lowest 33%	**181**	**25**	475	65	70	10	**60**	**19**	227	72	30	10
	Middle 33%	52	7	**554**	**78**	109	15	14	4	**245**	**77**	59	19
	Highest 33%	25	3	537	74	**164**	**23**	5	2	223	71	**88**	**28**
Arch Height Right	Lowest 33%	**185**	**25**	485	66	60	8	**59**	**18**	236	73	27	8
	Middle 33%	51	7	**555**	**78**	105	15	14	5	**240**	**77**	58	19
	Highest 33%	22	3	526	73	**178**	**25**	6	2	219	69	**92**	**29**
Arch Index Left	Lowest 33%	**185**	**26**	471	65	65	9	**61**	**19**	226	71	30	10
	Middle 33%	53	7	**561**	**78**	106	15	14	4	**249**	**79**	54	17
	Highest 33%	20	3	534	74	**172**	**24**	4	1	219	69	**94**	**30**
Arch Index Right	Lowest 33%	**190**	**26**	470	65	61	9	**64**	**20**	226	71	27	9
	Middle 33%	52	7	**560**	**78**	109	15	10	3	**253**	**80**	54	17
	Highest 33%	16	2	536	74	**173**	**24**	5	2	216	68	**96**	**30**
Bony Arch Index Left	Lowest 33%	**185**	**26**	475	66	61	9	**65**	**21**	224	71	27	9
	Middle 33%	54	8	**553**	**77**	113	16	11	4	**251**	**79**	55	17
	Highest 33%	18	3	539	74	**169**	**23**	3	1	220	69	**95**	**30**
Bony Arch Index Right	Lowest 33%	**188**	**26**	475	66	58	8	**63**	**20**	226	72	27	9
	Middle 33%	54	8	**553**	**77**	113	16	12	4	**256**	**81**	49	16
	Highest 33%	16	2	538	74	**172**	**24**	4	1	213	67	**101**	**32**

[a]Highlighted cells are where the largest agreement might be expected. Arch height and arch height indices are separated into tertiles.

tertiles of arch heights, arch index, or bony arch index in 19% to 21% of the cases; the normal plantar surface matched with the middle tertiles of arch heights, arch indices, or bony arch indices in 77% to 81% of the cases; the high plantar surface matched with the highest tertiles of arch heights, arch indices, or bony arch indices in 28% to 32% of the cases. For both men and women, the highest and lowest 33% of arch heights or arch indices were more likely to be classified as a normal plantar surface (65% to 74% of cases) than a high or low surface. The lowest tertiles were much less likely to be classified as high (8% to 10% of cases) and the highest tertiles were much less likely to be classified as low (1% to 3% of cases). Overall, arch height was correctly classified by plantar surface 42% and 41% of the time for men and women, respectively.

7. DISCUSSION.

a. The present study demonstrates that prescribing running shoes on the basis of the shape of plantar foot surface does not influence injury risk in US Army BCT. Even after controlling for known intrinsic injury risk factors such as physical fitness (71, 72, 74, 77, 81, 87, 99-102), age (106, 121, 229), physical activity prior to BCT (66, 72-74, 77, 100, 102, 103), cigarette smoking (73, 77, 87, 88, 100), and menstrual status (104, 105), there were no differences in injury rates between the C and E groups. Known extrinsic injury risk factors in BCT include training company (73, 87) and time of year in which training is conducted (90, 106). With regard to training company, subjects were distributed across 38 companies in 9 training battalions. Table 32 compares injury incidence between the C and E groups in each company. Because of the small number of subjects in some companies, the Fisher Exact Test was used for comparisons. Of the 76 comparisons, only 3 (4%) reached the $p \leq 0.10$ level. Thus, across groups, company-level factors had little effect. Injury rates in BCT and in AIT have also been shown to vary by season (90, 106), and these seasonal variations are associated with differences in temperature (90, 106-108). The first group of subjects began BCT in March and the last group graduated in July. There were 11 training periods, as shown in Table 33. Of the 22 comparisons, only 2 (9%) reached the $p \leq 0.10$ level; one comparison showed injury incidence higher in the C group the other in the E group. Thus, it is unlikely that seasonal variations played a major role in this study.

Table 32. Injuries by Group and Training Company

Company	Men					Women				
	n		Injured (%)		p-value	n		Injured (%)		p-value
	C	E	C	E		C	E	C	E	
1	0	0	---	---	---	0	2	---	100	---
2	0	0	---	---	---	4	3	75	100	> 0.99
3	42	31	21	23	0.99	13	22	39	77	0.03
4	21	23	33	26	0.74	35	19	63	63	> 0.99
5	21	26	29	46	0.25	5	2	60	50	> 0.99
6	35	30	31	47	0.31	22	8	68	63	> 0.99
7	32	25	19	23	0.53	14	14	57	43	0.71
8	43	37	47	43	0.82	12	19	58	63	> 0.99
9	51	47	35	36	> 0.99	21	23	48	65	0.36
10	32	27	25	33	0.57	13	14	54	50	> 0.99

Table 32. (continued)

Company	Men					Women				
	n		Injured (%)		p-value	n		Injured (%)		p-value
	C	E	C	E		C	E	C	E	
11	27	30	59	60	> 0.99	18	17	89	88	> 0.99
12	23	27	22	26	> 0.99	12	18	67	72	> 0.99
13	61	67	24	34	0.01	13	24	69	78	0.69
14	43	36	47	39	0.65	12	19	50	79	0.13
15	25	25	60	44	0.40	16	17	50	71	0.30
16	26	21	50	43	0.77	12	10	92	80	0.57
17	17	19	29	53	0.19	8	6	100	33	0.02
18	23	34	39	44	0.79	12	13	83	69	0.65
19	22	19	23	37	0.49	11	6	73	67	> 0.99
20	22	26	36	58	0.17	15	10	67	80	0.66
21	28	29	39	41	> 0.99	12	11	50	82	0.19
22	13	18	31	33	> 0.99	8	20	88	80	0.62
23	21	26	52	42	0.56	13	4	69	25	0.25
24	22	22	46	32	0.54	8	14	100	79	0.27
25	48	39	38	31	0.65	17	14	59	68	0.28
26	56	50	46	44	0.85	17	15	82	67	0.42
27	36	29	44	55	0.46	17	16	94	75	0.18
28	27	27	48	59	0.59	8	8	50	63	> 0.99
29	35	34	31	41	0.46	8	7	63	57	> 0.99
30	19	14	32	29	> 0.99	7	7	27	71	0.29
31	31	31	32	45	0.43	12	9	58	78	0.64
32	28	42	25	36	0.43	12	22	75	68	0.65
33	6	18	17	22	> 0.99	8	10	63	40	0.64
34	34	42	27	26	> 0.99	19	16	63	56	0.74
35	67	69	43	44	> 0.99	34	28	74	64	0.58
36	13	24	23	4	0.12	6	3	50	67	> 0.99
37	2	3	50	0	0.40	1	1	0	0	---
38	0	1	---	0	---	0	0	---	---	---
Unknown	27	21				22	21			

Table 33. Distribution of Injuries by Group and Training Period

Training Date	Men					Women				
	N		Injured (%)		p-value	N		Injured (%)		p-value
	C	E	C	E		C	E	C	E	
9 March – 11 May	0	0	---	---	---	4	5	100	89	0.44
16 March – 18 May	84	80	26	31	0.49	37	42	54	69	0.25
23 March – 25 May	110	92	34	40	0.38	48	41	63	56	0.67
30 March – 1 June	133	131	35	39	0.61	64	72	64	69	0.59
6 April – 8 June	129	128	43	27	0.01	41	59	56	76	0.05
13April – 15June	110	119	36	47	0.11	58	45	68	81	0.17
20 April – 22 June	84	95	43	38	0.54	45	37	71	76	0.80

Table 33. (continued)

Training Date	Men					Women				
	n		Injured (%)		p-value	N		Injured (%)		p-value
	C	E	C	E		C	E	C	E	
27April – 29 June	104	89	42	38	0.66	34	29	71	72	0.99
4 May – 6 July	148	135	38	47	0.12	52	47	65	70	0.67
11 May – 13 July	148	195	33	31	0.73	77	69	66	61	0.61
18 May – 20 July	2	3	50	0	0.40	1	1	0	0	---
Unknown	27	21				22	21			

b. As noted earlier, motion control shoes are designed for low-arched individuals to presumably control for excessive pronation; cushioned shoes are designed for high-arched individuals to presumably provide cushioning to reduce ground impact forces by allowing for more foot pronation (21-24). If injury risk could be reduced by prescribing running shoes on the basis of plantar foot shape, that reduced risk might be best seen by comparing C and E subjects at the extremes; that is, those with high and low arches. This is because E subjects wore shoes specifically designed for their foot type (motion control and cushion) while C subjects wore a stability shoe designed for another foot type. Contrary to expectation, comparing E and C subjects in this manner indicated that injury risk was slightly elevated in the E group. This indicated that even with the extreme foot types, prescribing running shoes on the basis of plantar surface determination did not reduce injury risk and may have elevated it slightly in this study.

c. All C group subjects wore a stability shoe regardless of plantar surface type, and injury risk was almost identical among the three plantar surface types (high, middle, low) within this group. Stability shoes presumably offer some cushioning with some motion control characteristics (8). When E group subjects were examined separately, high-arched men who wore the cushioned shoe were at higher injury risk, although this increased injury risk was not seen among high-arched women who wore the cushioned shoe. It is possible that under some circumstances high levels of cushioning may attenuate plantar feedback (43) and result in gait alterations (40, 41) that increase the likelihood of injury.

d. Two shoes (New Balance 857 and the Nike Air Max Moto) were classified differently in the AAFES system compared with the Runner's World or manufacture typing. Nonetheless, when the subjects in the E group who wore these two shoes were compared with all the C subjects, injury risks differed little. Further, when subjects wearing these two shoes were eliminated from the E group and the remaining E group subjects compared with the C group, injury risk still differed little.

e. As noted in the background section of this paper, it is not clear whether gait mechanics differ in high- and low-arched individuals who are not symptomatic or who have not had a prior injury (12-18). There is some evidence that symptomatic individuals or individuals with prior injury may be more likely to have altered gait mechanics (12-14). We did not obtain the symptomology of the subjects in this study, but they can be assumed to be healthy and relatively symptom-free since they had been initially cleared for BCT in the MEPS and further evaluated at the physical examination station in the reception station when they arrived for BCT. When asked on the questionnaire whether they had had a previous lower limb injury, only 15%

(316/2146) of the men and 15% of the women (122/915) responded positively. However, a global question like this may not capture all subjects with prior lower limb injury: studies comparing injury rates over various recall periods have shown that as the recall period increases, self-reported injury rates decrease (109-111). Nonetheless, the screening procedures and the low positive response rate to the injury question suggest that the number of symptomatic subjects in this study is probably low.

f. The current study is not in accord with a previous investigation by our group (25) that showed a postwide decrease in serious injuries at Fort Drum, New York, after initiation of a running shoe prescription program. However, there were many methodological differences between the current study and the previous one. The current study involved only a prescription based on the shape of the plantar foot surface; the previous study involved a prescription based on an evaluation of foot arch height and foot flexibility. The current study involved a population of recruits in a situation where we could assure that the prescribed shoe was obtained and there was follow-up to assure that the prescribed shoe was worn during the entire course of the study. The previous study involved Soldiers who were given the shoe prescription, but there was little follow-up to determine whether they had actually made the recommended purchase. Additionally, investigators had no knowledge of when or how often the shoes were used for training. In fact, in a survey involving a convenience sample of 122 Fort Drum Soldiers (out of an average 9,752 estimated to be on post), only 11% said that they had followed the shoe prescription advice. The current study involved a prospective shoe prescription with follow-up for any injury occurring in a subsequent 9-week period of a standardized training program. The previous study involved a retrospective examination of medical visits to a physical therapy clinic before and after the shoe program was initiated. A number of temporal factors were potential confounders in the previous study, and these were discussed at length in the paper (25). The major potential confounder was the change in the surveillance system used to track injuries, which occurred at the exact point when injuries began to decrease. The current study was prospective and involved two groups training side by side in a well-regulated BCT setting. Thus, the current study involved manipulation of only one variable (running shoe prescription based on plantar foot shape), considerably better knowledge about the shoe actually worn during training, and a more controlled training environment.

a. <u>Plantar Surface Determination and Measured Arch Height and Arch Indices.</u>

(1) The prescription of running shoes was based on the plantar foot surface evaluation because this method was being used in BCT at the time of the study and because it is similar to a common self-evaluation technique (the wet test) recommended by running magazines and other publications (8-11). However, this study found that although average arch height values differed among the three plantar surface determinations, there was considerable overlap in the individual arch height values within the three plantar surface determinations.

(2) Over 75% of individuals in the middle distribution of measured arch heights were classified as having normal plantar foot surfaces. But there was also a strong bias for those having high and low measured arch height to be classified as having a normal plantar foot surface (55% to 71% of cases). In fact, only 24% to 44% of the high and low plantar surface determination cases were correctly classified in the highest or lowest measured arch heights.

The two extremes showed much less overlap. High plantar surface cases were seldom in the lowest measured arch height or arch indices (≤ 7% of cases) and low plantar surface cases were rarely in the highest of the arch heights or arch indices (≤ 4%). The bias toward the normal plantar classification brings into question the practice of using plantar surface ratings as a surrogate for arch height when this is used for individual assessment.

b. <u>Foot Arch Height, Foot Indices, and Injuries.</u>

(1) Injury risk showed little association with arch height or the arch indices. Although injury risk tended to be somewhat higher among individuals with low arches, this was not an independent injury risk factor when considered in the multivariate models.

(2) Two studies (4, 5) have suggested that foot arch height is associated with injury incidence during military training activities. Cowan et al. (4) took pictures of the right foot of 246 male infantry recruits while they stood with their weight on that foot. A calibration device was included in the picture frame and pictures were digitized to determine arch heights and foot lengths. Recruits were classified into those with the highest 20% and lowest 20% of 1) arch heights (floor to navicular bone), 2) arch index, and 3) bony arch index. After this evaluation, the recruits participated in the 12-week Marine basic training program. Recruits with the highest arch heights, highest arch index, or highest bony arch index were at the highest risk of a lower extremity injury; lower extremity injury risk was lowest among those with the lowest arch height, arch index, or bony arch index. Another study (5) collected bony arch index data on 423 Navy Sea, Air, and Land (SEAL) candidates prior to their 25-week training program. Methods for obtaining the measurements (photographs, direct measures, etc.) were not described and the units of measure were not noted. Compared with those with “normal” bony arch values (20.0–22.8), those defined as pes cavus (> 22.8) or pes planus (< 20.0) tended to have a higher incidence of stress fractures, Achilles tendinitis, and iliotibial band syndrome, although the differences were not statistically significant.

(3) Arch height and arch index values in the current study can be compared directly with those of Cowan et al. (4), since the measures were obtained using the same anatomical landmarks. As shown in Table 34, men in the current study generally demonstrated a wider range of values for all three measures when compared with those in the Cowan et al. (4) study. Average values for all three measures of the right foot of the men in the current study were 10% to 13% lower than the right foot of the men in the Cowan et al. (4) study.

(4) Cowan et al. (4) examined the association of lower extremity injuries with arch height and arch height indices. To make the data from the current study somewhat comparable to that of Cowan et al. (4), the incidence of lower extremity overuse injuries (TRII) was calculated using the Cowan et al. cutpoints for arch height and the arch height indices. Comparisons are shown in Table 35. Injury incidence is the proportion (%) of subjects with one or more injuries. Although there is a slight trend for those at the extreme categories to have a higher injury incidence in the current study (risk ratio~1.1), these differences are not statistically significant and contrast with those of Cowan et al. (4). Differences in subject populations (infantry recruits versus general Army recruits), methods of measurement (pictures versus direct measurements), length of training time (9 weeks versus 12 weeks), training environments (infantry basic training

versus general Army basic training), and injury definitions (lower extremity versus lower extremity overuse) might account for some of these differences.

Table 34. Comparison of Range of Arch Height Measurements in Cowan et al. (58) and Present Study

Measure	Level of Measure	Cowen et al. (58)	Current Study			
		Men	Men		Women	
		Right Foot	Right Foot	Left Foot	Right Foot	Left Foot
Navicular Height (mm)	Mean ±SD	46.0 ± 6.1	41.4 ± 7.7	39.5 ± 8.2	37.5 ± 6.9	36.3 ± 7.1
	20% Lowest	27.2–40.8	13.8–34.8	9.3–32.8	16.6–31.7	15.3–30.0
	60% Middle	40.9–50.8	34.9–47.6	32.9–46.1	31.8–42.9	30.1–42.1
	20% Highest	50.9–60.5	47.7–69.0	46.2–69.0	43.0–63.5	42.2–59.4
Arch Index	Mean ±SD	0.17 ± 0.02	0.15 ± 0.03	0.15 ± 0.03	0.15 ± 0.03	0.15 ± 0.03
	20% Lowest	0.10–0.15	0.05–0.13	0.03–0.12	0.03–0.13	0.06–0.12
	60% Middle	0.15–0.19	0.13–0.18	0.12–0.17	0.13–0.18	0.12–0.18
	20% Highest	0.19–0.24	0.18–0.26	0.17–0.27	0.18–0.27	0.18–0.25
Bony Arch Index	Mean ±SD	0.24 ± 0.04	0.21 ± 0.04	0.20 ± 0.05	0.21 ± 0.04	0.20 ± 0.04
	20% Lowest	0.14–0.21	0.06–0.18	0.04–0.17	0.09–0.18	0.08–0.17
	60% Middle	0.21–0.27	0.18–0.25	0.17–0.24	0.18–0.25	0.17–0.24
	20% Highest	0.27–0.34	0.25–0.40	0.24–0.39	0.25–0.37	0.24–0.35

Table 35. Comparison of Incidence of Lower Extremity Overuse Injuries in Current Study and Lower Extremity Injuries in Cowan Study Using the Cutpoints of Cowan et al. (4)

Measure	Level of Measure	Cowen et al. (58)			Current Study		
		n	Injured (%)	p-value	n	Injured (%)	p-value
Arch Height	Low 20%	49	29	< 0.05	1002	26.9	0.54
	Middle 60%	148	37		895	24.8	
	High 20%	49	52		245	26.9	
Arch Index	Low 20%	49	27	< 0.05	932	27.3	0.42
	Middle 60%	148	37		941	24.7	
	High 20%	49	53		269	26.8	
Bony Arch Index	Low 20%	49	22	< 0.05	1059	26.7	0.60
	Middle 60%	148	39		894	24.9	
	High 20%	49	53		189	27.5	

[a]Cutpoints for categories were those used in the Cowan et al. (4) study

(5) Table 36 compares incidence of stress fractures serious enough to be sent to the PTRP in the present study with the stress fracture data in the Kaufman et al. study (5), with stress fracture incidence stratified by the bony arch index. The cutpoints for the bony arch index categories were those used in the respective studies (current study and Kaufmann study), since the units of measurement in the Kaufmann et al. (5) study were not clear. Note that, in the current study, only 14 men and 29 women had stress fractures. Neither study shows significant differences among those with normal versus high or lower bony arch indices. Although Kaufman et al. (5) showed a tendency toward higher stress fracture incidence with both high and low arches, the current study showed that subjects with a low bony arch index tend to have fewer

stress fractures, while subjects with a higher bony arch index tend to have more. Differences in subject populations (Army recruits versus SEAL candidates) and possibly in the methods of measurement, length of training time (9 weeks versus 25 weeks), and training environments (Army BCT versus SEAL training) must be considered.

Table 36. Comparison of Incidence of Stress Fractures in Current Study and Kaufman et al. (5) Study Using Separate Cutpoints

Study	Categories and Cutpoints for Bony Arch Index[a]	Men			Women		
		n	Stress Fracture Incidence (%)	Risk Ratio (95%CI)	n	Stress Fracture Incidence (%)	Risk Ratio (95%CI)
Kaufman et al. (5)	Pes Planus (< 20.0)	141	10.8	1.9 (0.8–4.3)			
	Normal (20.0–22.8)	138	5.8	1.0			
	Pes Cavus (> 22.8)	139	9.9	1.7 (0.7–4.0)			
Current Study, Right Foot	Low 20%	430	0.47	0.8 (0.2–3.5)	181	1.10	0.3 (0.1–1.4)
	Middle 60%	1283	0.62	1.0	551	3.27	1.0
	High 20%	435	1.15	1.8 (0.6–5.6)	181	4.97	1.5 (0.7–3.3)
Current Study, Left Foot	Low 20%	429	0.23	0.3 (0.1–1.2)	185	2.70	0.8 (0.3–2.2)
	Middle 60%	1287	0.78	1.0	546	3.30	1.0
	High 20%	432	0.93	1.2 (0.4–3.8)	184	3.36	1.0 (0.4–2.5)

[a]Cutpoints boney arch index likely differed in the two studies

c. <u>Injury Rates in BCT.</u>

(1) Table 37 displays BCT studies showing both cumulative injury incidence (recruits with one or more injuries during BCT) and injury rates (incidence/month). All the studies shown have been conducted at Fort Jackson, South Carolina. Groups that involved specific injury-reduction interventions have been removed. The specific injury indices (CII, III, MII and TRII) used in the most recent studies (2003 and the current 2007 study) are identified. Cumulative injury incidence ranged from 17% to 37% for men and 41% to 67% for women (75, 77, 81, 82, 84, 86, 112)

(2) The variations in injury rates in Table 37 may be due to a number of factors including different ways of collecting data, different injury definitions, changes to BCT procedures, seasonal effects, changes in recruiting polices, and other factors. Injury rates reached a maximum in the 1994–1996 survey periods and declined in the 1998–2000 period when concerted efforts were made to lower rates (3). Current rates (from the present study) are at historic highs.

(3) From 1984 to 2000 (during which time the 1994–1998 injury peaks occurred), injury data were collected from medical records by many of the same investigators using the same techniques. Thus, the rise and subsequent fall in injury rates in this period are not likely due to differences in data collection techniques. In 2003 and 2007, data were collected from a surveillance system as ICD-9 codes and selected code groups were used to develop injury indices. Injury rates were higher in 2007 than 2003 regardless of the index used. While some investigators have used a variety of injury definitions (time-loss, lower extremity overuse, musculoskeletal, etc.), Table 36 generally takes the broadest injury definition in these studies, best described as any visit to a medical care provider for physical damage to the body (an exception is the TRII, which considers only lower extremity overuse injuries). Thus, while slight

differences in injury definition may play some role in the rate differences, the contribution is likely small.

Table 37. Cumulative Incidence of Injury and Injury Incidence Rates during US Army Basic Combat Training

Length of Training	Study (Reference Number)	Data Collection	Year Data Collected	Recruits (n)		Cumulative Injury Incidence (%)		Injury Incidence Rate (%/month)	
				Men	Women	Men	Women	Men	Women
8 weeks	112	Questionnaire	1978	347	770	26	62	13	31
	75	Medical Records	1980	1840	644	21	41	10	21
	74	Medical Records	1984	124	186	27	51	14	25
	82	Medical Records	1988	509	352	27	57	14	29
	81	Medical Records	1994	ND[b]	165	ND[a]	67	ND[a]	33
	77	Medical Records	1998	604	305	31	58	15	29
9 weeks	84	Medical Records	1998	655	498	30	65	13	29
	85	Medical Records	2000	441	554	17	47	8	21
	86	Surveillance System	2003	569	377	[b]CII–31 III–29 MII–30 TRII–20	[b]CII–54 III–53 MII–53 TRII–43	[b]CII–14 III–13 MII–13 TRII–9	[b]CII–24 III–23 MII–24 TRII–19
	Current Study	Surveillance System	2007	2147	915	[b]CII–37 III–34 MII–36 TRII–26	[b]CII–67 III–63 MII–67 TRII–54	[b]CII–17 III–15 MII–16 TRII–12	[b]CII–30 III–28 MII–30 TRII–24

[a]ND=No data collected on other gender.
[b]Abbreviations: CII=Comprehensive Injury Index; III=Installation Injury Index; MII=Modified Installation Injury Index; TRII=Training Related Injury Index

(4) Changes in the BCT program of instruction have occurred since 2003 in response to experiences in Iraq and Afghanistan. Recruits undergo weapons immersion in which they carry their weapons with them at all times during all training and into the barracks at night. There is increased emphasis on marksmanship training, including convoy live-fire operations, reflex firing, and close-quarters marksmanship. Soldiers wear body armor much of the day. Convoy operations are emphasized and recruits are drilled on dismounting and assaulting from vehicles. Urban warfare techniques receive increased time, especially room-clearing techniques. Counterinsurgency instruction is now part of the training, with emphasis on situational awareness, especially as related to frequent drills that deal with improvised explosive devices. Recruits are drilled on checkpoint techniques, searching vehicles for explosives, and guarding detainees. Combatives (hand-to-hand combat) receives increased attention. The field training exercise, in which Soldiers live and operate continuously in the field, has been extended from 3 days to 5 days, so that recruits now spend a total of 21 days in the field (113-115). How these training changes influence injury rates is not known.

(5) Injury rates have also been shown to vary by season, with lower rates in the fall and winter and higher rates in the summer (90, 106). Much of the variation across seasons appears to be due to environmental temperatures, with lower temperatures associated with lower injury rates. In the present study, subjects were in training from early March to mid-July and temperatures would generally be cooler in the early part of the study and warmer in the latter part. As noted earlier, seasonal variation is likely to play a relatively minor role in the injury rates in the present study because subjects were likely initially training in cooler weather, which gradually became somewhat warmer later in the study.

(6) Because of difficulties in recruiting in an all-volunteer Army during wartime, the Department of Defense has relaxed many of the previous criteria for entry into service. In the fiscal year 2006 defense budget, Congress granted all the services authorization to increase the maximum recruiting age to 42 and the Army progressively raised the age from 35 to 42 during 2006 (116-118). The current study and others (73, 100, 104) have demonstrated that older age is an injury risk factor in BCT. The Army has also been recruiting fewer service members with high school diplomas and has been recruiting more with General Education Diplomas (GED), even to the extent of an Army-sponsored program that helps recruits earn a GED before enlistment (118-121). Previous studies showed that recruits with GEDs had higher attrition and higher injury rates in BCT (87, 122). We were not able to partition out subjects with GEDs in the current study because the DMDC data provided by the AMSA did not distinguish GEDs from high school graduates.

(7) Beginning in 1999, new recruits arriving at the reception station for BCT were not allowed to enter BCT until they had passed a minimum physical fitness test consisting of push-ups, sit-ups, and a 1-mile run (123). Those who failed this test remained in the reception station and entered a training unit that concentrated on structured fitness improvements. Once the new recruit passed the test, they were allowed to enter BCT. The test was well administered (personal observations, Knapik and Hauret), and the program (testing plus training) was shown to reduce injury incidence compared with no program (123). In May 2004, this test was no longer conducted in the reception station and administration was turned over to recruiters, who tested potential recruits prior to their departure for the reception station (3). By 2006, this fitness test had been eliminated. A new fitness test was administered at the MEPS, but only to potential recruits who exceeded the current entry-level body fat standard (124). Potential recruits eligible for the test are those who 1) exceed the weight-for-height entrance standard and 2) have body fat measurements, determined by the circumferential technique (125, 126), that do not exceed 30% for men or 36% for women (118, 127). Individuals meeting these criteria can take a fitness test consisting of push-ups and a modified 5-minute Harvard Step Test (128). If they pass this test, they receive a body-fat waiver to enter BCT. This procedure is currently under evaluation by the Accessions Medical Analysis and Research Activity (AMSARA). The previous body fat maximum for entry had been based on age and was 24% for 17–20-year-old men and and 30% for women of the same age (125).

(8) Figures 5, 6, 7, and 8 show temporal changes among new BCT recruits in performance on push-ups, sit-ups, the 2-mile run, and the 1-mile run. These data were compiled from a number of published articles as previously described (129). The last points on each of these graphs (2007) represent the average push-up, sit-up, and run performance of the current

cohort of subjects (all men combined and all women combined). The push-up and sit-up scores changed little over the 23-year-period from 1984 to 2007, as indicated by the low R^2 values. However, there were strong and systematic year-to-year declines in 2-mile and 1-mile run performance, and the current study emphasizes that these trends are continuing. Part of the decline in aerobic fitness may be attributed to an increase in body weight and body fat. Figures 9 and 10 show temporal tends in body weight and BMI, with the last points on these graphs (2007) from the current cohort of subjects. Both body weight and BMI (the latter a surrogate for body fat, 96, 130) have increased over time. An increase in weight is known to reduce run times (131, 132) and the temporal increase in body fat (as indicated by the BMI) may account for at least a portion of reduced run performance. On the other hand, one study indicated that the body weight from 1978 to 1998 was about half fat and half fat-free mass (133). Thus, the decline in run time may be somewhat offset by increases in fat-free mass (most of which is muscle mass), since the increase in muscle tissue can contribute to oxidative energy production. At any rate, the temporal decline in run performance and increases in body weight and BMI continue in the present cohort of subjects. Higher levels of body fat (77) or BMI (77) have not been demonstrated to be a consistent risk factor for injuries in BCT. However, lower levels of physical fitness, especially aerobic fitness, have consistently been demonstrated to be injury risk factors (71, 72, 74, 77, 81, 87, 99-102).

(9) In summary, the historically high injury rates may be ascribed to a number of factors. It is possible that changes in the BCT program of instruction played a role. Changes in recruiting policies allow entry by older, less-fit, less-educated recruits and these are known injury risk factors. The continuing temporal trend of lower entry-level fitness may also be a factor, since low aerobic fitness is a strong injury risk factor.

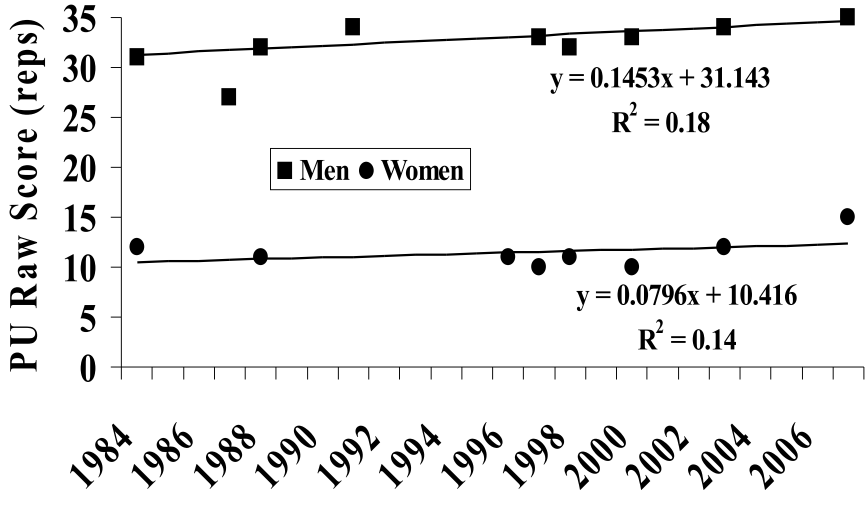

Figure 5. Temporal Changes in Push-up Scores of Recruits on Entry to BCT.

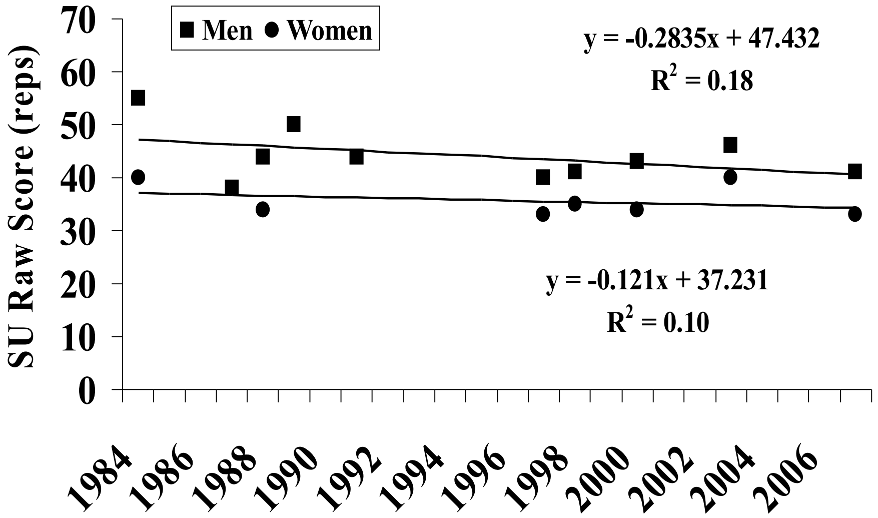

Figure 6. Temporal Changes in Sit-up Scores of Recruits on Entry to BCT.

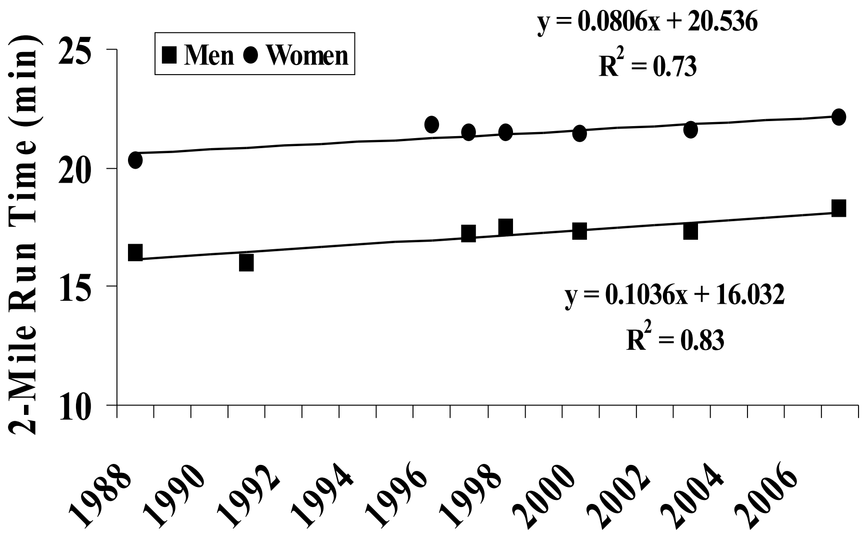

Figure 7. Temporal Changes in 2-Mile Run Times of Recruits on Entry to BCT.

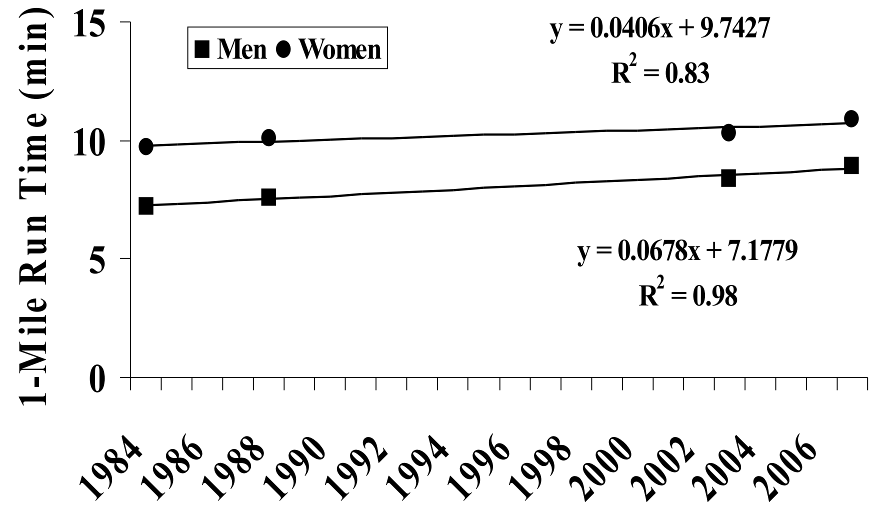

Figure 8. Temporal Changes in 1-Mile Run Times of Recruits on Entry to BCT.

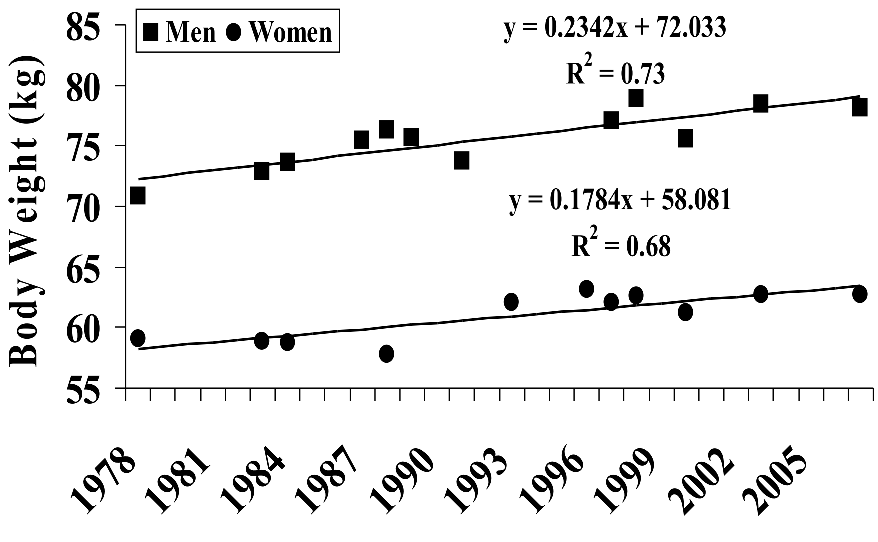

Figure 9. Temporal Changes in Body Weight of Recruits on Entry to BCT.

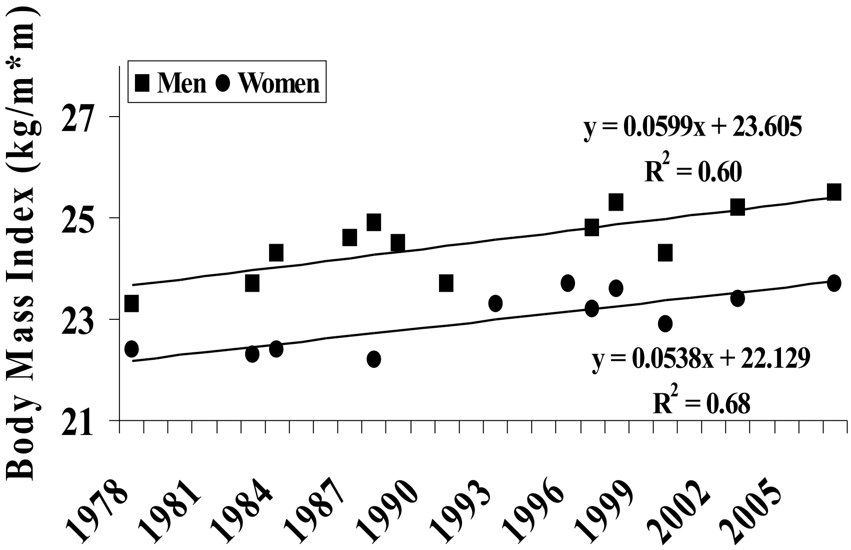

Figure 10. Temporal Changes in Body Mass Index of Recruits on Entry to BCT.

d. Injury Risk Factors. Despite the fact that there were no differences in injury rates/risks between the C and E groups, the present study found a number of risk factors that confirmed and expanded on previous work in BCT.

(1) Physical Fitness.

(a) In the present study, higher injury risk was associated with lower aerobic fitness, as has been found in much of the literature when aerobic fitness is measured with either a maximal effort run (71, 72, 74, 77, 81, 87, 99-101) or VO_2max (77, 134). In the present study, the injury-aerobic fitness relationship depended on the level of performance, with lower performance resulting in progressively higher injury risk. We found much weaker associations between injury risk and the 1-mile run time, but sample sizes were very small (limiting statistical power) and the highest injury risk was found in the least fit group.

(b) Individuals with lower levels of aerobic fitness will be required to work at a larger percentage of their maximal capacity during physical activities in BCT and they will fatigue more rapidly (135-137), possibly leading to injury. Consider two individuals with widely different 2-mile run times. Using the Mello equation (138), an individual who has a 2-mile run time of 11.8 minutes can be predicted to have a VO_2max of 60 $ml \cdot kg^{-1} \cdot min^{-1}$; an individual with a 17.8 minute 2-mile run time would have a VO_2max of 40 $ml \cdot kg^{-1} \cdot min^{-1}$. If these two individuals were walking rapidly with a pack and load-carrying equipment, the energy requirement could be 20 $ml \cdot kg^{-1} \cdot min^{-1}$(1 liter of oxygen is the energy equivalent of about 4.85 kilocalories (139)). The individual with the lower VO_2max would use 50% (20/40=50%) of his maximal capacity, while the individual with the higher VO_2max would use only 33% of his maximal capacity (20/60=33%). Thus, the individual with the low VO_2max would experience greater physiological stress at any given absolute activity level. Individuals with lower aerobic capacity may perceive long-term low intensity tasks as more difficult (140). The lower fit individual is likely to fatigue more rapidly for both cardiovascular and metabolic reasons (136, 141). Fatigue has been shown to result in changes in economy (142, 143) and gait (142-147) that may put more stress on body regions not accustomed to the stress. The combined cardiovascular, metabolic, biomechanical, and perceptual stress could make injuries more likely in these less fit individuals.

(c) Also in consonance with past studies, higher injury risk was associated with lower muscular endurance, as measured by either the 2-minute push-ups or the 2-minute sit-ups (73, 77). In the present study, the relationship was such that progressively lower performance levels resulted in progressively higher injury risk. There were much weaker associations between injury risk and the 1-minute push-ups or sit-ups, but the sample sizes were small, thereby limiting statistical power. In the case of the 1-minute sit-up, the trends were in the expected direction of higher injury risk with lower fitness level.

(d) Like aerobic fitness, individuals with lower levels of muscular endurance will be required to work at a larger percentage of their maximal muscular endurance capacity during physical activities in BCT that require this fitness component (such as the confidence obstacle course, high towers, and bayonet training). In a manner analogous to aerobic fatigue, individuals with lower muscular endurance may perceive a greater level of stress and need to recruit different muscle groups as the active muscle groups begin to fatigue (146, 148, 149). The unaccustomed stress may make injuries more likely.

(2) Physical Characteristics.

(a) There was no increase in injury risk among subjects who were of lower stature, greater weight, or higher BMI. These data are generally in consonance with past studies in BCT that showed no association between injuries and these three variables (73, 74, 77, 104, 150). Jones et al. (74) did find that shorter women had higher injury incidence than taller women, but this finding was not duplicated by the men or found in other studies (77, 150).

(b) As noted earlier, the MEPS have been allowing men with body fat values up to 30% and women with body fat values up to 36% to enter the Army if they could pass a fitness test. It was thought that this would provide a wider range of BMIs and if an association existed between BMI and injuries the present study would be more likely to detect it than past studies with smaller sample sizes and less variation in BMI (see 129). Thus, the BMI values in this study were divided into deciles to examine whether or not an association existed at the extremes of BMI. Table 38 shows the results of a univariate Cox regression examining the association between injury risk and BMI separated into deciles. For the men, injury risk tended to increase slightly among those within the highest and lowest deciles. There is less statistical power among the women because of the smaller sample size, but there is a suggestion of some higher injury risk in the lowest female BMI deciles but not in the highest deciles.

Table 38. Hazard Ratios by BMI in Deciles

BMI (kg/m^2)	n	Hazard Ratio (95%CI)	p-value
Men			
15.21–20.23	219	1.36 (1.00–1.86)	0.05
20.24–21.59	211	1.13 (0.82–1.56)	0.45
21.60–22.71	211	1.04 (0.76–1.44)	0.80
22.72–23.87	211	1.15 (0.83–1.56)	0.41
23.88–25.06	221	1.00	---
25.07–26.35	209	1.04 (0.75–1.45)	0.80
26.36–27.75	216	1.53 (1.13–2.07)	< 0.01
27.76–29.29	213	1.09 (0.77–1.50)	0.62
29.30–31.41	214	1.14 (0.8)-1.57)	0.42
31.42–39.56	215	1.31 (0.96–1.79)	0.09
Women			
14.14–19.40	91	1.25 (0.89–1.75)	0.20
19.41–20.70	89	0.94 (0.66–1.33)	0.71
20.71–21.78	93	0.87 (0.60–1.24)	0.43
21.79–22.68	93	0.79 (0.55–1.13)	0.20
22.69–23.80	93	1.00	---
23.81–24.55	93	0.98 (0.69–1.39)	0.92
24.56–25.58	90	0.95 (0.67–1.36)	0.79
25.59–26.44	92	0.82 (0.57–1.17)	0.28
26.45–27.97	93	1.00 (0.71–1.42)	0.99
27.98–34.01	88	0.80 (0.56–1.15)	0.22

(3) Cigarette Smoking.

(a) Five items on the questionnaire dealt with smoking (Questions 8 through 12, Appendix D). All of these questions demonstrated associations with injury risk in both men and woman in univariate analysis. In the multivariate analysis, age at smoking onset was an independent injury risk factor for men and both 1) smoking in the last 30 days and 2) when the subject quit smoking were independent risk factors for injury risk in the women. There is likely to be a considerable amount of colinearity among the smoking questions. For example, 84% of men and 87% of women who had smoked 100 cigarettes in their life also had smoked on at least 1 day in the 30 before BCT. The question that accounted for the greatest proportion of the injury odds would be the question retained in the multivariate model.

(b) It has been a consistent finding that cigarette smoking prior to basic training was associated with increased injury risk in both the US Army (73, 77, 151, 152) and the Armies of other countries (100, 153). Further, smoking was associated with injury in infantry soldiers (154) and in other occupational groups (134, 155-159). Basic training studies that included various levels of smoking have shown a dose-response relationship, such that the likelihood of injuries increased with more cigarettes smoked (73, 77, 100, 151). Further, cigarette smoking was previously shown to be an independent risk factor for injury when considered in multivariate models (73, 77, 154). The present study confirmed a dose-response relationship between the likelihood of injury and either days of smoking or cigarettes per day in the 30 days prior to BCT.

That is, injury risk progressively increased with either more days of cigarette smoking or more cigarettes per day.

(c) The present study expanded on the finding discussed above in two important ways. First, it was found that there was generally a dose-response relationship between the age at which the subject started smoking and injury risk. That is, injury risk progressively increased with younger age of smoking onset. Second, there was a dose-response relationship between the likelihood of injury and the time elapsed since subjects had quit smoking. That is, injury risk decreased with increasing time since smoking cessation. It is possible to hypothesize that the mechanisms accounting for the higher injury risk in smokers may have more time to develop in individuals who have smoked for a longer period of time. Conversely, these mechanisms might have more time to dissipate the longer it has been since the subject ceased smoking.

(d) With regard to the possible mechanisms and the biological plausibility of the association between injury risk and cigarette smoking, there is considerable literature showing that cigarette smoking affects tissue healing, tissue strength, and immune function. Wound healing in smokers is delayed and less complete, complications are more likely to arise, and cosmetic results are less satisfying (160-168). Bone healing is impaired in smokers (160, 169-172), fractures are more likely (161, 173, 174), and experimental fractures in nicotine-exposed rabbits produce weaker bone tissue, less callus formation, and result in delayed or inhibited bone union (170, 171). In repair of ligamentous tissue, smokers have less tissue density, less collagen production, more joint laxity, and less favorable surgical outcomes than nonsmokers (163, 175).

(e) Collagen deposition is the major factor that determines the tensile strength of wounds (176, 177). Shortly after an injury, fibroblasts migrate to the site of the injury to synthesize and deposit a matrix composed of collagen on which glycoproteins form (178). In cell preparations, cigarette smoke extracts have been shown to reduce collagen content; decrease fibroblast recruitment, proliferation, migration, and contraction; lead to delayed wound closure; and reduce the amount of new tissue formation (179-182). Damage to the medial collateral ligament resulted in less cellular density and reduced expression of Type I collagen in mice exposed to cigarette smoke for 2 months (175). Human studies involving experimentally induced arm wounds showed that smokers produced less hydroxyproline, a marker of collagen production (183, 184), and synthesized less Type I and Type III collagen (185); noncollagen protein was apparently not affected (184). The metabolic pathway for collagen deficit in smokers may involve reduced conversion of proline to hydroxyproline, since this pathway requires molecular oxygen and smokers exhibit reduced tissue oxygenation (186).

(f) The immune system is important for wound healing, since macrophages, leukocytes, and lymphocytes regulate various steps in the wound-healing process and remove or assist in removal of damaged tissue (187-190), although the effects of T-lymphocytes are complex and not fully understood (190). The macrophages of smokers have lower phagocytosis activity, lower responsiveness to bacterial challenge, and reduced gene expression of proinflammatory cytokines important for tissue healing (191-193). Leukocytes are also affected by smoking in that that they show reduced chemotaxis (30, 55, 217). Smoking increases the leukocyte count in venous blood in a dose-dependent manner, and smoking for a longer period of time results in an even higher leukocyte count (184, 194-205). Differential counts indicate that neutrophils, monocytes, and lymphocytes are significantly elevated, with a tendency for eosinophils and basophils to be elevated as well (194).

(g) Most of the effects cited above have only involved acute exposure to tobacco or smoking while injuries are healing. The mechanism or mechanisms whereby smoking influences injuries in BCT must take into account the fact that subjects ceased smoking at the beginning of training; thus the mechanism must be associated with some longer-lasting effect of smoking. This effect does not have to be extremely long because BCT is only 9 weeks in duration. Evidence for the longer-term effects of smoking come from studies on collagen metabolism, skin damage, immune function, and possibly effects on bone tissue. One study (206) followed weekly urinary hyrdoxyproline/creatine levels (indicative of collagen metabolism) from individuals 14 weeks after they ceased smoking. It was estimated (by mathematical modeling) that hyrdoxyproline/creatine levels would return to the level of nonsmokers in about 71 weeks, among those who had previously smoked ≤ 40 cigarettes/day, while it would take 120 weeks to reach the same level in those who had been smoking > 40 cigarettes/day. Other studies have shown that tobacco users have more than twice the risk of moderate to severe facial wrinkling (indicative of skin damage) compared with nonusers, even after controlling for age, sun exposure, and body mass index (207-209). Smoking reduction (at least 50%) for 6 to 8 weeks prior to surgery (at 10 day post-surgery) has been shown to be associated with an almost threefold reduction in postsurgical complications (210). Immune studies suggest that the smoking-induced leukocytosis slowly decreases over time once smoking ceases (196, 198, 200, 201, 203, 204, 211). One day to 6 weeks after smoking cessation, the leukocyte count was still elevated (200, 201). Three months after smoking cessation, the neutrophil concentration tended to decrease but was still elevated relative to when subjects were smoking (198). Leukocyte counts approached the level of nonsmokers the longer it had been since the individual stopped smoking, but men who had quit smoking for 10 years or more still had higher leukocyte counts that nonsmokers in one study (204). Another investigation showed that men and women who had quit smoking for an average of 11 years had counts similar to those who had never smoked (203).

(h) With regard to long-term effects on bone tissue, diminishing nicotine over a 2- to 4-week period after experimentally induced fractures in rabbits, resulted in bone vascularization similar to nonsmoking controls; however, the trabecular bone area still tended to be lower (170). Cross-sectional investigations have not been consistent in showing differences between smokers and nonsmokers in terms of bone mineral density, bone mineral content, or cortical area (212-229). Some of these differences can be explained on the basis of physical characteristics and age. Smokers tend to be smaller and leaner than nonsmokers. There have been little differences in bone mineral density or cortical area in cross-sectional studies that have either controlled for body mass or fat mass, or in studies where body weight or body mass index have been the same among smokers and nonsmokers, (212, 214-217). Also, when women are stratified on age, there is little effect of smoking on bone mineral density (BMD) until about age 50 (postmenopausal); after age 50, smokers have progressively less BMD (230). However, this age-related trend is not apparent in younger men. Cross-sectional studies showed that younger male smokers have lower bone mineral density and less cortical thickness than younger male nonsmokers (213, 226, 229). Further, and in contrast to cross-sectional studies, longitudinal studies (219, 231-233) generally show that young female smokers have greater losses in bone mineral density or cortical area over time compared with young female nonsmokers. Factors which may influence bone mineral density and for which there is some evidence of differential effects in smokers and nonsmokers include estrogen levels, adrenal cortical hormones, vitamin D levels, calcium absorption, parathyroid hormones, and free radicals (234). Thus, it may be possible that some of the association between smoking and injury is at least in part mediated by changes in the bone.

(i) Besides physiological mechanisms, psychosocial factors must also be considered in accounting for the association between cigarette smoking and injury. Air Force recruits who were cigarette smokers had higher scores than nonsmokers on various measures of risk taking. These included an overall measure of risk-taking, in addition to greater rebelliousness, less seat belt use, more risky sex, more favorable view of illegal drug use, more alcohol use, more binge drinking, less physical activity, less intake of fruits and vegetables, and greater intake of high-fat foods (235). In civilian studies, smokers had more motor vehicle accidents, more traffic violations, less seat belt use, less physical activity, more alcohol consumption and lower intake of fruits and vegetables (236-238). Heavy smoking (≥ 20 cigarettes/day) is much more likely to be associated with multiple risk behaviors (238). It is possible that this higher risk-taking behavior of smokers manifests itself in the activities of BCT and results in a higher injury rate among smokers.

(j) It might be thought that recruits who smoke are more likely to have lower levels of aerobic fitness because of the effects of smoking on oxygen transport (239, 240) and/or possible damage to lung tissue (241). In cross-sectional studies, it has been shown that younger (average age ~22 years) smokers and non-smokers have similar aerobic fitness but that older smokers (average age > 40 years) have lower aerobic capacities than older nonsmokers (77, 134, 242, 243), A longitudinal study suggested that the differences in aerobic capacity between smokers and nonsmokers were progressive with age (244). Since the age range in the present study was greater than that of previous studies, it seemed that it might be possible to identify differences in aerobic fitness between smokers and nonsmokers. However, only 3% of men and 6% of women were over age 35 years and even fewer of these had 2-mile run times. Table 39 shows the 2-mile run times of the male and female smokers grouped by age. For the men, analysis of variance indicated that there were no significant differences for the main effects of age (p=0.32) or smoking status (p=0.22) or in the age-by-smoking status interaction (p=0.92).

Table 39. Two-Mile Run Times of Smokers and Nonsmokers Grouped by Age

	Men				Women			
	Smokers[a]		Nonsmokers		Smokers[a]		Nonsmokers	
Age Group (years)	n	2-mile Run Time (min) (mean±SD)	n	2-mile Run Time (min) (mean±SD)	n	2-mile Run Time (min) (mean±SD)	n	2-mile Run Time (min) (mean±SD)
17.0–19.9	151	18.3 ± 3.0	256	18.0 ± 3.2	44	21.8 ± 3.8	124	22.1 ± 3.4
20.0–24.9	15	18.4 ± 3.1	395	18.3 ± 3.0	53	22.0 ± 3.3	126	21.9 ± 3.7
25.0–29.9	50	18.9 ± 3.3	132	18.5 ± 3.1	15	23.4 ± 3.5	46	21.7 ± 3.1
≥ 30	30	18.8 ± 3.6	80	18.4 ± 2.9	13	22.6 ± 2.0	47	22.6 ± 4.0
All	381	18.4 ± 3.1	868	18.3 ± 3.1	125	22.2 ± 3.4	343	22.1 ± 3.6

[a]Smokers were those who said they had smoked on at least 20 of 30 days before BCT

For women, results were similar, in that there were no main effects of age (p=0.60) or smoking status (p=0.39) or in the age-by-smoking status interaction (p=0.42). It may be that the effects of smoking on aerobic capacity do not manifest until after 40 years of age (243).

(4) Physical Activity.

(a) Six questions on the questionnaire dealt with physical activity prior to BCT. Questions dealing with broad-spectrum physical activity (Questions 13 and 14) or running (Questions 15 and 16) generally showed systematic dose-response relationships with overall injury risk. That is, as activity increased, injury risk decreased. The questions on weight training (Questions 17 and 18) were less consistent, but individuals who did not train with weights in the 2 months prior to BCT tended to have higher injury risk than those who performed some weight training. The results reported here are generally in agreement with past BCT studies indicating that higher levels of self-reported physical activity were associated with lower injury risk in BCT (66, 73, 77, 102, 104).

(b) Low frequency of running or jogging prior to BCT or a short length of time running or jogging prior to BCT were associated with injury risk. In BCT, subjects performed a great deal of weight-bearing physical activity primarily in the form of standing (in formation), walking, walking with loads, and running. It seems reasonable that a higher frequency of weight-bearing physical training prior to BCT would result in less susceptibility to injury. Physical activity has several favorable influences on the body. Physical activity of the proper intensity, frequency, and duration can increase aerobic fitness, muscle strength, and general health, and can reduce body fat (245-249). Bone mineral density is higher in physically active individuals (152, 226, 227, 250) and higher bone mineral density has been associated with greater weekly physical activity (227). These and other factors may assist in reducing susceptibility to injury (123).

(5) Age. In the univariate analysis, age was related to injury risk such that as age increased so did injury risk. Other BCT investigations have also shown that older age was an injury risk factor (66, 73, 77, 100). However, this finding contradicts studies of infantry Soldiers (251) and predominately infantry Soldiers (252) that have shown younger age to be an injury risk factor. One possible explanation (251) might be that, in the infantry, younger Soldiers may perform more of the arduous occupational tasks and thus be more susceptible to injury than older Soldiers, who are likely to be of higher rank and working in supervisory or staff positions. BCT training differs from the operational infantry in that all individuals perform the same training tasks; under these conditions older individuals appear to be more susceptible to injury. With aging, there is a loss of muscle mass, muscle strength, muscular endurance, aerobic capacity, and flexibility (253, 254). The loss of aerobic capacity and muscular endurance can begin by age 25 years (254) and these age-related changes may make injuries more likely.

(6) Prior Injury.

(a) A prior lower limb injury was an injury risk factor for women in both the univariate and multivariate analyses, but was not an injury risk factor for men. However, male subjects who reported that they had not fully recovered from a prior injury were more likely to sustain an injury in BCT. Studies on the influence of prior injury on injuries in BCT have not reported consistent findings, possibly because investigators have asked the question concerning prior injuries in a number of different ways and have used different injury definitions. Two studies (73, 255) asked male infantry recruits to list their previous injuries by anatomical location and found that only prior ankle sprains were associated with musculoskeletal injury (both studies used the same database). Subsequently, another study (87) in male and female BCT recruits found no association between overall injury risk and 1) any prior injury that resulted in time loss for ≥ 1 week, 2) a prior exercise or sport injury that prevented participation for ≥ 1 week, 3) an injury requiring surgery, or 4) an injury requiring hospitalization. In female Marine recruits, Rauh et al. (104) found no association between non–stress fracture overuse injuries in training and a prior history of lower extremity stress fracture; however, they did find a higher risk of a non–stress fracture overuse injuries in training with a prior history of a lower-extremity non–stress fracture injury, in general agreement with the present study in female Army recruits. Finally, Shaffer et al. (102) found a *lower* risk of stress fractures among male Marine recruits who had a prior injury and had fully recovered from that injury.

(b) Despite the mixed findings in BCT, other studies of military groups (256-258), athletes (103, 259-265), and industrial workers (266) have reported that prior injuries were associated with current injuries, especially if an injury had occurred in the preceding year (260-262, 265, 267). Many injuries may be chronic or recurrent, accounting for at least a part of this relationship.

(c) Many of the investigations showing an association between prior injuries and current injuries (104, 256-262, 264-267) examined individuals whose average age was older than that of Soldiers in BCT. It might be that older individuals have had more time to accumulate injuries and are more susceptible to the influence of prior injuries because of lower fitness levels, as mentioned above (253, 254). However, this does not appear to be the case in the current study. When subjects were stratified by age and their responses to the prior injury question, younger women were more likely to be injured in training if they had a prior injury, as shown in Table 40.

Table 40. Injury Incidence Stratifying Prior Lower Limb Injury on Age

Age (years)	Men			Women		
	No Prior Lower Limb Injury (% Injured)	Prior Lower Limb Injury (% Injured)	p-value[a]	No Prior Lower Limb Injury (% Injured)	Prior Lower Limb Injury (% Injured)	p-value[a]
17.0–19.9	34.9	34.0	0.87	63.3	77.3	0.07
20.0–24.9	36.3	38.4	0.63	63.0	84.2	0.01
25.0–29.9	43.8	39.5	0.60	75.8	75.0	0.95
≥ 30	43.0	39.4	0.70	76.7	78.3	0.87

[a]Chi-square statistic

(7) Component.

(a) In the present study, subjects in the active Army tended to have a higher injury rate than National Guard or Reserve Soldiers. Active Army status was an independent injury risk factor when the fitness variables were not included in the multivariate analyses.

(b) Component was not an injury risk factor in a previous study (87), but several recent policy changes affecting how new National Guard and reserve enlistees are processed may account for this difference. National Guard and Army Reserve units are currently experiencing recruiting problems, presumably because units can be expected to deploy more often and deployments have a perceived negative effect on the lifestyles of reservists/National Guard personnel (268). To reduce attrition among those who sign up for guard or reserve duty, units have initiated the recruit sustainment program (RSP) (269). The goal of the RSP is to ensure that new recruits "ship to BCT mentally prepared, physically ready, and administratively correct." The RSP prepares recruits for basic training by providing them with physical training and military knowledge (e.g. chain-of-command, rank structure, uniform code of military justice) and by assuring they have no physical, criminal, or other types of problems prior to BCT. Recruits are given a fitness test (generally a 1-minute push-up event, a 1-minute sit-up event, and a 1-mile run for time) several times before BCT and perform physical training during scheduled drills. They are provided information on physical training to improve their fitness outside scheduled drills and keep physical training logs. Smoking is prohibited at all drills and there is an emphasis on smoking cessation (269; personal communication, CPT Mayb Sersland, Maryland National Guard). This program may have been successful in reducing injury rates in BCT, especially those from the physical training portion, since increasing physical fitness prior to BCT has been shown to reduce injuries (123).

(c) A similar program, the Pennsylvania Pre-Initial Entry Training Program, has previously been documented. This consisted of a 36-hour centralized program of instruction at Fort Indiantown Gap, Pennsylvania, which included increased emphasis on physical training and identification of pre-existing physical problems (270, 271).

(8) Marital Status. Individuals who were married or of "other" marital status (the latter mostly divorced or widowed) tended to have a higher injury risk than single individuals, and marital status was an independent injury risk factor among the women. Similar findings were previously reported in BCT, but when marital status was stratified on age there was no difference among married and single recruits (71, 87). A similar stratification of data from the current study is shown in Table 41. There was a tendency for those of "other" marital status to have higher injury incidence regardless of age, but because of the small number of cases in the "other" category, this difference is not statistically significant. The basis of the association between injury and marital status is not clear.

Table 41. Injury Incidence Stratifying Marital Status on Age

Age Group (years)	Men				Women			
	Single (% injured)	Married (% injured)	Other (% injured)	p-value	Single (% injured)	Married (% injured)	Other (% injured)	p-value
17.0–19.9	35.2	28.2	0.0[a]	0.51	64.4	63.8	100.0[e]	0.44
20.0–24.9	35.3	42.8	38.5[b]	0.20	63.8	68.1	80.0[f]	0.38
25.0–29.9	46.0	38.7	47.6[c]	0.43	72.3	76.5	82.4[g]	0.70
≥ 30	43.3	37.7	51.5[d]	0.42	75.0	78.2	80.8[h]	0.94

[a]n=1, [b]n=13, [c]n=21, [d]n=33, [e]n=2, [f]n=12, [g]n=17, [h]n=26

(9) Menstrual Dysfunction.

(a) In the current study, women reporting no menstrual period in the last year were at higher injury risk. The sample size was small (n=30), but risk was elevated 1.8 times compared with women who had menses 10–12 times in the previous year. Past studies (104, 105) have showed elevated risk of stress fractures among female Marine Corps recruits who had missed six or more consecutive menses in the last year, with weaker relationships between missing six consecutive menses and non–stress fracture overuse injuries. Surveys of young (average 26 years) active duty Army women (272) and women in Marine Corps Officer Candidate School (273) have also shown that menstrual irregularities are associated with higher stress fracture incidence. In the present study, there was no association between overall injury incidence and a positive response to the questionnaire item that asked if women in the last year had ever gone 6 months in a row without a cycle (Question 24). It was only the most extreme case of menstrual dysfunction in the last year that had a higher likelihood of injury.

(b) Besides military studies, investigations of female athletes have also suggested that those with menstrual irregularities have a higher overall injury incidence (274), take longer to recover from injuries (275), and specifically have a higher incidence of stress fractures and frank fractures (274, 276, 277). It has been hypothesized that amenorrhea results in hormonal changes, especially lower estrogen levels, which leads to a reduction in bone mineral density and increasing fracture likelihood (274, 275, 277, 278). Bennell et al. (279) cautioned that athletes with menstrual disturbances also have other risk factors like greater training loads, lower calcium intake, and differences in soft tissue composition. In BCT, the training load is similar for all recruits and all recruits have access to the same calcium sources in the mess hall. Nonetheless, in a BCT study in 1993 calcium intake of recruits was only 73% of the Military recommended daily allowance (81). One study found that amenorrheic women still had lower bone mineral density after controlling for calcium intake (277).

(10) Prior Pregnancy.

(a) In the current study, a longer time since last pregnancy was associated with higher injury risk. A previous BCT study found no relationship between injury risk and prior pregnancy (87), but no other studies could be found on the effects of prior pregnancy on injuries in physically active women. The American College of Obstetricians and Gynecologists note that "many of the physiological and morphological changes of pregnancy persist 4–6 weeks postpartum" and recommend that "prepregnancy exercise routines may be resumed gradually as soon as it is medically safe" (280).

(b) It seemed possible that prior pregnancy covaried with age, because those who had been pregnant > 12 months ago were also likely to be older, and older age was strongly associated with injury in the present study. Table 42 shows injury incidence with pregnancy history, stratified by age. There are very few cases in the 1–6 and 7–12 month groups. Despite this, injury risk tends to be higher among women who have been pregnant ≥ 7 months ago in all age groups except the youngest. Thus, there is little support for the hypothesis that the association between pregnancy and injury is related to age in this study.

(c) One possible mechanism may be the effects of pregnancy on joint laxity. During pregnancy, relaxin acts in concert with estrogen to increase ligament laxity by reducing the density of collagen fiber bundles (281). This could increase the likelihood of ligament injury due to excessive joint flexibility (282, 283**).** However, the highest levels of relaxin occur in the first trimester and relaxin levels decline for the rest of pregnancy with no antepartum surge, although it continues to be released by the corpus luteum throughout pregnancy (281). Joint relaxation in the symphysis pubis increases during pregnancy but returns to baseline 3 to 5 months post delivery (283). Thus, it seems unlikely that joint laxity accounts for the relationship between prior pregnancy and injury. Some longer-term effects of pregnancy cannot be altogether ruled out (283).

Table 42. Injury Incidence with Pregnancy History Stratified by Age

Age (years)	Pregnancy History: Never Pregnant n	Never Pregnant Injured (%)	Pregnant 1–6 Months Ago n	Pregnant 1–6 Months Ago Injured (%)	Pregnant 7–12 Months Ago n	Pregnant 7–12 Months Ago Injured (%)	Pregnant ≥ 13 months Ago n	Pregnant ≥ 13 months Ago Injured (%)	p-value (Chi Square/ Linearity Test)
17.0–19.9	264	63.6	7	57.1	21	76.2	36	66.7	0.66 / 0.46
20.0–24.9	246	59.8	12	58.3	20	75.0	77	77.9	0.02 /< 0.01
25.0–29.9	55	65.5	2	50.0	8	75.0	53	83.0	0.18 / 0.04
≥ 30	34	67.6	3	33.3	6	83.3	71	81.7	0.12 / 0.08

8. CONCLUSIONS

a. This prospective study demonstrated that prescribing running shoes based on the static weight-bearing plantar foot surface shape had little influence on injury risk in BCT, even after control of known injury risk factors. There was little difference in injury rates among those who were prescribed a different type of shoe (motion control, stability, or cushion) based on plantar foot shape and those who received a stability shoe regardless of plantar foot shape. When high- and low-arched individuals wore a stability shoe, their injury rates were similar to normal-arched individuals who wore a stability shoe. High-arched men who wore cushioned shoes tended to be at slightly higher injury risk than high-arched men who wore stability shoes.

b. There was no consistent association between arch height and injury risk, although low-arched individuals tended to have higher injury risk. Plantar foot shapes judged as high, normal, or low did correspond to measured arch heights on an average, group basis; however, there was considerable disparity among the plantar foot shape determinations and the measured arch heights, making individual estimates subject to high levels of misclassification. Plantar surface determinations corresponded to measured arch heights only about 66% of the time.

c. Injury incidence in this study was historically high, when compared with previous surveys conducted during US Army BCT at Fort Jackson. Changes in the BCT program of instruction; changes in recruiting policies allowing entry to older, less fit, and less educated recruits; and the continuing temporal trend of lower entry-level fitness may account for at least a part of the higher injury rates.

d. The present study confirmed and expanded on several BCT injury risk factors. In consonance with previous investigations, factors increasing injury risk included older age, less physical fitness on entry, less physical activity prior to entry, cigarette smoking, and menstrual dysfunction. Findings related to cigarette smoking were expanded upon by showing that injury risk progressively increased with younger onset of smoking and progressively decreased the longer the individual had quit smoking. Active duty Army recruits were at higher injury risk than guard or reserve recruits possibly due to better pre-BCT preparation of the latter, especially pre-BCT physical training). For women, prior lower limb injury and prior pregnancy also increased injury risk.

9. RECOMMENDATION. It is not necessary to prescribe running shoes to BCT recruits on the basis of the shape of the plantar surface of the foot since this procedure is not protective against injury any more than being prescribed a single shoe regardless of plantar foot shape. The current practice of prescribing shoes in this manner in BCT can be discontinued. It is still recommended that recruits receive a new shoe on entry to BCT, since older shoes have previously been shown to increase injury risk (66).

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APPENDIX A
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127. VanAntwerp RL (2006). MEMORANDUM FOR Franklin L. Hagenbeck, Deputy Cheif of Staff, G-1, United States Army, 300 Pentagon, Washington DC 20310-0300. Subject:

Recommendation for 12-Month Waiver of AR 600-9 Requirements for Soldiers Who Enter the Army with Automatic Body Fat Waivers after Passing Assessment of Recruit Motivation and Strength (ARMS) Testing. February 7:
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APPENDIX B
REQUEST LETTER

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APPENDIX C
APPROVAL TO CONDUCT THE STUDY

From: Duchesneau, Caryn L Ms USAMRMC
Sent: Tuesday, March 20, 2007 10:32 PM
To: Knapik, Joseph J Dr USACHPPM
Cc: 'james.patton@hqda.army.mil'; 'steven.bullock@us.army.mil'; 'trone@nhrc.navy.mil'; Brosch, Laura R COL USAMRMC; Duchesneau, Caryn L Ms USAMRMC; Kline, Andrea J Ms USAMRMC; Bennett, Jodi H Ms USAMRMC; Smith, Catherine A Ms USAMRMC; DePaul, Debra Ms AMDEX
Subject: A-14153, Amendment #1 Approval Memo (Proposal Log Number CHPPM-77G039-12MA5K1) (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE

SUBJECT: Amendment # 1 for the Protocol, "Physical Training Footwear and Musculoskeletal Injuries," Submitted by Joseph Knapik, Sc.D., U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), Aberdeen Proving Ground, Maryland, Proposal Log Number CHPPM-77G039-12MA5K1, HRPO Log Number A-14153

1. The subject protocol was approved by the U.S. Army Medical Research and Materiel Command's (USAMRMC's) Human Subjects Research Review Board (HSRRB) on 1 March 2007 via an expedited review IAW 32 CFR 219.110. The USAMRMC HSRRB serves as the Institutional Review Board (IRB) of Record for this protocol.

2. The request to modify the protocol was received by the USAMRMC HSRRB on 18 March 2007. The changes have been reviewed for compliance with applicable human subject protection regulations.

3. The amendment adds a script for use during recruitment briefings.

4. The change proposed in the amendment does not pose any new or additional risks to participants beyond those identified in the previously approved protocol. The protocol amendment is approved.

5. In accordance with 32 CFR 219.109(e), the Principal Investigator should submit a continuing review report no later than 29 January 2008 to ensure continuing review is completed prior to 29 February 2008, the study approval expiration date. A copy of the final report should be submitted as soon as possible after completion of the study.

6. Any amendments to the protocol require review and approval by the USAMRMC HSRRB prior to implementation.

7. The point of contact for this action is Debra DePaul, R.N., M.S.N., at 301-619-2620.

CARYN L. DUCHESNEAU, CIP
Vice Chair, Human Subjects
Research Review Board
U.S. Army Medical Research and Materiel Command

Note: The official signed copy of this approval is housed with the protocol file at the Office of Research Protections, 504 Scott Street, Fort Detrick, MD 21702. Signed copies will be provided upon request.

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APPENDIX D. LIFESTYLE QUESTIONNAIRE (EXAMPLE)

Physical Training Footwear & Musculoskeletal Injuries: Trainee Survey

PLEASE READ ALL DIRECTIONS AND QUESTIONS CAREFULLY.

- **Answer all questions to the best of your recollection.**
- **Ask research staff for help if you need it.**

About You

1. Today's date: |___|___| / |___|___| / |___|___|___|___|
   MONTH DAY YEAR

2. What is your name? ________________________________
   (LAST NAME, FIRST NAME, MIDDLE INITIAL)

3. What is your SSN? |___|___|___|-|___|___|-|___|___|___|___|

4. What is your birth date? |___|___| / |___|___| / |___|___|___|___|
   MONTH DAY YEAR

5. Are you…
   - ☐ 1 Male
   - ☐ 2 Female

6. Which service branch are you in?
   - ☐ 1 Air Force
   - ☐ 2 Army
   - ☐ 3 Marine Corps
   - ☐ 4 Navy

7. Prior to entering basic training, what type of shoes did you wear most of the day?
   - ☐ 0 Don't know
   - ☐ 1 Boots
     Name or type, _______________
   - ☐ 2 Dress shoes
     Name or type, _______________
   - ☐ 3 Women Only: Dress shoes with heels (1" or less)
     Name or type _______________
   - ☐ 4 Women Only: Dress shoes with heels (More than 1")
     Name or type, _______________
   - ☐ 5 Running shoes
     Name or type, _______________

☐6 Sandals
Name or type, ______________

☐7 Other
Please specify, ______________

Tobacco Use

8. Have you smoked at least 100 cigarettes in your life? (100 cigarettes = 5 packs)

   ☐1 YES
   ☐2 NO

9. About how old were you when you smoked a whole cigarette for the first time?
   (If you have never smoked a whole cigarette, write 00)

   |___|___| Years Old

10. During the past 30 days, on how many days did you smoke a cigarette?
    (If you have never smoked or not smoked in the last 30 days, write 00)

    |___|___| Days

11. During the past 30 days, on the days you smoked, how many cigarettes did you smoke per day?
    (If you have never smoked or not smoked in the last 30 days, write 00)

    |___|___| Cigarettes

12. If you used to smoke cigarettes and quit, how many months ago did you quit?
    (If you have never smoked, write 00)

    |___|___| Months

Physical Activity

13. Compared to others your same age and sex, how would you rate yourself as to the amount of physical activity you performed prior to entering basic training?

    ☐1 Much less active
    ☐2 Somewhat less active
    ☐3 About the same
    ☐4 Somewhat more active
    ☐5 Much more active

14. Over the last 2 months, what was the average number of times per week you exercised or played sports for at least 30 minutes at a time?

    ☐0 Never
    ☐1 Less than 1 time per week
    ☐2 1 time per week
    ☐3 2 times per week
    ☐4 3 times per week
    ☐5 4 times per week

- ☐6 5 times per week
- ☐7 6 times per week
- ☐8 7 times or more per week

15. Over the last 2 months, how many times per week did you run or jog?

- ☐0 Never
- ☐1 Less than 1 time per week
- ☐2 1 time per week
- ☐3 2 times per week
- ☐4 3 times per week
- ☐5 4 times per week
- ☐6 5 times per week
- ☐7 6 times per week
- ☐8 7 times or more per week

16. How long were you running or jogging before you entered basic training?

- ☐0 Did not run or jog
- ☐1 1 month or less
- ☐2 2 months
- ☐3 3 months
- ☐4 4 to 6 months
- ☐5 7 to 11 months
- ☐6 1 year or more

17. Over the last 2 months, how often per week did you perform weight training exercises?

- ☐0 Never
- ☐1 Less than 1 time
- ☐2 1 time
- ☐3 2 times
- ☐4 3 times
- ☐5 4 times
- ☐6 5 times
- ☐7 6 times
- ☐8 7 times or more

18. How consistently, 2 or more times per week, have you been performing weight training?

- ☐0 Did not weight train > 2/wk
- ☐1 1 month of less
- ☐2 2 months
- ☐3 3 months

☐4 4 to 6 months
☐5 7 to 11 months
☐6 1 year or more

Injury History

19. Have you ever injured bone, muscle, tendon, ligaments, and/or cartilage in one or both of your lower limbs?

☐1 YES ☐2 NO

20. Did any of these injuries prevent you from participating in your normal physical activities for at least one week?

☐0 Does not apply, never been injured
☐1 YES
☐2 NO

21. Following these injuries, were you able to eventually return to 100% of your normal physical activities?

☐0 Does not apply, never been injured
☐1 YES
☐2 NO

If you are a **man**, stop here and wait for further instructions.

If you are a **woman**, complete questions 21 through 25 on the following page.

Women Only: Menstrual History

22. At what age did you start to menstruate?
(If you have not had a menstrual cycle, write 00)

|___|___| Years

23. Over the last 12 months, how many menstrual periods did you have?
(If you have not had a menstrual period, write 00)

|___|___| Menstrual Periods

24. During the last 12 months, have you ever missed six or more months in a row between menstrual cycles?

☐0 N/A, I have never had a menstrual period

☐1 No, I have never missed 6 or more months in a row between menstrual cycles

☐2 Yes, I have missed 6 months or more in a row between menstrual cycles

25. In the last 12 months, have you taken birth control pills or any other hormonal therapy?

☐1 YES

☐2 NO

26. If you have ever been pregnant, how many months ago were you last pregnant?
(If you have never been pregnant, write 00)

|___|___| Months

Stop here and wait for further instructions from the staff.

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APPENDIX E
QUESTIONNAIRE USED TO OBTAIN INFORMATION ON SHOE CHANGES DURING BCT

Military Physical Training Footwear Project
PT Shoe Not Purchased in the Reception Station PX

Name ______________________________ SSN _____________________________

1. List the make and model of the shoe that WAS NOT the shoe you purchased in the Reception Station PX (for example: Asics Gel Cumulus, New Balance 644, Asics GT1120, Asics Foundation, Saucony Grid Omni 5, etc) ____

2. SHOE SIZE of the shoe that was not purchased in the Reception Station PX ________

3. What % of the time did you wear these shoes for PT during basic training _____ %

4. Did you change your running shoes because:
   a. Other shoes hurt feet/shoes caused pain
   b. Other shoes were uncomfortable
   c. Another reason (explain)____

5. Did you replace your running shoes more than one time during BCT?
___ No
___ Yes

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APPENDIX F
CRITERIA FOR ASSIGNING STRESS FRACTURE CASES TO THE PTRP

All stress fracture cases sent to the PTRP were diagnosed with X-ray, bone scan, and/or MRI. Bone scans alone were not sufficient for the diagnosis and a stress fracture must have had clinical signs and symptoms with X-ray or MRI confirmation. Most MRIs were reserved for femoral neck and talar dome stress fractures, as these were difficult to visualize on X-rays.

Not all subjects diagnosed with stress fractures were sent to the PTRP. Subjects who could be considered “low risk,” based on a consideration of clinical findings, bone scan, X-ray and cortical involvement were not sent to the PTRP even if they were diagnosed with stress fractures. Thus, only the more serious stress fracture cases entered the PTRP

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APPENDIX G
ACKNOWLEDGEMENTS

We would like to thank Ms Carol Pace and Mr Jason Brown for assistance with data collection. Ms Carol Pace and Ms Claudia Coleman put forth dedicated efforts to obtaining many of the references used in this paper. Mr James Allen provided us with critical subject information in the Reception Station. LTC Sonya Corum coordinated collection of the APFT scores and arranged for us to interview subjects after BCT to determine whether they had changed their shoes. Thanks to Ms Colleen Barkley for conversations regarding the clinical care of injured recruits and for her clinical observations, which were examined as part of this study. COL David Niebuhr and MAJ Sherly Bedno provided information on the Harvard Step Test in the Military Entrance Processing Stations. CPT Mayb Sersland explained to us the National Guard and Army Reserve Recruit Sustainment Program. Ms Anita Spiess edited the final manuscript.