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

USACHPPM

EPIDEMIOLOGICAL REPORT NO. 12-HF-05SBA-07C

INJURY-REDUCTION EFFECTIVENESS
OF PRESCRIBING RUNNING SHOES
BASED ON PLANTER SHAPE
IN MARINE CORPS BASIC TRAINING
SAN DIEGO, CA, AND PARRIS ISLAND, SC
MARCH – OCTOBER 2007

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

Naval Health Research Center
San Diego, CA

Approved for Public Release, Distribution Unlimited

CHPPM FORM 432-E (MCHB-CS-IPD), OCT 03

Readiness Thru Health

ACKNOWLEDGEMENTS

This research was supported by the Naval Health Research Center, Work Unit No. 60626. This research was conducted in compliance with all applicable federal regulations governing the protection of human subjects in research (protocol NHRC.2007.009 and NHRC.2007.005). We would like to express our appreciation to the following members of our research team from the Naval Health Research Center in San Diego, CA: Carol Macera, Mitchell Rauh, and Richard Shaffer. Additional thanks are due to James Reading from MCRD, San Diego, CA.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
MAY 2009	FINAL	MARCH 2007–OCTOBER 2007

4. TITLE AND SUBTITLE
Injury-Reduction Effectiveness of Assigning Running Shoes Based on Plantar Shape in Marine Corps Basic Training, San Diego, CA, and Parris Island, SC, March – October 2007

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Joseph J Knapik, Daniel W Trone, David I Swedler, Timothy Bockelman, Adriana Villasenor, Emily Schmied, Steve Bullock, Peggy Han, Bruce H Jones

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Health Research Center, San Diego CA
US Army Center for Health Promotion and Preventive Medicine, Aberdeen Proving Ground MD

8. PERFORMING ORGANIZATION REPORT NUMBER
12-HF-05SBA-07C

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Safety Oversight Council, Military Training Task Force, Pentagon, Washington DC

10. SPONSOR/MONITOR'S ACRONYM(S)
DSOC, MTTF

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT: Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
In response to a request from the Military Training Task Force of the Defense Safety Oversight Council, this study examined whether prescribing running shoes based on the shape of the plantar surface influenced injury risk in Marine Corps basic training. After foot examinations, Marine Corps recruits in an experimental group (E, n=408 men, 314 women) were prescribed motion-control, stability, or cushioned shoes for plantar shapes indicative of low, medium, or high arches, respectively. A control group (C, n=432 men, 256 women) received a stability shoe regardless of plantar shape. Injuries during training were determined from outpatient visits provided by the Armed Forces Health Surveillance Center. Other known injury risk factors (e.g., fitness, smoking, prior physical activity) were obtained from a questionnaire, existing databases, or the training units. Multivariate Cox regression controlling for other risk factors showed little difference between the E and C groups among men (hazard ratio(E/C)=1.04, 95% confidence interval=0.83–1.29) or women (hazard ratio(E/C)=0.82, 95% confidence interval = 0.65–1.14). This prospective study demonstrated that assigning shoes based on the shape of the plantar foot surface had little influence on injuries after control of other injury risk factors.

15. SUBJECT TERMS:
Physical fitness, physical activity, height, weight, body mass index, age, arch height, smoking, prior injuries, menstrual history, push-ups, crunches, 1.5 mile run.

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESONSIBLE PERSON Dr. Joseph Knapik
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER *(include area code)* 410-436-1328

Standard Form 298 (Rev.8/98)
Prescribed by ANSI Std. Z39.18

Department of the Army
US ARMY CENTER FOR HEALTH PROMOTION AND PREVENTIVE MEDICINE
5158 BLACKHAWK ROAD
ABERDEEN PROVING GROUND MD 21010-5403

MCHB-TS-DI

EXECUTIVE SUMMARY
EPIDEMIOLOGICAL REPORT NO. 12-HF-05SBA-07C
INJURY REDUCTION EFFECTIVENESS OF PRESCRIBING RUNNING SHOES BASED ON PLANTAR SHAPE IN MARINE CORPS BASIC TRAINING
SAN DIEGO, CA, AND PARRIS ISLAND, SC
MARCH – OCTOBER 2007

1. INTRODUCTION AND PURPOSE.

a. In 2003, the Secretary of Defense directed the Department of Defense to reduce preventable mishaps or injuries by 50 percent. The Under Secretary of Defense for Personnel and Readiness responded by establishing the Defense Safety Oversight Council (DSOC), which chartered nine task forces to develop recommendations to reduce preventable injuries. One of these, the Military Training Task Force (MTTF), 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 fifth out of 21 projects.

b. In Marine Corps recruit training, new recruits are prescribed running shoes based on the amount of foot surface contacting the floor (i.e., the plantar shape of the foot). The plantar shape during weight-bearing is presumed to reflect the longitudinal foot arch height. Shoe manufacturers market three classes of running shoes designed for individuals with high, normal, and low arches: cushioned, stability, and motion-control shoes, respectively. These shoes presumably reduce injuries by compensating for hypothetical differences in running mechanics. The primary purpose of this study was to determine whether or not injury risk can be reduced by prescribing running shoes based on the static weight-bearing plantar foot shape. Secondary purposes were to 1) examine the association between the shape of the plantar foot surface and actual arch height, 2) examine the relationship between arch height and injuries, and 3) examine risk factors for injuries in Marine Corps recruit training.

2. METHODS.

a. Subjects were male and female volunteers engaged in Marine Corps recruit training. The men trained at the Marine Corps Recruit Depot (MCRD) at San Diego, California, and the women trained at the MCRD at Parris Island, South Carolina. Just prior to training, volunteer recruits completed a questionnaire that asked about tobacco use, physical activity, injury history, and (for women) menstrual history. To determine the shape of the plantar surface of the foot (plantar shape), the barefoot subject mounted an illuminated box device that reflected the underside of their feet. A trained observer made a determination of the plantar shape as high, normal, or low based on templates: more area in the middle third of the plantar surface indicated a low plantar shape and less area a high plantar shape. After the plantar shape determinations, each subject's' longitudinal foot arch heights were measured with a digital caliper as the distance from standing surface to the inferior medial border of the navicular tuberosity.

b. Subjects were randomized into either an experimental (E) or a control (C) group. The C group subjects received a standard issue New Balance 767 (stability shoe) regardless of plantar shape. The E group subjects received a shoe based on their plantar shape: if the E group subject had a low plantar shape, a New Balance 587 (motion-control shoe) was provided; if the E group subject had a high plantar shape, a New Balance 881 (cushioned shoe) was provided; if the E group subject had a normal plantar shape, a New Balance 767 (stability shoe) was provided.

c. Injury data were obtained from the Defense Medical Surveillance System (DMSS) of the Armed Forces Health Surveillance Center (AFHSC). The AFHSC regularly incorporates into the DMSS data on ambulatory (outpatient) encounters that occur within military treatment facilities (MTFs). The DMSS provided visit dates and ICD-9 codes for all outpatient medical visits within the recruit's training time. Injuries were determined using standard ICD-9 codes. Additional data obtained included attrition from training, physical fitness test scores (pull-ups (for men), flexed arm hang (women), crunches, and 1.5-mile run), physical characteristics (height, weight, body mass index, abdominal circumference), and demographics (date of birth, component, educational level, marital status, race/ethnicity).

3. RESULTS.

a. There were 917 men and 694 women who volunteered for the study. Not considered in the analyses were volunteers who were missing graduation dates in unit records, who did not enter basic training due to medical or administrative reasons, who left the test area before receiving a group assignment, or those whose data were not obtained from the DMSS. The final cohort considered for analysis consisted of 840 men and 571 women.

b. Overall injury rates during recruit training differed little between the E and the C groups among the men (E=5.8, C=5.7 injuries/1000 person days, p=0.95) or the women (E=5.0, C=6.0 injuries/1000 person-days, p=0.16). Univariate Cox regression (a survival analysis technique) found little difference in injury risk between the E and C men (hazard ratio (E/C)=1.01, 95 percent confidence interval (95%CI)=0.82–1.24) or women (hazard ratio (E/C)=0.88, 95%CI=0.70–1.10). In multivariate Cox regression controlling for other known injury risk factors, there was also little difference in injury risk between the E and C groups for either men (hazard ratio (E/C)=1.04, 95%CI=0.83–1.29) or women (hazard ratio (E/C)=0.82, 95%CI=0.65–1.14).

c. There were no differences in injury risk when the 20 percent of recruits with the highest measured foot arch height were compared with the 60 percent of recruits in the middle distribution of arch heights. Similarly, there were no differences in injury risk when the 20 percent of recruits with the lowest measured foot arch heights were compared with the 60 percent of recruits in the middle distribution of arch heights.

d. For the men's right foot arch, plantar shapes rated as low, normal, and high had mean arch height measurements(± standard deviation) of 28.1 ±5.5, 36.4 ±6.9, and 40.2 ±8.5 millimeters, respectively ($p<0.01$); for women, these values were 28.4 ±7.2, 35.1 ±6.9 and 36.7 ±7.3, respectively ($p<0.01$). Arch heights were categorized into the percentile distributions found in the plantar shapes and a "match" was defined as an arch height category that matched the low, normal, and high plantar shape category. Overall, arch height categories were matched to plantar shape categories only 64 percent of the time. Normal plantar shapes had the largest numbers of matches (over 80 percent), while high and low plantar shapes matched only 23 percent and 31 percent of the time, respectively.

e. In univariate analysis, factors significantly associated with increased injury risk in both men and women included older age, slower 1.5-mile run times, fewer abdominal crunches, cigarette smoking prior to training, and, for women, less frequent physical activity prior to training and abnormal menses (oligomenorrhea). In multivariate analysis, factors significantly associated with injury risk for men included slower 1.5-mile run times, cigarette smoking prior to training, and not participating in high school sports. In multivariate analysis, risk factors for women included older age, heavier body weight, slower 1.5-mile run times, less frequent running, and weight lifting prior to recruit training.

4. 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 Marine Corps recruit training even after controlling for other injury risk factors. There was little difference in injury risk among those who were assigned a shoe (motion control, stability, or cushioned) based on plantar shape and those who were assigned a stability shoe regardless of plantar shape.

b. Injury risk was not associated with measured arch height.

c. Plantar foot shapes visually judged as low, normal, and high had progressively higher average arch heights. Despite this, there were a considerable number of mismatches when plantar shapes were matched with corresponding percentiles of arch heights. Arch heights matched corresponding percentiles of measured plantar shapes only about 64 percent of the time.

d. In consonance with previous Army, Air Force, and some Marine Corps data, injury risk was greater among recruits who were older, smokers, less fit, and less physically active, as well as among women who had abnormal menses.

5. RECOMMENDATION. If the goal is injury prevention, it is not necessary to assign running shoes to Marine Corps recruits based on a visual inspection of the static, weight-bearing plantar shape. Assigning running shoes on this basis was no more protective against injury than issuing a single stability shoe regardless of plantar shape. It is still recommended that recruits receive a new shoe on entry to Marine Corps recruit training since older shoes have previously been shown to be associated with higher injury risk.

CONTENTS

Appendices

USACHPPM REPORT NO. 12-HF-05SBA-07C
INJURY REDUCTION EFFECTIVENESS OF PRESCRIBING RUNNING SHOES BASED ON PLANTAR SHAPE IN MARINE CORPS BASIC TRAINING
SAN DIEGO, CALIFORNIA, AND PARRIS ISLAND, SOUTH CAROLINA
MARCH – OCTOBER 2007

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 mishaps or injuries by 50 percent. In 2006, the goal became to reduce mishaps or injuries by 75 percent. The Under Secretary of Defense for Personnel and Readiness responded to the directive 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, the Military Training Task Force (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 fifth out of 21 projects. The chairman of the MTTF requested the assistance of the United States (US) Army Center for Preventive Medicine (CHPPM) and the Naval Health Research Center (NHRC) in organizing a tri-service effort to address footwear prescription.

b. The practice in the United State Marine Corps at the time of the study was to assign running shoes based on the amount of foot surface contacting the floor (i.e., the shape of the plantar foot surface). The plantar foot shape during weight-bearing was presumed to reflect foot arch height. Shoe manufacturers market three classes of running shoes designed for individuals with high, normal, and low arches: cushioned, stability, and motion control, respectively. These shoes presumably reduce injuries by compensating for presumed differences in running mechanics (1). At the time this study was conceived there was insufficient evidence in the scientific literature to determine whether this strategy does, in fact, reduce injuries (2).

c. The primary purpose of this study was to determine whether or not injury risk can be reduced by assigning running shoes based on the static weight-bearing plantar foot shape. There were three secondary purposes to this study. As noted above, the shape of the plantar foot surface is assumed to reflect foot arch height, but this assumption has not been examined. Thus, a secondary purpose was to examine the association between the shape of the plantar foot surface and arch height. A few studies have suggested that a relationship may exist between injuries and foot arch height (3, 4). Thus, another secondary purpose was to examine the relationship between arch height and injuries. Finally, this study also presents the opportunity to see if fitness and lifestyle factors that have been found to increase injury risk in previous Army and Air Force basic training (5-9) also increase injury risk in Marine recruit training. Previous studies of Marine Corps recruit training identified some injury risk factors and the present investigation was designed to expand on those (10, 11).

3. AUTHORITY.

a. Under Army Regulation 40-5 (12), the US Army Center for Health Promotion and Preventive Medicine (CHPPM) is responsible for providing epidemiological consultation services upon request. This project was initiated by the MTTF of the DSOC: a letter of request is in Appendix B. The studies recruited Service Members participating in basic training in the Army, Air Force, and Navy. Personnel from the Naval Health Research Center (NHRC) collected and prepared Marine Corps recruit data. At the request of the NHRC, CHPPM agreed to assist with analyzing the data and completing the scientific report on the project.

b. Employing the criteria of the Council of the State and Territorial Epidemiologists (13), it was determined that this project constituted research. Thus, research protocols were submitted to the NHRC Institutional Review Board (IRB) at San Diego, CA. The IRB approved the research protocols (numbers NHRC.2007.0005 and NHRC.2007.0009).

4. BACKGROUND

The significant burden of injury to service members of the US Armed Forces has been widely discussed (14, 15). Injuries are a significant problem in military populations and have a major impact on operational readiness. The services lose millions of dollars annually from medical costs, lost training time, and attrition associated with injury. In 1999, musculoskeletal conditions were responsible for at least 14,000 hospital admissions and almost 4.3 million outpatient visits among active-duty personnel in the Armed Services (14). Injury-related conditions account for limited duty rates of 40 to 120 days per 100 soldiers per month (16). In training populations, the incidence of both musculoskeletal injury and stress fracture is higher among women than among men, and accounts for considerable female attrition (5, 17, 18). The occurrence of a training-related injury is associated with poor long-term military outcomes (18). Injury rates vary in different studies but generally about 25 percent of all men and 50 percent of all women will experience an injury during the course of basic training (5, 14). The majority of overuse injuries to the lower extremities appear to come from physical fitness training activities, specifically running (19, 20).

In the US Marine Corps, basic trainees are assigned running shoes on the basis of foot shape (presumed to be a good estimate of foot arch height), under the assumption that this reduces injuries. Whether or not this technique reduces injuries has not been specifically tested. In addition to the lack of specific evidence for the efficacy of prescribing running shoes, no DoD-wide study has been performed to determine injury rates or risk factors in the basic training programs of the various services using the same injury metrics. Several studies have documented injury rates for each of the services (6, 7, 9, 21-25), but between-service comparisons are not possible because of different injury definitions and different methods of collecting injury data.

a. Foot Arch Height and Injuries

(1) The practice of measuring foot arch height as a means of avoiding musculoskeletal injury is questionable (2, 26). Measuring arch height is often considered useful, quantifiable information regarding foot structure, shock absorption capabilities, and movement function. However, arch-height measurement is confounded by both bone and soft-tissue variation between individuals. Feet have been classified into low, normal, or high arch types on the basis of shape of the plantar surface of the foot, but no consistent objective criteria exist (2). Another limitation of arch-height classification is that the categorization does not take into account foot flexibility, which can be related to injury (27). Measurement of static weight-bearing arch height has been reported to be unrelated to the magnitude of ground reactive forces during running (28, 29), so the relationship of arch height to shock-absorption capabilities appears uncertain. These studies suggest that a predisposition to lower-extremity injury might not be predicted by measuring arch height.

(2) Army investigators measured the level of agreement among six clinicians on the classification of foot types into flat, normal, or high arched, based on observation of photographs of different angles of the feet (30). 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 (26). 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 high arched. It can be concluded that static observation of arch height alone is of little predictive clinical value and is therefore of minor importance (2).

(3) Does individually fitting a pair of running shoes influence injury risk? Running shoe companies have diversified their shoes for each sex, by body frame, arch height, gait, and various levels of midsole cushioning. Some services utilize objective methods to evaluate longitudinal foot arch height and prescribe certain types of shoes for those specific foot types under the assumption that this will prevent injuries. While this practice has reasonable theoretical basis, the practice of prescribing footwear based upon longitudinal arch height is an unproven prevention strategy (2). An Army retrospective cohort study conducted at Ft. Drum, New York, reported that recommending a running shoe on the basis of foot arch height, ankle flexibility, and body weight resulted in a lower injury rate than the standard practice of soldiers purchasing shoes on their own (31). However, the authors cautioned that the presence of a major confounder (medical providers changed the method of recording injury data during the study)

resulted in only tentative support for the program's effectiveness in reducing injuries. This study involved only the Army and it is not known whether trainees from the different services would have similar responses to this shoe fitting strategy.

(4) At the inception of this project, the DSOC desired to definitively answer whether or not prescribing running shoes on the basis of foot shape influences injury rates. In order to make service-specific or DoD-wide recommendations regarding this practice, a tri-service study was needed to determine both efficacy and the best protocol for implementation.

b. Injuries and Footwear

(1) There are a large number of biomechanical studies involving running shoes (32-38) 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 occurrences of injury are sparse. Two case studies and several epidemiological investigations provide some evidence that ill-fitting and older shoes may result in higher injury rates. These studies are reviewed below.

(2) Wilk et al. (39) 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. On the basis of one case the authors could not establish an association between the injury and the shoe. Plantar fasciitis is a common running injury (40-42) and the problem in this case could have been caused by other factors as well as the shoe's heel counter.

(3) Burgess and Ryan (43) reported a case study of a 26-year old man who forgot to bring 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 was five times more malleable than the "tennis" shoe.

(4) Gardner et al. (44) 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 reported that their shoes were 6 to 12 months old were 2.3 times

more likely to experience a stress fracture during recruit training compared with those who reported that their shoes were less than one month old.

(5) In another study, injuries were compared in Israeli Defense Force recruits training in either 1) modified high-topped basketball shoes with ethyl vinyl acetate soles or 2) regular combat boots with molded double-density polyurethane soles. Experiments showed that tibial accelerations while walking on concrete were 19 percent 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) (45).

(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 (46).

(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 and the case study of the runner in tennis shoes suggested an association between lower shock absorbency and stress fractures. Furthermore, there is a mileage-related loss of shock absorbency in older running shoes (47). 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 (31) examined the effectiveness of a running shoe prescription program at Fort Drum, New York, designed to reduce injuries. A physical therapist examined the feet of newly arriving Soldiers and classified them based on observed arch height (high, medium, or low) and flexibility (normal or rigid). A category of running shoes (motion control, stability, or cushioned) was then recommended on the basis of the foot examination. Codes from the 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 soldier-months before the program began and 18.6 cases/1000 soldier-months 5–14 months after the program began (relative risk (after/before)=0.50, $p< 0.01$). 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 were 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. Since the outcome of this retrospective study were questionable, it was considered imperative that the program be tested in a randomized prospective cohort study.

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

(1) Cumulative injury incidence (proportion of trainees who experience one or more injuries during training) and injury rates (injured trainees per month) have been examined in the basic training units of the Army, Navy, Marine Corps, and Air Force (6-9, 17, 22, 24, 44, 48-55). These data are shown in Table 1. US Army Basic Combat Training (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 investigations are included of US Army infantry basic training, which is 12 weeks long.

(2) It might be expected that injury rates would differ across the services because of differences in the types and intensity of training. However, direct comparisons of service-specific rates in Table I are confounded by the use of different injury collection methods and different injury definitions, even within the same service. With regard to data collection, many investigations used medical records screening (6, 21, 50, 54, 56-58), but other studies used medical surveillance systems (8, 24, 25, 55, 59) or questionnaires (23, 51). 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 (8, 9, 24, 50, 54, 55, 57, 58), but other studies have included only musculoskeletal injuries (6) or lower extremity overuse injuries (6, 10, 21). One study used self-reporting and included any injury regardless of whether or not the trainees sought medical care (51).

Table 1. Cumulative Incidence of Injury and Injury Incidence Rates during Army, Navy, Marine Corps and Air Force Basic 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	60[a]	1978	347	770	26.2	62.0	13.1	31.0
		50	1980	1,840	644	20.7	41.2	10.4	20.6
		6	1984	124	186	27.4	50.5	13.7	25.3
		56	1988	509	352	27.0	57.0	13.5	28.5
		54	1994	ND	165	ND	66.7	ND	33.3
		21	1996	159	84	41.5	65.5	20.8	32.8
		9	1998	604	305	30.8	58.0	15.4	29.0
	9 weeks	57	1998	655	498	29.98	65.3	13.3	29.0
		58[b]	2000	682/441	579/554	13.5/16.9	36.1/46.8	6.0/7.5	16.0/20.8
		59[bc]	2003	442/569	295/377	19.5/27.9	41.0/47.7	8.7/12.4	18.2/21.2
		55	2007	2,147	915	36.9	64.7	16.4	28.8
	12 weeks (Infantry)	7	1988	303	ND	45.9	ND	15.3	ND
		[d]	1996	768	ND	48.0	ND	16.0	ND
Marine Corps	12 weeks	23	1993	1,143	ND	39.6	ND	14.4	ND
		25	1995–96	ND	2,766	ND	44.0	ND	14.7
		22	1993–94	176	241	25.6	44.0	9.3	14.7
		61	1993	434	366	22.8	53.0	8.3	17.7
			1995	396	1,498	29	49	10.5	16.3
			1995	2,546	ND	25	ND	9.1	ND
		10	1999	ND	824	ND	48.5	ND	16.2
Navy	9 weeks	25	1996	ND	8,865	ND	37.2	ND	12.4
Air Force	6 weeks	24	1994–95	8,660	5,250	16.8	37.8	11.2	25.2
		8	2007	1,979	723	27.6	46.9	18.4	31.3

Legend:
ND = no data collected on this gender

Notes:
[a] Injury data from self-report questionnaire
[b] Cohort study with two groups
[c] Injury data from surveillance system
[d] Previously unpublished data (1998)

(3) In addition to cumulative injury incidence and injury rates, injury risk factors have been identified in some of the military services. Like comparison of injury rates, relative risks across services cannot be compared quantitatively because of different injury collection methods and different injury definitions. Further, some risk factors identified in one service have not been investigated in other services. In Army, Air Force and Marine Corps training, risk factors included female gender (6, 7, 9, 22, 24, 48-53), low aerobic fitness (6, 8-11, 23, 48, 49, 54, 61,

62), cigarette smoking prior to BCT (7-9, 61-63), and low physical activity prior to basic training (6-11, 44, 49, 62). In Army and Navy trainees, longer running mileage during basic training was an injury risk factor (19, 64). Low muscular endurance has been associated with injuries in Army and Air Force basic training (7-9). In Army BCT, training in the summer was associated with higher overall injury risk compared with training in the fall (65). In male Marine Corps recruits, older running shoes were associated with a higher risk of stress fractures (44). Among female Marine Corps recruits and Army recruits, menstrual irregularities have been associated with higher injury risk (10, 55). Multivariate analyses in Army and Air Force basic training 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 (7, 9, 55, 66).

d. Objectives. The purposes of this study were to (1) examine whether or not prescribing running shoes on the basis of foot shape influences injury risk during basic training, 2) examine the association between the shape of the plantar foot surface and actual arch height, 3) examine the relationship between arch height and injuries, and 4) examine risk factors for injuries in Marine Corps recruit training.

5. METHODS

a. Subjects. Subjects were volunteers from among male basic trainees at the MCRD, San Diego, California, and female basic trainees at the MCRD, Parris Island, South Carolina. On entry to basic training, potential volunteers were briefed on the purposes and risks of the study and those wishing to participate in the investigation signed an informed consent statement. The informed consent statements and research protocols were approved by the institutional review board of the Naval Health Research Center (Appendix C). Separate approvals were required for the San Diego portion of the study (men; protocol number NHRC.2007.0005) and for the Parris Island portion (women; protocol number NHRC.2007.0009).

b. Study Design. This was a randomized prospective cohort study. Subjects served in either an experimental (E) group or a control (C) group. E group subjects were prescribed a running shoe based on the shape of the plantar surface of their feet. The C group subjects received a standard issue stability running shoe regardless of the shape of their plantar surface. All enrolled subjects were followed until graduation or separation from their original training unit.

c. Procedures.

(1) All initial testing was performed between March and July 2007. Immediately after the informed consent was obtained, subjects were administered a questionnaire that asked about tobacco use, physical activity, injury history, and (for women) menstrual history. This questionnaire is in Appendix C. The questionnaire for men did not contain the last page with the questions on menstrual history.

(2) To determine the shape of the plantar surface of the foot (plantar surface evaluation), the barefoot subject 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. This provided a view of the footprint from above, showing how much of the foot was in contact with the acrylic surface. The subjects were instructed to stand with equal weight on each foot with their feet comfortably apart. The plantar surface area (footprint) was examined. A determination was made as to whether the plantar surface was high arched, normal arched, or low arched, based on templates (1): more area in contact with the Plexiglas surface in the middle third of the plantar surface indicated a low plantar shape, less area in contact with the Plexiglas surface indicated a high plantar shape. In a subsample of cases (n=66), two raters made independent determinations of the plantar shape and those determinations were recorded independently for the purposes of calculating between-rater reliability.

Figure 1a.High-Arched Feet

Figure 1b. Normal Arched Feet

Figure 1. Plantar Foot Shape Device

(3) After the plantar foot shape was determined, the subjects' foot lengths and foot arch heights were measured with the device shown in Figures 2 and 3. Total foot length and medial metatarsophalangeal joint (MPJ) length were determined using a measuring ruler built into the device. Total foot length was measured as the distance from the most distal aspect of the longest toe to the most posterior part of the heel. MPJ length was measured as the distance from the first (proximal) MPJ to the most posterior part of the heel. Foot arch height was measured with a digital 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 stood 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

(4) Following all foot measurements, participating recruits were randomized into one of the two groups (C or E), using a group assignment order that was randomly generated by a statistical software program. To eliminate any potential bias, group assignment was made by a single study staff member not conducting the foot type assessments. Recruits assigned to the C group received a stability shoe, the New Balance 767ST. Recruits assigned to the E group received a shoe based on the determined shape of the plantar surface of their foot. If an E group recruit had a low arch, a motion-control shoe, New Balance 587NV, was assigned. Motion-control shoes presumably help limit excessive pronation through the use of harder midsole materials (polyurethane) and other features that are specific to particular models. If the E group recruit had a high arch, a cushioned shoe, New Balance 881WG, was assigned. Cushioned shoes contain softer midsole material such as ethyl vinyl acetate (EVA) that presumably allows for greater shock absorption and permits more pronation. If the E group recruit had a normal arch, a stability shoe was assigned, a New Balance 767ST. The stability shoe is midway between motion-control and cushioned shoes, containing some motion-control features and double density midsoles (EVA and polyurethane). All participating recruits were asked their shoe size and a shoe of the proper size was assigned. If the assigned shoe did not fit properly, different shoe sizes were tried until a proper fit was achieved. All foot measurements, prescribed shoe type (brand and model), and shoe size were recorded on a data sheet (see Appendix D).

d. Physical Characteristics and Physical Fitness.

(1) Additional data were obtained from an existing administrative data source collected and maintained by the Recruit Training Regiment (RTR) staff as standard procedure. These data included weight, height, and physical fitness test scores measured before the first day of recruit training. Each recruit's weight and height were measured in socks, T-shirts, and shorts using a standard, calibrated mechanical physician's beam scale with stadiometer.

(2) For the men, the fitness test consisted of three events: pull-ups, abdominal crunches, and a 1.5-mile run, administered in that order. The three fitness test events were administered by drill instructors using standardized procedures. For the pull-up, the recruit grasped a horizontal bar with both hands, palms facing away (pronated). The starting position was with the arms fully extended beneath the bar, feet free from touching the ground, and the body motionless. One repetition consisted of raising the body with the arms until the chin was above the bar, with no swinging or "kipping," and then lowering the body until the arms were fully extended. The motion was repeated as many times as possible with no time limit and the number of repetitions served as the event score. For the abdominal crunch, the recruit's knees were bent and arms were placed across the chest with the hands resting on the shoulders or upper chest. A second person was allowed to hold the recruit's feet to keep the heels firmly on the ground. The recruit raised his upper body to a vertical position so that elbows touched the knees or thighs and then returned to the starting position such that the shoulder blades touched the ground before beginning a new repetition. Scores were the number of pull-ups successfully completed or

crunches successfully completed within a 2-minute time period. The performance measure for the run was the time taken to complete the 1.5-mile distance. Time between events was no less than 10 minutes.

(3) The women at Parris Island performed identical abdominal crunch and 1.5-mile run events. However, instead of the pull-up, they performed a flexed arm hang. The goal of the that event was for the recruit to hang (maintaining elbow flexion) for as long as possible. The recruit grasped a horizontal bar with both hands. The recruit flexed her arms at the elbow, chin held above the bar and not touching it, with the body motionless. The recruit could drop down below the bar; however, once the recruit's arms were fully extended or she dropped off the bar, the clock was stopped. The performance score was the time on the bar.

e. Demographics. The Defense Medical Surveillance Activity (now the Armed Forces Health Surveillance Center) provided demographic data for the recruits 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 Processing Station (MEPS). Information obtained from the DMSS on the study subjects included date of birth, component (active Marine Corps or reserve Marine Corps), educational level, marital status, and race/ethnicity.

f. Attrition from Training. Some subjects did not complete the entire basic training cycle but their data were included for the time they remained in training, as described below. For the purposes of this investigation, reasons for attrition included discharge from the Marine Corps or reassignment to a new company (recycle). Discharges and recycles were obtained from a local data system maintained by the San Diego and Parris Island MCRDs.

g. Injury Outcome Measures.

(1) Besides demographic data, the DMSS regularly incorporates data on ambulatory (outpatient) encounters that occur within military treatment facilities (MTFs). The DMSS provided visit dates and ICD-9 codes for all outpatient medical visits within the recruit training timeframe for 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 Related Injury Index (TRII), the Comprehensive Injury Index (CII), and the Modified Overuse Injury Index (MOII). These indices include specific ICD-9 codes, as described previously (53). The MOII has not been described previously and the ICD-9 codes included in this index are shown in Appendix E.

(2) The III and TRII were developed by personnel at the DMSS. The III has been used to compare overall injury rates (acute and overuse) among military posts and is reported on a

monthly basis at the Armed Forces Health Surveillance Center website (http://afhsc.army.mil). The TRII is limited to lower extremity overuse injuries and has been used to compare injury rates among Army basic training posts. The TRII is reported on a monthly basis to the Army Training and Doctrine Command surgeon.

(3) The MIII, CII, and MOII were developed by personnel in the Injury Prevention Program at the CHPPM. 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 MOII captures the subset of musculoskeletal injuries presumably resulting from cumulative microtrauma (overuse injuries) such as stress fractures, stress reactions, tendonitis, bursitis, fasciitis, arthralgia, neuropathy, radiculopathy, shin splints, synovitis, sprains, strains, and musculoskeletal pain (not otherwise specified).

h. Data Analysis.

(1) Data were compiled and analyzed using SPSS version 16.0.1. Age was calculated from the date of birth in the DMDC data to the date of the informed consent briefing. Body mass index (BMI) was calculated as weight/height^2 (67). Arch indices for each foot 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 calculated because it might be assumed that an individual with a greater foot length might have a higher foot arch.

(2) The E and C groups were compared on attrition, the questionnaire variables, age, physical characteristics, physical fitness, demographic characteristics, foot measurements and foot indices. For dichotomous, nominal, and ordinal variables comparisons were made using the chi-square statistic; for continuous measures, E and C group comparisons were performed using an independent sample t-test. To determine the magnitude of differences between the groups Cohen's d-value (68) was calculated as the absolute value of the difference between the means of the C and E groups, divided by the standard deviation of the C group ($|mean_C – mean_E|/SD_C$). Effect sizes were defined as small (d=0.2), medium (d=0.5) and large (d=0.8), as specified by Cohen (68). 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:

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

Those who attrited from training were considered only for the time in training (time at risk). Comparisons between the E and C groups were made using a chi-square for person-time (69).

(4) Cox regression was used to examine the associations between potential risk factors (including group assignment) and time to first CII injury. For each analysis, once a subject had an injury, his or her contribution to time in basic training was terminated. Those who attrited from training had their time censored (i.e., end of time at risk) at the day they left their training company. All potential risk factors were entered into the regression model as categorical variables. Some interval and ordinal variables were combined to increase statistical power. Most continuous variables were divided into four equal-sized categories based on the distribution of the scores. Age was categorized into 3 groups (17–19, 20–24, ≥25 years). Arch height measurements and arch indices were separated into categories comprising the highest and lowest 20 percent of values (leaving 60 percent in the central distribution). For all Cox regressions, simple contrasts were used, comparing the hazard at the baseline level of a variable (defined with a hazard ratio (HR) of 1.00) with other levels of the same categorical variable. Univariate Cox regressions established the individual association between time to first injury and levels of each potential risk factor. Potential risk factors were included in a multivariate Cox regression model if they achieved $p< 0.10$ in the univariate analyses (70). Multivariate Cox regressions established the effect of multiple risk factors (including group assignment) on injury risk.

(5) Measures of arch height and the arch indices were compared with plantar surface determinations. Analysis of variance (ANOVA) was used to determine if there were differences in the measured arch heights and arch indices for the three plantar shapes (low, normal, and high). The proportion (%) of subjects in each of the three plantar shapes was compared with the same proportion (%) in the measured arch height and arch indices and the number of recruits in both categories were considered those correctly classified.

6. RESULTS.

a. Subjects and Attrition.

(1) There were 917 men and 694 women who volunteered for the study. Subjects in the first platoon began basic training on 13 March 2007 and graduated on 31 May 2007. Subjects in the last platoon began training on 31 July 2007 and graduated on 18 September 2007.

(2) Not considered in the analyses were volunteers with missing graduation dates, those not entering basic training (attrited before the first day of basic training), those who did not receive a group assignment, and/or those whose data were not obtained from the DMSS. Of the original cohort of volunteers, no graduation date was obtained from the RTR on 33 recruits (28 men and 5 women). There were 111 recruits (13 men and 98 women) who did not enter basic training for medical or administrative reasons. Also, 55 volunteers (35 men and 20 women) left the test area before receiving a group assignment and the DMSS did not return data on 50 volunteers (26 men and 24 women). Some volunteers were in multiple problem categories: for

example, 37 volunteers had no DMSS data and did not enter basic training. The final cohort consisted of 840 men and 571 women.

(3) Among the men, 15.3 percent of the C group and 11.5 percent of the E group attrited from training (p=0.11). Among the women, 12.1 percent of the C group and 11.5 percent of the E group attrited from training (p=0.83). These subjects were considered for analysis until the time they left training.

b. Comparisons of C and E Groups. Not all subjects had complete measurements on all variables. This occurred primarily because the recruits did not provide a response on the questionnaire or the training unit did not have some specific information. Therefore, sample sizes shown in the tables below differ, depending on the completeness of the data.

(1) Age, Physical Characteristics, and Fitness Test Scores. Table 2 compares group differences in age, physical characteristics, and fitness scores for men and women at the start of training. Differences in the physical characteristics between the E and C groups were small for both men and women. With regard to physical fitness, group differences were also small between the C and E group women. For the most part this was also true of the men, but the C group men performed an average of 1 more pull-up and 3 more crunches than the E group men.

Table 2. Group Comparisons of Age, Physical Characteristics, and Fitness Scores at Start of Training

	Men						Women					
	C		E				C		E			
	n	Mean ±SD	n	Mean ±SD	p-value[a]	d-value[b]	n	Mean ±SD	n	Mean ±SD	p-value[a]	d-value[b]
Age (yr)	415	20.6 ± 2.2	393	20.7 ± 2.2	0.57	0.05	256	19.2 ± 2.0	312	19.1 ± 2.0	0.41	0.05
Height (in)	394	69.6 ± 2.7	377	69.4 ± 2.8	0.38	0.07	232	64.2 ± 2.6	281	63.8 ± 2.7	0.12	0.15
Weight (lb)	394	171 ± 27	376	169 ± 27	0.23	0.07	257	132 ± 17	313	131 ± 16	0.40	0.06
BMI (kg/m^2)	394	24.9 ± 3.4	376	24.6 ± 3.5	0.38	0.09	232	22.5 ± 2.3	281	22.6 ± 2.4	0.90	0.04
Pull-Ups (reps)	401	8 ± 5	381	9 ± 5	<0.01	0.10	NA					
Flexed Arm Hang (sec)	NA						254	45 ± 17	313	45 ± 17	0.60	0.00
Crunches (reps)	401	62 ± 17	381	65 ± 18	<0.01	0.18	255	66 ± 19	313	67 ± 20	0.67	0.05
1.5-Mile Run (min)	401	11.3 ± 1.1	381	11.2 ± 1.1	0.16	0.09	255	13.9 ± 1.2	313	13.8 ± 1.2	0.43	0.08

Legend:
C=control group
E=experimental group
NA=not applicable (test not performed)
SD=standard deviation

Notes:
[a] Independent sample t-test
[b] Cohen's d-value

(2) Demographic Characteristics. Table 3 shows group comparisons on the demographic variables. The distribution of subjects was similar within the two groups for component, educational level, race, and marital status among both men and women.

Table 3. Group Comparisons on Demographic Characteristics

Variable	Level of Variable	Men C (%) n=432	Men E (%) n=408	Men p-value[a]	Women C (%) n=342	Women E (%) n=331	Women p-value[a]
Component	Active Marine Corps Marine Corps Reserves	87.0 13.0	89.7 10.3	0.23	82.9 17.1	82.8 17.2	0.98
Educational Level	High School Graduate Some College or Graduate Unknown	94.0 5.3 0.7	95.6 3.9 0.5	0.58	94.9 1.6 3.5	97.7 1.3 1.0	0.11
Race	White Hispanic Black Other Unknown	73.8 14.4 4.4 4.4 3.0	77.0 12.0 3.9 5.1 2.0	0.66	79.0 2.3 12.8 5.1 0.8	78.3 2.2 15.6 2.9 1.0	0.63
Marital Status	Single Married Other[b]	94.2 5.6 0.2	92.6 6.1 1.2	0.22	95.7 4.3 0.0	97.1 2.5 0.3	0.35

Legend:
C=control group
E=experimental group

Notes:
[a] Chi-square statistic
[b] Divorced, separated, widowed

(3) Questionnaire Data.

(a) Table 4 compares the groups on the ordinal and nominal questionnaire variables (Appendix C). For most questions, the distribution of E and C subjects across the response categories was similar, although there were a few exceptions. Compared with the C group men, the E group men had more smokers (Question 8) and more with a prior lower limb injury (Question 19).

Table 4. Group Comparisons on Ordinal/Nominal Questionnaire Variables

Question	Sample Sizes	Response Category	Men C (%)	Men E (%)	Men p-value[a]	Women C (%)	Women E (%)	Women p-value[a]
Q7. Shoe Type Prior to Basic Training	Men C=415 Men E=395 Women C=253 Women E=311	Boots Dress Running Heels ≤ 1 inch[b] Heels ≥ 1 inch[b] Sandals Other Unsure	18.8 4.8 57.6 0.0 0.0 2.2 11.3 5.3	22.5 5.3 55.2 0.0 0.0 2.0 10.6 4.3	0.82	1.2 2.0 1.2 1.6 61.7 28.1 2.4 2.0	3.2 2.3 1.3 3.9 56.6 25.4 6.1 1.3	0.14
Q8. Smoked 100 Cigarettes in Lifetime	Men C=431 Men E=403 Women C=256 Women E=313	No Yes	64.7 35.3	57.3 42.7	0.03	74.6 25.4	77.6 22.4	0.40

Question	Sample Sizes	Response Category	Men C (%)	Men E (%)	Men p-value[a]	Women C (%)	Women E (%)	Women p-value[a]
Q13. Self Rating of Physical Activity	Men C=422 Men E=407 Women C=257 Women E=314	Much less active Somewhat less active About the same Somewhat more active Much more active	4.5 18.0 30.6 36.3 10.7	3.4 15.5 31.0 38.1 12.0	0.75	2.7 12.1 33.5 42.4 9.3	1.9 13.1 30.6 42.7 11.8	0.79
Q14. Frequency of Exercise or Sports Last 2 Months	Men C=425 Men E=408 Women C=257 Women E=314	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	2.8 8.5 6.1 20.5 24.5 15.3 12.2 6.0 3.5	2.9 5.9 9.1 20.6 24.0 15.4 11.5 5.6 4.9	0.68	0.8 4.3 7.8 19. 5 22.2 19.5 16.3 5.8 3.9	0.6 4.1 8.9 20.7 25.5 17.8 10.5 7.0 4.8	0.71
Q15. Frequency of Running or Jogging Last 2 Months	Men C=427 Men E=407 Women C=257 Women E=314	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	3.7 7.5 11.0 20.1 26.0 16.2 9.1 3.5 2.8	4.2 8.6 11.5 19.9 23.1 16.2 9.1 4.7 2.7	0.99	0.8 8.6 12.1 24.1 22.6 15.6 10.1 3.9 2.3	0.6 7.3 12.4 27.1 23.2 16.2 8.3 3.5 1.3	0.97
Q16. Length of Time Ran or Jogged Prior to Basic Training	Men C=430 Men E=406 Women C=257 Women E=314	Did not run or jog ≤ 1 month 2 months 3 months 4–6 months 7–11 months ≥ 12 months	6.3 38.6 20.9 15.6 6.7 4.0 7.9	8.6 34.2 24.4 12.6 10.8 3.4 5.9	0.11	3.9 14.4 17.9 10.9 18.7 12.1 22.2	5.1 17.8 14.3 13.4 19.7 8.6 21.0	0.52
Q17. Frequency of Exercise with Weights Prior to Basic Training	Men C=431 Men E=408 Women C=257 Women E=314	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	14.2 12.3 9.5 19.5 17.9 11.1 7.7 4.6 3.2	20.8 10.3 7.1 22.1 16.7 8.1 7.1 4.2 3.7	0.22	22.2 8.6 16.7 19.1 16.3 8.9 4.3 1.6 2.3	22.3 16.9 12.7 16.6 13.7 8.9 4.5 1.9 2.5	0.24
Q18. Length of Time Performing Weight Training ≥ 2 Times/Week	Men C=429 Men E=404 Women C=257 Women E=314	No training ≤ 1 month 2 months 3 months 4–6 months 7–11 months ≥ 12 months	29.4 23.3 19.3 11.4 8.9 2.3 5.4	34.2 22.5 14.6 9.7 8.7 2.2 8.2	0.29	44.4 17.1 12.5 4.3 10.1 3.9 7.8	46.8 17.8 10.8 5.4 8.0 3.8 7.3	0.95

Question	Sample Sizes	Response Category	Men C (%)	Men E (%)	Men p-value[a]	Women C (%)	Women E (%)	Women p-value[a]
Q19. Had a Prior Lower Limb Injury	Men C=430 Men E=407 Women C=257 Women E=314	No Yes	90.2 9.8	86.2 13.8	0.07	76.7 23.3	79.3 20.7	0.45
Q20. Did Lower Limb Injury Prevent You from Doing Normal Physical Activity	Men C=429 Men E=406 Women C=257 Women E=313	No injury No Yes	90.4 4.2 5.4	86.5 4.7 8.9	0.13	76.7 5.8 17.5	79.6 5.1 15.3	0.71
Q21. Returned to Normal Physical Activity Since Injury	Men C=427 Men E=07 Women C=257 Women E=314	No injury No Yes	90.9 0.5 8.7	86.2 0.0 13.8	0.03	76.7 0.0 23.3	79.3 1.3 19.7	0.18
Q24. Gone ≥ 6 Months without Menstrual Cycle[b]	Women C=257 Women E=314	Never had a Period No Yes	NA			7.4 90.7 1.9	7.6 87.3 5.1	0.14
Q25. Used Birth Control in Past 12 Months[b]	Women C=257 Women E=314	No Yes				64.6 35.4	67.5 32.5	0.46

Legend:
C=control group
E=experimental group
NA=not applicable; Q=question number on the survey

Notes:
a. Chi-square statistic
b. Not considered in the analysis for men

(b) Table 5 examines group differences in the continuous questionnaire variables. Here again, differences between groups were small. Few women had been pregnant, but the time since the last pregnancy was considerably longer for the C group than for the E group women. This was primarily because two C group women reported being pregnant 114 and 157 months ago (10 and 13 years ago) whereas the longest time since pregnancy for the E group women was 36 months. The median time since last pregnancy was 34 months for the C group and 16 months for the E group.

Table 5. Group Comparisons on Continuous Questionnaire Variables

Question	Men						Women					
	C		E				C		E			
	n	Mean ±SD	n	Mean ±SD	p-value[a]	d-value[b]	n	Mean ±SD	n	Mean ±SD	p-value[a]	d-value[b]
Q9. Age Started Smoking (years)[c]	254	16 ± 3	258	16 ± 2	0.45	0.00	106	15 ± 2	114	15 ± 3	0.70	0.00
Q10. Days Smoked Cigarettes in Last 30 Days[c] (n)	151	15 ± 11	149	13 ± 11	0.17	0.18	60	17 ± 11	70	20 ± 11	0.13	0.27
Q11. Cigarettes per Day Over Last 30 Days[c] (n)	147	8 ± 13	155	7 ± 7	0.27	0.08	60	6 ± 6	71	7 ± 7	0.56	0.17
Q12. Quit Smoking (months)[d]	41	13 ± 16	56	15 ± 17	0.49	0.13	33	17 ± 14	20	14 ± 15	0.51	0.21
Q22. Age at Menarche (years)	NA						257	13 ± 1	314	13 ± 1	0.19	0.00
Q23 Menstrual Cycles (n/year)							257	11 ± 2	314	11 ± 3	0.23	0.00
Q26. Time Since Last Pregnancy (months)[e]							6	59 ± 62	10	16 ± 10	<0.01	0.70

Legend:
C=control group
E=experimental group
Q=question number on the survey
NA=not applicable
SD=standard deviation

Notes:
[a] Independent sample t-test
[b] Cohen's d-value
[c] Only subjects who reported smoking included
[d] Only subjects who reported that they had quit smoking were included
[e] Only subjects who reported that they had been pregnant were included

(4) Foot Measurements and Arch Indices.

(a) The kappa coefficient between the two raters on the plantar surface evaluations was 0.91 for the right foot and 0.91 for the left foot (n=66). Table 6 shows the distribution of subjects by plantar shape. For women, the distribution of plantar shapes was similar for the C and E groups. Compared with the men in the C group, the E group tended to have slightly fewer men with normal plantar shapes and slightly more with high plantar shapes.

Table 6. Distribution of Subjects by Plantar Shape

Foot	Plantar Shape	Men					Women				
		C		E			C		E		
		n	%	n	%	p-value[a]	n	%	n	%	p-value[a]
Right Foot	Low	27	6.3	35	8.6	0.11	21	8.2	39	12.5	0.25
	Normal	369	85.8	328	80.4		186	72.4	216	69.0	
	High	34	7.9	45	11.0		50	19.5	58	18.5	
Left Foot	Low	32	7.4	30	7.4	0.12	25	9.7	40	12.8	0.48
	Normal	355	82.6	318	77.9		180	70.0	216	69.0	
	High	43	10.0	60	14.7		52	20.2	57	18.2	

Legend: C=control group; E=experimental group Notes: [a] Chi-square statistic

(b) Table 7 compares group differences in the foot measurements and arch indices. The men in the C group and the women in the E group tended to have slightly longer foot lengths, but the differences were small, amounting to an average of 0.3 cm. C group men also tended to have slightly longer MPJ lengths, but again this amounted to an average of only 0.2 cm. For all measures, Cohen's effect sizes (d-values) were generally very small between the E and C groups.

Table 7. Group Comparisons on the Foot Measures and Arch Indices

Measure	Men				Women			
	C (n=397) Mean ±SD	E (n=373) Mean ±SD	p-value[a]	d-value[b]	C (n=158) Mean ±SD	E (n=178) Mean ±SD	p-value[a]	d-value[b]
Right Foot Total Length (cm)	26.9 ± 1.3	26.8 ± 1.2	0.05	0.08	24.1 ± 1.1	24.3 ± 1.2	0.12	0.18
Left Foot Total Length (cm)	27.0 ± 1.3	26.8 ± 1.2	0.02	0.15	24.1 ± 1.1	24.4 ± 2.0	0.10	0.18
Right Foot MPJ Length (cm)	19.9 ± 1.1	19.8 ± 1.2	0.10	0.09	17.9 ± 0.9	18.0 ± 1.0	0.41	0.11
Left Foot MPJ Length (cm)	19.9 ± 1.2	19.7 ± 1.1	0.09	0.17	17.9 ± 0.9	18.0 ± 1.0	0.56	0.11
Right Foot Arch Height (mm)	36.1 ± 7.3	36.0 ± 7.6	0.95	0.01	35.2 ± 7.0	34.0 ± 7.6	0.13	0.17
Left Foot Arch Height (mm)	35.7 ± 8.0	36.1 ± 7.6	0.47	0.05	34.8 ± 6.8	34.1 ± 6.7	0.36	0.10
Right Arch Index	0.1343 ± 0.0280	0.1349 ± 0.0290	0.76	0.02	0.1464 ± 0.0292	0.1404 ± 0.0324	0.08	0.21
Left Arch Index	0.1326 ± 0.0307	0.1350 ± 0.0288	0.25	0.08	0.1442 ± 0.0283	0.1402 ± 0.0297	0.22	0.14
Right Bony Arch Index	0.1820 ± 0.0390	0.1830 ± 0.0404	0.73	0.03	0.1976 ± 0.0405	0.1902 ± 0.0449	0.12	0.18
Left Bony Arch Index	0.1807 ± 0.0431	0.1838 ± 0.0404	0.31	0.07	0.1947 ± 0.0395	0.1908 ± 0.0414	0.38	0.10

Legend: C=control group; E=experimental group; SD=standard deviation. Notes: [a] Independent sample t-test; [b] Cohen's d-value

c. Injury Rates and Injury Risk Factors

(1) Table 8 shows the person-time injury incidence rates for the various injury indices and compares the rates in the C and E groups. Among the men, the incidence rates for the C and E groups were very similar. Among the women, the incidence rates for the E group were somewhat lower than those for the C group.

Table 8. Comparison of Injury Incidence Rates between the E and C Groups

Injury Index	Men				Women			
	Injury Incidence Rate (injuries/ 1000 person-days)				Injury Incidence Rate (injuries/ 1000 person-days)			
	C (n=432)	E (n=408)	Rate Ratio-C/E (95%CI)	p-value[a]	C (n=257)	E (n=314)	Rate Ratio-C/E (95%CI)	p-value[a]
Installation Injury Index	5.14	5.40	0.95 (0.77–1.19)	0.70	5.43	4.57	1.19 (0.91–1.55)	0.24
Modified Installation Injury Index	5.24	5.40	0.97 (0.78–1.21)	0.79	5.90	4.59	1.20 (0.93–1.56)	0.19
Modified Overuse Injury Index	4.14	4.06	1.02 (0.79–1.31)	0.89	3.29	2.80	1.18 (0.83–1.66)	0.41
Training-Related Injury Index	3.56	3.63	0.98 (0.75–1.28)	0.88	1.49	2.03	1.18 (0.79–1.77)	0.48
Comprehensive Injury Index	5.72	5.76	0.99 (0.80–1.22)	0.95	6.00	4.96	1.21 (0.94–1.57)	0.16

Legend:
C=control group
E=experimental group
CI=confidence interval

Notes:
[a] Chi-square statistic for person-time (69)

(2) Table 9 shows the univariate Cox regression examining the association of time to first CII injury with group, age, physical characteristics, and fitness test scores. Among the men, injury risk was almost identical in the E and C groups. Higher injury risk among the men was associated with age, lower performance on pull-ups, lower performance on crunches, and slower 1.5-mile run times. Among the women, those in the C group tended to be at slightly higher injury risk than those in the E group. Higher injury risk among the women was associated with older age, lower body weight, lower performance on the flexed arm hang, lower performance on the crunches, and slower 1.5-mile run times.

Table 9. Injury Hazard Ratios by Group, Age, Physical Characteristics, and Fitness Test Scores (Univariate Cox Regression)

	Men				Women			
Variable	Level of Variable	n	Hazard Ratio (95%CI)	p-value	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Group	C	432	1.00	---	C	256	1.00	---
	E	408	1.01 (0.82–1.24)	0.94	E	314	0.88 (0.70–1.10)	0.15
Age (yr)	18–19	408	1.00	---	18–19	470	1.00	---
	20–24	361	1.27 (1.02–1.58)	0.03	20–24	88	1.04 (0.73–1.48)	0.82
	≥25	39	0.80 (0.44–1.43)	0.44	≥25	9	2.46 (1.09–5.55)	0.03
Height (in)	60–67	161	0.98 (0.71–1.36)	0.90	53–62	151	1.13 (0.75–1.17)	0.55
	68–69	243	0.87 (0.64–1.18)	0.37	63–64	151	1.03 (0.68–1.57)	0.88
	70–71	183	1.10 (0.81–1.50)	0.55	65–66	121	0.88 (0.57–1.37)	0.57
	72–78	184	1.00	---	67–71	89	1.00	---
Weight (lb)	103–148	192	1.00	---	87–119	145	1.00	---
	149–167	202	0.90 (0.66–1.23)	0.52	120–132	145	0.76 (0.54–1.06)	0.11
	168–191	191	1.14 (0.85–1.55)	0.38	133–143	142	0.66 (0.46–0.94)	0.02
	192–251	185	0.95 (0.69–1.31)	0.75	144–180	133	0.63 (0.44–0.91)	0.01
Body Mass Index (kg/m^2)	16.0–22.0	193	1.00	---	15.4–20.7	128	1.00	---
	22.1–24.6	191	0.82 (0.60–1.12)	0.21	20.8–22.7	128	1.07 (0.73–1.57)	0.73
	25.7–27.7	191	0.97 (0.72–1.31)	0.83	22.8–24.4	126	1.00 (0.68–1.46)	0.98
	27.8–33.6	192	0.92 (0.68–1.25)	0.60	24.5–35.6	127	0.90 (0.60–1.33)	0.58
Flexed Arm Hang (sec)	NA				5–30	146	1.35 (0.95–1.92)	0.10
					31–44	143	1.09 (0.76–1.57)	0.63
					45–58	136	0.79 (0.54–1.18)	0.25
					59–70	141	1.00	---
Pull-Ups (reps)	0–4	212	1.56 (1.15–2.21)	<0.01	NA			
	5–8	222	1.18 (0.86–1.62)	0.29				
	9–11	154	1.34 (0.96–1.88)	0.09				
	12–26	194	1.00	---				
Crunches (reps)	13–51	202	1.56 (1.15–2.21)	<0.01	13–51	144	1.79 (1.22–2.62)	<0.01
	52–61	194	1.11 (0.81–1.54)	0.52	52–62	140	1.12 (0.74–1.69)	0.58
	63–73	200	1.03 (0.75–1.43)	0.84	63–80	155	1.49 (1.02–2.02)	0.04
	74–159	186	1.00	---	81–130	128	1.00	---
1.5-Mile Run (min)	8.25–10.45	195	1.00	---	10.1–13.0	144	1.00	---
	10.46–11.17	212	1.22 (0.88–1.68)	0.23	13.1–14.0	143	1.40 (0.94–2.10)	0.10
	11.18–12.00	195	1.32 (0.96–1.83)	0.09	14.1–14.7	138	1.99 (1.35–2.93)	<0.01
	12.01–15.03	180	2.02 (1.48–2.77)	<0.01	14.8–17.4	142	1.89 (1.28–2.78)	<0.01

Legend: C=control group, E=experimental group, CI=confidence interval, NA=not applicable

(3) Table 10 shows the univariate Cox regression examining the association between time to first injury and the demographic characteristics. Men were at higher injury risk if they were White, compared with "other." The "other" category consisted of 7 Native Americans, 30 recruits of Asian descent and 3 with only "other" coded as their race. Among women, those whose educational status was unknown were at higher injury risk.

Table 10. Injury Hazard Ratios for Demographic Characteristics (Univariate Cox Regression)

Variable	Level of Variable	Men n	Men Hazard Ratio (95%CI)	Men p-value	Women n	Women Hazard Ratio (95%CI)	Women p-value
Component	Active Marine Corps	742	1.00	---	472	1.00	---
	Marine Corps Reserves	98	1.17 (0.86–1.59)	0.32	98	1.10 (0.79–1.53)	0.57
Educational Level[a]	HS Graduate	796	1.00	---	548	1.00	---
	Some College/Graduate	39	1.22 (0.77–1.94)	0.40	8	1.45 (0.60–3.52)	0.41
	Unknown	5	1.69 (0.54–5.26)	0.37	12	2.16 (1.06–4.37)	0.03
Race	White	633	1.00	---	448	1.00	---
	Black	35	0.86 (0.48–1.53)	0.61	82	0.89 (0.61–1.31)	0.56
	Asian	111	0.95 (0.70–1.30)	0.76	13	0.69 (0.26–1.86)	0.47
	Other	40	0.44 (0.23–0.85)	0.02	22	0.94 (0.48–1.83)	0.86
	Unknown	21	0.86 (0.43–1.74)	0.68	5	0.90 (0.22–3.62)	0.88
Marital Status[b]	Single, Never Married	785	1.00	---	550	1.00	---
	Married	49	1.09 (0.70–1.72)	0.70	19	0.87 (0.41–1.83)	0.71
	Other	6	1.74 (0.65–4.67)	0.27	1	---	---

Legend:
CI=confidence interval
HS=high school

Notes:
[a] The two women who were not high school graduates were not considered in the analysis
[b] The one women of "other" marital status was not considered in the analysis

(4) Table 11 shows the univariate associations between time to first injury and the questionnaire variables. Among the men, higher injury risk was associated with smoking 100 cigarettes in a lifetime, beginning smoking at an older age, smoking in the 30 days before basic training, having smoked and quit more than 12 months ago, lower self-rating of physical activity, and not having played high school sports. Among the women, higher injury risk was associated with beginning smoking in their teens (12–17 years), smoking more than 10 cigarettes per day in the 30 days before recruit training, having smoked and quit more than 12 months ago, lower self-rating of physical activity, less frequent exercise/sports, less frequent running/jogging, less frequent weight training, age of menarche, fewer menstrual cycles in the last year, having missed menstrual cycles 6 months out of the last year, and taking birth control pills in the last year.

Table 11. Injury Hazard Ratios for Questionnaire Variables (Univariate Cox Regression)

Variable[a]	Response Category	Men n	Men Hazard Ratio (95%CI)	Men p-value	Women n	Women Hazard Ratio (95%CI)	Women p-value
Q7. Shoe Type Worn Before Recruit Training	Boots	167	1.00	---	13	1.00	---
	Dress	41	1.17 (0.72–1.92)	0.53	12	0.39 (0.08–2.00)	0.26
	Heels ≤ 1 inch[a]	0	---	---	7	1.11 (0.27–4.66)	0.88
	Heels >1 inch[a]	0	---	---	16	0.99 (0.30–3.24)	0.99
	Athletic	457	0.80 (0.61–1.05)	0.11	331	1.11 (0.46–2.71)	0.82
	Sandals	17	1.26 (0.63–2.52)	0.51	150	1.02 (0.41–2.54)	0.96
	Other	89	1.19 (0.83–1.71)	0.35	25	0.77 (0.25–2.34)	0.64
	Unsure	39	0.89 (0.51–1.49)	0.60	9	0.79 (0.19–3.32)	0.75

Variable[a]	Response Category	Men n	Men Hazard Ratio (95%CI)	Men p-value	Women n	Women Hazard Ratio (95%CI)	Women p-value
Q8. Smoked 100 Cigarettes in Life	No	510	1.00	---	433	1.00	---
	Yes	324	1.29 (1.04–1.59)	0.02	135	1.22 (0.91–1.63)	0.19
Q9. Age Started Smoking	Never Smoked	313	1.00	---	348	1.00	---
	6–11 years old	27	1.23 (0.67–2.29)	0.51	13	1.41 (0.62–3.21)	0.41
	12–17 years old	331	1.21 (0.88–1.43)	0.37	173	1.35 (1.02–1.79)	0.03
	≥ 18 years old	154	1.34 (1.01–1.79)	0.05	33	1.04 (0.59–1.84)	0.89
Q10. Smoked Cigarettes in Last 30 Days	No	519	1.00	---	437	1.00	---
	Yes	302	1.26 (1.02–1.57)	0.03	129	1.17 (0.87–1.58)	0.30
Q11. Cigarettes per Day in Last 30 Days	None	519	1.00	---	437	1.00	---
	1–9 cigarettes/day	201	1.26 (0.98–1.61)	0.07	98	1.07 (0.76–1.50)	0.71
	≥10 cigarettes/day	101	1.28 (0.93–1.76)	0.13	32	1.57 (0.94–2.63)	0.08
Q12. Smokers and Quitters	Never	420	1.00	---	385	1.00	---
	Smoker	302	1.29 (1.02–1.62)	0.03	129	1.22 (0.90–1.66)	0.21
	Quit 1–12 months	61	1.33 (0.89–1.99)	0.16	32	1.07 (0.61–1.89)	0.82
	Quit >12 months	33	1.73 (1.06–2.81)	0.03	20	2.59 (1.47–4.57)	<0.01
Q13. Self Rating of Physical Activity	Much Less Active	33	1.88 (1.02–3.45)	0.04	13	1.71 (0.63–4.60)	0.29
	Somewhat Less Active	39	1.75 (1.14–2.07)	0.01	72	1.88 (1.05–3.35)	0.03
	About the Same	255	1.45 (0.97–2.17)	0.07	181	1.94 (1.17–3.22)	0.01
	Somewhat More Active	308	1.35 (0.91–2.01)	0.14	243	1.34 (0.81–2.22)	0.26
	Much More Active	94	1.00	---	61	1.00	---
Q14. Frequency of Exercise or Sports Before Training	≤ 1 time/week	147	1.26 (0.89–1.77)	0.20	76	1.90 (1.23–2.93)	<0.01
	2–4 times/week	501	1.19 (0.90–1.56)	0.22	358	1.45 (1.09–2.03)	0.03
	≥ 5 times/week	185	1.00	---	136	1.00	---
Q15. Frequency of Running/Jogging Before Training	≤ 1 time/week	194	1.28 (0.91–1.80)	0.15	119	2.47 (1.35–4.06)	<0.01
	2–4 times/week	507	1.07 (0.79–1.44)	0.68	369	1.72 (1.09–2.72)	0.02
	≥ 5 times/week	133	1.00	---	82	1.00	---
Q16. Length of Time Running/Jogging Before Training	≤ 1 month	367	0.90 (0.64–1.27)	0.53	118	1.13 (0.80–1.62)	0.49
	2–6 months	380	0.86 (0.61–1.21)	0.38	271	0.94 (0.70–1.27)	0.70
	≥ 7 months	89	1.00	---	181	1.00	---
Q17. Frequency of Exercise with Weights, Last 2 Months	≤ 1 time/week	311	1.19 (0.87–1.64)	0.28	284	2.01 (1.11–3.64)	0.02
	2–4 times/week	400	0.99 (0.72–1.35)	0.94	237	1.89 (1.04–3.44)	0.04
	≥ 5 times/week	128	1.00	---	49	1.00	---
Q18. Length of Time Performing Weight Training	≤ 1 month	455	1.04 (0.72–1.15)	0.83	360	0.85 (0.58–1.26)	0.42
	2–6 months	303	0.89 (0.61–1.32)	0.57	145	0.77 (0.50–1.20)	0.25
	≥ 7 months	75	1.00	---	65	1.00	---
Q19. Prior Lower Limb Injury	No	739	1.00	---	446	1.00	---
	Yes	98	1.18 (0.87–1.62)	0.29	124	1.22 (0.90–1.65)	0.19
Q20. Did Lower Limb Injury Prevent Activity[c]	No	37	1.00	---	31	1.00	---
	Yes	59	0.79 (0.44–1.44)	0.45	92	1.37 (0.72–2.60)	0.33
Q21. After Recovery, Returned to 100%[c]	No	2	2.68 (0.36–19.75)	0.33	3	0.90 (0.12–6.48)	0.91
	Yes	91	1.00	---	121	1.00	---
Q22. Injury Due to Sports[c]	No	56	1.00	---	63	1.00	---
	Yes	37	0.89 (0.49–1.63)	0.71	59	1.05 (0.63–1.74)	0.86

Variable[a]	Response Category	Men			Women		
		n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
Q23 Rate Current Physical Fitness	Poor/fair Good Very Good/Excellent	211 415 198	1.18 (0.87–1.60) 1.18 (0.90–1.55) 1.00	0.29 0.22 ---	170 308 92	1.19 (0.81–1.78) 0.93 (0.65–1.35) 1.00	0.37 0.72 ---
Q24. Played High School Sports	No Yes	202 636	1.45 (1.15–1.82) 1.00	<0.01 ---	141 423	0.95 (0.70–1.28) 1.00	0.73 ---
Q25. Age at Menarche	8–10 years 11–14 years 15–26 years	NA			39 488 43	0.58 (0.31–1.09) 1.00 1.02 (0.63–1.65)	0.09 --- 0.94
Q26. Menstrual Periods in Last Year	0–9 10–12 ≥ 13				73 463 34	1.43 (1.00–2.04) 1.00 0.63 (0.32–1.23)	0.05 --- 0.18
Q27. 6 Months without Cycles, in Last Year	No Yes NA				506 21 43	1.00 1.63 (0.91–2.92) 1.37 (0.89–2.10)	--- 0.10 0.16
Q28. Taken Birth Control Pills, Last 12 Months	No Yes				377 193	1.00 1.25 (0.96–1.64)	--- 0.09
Q29. Time Since Last Pregnancy	Never Pregnant 1–12 months ≥ 12 months				551 5 11	1.00 1.10 (0.27–4.42) 1.23 (0.46–2.73)	--- 0.89 0.79

Legend:
CI=confidence interval
Q=question number on the survey

Notes:
[a] Not included in the analysis for men
[b] Only includes recruits who reported a previous lower limb injury and answered the question

(5) It appeared that some women may have misinterpreted the response categories for Question 27 (Appendix C), which asked if the woman had missed 6 or more menstrual cycles in a row in the last year. The NA (not applicable) response says "I have never had a menstrual period." It is possible that the response was read as "I have never missed a menstrual period." If their NA response for Question 27 was correct, then Question 25 should have been answered "00" which meant the woman had not started menstruating (amenorrhea). However, no woman responded "00" for Question 25. We included the women responding in the "NA" category with those who responded that they had not missed six cycles in a row and compared them with those (n=21) who had missed 6 cycles in a row. The injury risk for the women who had missed 6 cycles in a row in the last year (compared with the combined "NA": and "No" group) was 1.59, 95%CI=0.89–2.85, p=0.12.

(6) Table 12 shows the univariate associations between time to first injury and the plantar surface determinations. Men and women with higher plantar surfaces generally had modestly elevated injury risk compared with those with normal plantar surfaces. Men with low plantar surfaces had modestly reduced injury risk compared with those with normal plantar surfaces. Women with normal and low plantar surfaces differed little in injury risk.

Table 12. Injury Hazard Ratios for Plantar Surface Evaluations (Univariate Cox Regression)

Foot	Plantar Surface Determination	Men			Women		
		n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
Right	High	79	1.03 (0.72–1.47)	0.88	105	1.16 (0.84–1.62)	0.36
	Normal	697	1.00	---	406	1.00	---
	Low	62	0.85 (0.56–1.30)	0.46	57	0.98 (0.63–1.54)	0.94
Left	High	103	1.15 (0.84–1.56)	0.38	106	1.30 (0.94–1.78)	0.11
	Normal	673	1.00	---	398	1.00	---
	Low	62	0.73 (0.46–1.15)	0.17	64	1.02 (0.67–1.55)	0.94

Legend:
CI=confidence interval

(7) Table 13 shows the association between the time to the first injury and arch height, arch index, and bony arch index. For each variable, data are grouped in the lowest 20 percent of values, middle 60 percent of values, and highest 20 percent of values. For both men and women, there was very little difference in injury risk when the lowest and highest 20 percent were compared with the mid 60 percent group.

Table 13. Injury Hazard Ratios for Arch Height and Arch Indices (Univariate Cox Regression)

Variable	Men				Women			
	Level of Variable (Proportional Distribution Within Variable)	n	Hazard Ratio (95%CI)	p-value	Level of Variable (Proportional Distribution Within Variable)	n	Hazard Ratio (95%CI)	p-value
Arch Height Right	12.2–30.3 mm (low 20%)	154	0.99 (0.74–1.32)	0.94	15.1–28.3 mm (low 20%)	67	0.98 (0.63–1.53)	0.94
	30.4–42.2 mm (mid 60%)	463	1.00	---	28.4–41.1 mm (min 60%)	202	1.00	---
	42.3–61.6 mm (high 20%)	153	1.12 (0.85–1.48)	0.43	41.2–55.8 mm (high 20%)	67	0.91 (0.58–1.42)	0.67
Arch Height Left	11.6–29.7 mm (low 20%)	154	1.00 (0.75–1.33)	0.98	18.7–28.3 mm (low 20%)	67	0.97 (0.62–1.51)	0.89
	29.8–42.8 mm (mid 60%)	461	1.00	---	28.4–40.2 mm (mid 60%)	202	1.00	---
	42.9–70.7 mm (high 20%)	155	1.10 (0.83–1.45)	0.50	40.3–55.8 mm (high 20%)	67	0.98 (0.63–1.51)	0.92
Arch Index Right	0.0410–0.1128 (low 20%)	153	0.95 (0.71–1.27)	0.72	0.0613–0.1173 (low 20%)	67	1.16 (0.75–1.78)	0.51
	0.1129–0.1579 (mid 60%)	464	1.00	---	0.1174–0.1718 (mid 60%)	202	1.00	---
	0.1580–0.2505 (high 20%)	153	1.24 (0.95–1.63)	0.12	0.1719–0.2417 (high 20%)	67	0.96 (0.61–1.50)	0.85
Arch Index Left	0.0456–0.1094 (low 20%)	154	0.84 (0.62–1.13)	0.24	0.0724–0.1167 (low 20%)	67	1.04 (0.67–1.61)	0.86
	0.1095–0.1587 (mid 60%)	461	1.00	---	0.1168–0.1664 (mid 60%)	202	1.00	---
	0.1588–0.2526 (high 20%)	155	1.03 (0.78–1.36)	0.86	0.1665–0.2335 (high 20%)	67	0.93 (0.60–1.45)	0.75
Bony Arch Index Right	0.0556–0.1511 (low 20%)	152	0.95 (0.71–1.27)	0.71	0.0823–0.1567 (low 20%)	67	1.11 (0.72–1.71)	0.63
	0.1512–0.2136 (mid 60%)	464	1.00	---	0.1568–0.2321 (mid 60%)	202	1.00	---
	0.2137–0.3522 (high 20%)	154	1.13 (0.86–1.49)	0.39	0.2322–0.3285 (high 20%)	67	0.91 (0.58–1.43)	0.69
Bony Arch Index Left	0.0647–0.1473 (low 20%)	153	0.92 (0.69–1.24)	0.59	0.0973–0.1572 (low 20%)	67	1.11 (0.73–1.69)	0.64
	0.1474–0.2169 (mid 60%)	461	1.00	---	0.1573–0.2244 (mid 60%)	202	1.00	---
	0.2170–0.3400 (high 20%)	156	1.01 (0.76–1.34)	0.93	0.2245–0.3302 (high 20%)	67	0.77 (0.48–1.22)	0.26

Legend: CI=confidence interval

(8) Table 14 shows the results of the backward-stepping multivariate Cox regression with group (E and C) forced into the model. Subjects with complete data on all the variables included 763 men (91 percent of the male sample) and 563 women (98 percent of the female sample).

Among the men, injury risk was about the same for the E and C groups. However, injury risk was independently associated with slower run times, smoking cigarettes in the 30 days before basic training, and not participating in high school sports. Among the women, injury risk was slightly lower in the E group. Injury risk was independently associated with older age, less body weight, slower run times, less running and jogging in the 2 months before basic training, less weight lifting in the 2 months before basic training, and missing six or more menstrual cycles in the last year.

Table 14. Injury Hazard Ratios for Study Variables (Multivariate Cox Regression)

Variable	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Men				
Group	C E	388 375	1.00 1.04 (0.83–1.29)	--- 0.76
1.5-Mile Run (min)	8.25–10.45 10.46–11.16 11.17–12.00 12.01–15.33	191 207 192 173	1.00 1.18 (0.85–1.64) 1.25 (0.90–1.74) 1.85 (1.34–2.56)	--- 0.32 0.19 <0.01
Q10. Smoked Cigarettes in Last 30 Days	No Yes	486 277	1.00 1.24 (0.99–1.56)	--- 0.06
Played High School Sports	No Yes	179 584	1.30 (1.02–1.67) 1.00	0.04 ---
Women				
Group	C E	253 310	1.00 0.82 (0.65–1.14)	--- 0.11
Age (yr)	17–19 20–24 ≥24	467 87 9	1.00 1.12 (0.78–1.61) 3.60 (1.53–8.46)	--- 0.54 <0.01
Weight (lb)	87–119 120–132 133–143 144–180	144 149 139 131	1.00 0.74 (0.52–1.06) 0.56 (0.39–0.81) 0.62 (0.42–0.90)	--- 0.10 <0.01 <0.01
1.5–Mile Run (min)	10.1–13.0 13.1–14.0 14.1–14.7 14.8–17.4	144 142 136 141	1.00 1.45 (0.97–2.18) 1.89 (1.28–2.80) 1.84 (1.24–2.72)	--- 0.07 <0.01 <0.01
Q15. Frequency of Running/Jogging in Last 2 Months (times/week)	≤ 1 2–4 ≥ 5	116 366 81	2.17 (1.29–3.66) 1.63 (1.02–2.62) 1.00	<0.01 0.04 ---
Q17. Frequency of Exercise with Weights in Last 2 Months (times/week)	≤ 1 2–4 ≥ 5	281 234 48	2.08 (1.09–3.96) 2.38 (1.24–4.57) 1.00	0.03 <0.01 ---
Missed 6 or More Menstrual Cycles in Last Year	No Yes NA	499 21 43	1.00 1.93 (1.05–3.54) 1.47 (0.95–2.28)	--- 0.03 0.08

Legend: C=control group, E=experimental group, CI=confidence interval, NA=not applicable Q=question number on the survey

(9) Because of the potential problem with Question 27 (missing six or more menstrual cycles in the last year) mentioned above, the women's multivariate analysis presented in Table 14 was rerun with the women who responded "NA" grouped with those in the "No." Table 15 shows that this had little effect on the multivariate hazard ratios.

Table 15. Injury Hazard Ratios for Study Variables with Question 27 Regrouped (Women Only, Multivariate Cox Regression)

Variable	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Group	E C	253 310	1.00 0.83 (0.67–1.16)	--- 0.12
Age (yr)	17–19 20–24 ≥24	467 87 9	1.00 1.15 (0.81–1.65) 3.49 (1.49–8.18)	--- 0.44 <0.01
Weight (lb)	87–119 120–132 133–143 144–180	144 149 139 131	1.00 0.75 (0.53–1.06) 0.56 (0.39–0.81) 0.63 (0.43–0.92)	--- 0.11 <0.01 0.02
1.5–Mile Run (min)	10.1–13.0 13.1–14.0 14.1–14.7 14.8–17.4	144 142 136 141	1.00 1.45 (0.96–2.17) 1.89 (1.28–2.81) 1.83 (1.24–2.71)	--- 0.08 <0.01 <0.01
Q15. Frequency of Running/Jogging in Last 2 Months (times/week)	≤ 1 2–4 ≥ 5	116 366 81	2.18 (1.29–3.67) 1.62 (1.01–2.60) 1.00	<0.01 0.05 ---
Q17. Frequency of Weight Lifting in Last 2 Months (times/week)	≤ 1 2–4 ≥ 5	281 234 48	2.08 (1.09–3.97) 2.35 (1.23–4.50) 1.00	0.03 <0.01 ---
Missed 6 or More Menstrual Cycles in Last Year	No or NA Yes	499 21	1.00 1.86 (1.01–3.39)	--- 0.05

Legend:
C=control group
E=experimental group
CI=confidence interval
NA=not applicable
Q=question number on the survey

d. Injury Subgroup Analyses.

(1) Injury risk was examined for the three plantar foot shapes considering the E and C groups separately. Table 16 shows the univariate Cox regression. Although confidence intervals were wide, men with low arches tended to have lower injury risk than men with normal arches, regardless of whether they both wore stability shoes (C group) or those with low arches wore motion-control shoe. Men with high arches, however, differed little in injury risk from those with normal arches, again regardless of whether they both wore stability shoes (C group) or those with high arches wore the cushioned shoes (E group). The injury risk for women with high or

low arches differed little from that for women with normal arches, regardless of whether they both wore the same type of shoe (C group) or different types of shoe (E group).

Table 16. Injury Hazard Ratios by Group and Plantar Foot Shape (Univariate Cox Regression)

			Men			Women		
Subjects	Shoe Type	Plantar Foot Shape	n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
C Subjects Only	Stability	Low	28	0.56 (0.20–1.18)	0.13	23	1.00 (0.52–1.93)	0.99
	Stability	Normal	380	1.00	---	197	1.00	---
	Stability	High	22	0.97 (0.49–1.89)	0.92	36	0.94 (0.54–1.62)	0.81
E Subjects Only	Motion Control	Low	40	0.66 (0.37–1.16)	0.15	47	0.92 (0.54–1.58)	0.92
	Stability	Normal	329	1.00	---	222	1.00	---
	Cushioned	High	39	1.06 (0.64–1.75)	0.82	44	1.36 (0.84–2.22)	0.22

Legend:
C=control group
E=experimental group
CI=confidence interval

(2) Injury risk for the E and C groups was compared within plantar foot shapes. Table 17 shows the results of the univariate Cox regression. Among those with normal plantar shapes, all of whom wore stability shoes, E and C group men differed little in injury risk; E women tended to have a slightly lower injury risk than C women. Among those with low and high plantar shapes, there was little difference in injury risk between the E and C groups for either men or women.

Table 17. Injury Hazard Ratios Comparing E and C Groups within Each Plantar Foot Shape (Univariate Cox Regression)

			Men			Women		
Plantar Foot Shape	Group	Shoe	n	Hazard Ratio (95% CI)	p-value	n	Hazard Ratio (95% CI)	p-value
Normal	E	Stability	329	1.02 (0.81–1.27)	0.90	222	0.84 (0.65–1.11)	0.15
	C	Stability	380	1.00	---	197	1.00	---
Low	E	Motion Control	40	1.22 (0.49–3.05)	0.68	47	0.68 (0.31–1.49)	0.33
	C	Stability	28	1.00	---	23	1.00	---
High	E	Cushioned	39	1.12 (0.50–2.51)	0.79	44	1.08 (0.55–2.11)	0.83
	C	Stability	22	1.00	---	36	1.00	---

Legend:
C=control group
E=experimental group
CI=confidence interval

(3) A separate analysis was performed comparing injury risk among only those individuals with high or low plantar shapes in the E and C groups. This removes the subjects with normal plantar shapes from the analysis and compares only the extreme plantar shapes. Table 18 shows that injury risk was about the same in the E and C groups.

Table 18. Injury Hazard Ratios by Group with Only High/Low-Arched Individuals by Plantar Surface Evaluation (Univariate Cox Regressions)

Group	Men			Women		
	n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
E	79	1.18 (0.64–2.16)	0.60	91	0.87 (0.53–1.46)	0.61
C	50	1.00	---	59	1.00	---

Legend:
C=control group
E=experimental group
CI=confidence interval

e. Comparison of Plantar Surface Determination with Arch Height and Arch Indices.

(1) Table 19 shows the plantar surface determinations with means and standard deviations of (mean ±SD) arch heights and arch indices. Progressively higher plantar shapes (i.e., from low to normal to high) had correspondingly higher mean arch heights, arch indices, and bony arch indices. Mean differences between the low and normal plantar surfaces were much greater than between the normal and high plantar surfaces. For the men, differences paired comparisons among the three plantar surface determinations (low, normal, high) were significantly different by the Tukey test (p< 0.01) for all three measures on both the right and left side. This was not the case for the women. Paired comparisons of differences between the high and normal plantar shapes (Tukey test) were not significantly different for the right foot arch height (p=0.32), left foot arch height (p=0.11), right arch index (p=0.12), and right bony arch index (p=0.12). Paired comparisons of differences between the high and normal plantar shapes (Tukey test) were significantly different for the left arch index (p=0.02) and the left bony arch index (p=0.02).

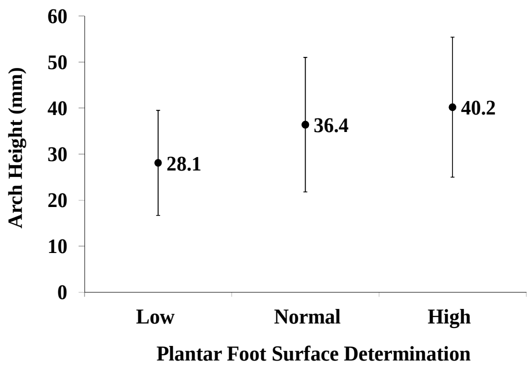
Table 19. Plantar Surface Determination and Corresponding Arch Height and Arch Indices

Gender, Foot	Plantar Surface Determination	n	Arch Height (mm) (mean ±SD)	p-value[a]	Arch Index (mean ±SD)	p-value[a]	Bony Arch Index (mean ±SD)	p-value[a]
Men, Right	Low Normal High	61 652 57	28.1 ± 5.5 36.4 ± 6.9 40.2 ± 8.5	<0.01	0.1050 ± 0.0224 0.1360 ± 0.0267 0.1501 ± 0.0326	<0.01	0.1406 ± 0.2980 0.1845 ± 0.0372 0.2050 ± 0.0459	<0.01
Men, Left	Low Normal High	61 652 57	28.8 ± 6.1 36.3 ± 7.5 39.8 ± 8.6	<0.01	0.1072 ± 0.2470 0.1350 ± 0.0286 0.1481 ± 0.0321	<0.01	0.1442 ± 0.0331 0.1840 ± 0.0402 0.2026 ± 0.0460	<0.01
Women, Right	Low Normal High	39 249 48	28.4 ± 7.2 35.1 ± 6.9 36.7 ± 7.3	<0.01	0.1156 ± 0.0294 0.1454 ± 0.0292 0.1545 ± 0.0298	<0.01	0.1551 ± 0.0396 0.1967 ± 0.0406 0.2093 ± 0.0407	<0.01
Women, Left	Low Normal High	39 249 48	28.5 ± 6.1 34.9 ± 6.4 36.9 ± 6.7	<0.01	0.1161 ± 0.0249 0.1436 ± 0.0276 0.1551 ± 0.0278	<0.01	0.1558 ± 0.0338 0.1949 ± 0.0382 0.2110 ± 0.0391	<0.01

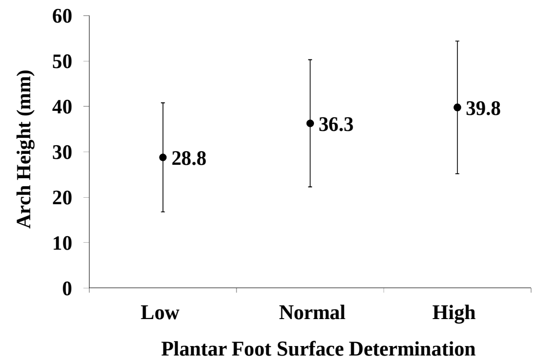
Legend: SD=standard deviation

Notes: a. Independent sample t-test

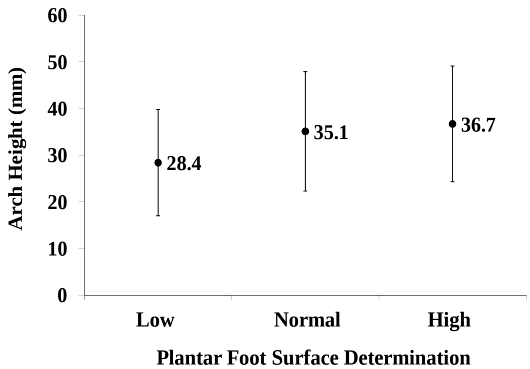
(2) Figure 4 graphically displays the plantar shapes plotted against the average measured arch height and showing ±2SD. Although mean values differ, there is considerable overlap in the measured arch heights for the three plantar shapes.



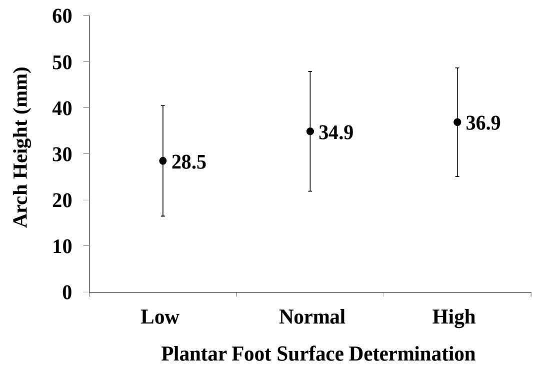
Men’s Right Foot



Men’s Left Foot



Women’s Right Foot



Women’s Left Foot

Figure 4. Comparison of Measured Arch Height with Plantar Foot Shape. (Mean values are displayed and vertical bars are ±2SD)

(3) Table 20 shows subjects cross-classified by plantar shape and measured arch height, arch index, and bony arch indices. Arch heights, arch indices, and bony arch indices are separated into the percentile distributions found in the left and right plantar shapes. A “match” was defined as an arch height or arch index in a particular percentile that fell into the same percentile of the plantar shape distributions (right and left foot considered separately). Among the men, the low plantar shape matched with the lowest distributions of arch heights, arch indices, or bony arch indices in 25 to 32 percent of the cases; the normal plantar shape matched

with the middle distributions of arch heights, arch indices, or bony arch indices in 83 to 86 percent of the cases; and the high plantar shape matched with the highest distributions of arch heights, arch indices, or bony arch indices in 14 to 26 percent of the cases. Among the women, the low plantar shape matched with the lowest distributions of arch heights, arch indices, or bony arch indices in 35 to 45 percent of the cases; the normal plantar shape matched with the middle distribution of arch heights, arch indices, or bony arch indices in 73 to 76 percent of the cases; and the high plantar shape matched with the highest distributions of arch heights, arch indices, or bony arch indices in 25 to 30 percent of the cases. For both men and women, the highest distributions of arch heights or arch indices were more likely to be classified as a normal plantar shape (65 to 86 percent of cases) than a high plantar shape (14 to 30 percent of cases). Low plantar shapes were much less likely to be in the highest distributions of arch heights or arch indices (0 to 5 percent of cases). Overall, arch heights and the arch indices were in the corresponding percentiles of plantar shapes 66 percent of the time among the men and 58 percent of the time among the women.

Table 20. Classification of Subjects by Plantar Surface Determination and Measured Arch Height and Arch Indices[a]

Variable	Percentiles of Arch Heights, Arch Indices, and Bony Arch Indices (Based on Distributions of Plantar Shapes)	Low Plantar Shape		Normal Plantar Shape		High Plantar Shape	
		n	%	n	%	n	%
Men							
Arch Height Right	0.1–7.4%	**16**	**28.1**	37	64.9	4	7.0
	7.5–83.2%	40	6.8	**500**	**85.6**	44	7.5
	83.3–100.0%	0	0.0	103	79.8	**26**	**20.2**
Arch Height Left	0.1–7.4%	**14**	**24.6**	38	66.7	5	8.8
	7.5–80.3%	43	7.7	**464**	**82.7**	54	9.6
	80.4–100.0%	0	0.0	115	75.7	**37**	**24.3**
Arch Index Right	0.1–7.4%	**17**	**30.4**	35	62.5	4	7.1
	7.5–83.2%	39	6.7	**501**	**85.6**	45	7.7
	83.3–100.0%	0	0.0	104	80.6	**25**	**19.4**
Arch Index Left	0.1–7.4%	**14**	**24.6**	39	68.4	4	7.0
	7.5–80.3%	42	7.5	**465**	**82.9**	54	9.6
	80.4–100.0%	1	0.7	113	74.3	**38**	**25.0**
Bony Arch Index Right	0.1–7.4%	**18**	**31.6**	35	61.4	4	7.0
	7.5–83.2%	36	8.4	**363**	**84.4**	31	7.2
	83.3–100.0%	2	0.7	242	85.5	**39**	**13.8**
Bony Arch Index Left	0.1–7.4%	**15**	**25.4**	39	66.1	5	8.5
	7.5–80.3%	41	7.3	**467**	**83.5**	51	9.1
	80.4–100.0%	1	0.7	111	73.0	**40**	**26.3**

Variable	Percentiles of Arch Heights, Arch Indices, and Bony Arch Indices (Based on Distributions of Plantar Shapes)	Low Plantar Shape		Normal Plantar Shape		High Plantar Shape	
		n	%	n	%	n	%
Women							
Arch Height Right	0.1–10.2%	**12**	**35.3**	17	50.0	5	14.7
	10.3–71.4%	18	8.7	**156**	**75.7**	32	15.5
	71.5–100.0%	3	3.2	67	70.5	**25**	**26.3**
Arch Height Left	0.1–11.4%	**16**	**42.1**	19	50.0	3	7.9
	11.5–69.9%	17	8.6	**145**	**73.6**	35	17.8
	70.0–100.0%	3	3.0	69	69.0	**28**	**28.0**
Arch Index Right	0.1–10.2%	**13**	**38.2**	18	52.9	3	8.8
	10.3–71.4%	17	7.9	**163**	**75.8**	35	16.3
	71.5–100.0%	3	3.5	59	68.6	**24**	**27.9**
Arch Index Left	0.1–11.4%	**15**	**39.5**	21	55.3	2	5.3
	11.5–69.9%	18	9.1	**144**	**73.1**	35	17.8
	70.0–100.0%	3	3.0	68	68.0	**29**	**29.0**
Bony Arch Index Right	0.1–10.2%	**12**	**36.4**	17	51.5	4	12.1
	10.3–71.4%	18	8.7	**154**	**74.8**	34	16.5
	71.5–100.0%	3	3.2	68	71.6	**24**	**25.3**
Bony Arch Index Left	0.1–11.4%	**17**	**44.7**	19	50.0	2	5.3
	11.5–69.9%	14	7.1	**149**	**75.6**	34	17.3
	70.0–100.0%	5	5.0	65	65.0	**30**	**30.0**

Notes:
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

7. DISCUSSION. The present study demonstrated that prescribing running shoes on the basis of the shape of plantar foot surface did not reduce injury risk in Marine Corps basic training. Men who wore the shoe assigned for their foot type had almost identical injury risk compared with those who received standard stability shoes, regardless of foot type. Women who received a shoe based on plantar shape tended to be at somewhat lower injury risk; however, this was primarily because the women with normal plantar shapes in the E group were at slightly lower risk that the women with normal plantar shapes in the C group (Table 17). Since women with normal plantar shapes in both the E and C groups received stability shoes, shoe type could not have been a factor in the injury risk. There was also some injury reduction advantage for women with low plantar shapes who received a motion-control shoe (see Table 17).

a. Compairson of Marine Corps, Air Force and Army Studies

(1) The results of the current study can be compared with the results of similar Army (71) and Air Force (8) basic training investigations because these studies were designed to be complementary; however, there were some important differences mandated by the respective Marine Corps, Air Force, and Army commands. Similarities in the studies included 1) tracking subjects in the same medical surveillance system, 2) calculation of injury indices in an identical manner, 3) identical lifestyle questionnaires, and 4) the same randomized prospective cohort design with a C group receiving a single stability shoe and an E group receiving a shoe prescribed on the basis of plantar shape. Major differences between the Services studies had to do with 1) the brands and models of the shoes provided and 2) the nature of the training environment. Table 21 shows the shoes used in the Marine Corps, Air Force, and Army investigations. Marine Corps and Army C group subjects received the same type of stability shoe, but C group subjects in the Air Force investigation received another type of stability shoe. E group subjects in the Marine Corps and Air Force study received 1 of only 3 shoes, one for each foot type; E subjects in the Army study could select from 19 different shoes, as long as the shoe they selected had been designated as appropriate for their plantar shape. There are also differences in the Marine Corps, Air Force, and Army basic training program of instruction and length of training (12, 6, and 9 weeks, respectively).

Table 21. Running Shoes Used in the Marine Corps, Air Force, and Army Studies Examining Whether Shoe Selection Based on Plantar Shape Reduces Injuries

	Experimental Group Shoes			
Service	Motion-Control Shoe	Stability Shoe	Cushioned Shoe	Control Group Stability Shoe
Marine Corps	New Balance 587	New Balance 767	New Balance 881	New Balance 767
Air Force	New Balance 587	New Balance 498	New Balance 755	New Balance 498
Army	Asics Gel Foundation 7 Brooks Addiction 7 Saucony Grid Stabil 6 New Balance 857[a]	Asics Gel 1120 Asics Gel 2120 Brooks Adrenaline GTS6 Brooks Adrenaline GTS7 Nike Structure Triax Nike Air Max Moto[a] Saucony Grid Omni 5 New Balance 717 New Balance 767	Asics Gel Cumulus Brooks Radius 6 Nike Air Pegasus Saucony Grid Trigon 4 New Balance 644 New Balance 755	New Balance 767

Notes:
[a] For two shoes, the Army classification differed from those of *Runner's World* and the manufacturer. One shoe 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, which the Army classified as a stability shoe, but *Runner's World* and the manufacture listed as a cushioned shoe.

(2) Despite the differences in the Marine Corps, Air Force (8), and Army (71) studies, the results generally concurred in showing that selecting running shoes based on plantar shape had little influence on injury risk in basic training. Hazard ratio comparisons for the three studies are

shown in Table 22. To more fully examine injury risk when shoes were assigned based on plantar shape, a meta-analysis was performed. The meta-analysis method was a general variance-based technique that employed univariate hazard ratios and confidence intervals in each study to produce a summary hazard ratio (SHR) and summary 95% confidence interval (S95%CI) that reflected the combined results of all the studies (72). As shown in Table 22, there was little difference in injury risk (SHR) whether subjects received a shoe based on plantar surface (E group) or received a stability shoe (C group).

Table 22. Meta-Analysis of Studies in the Marine Corps, Air Force, and Army Basic Training Examining Whether Shoe Selection Based on Plantar Shape Influences Injury Risk

Service	Men		Women	
	Hazard Ratio-E/C (95%CI)	Summary Hazard Ratio-E/C (S95%CI)	Hazard Ratio-E/C (95%CI)	Summary Hazard Ratio-E/C (S95%CI)
Marine Corps	1.01 (0.82–1.24)	1.04 (0.94–1.14)	0.88 (0.70–1.10)	1.05 (0.95–1.18)
Air Force	1.09 (0.92–1.29)		1.23 (1.00–1.53)	
Army	1.02 (0.89–1.17)		1.06 (0.90–1.24)	

Legend:
C=control group
E=experimental group
CI=confidence interval
S95%CI=summary 95% confidence interval

(3) 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 and to allow for more foot pronation (32-35). If injury risk could be reduced by prescribing running shoes based on plantar shape, that reduced risk might be best seen by comparing E and C subjects at the extremes; that is, those with high and low arches. This is because E subjects with high and low arches wore shoes specifically designed for their foot type (motion control and cushioned), while C subjects with high and low arches wore a stability shoe that was designed for another foot type. In the Marine Corps, Air Force and Army studies, comparisons were made between C and E group subjects with plantar shapes reflecting high and low arches and the HRs are shown in Table 23. Again, meta-analysis employing a general variance-based technique was used to combine the results of the three studies and the SHR and S95%CI indicated the combined results. Contrary to expectation, Table 23 indicates that injury risk was modestly elevated in the E group.

Table 23. Meta-Analysis of Studies in the Marine Corps, Air Force, and Army Basic Training Examining Injury Risk When Only High and Low Arched Individuals Are Considered

Service	Men		Women	
	Hazard Ratio-E/C (95%CI)	Summary Hazard Ratio-E/C (S95%CI)	Hazard Ratio-E/C (95%CI)	Summary Hazard Ratio-E/C (S95%CI)
Marine Corps	1.18 (0.64–2.16)	1.20 (0.99–1.44)	0.87 (0.53–1.46)	1.11 (0.88–1.39)
Air Force	1.14 (0.82–1.58)		1.23 (0.77–1.94)	
Army	1.23 (0.96–1.59)		1.16 (0.85–1.58)	

Legend:
C=control group
E=experimental group
CI=confidence interval
S95%CI=summary 95% confidence interval

(4) All C group subjects wore a stability shoe regardless of plantar shape. Since the stability shoe was designed for those with normal arch heights, it was reasonable to assume that C group subjects with high and low arches would be at higher injury risk than C group subjects with normal arch heights. This would be because high and low arched C group subjects received a stability shoe not designed for their arch height, while normal arched C group subjects received a stability shoe that was designed for their arch height. Table 24 shows the univariate HRs (low/normal or high/normal) for the Marine Corps, Air Force, and Army studies including only subjects who wore the stability shoes (C group). Also shown are the results of the meta-analysis, again employing a general variance-based technique combining the results of the three studies. The SHR and S95%CI indicated virtually no difference in injury risk when comparing individuals with low or high arches with those with normal arches, all of whom wore a stability shoe. These data suggest that regardless of arch height, all individuals in basic training can wear a stability shoe and injury risk will be similar.

Table 24. Meta-Analysis Combining Marine Corps, Air Force, and Army Studies and Including Only Subjects Who Wore the Stability Shoe Regardless of Plantar Shape

Study	Plantar Shape	Men			Women		
		n	Hazard Ratio (95%CI)	Summary Hazard Ratio (S95%CI)[a]	n	Hazard Ratio (95%CI)	Summary Hazard Ratio (S95%CI)[a]
Marine Corps	Low	28	0.56 (0.20–1.18)	Low 1.00 (0.79–1.26)	23	1.00 (0.52–1.93)	Low 0.97 (0.71–1.33)
	Normal	380	1.00		197	1.00	
	High	22	0.97 (0.49–1.89)		36	0.94 (0.54–1.62)	
Air Force	Low	79	1.09 (0.70–1.70)		23	1.50 (0.83–2.72)	
	Normal	714	1.00		280	1.00	
	High	119	1.11 (0.77–1.59)	High 0.99 (0.80–1.23)	41	0.84 (0.50–1.40)	High 0.98 (0.78–1.24)
Army	Low	137	1.01 (0.76–1.24)		38	0.74 (0.47–1.18)	
	Normal	768	1.00		345	1.00	
	High	162	0.93 (0.70–1.24)		81	1.05 (0.78–1.41)	

Legend: C=control group, E=experimental group, CI=confidence interval, S95%CI=summary 95% confidence interval

(5) Despite the general concurrence among the Marine Corps, Air Force (8), and Army (55) investigations, these studies are not in accord with a previous Army study (31) that showed a post-wide decrease in serious injuries at Fort Drum, New York, after initiation of a running shoe prescription program. Methodological differences between the Fort Drum project and the current Marine Corps study are similar to those previously outlined between the Ft Drum project and the Air Force (8) and Army basic training footwear studies (55). The current Marine Corps study involved a prescription based only on plantar shape; the Fort Drum project involved a prescription based on an evaluation of foot arch height and foot flexibility. The current Marine Corps study involved a population of recruits in a situation where there was assurance that the correct shoe was given to the recruit and worn during training. The Fort Drum project involved soldiers who were given the shoe prescription, but there was little follow-up to determine whether they actually purchased or wore the recommended shoe. In fact, a survey involving a convenience sample of 122 Fort Drum soldiers (out of 9,752 estimated to be on post) found that only 11 percent had followed the shoe prescription advice. The current Marine Corps study involved a prospective shoe prescription involving two randomly assigned groups (C and E) training side by side in a standardized program with follow-up for any injury occurring during the period. The Fort Drum project 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 Fort Drum project, which were discussed at length in the report on that study (31). The major potential confounder was a change in the medical surveillance system used to track injuries, which was discovered in investigating the time point when injuries dramatically decreased. In summary, the current Marine Corps study involved 1) a prospective design manipulating only one variable (running shoe prescription based on plantar shape), 2) considerably better information about the shoes worn, and 3) a more controlled training environment. Men and women in the current Marine Corps study trained in separate locations (San Diego, California, and Parris Island, South Carolina), but since the data on men and women were analyzed separately, gender-specific C and E groups had the same training environment.

b. Plantar Surface Determination and Measured Arch Height and Arch Indices.

(1) The prescription of running shoes was based on the plantar foot surface evaluation because this method was being used in Marine Corps at the time of the study. Further, this technique is similar to a common self-evaluation technique (the “wet test”) recommended by running magazines, shoe companies, and other publications (1, 73-75). This evaluation technique is used because, as noted above, plantar shape is presumed to reflect arch height and it is arch height for which running shoe types (motion control, stability, cushioned) are presumably designed (1). In the current study, average arch height values did differ among the three plantar shapes with higher plantar shapes reflecting higher arch heights. However, there was considerable overlap in the individual arch height values within the three plantar surface

determinations. This concurs with Army (55) and Air Force (8) complementary studies, which had similar findings.

(2) In the current study, 84 percent of men and 75 percent of the women in the middle distribution of measured arch heights were classified as having normal plantar shapes. However, there was also a strong bias for those with high and low measured arch heights to be classified as having normal plantar foot surfaces (50 to 80 percent of cases). In fact, only 20 to 35 percent of the measured arch heights were correctly matched with the high and low plantar shapes. Moreover, a lower percentage of those with high arches were correctly classified compared with those with low arches.

(3) Comparisons of the two extreme plantar shapes showed much less overlap. High plantar surface cases were seldom found in the lowest measured arch height or arch indices (≤ 15 percent of cases) and low plantar surface cases were rarely found in the highest of the arch heights or arch indices (≤ 3 percent). Nonetheless, the bias toward the normal plantar classification calls into question the practice of using plantar surface ratings as a surrogate for arch height when this is used for individual assessment.

c. Foot Arch Height, Foot Indices, and Injuries.

(1) In the present study, injury risk differed little among individuals with higher or lower arch heights, arch indices, or bony arch indices when compared with those with normal arch heights, arch indices, or bony arch indices. On the other hand, the Air Force (8) and Army (55) studies, which used methods identical to the present study, suggested that injury risk was higher among individuals with lower arch heights, arch indices, or bony arch indices when compared with those with normal arch heights or indices. Table 25 shows meta-analyses (general variance based method (72)) of HRs for low and high arch heights and arch indices, relative to middle arch heights and arch indices, in the Marine Corps, Air Force, and Army studies. The SHRs indicate that injury risk is 12 to 18 percent higher among men in the lowest 20 percent of the arch heights, arch indices, or bony arch indices, compared with those in the middle 60 percent. On the other hand, there is little difference in injury risk among men in the highest 20 percent of arch height, arch index, or bony arch index, compared with men in the middle 60 percent. Results are generally similar for the women, but there is more variability. The women’s SHRs indicate that injury risk is 8 to 22 percent higher among women in the lowest 20 percent of the arch height, arch index, or bony arch index, compared with those in the middle 60 percent. SHRs also indicate little difference in injury risk among women in the highest 20 percent of arch height, arch index, or bony arch index, compared with women in the middle 60 percent.

Table 25. Meta-Analyses of Hazard Ratios for Low and High Arch Heights, Arch Indices, and Bony Arch Indices (Compared with Middle Arch Heights and Arch Indices) in Marine Corps, Air Force, and Army Studies

Variable	Distribution within Variable	Marine Corps Hazard Ratios (95%CI)	Air Force Hazard Ratios (95%CI)	Army Hazard Ratios (95%CI)	Summary Hazard Ratios (95%CI)
Men					
Arch Height Left	Lowest 20% Middle 60% Highest 20%	1.00 (0.75–1.33) 1.00 1.10 (0.83–1.45)	1.11 (0.89–1.39) 1.00 0.86 (0.68–1.09)	1.17 (0.98–1.39) 1.00 1.01 (0.85–1.22)	1.12 (0.99–1.27) 0.98 (0.87–1.12)
Arch Height Right	Lowest 20% Middle 60% Highest 20%	0.99 (0.74–1.32) 1.00 1.12 (0.85–1.48)	1.43 (1.15–1.78) 1.00 1.07 (0.85–1.35)	1.10 (0.92–1.31) 1.00 1.02 (0.86–1.22)	1.18 (1.04–1.33) 1.05 (0.93–1.19)
Arch Index Left	Lowest 20% Middle 60% Highest 20%	0.84 (0.62–1.13) 1.00 1.03 (0.78–1.36)	1.28 (1.03–1.60) 1.00 0.94 (0.74–1.19)	1.16 (0.97–1.38) 1.00 1.01 (0.83–1.19)	1.13 (1.00–1.29) 0.99 (0.87–1.13)
Arch Index Right	Lowest 20% Middle 60% Highest 20%	0.95 (0.71–1.27) 1.00 1.24 (0.95–1.63)	1.40 (1.13–1.73) 1.00 1.05 (0.83–1.33)	1.14 (0.96–1.36) 1.00 1.02 (0.85–1.22)	1.18 (1.04–1.33) 1.08 (0.95–1.22)
Bony Arch Index Left	Lowest 20% Middle 60% Highest 20%	0.92 (0.69–1.24) 1.00 1.01 (0.76–1.34)	1.29 (1.04–1.61) 1.00 1.02 (0.81–1.29)	1.18 (0.99–1.41) 1.00 1.03 (0.86–1.23)	1.16 (1.03–1.31) 1.02 (0.09–1.16)
Bony Arch Index Right	Lowest 20% Middle 60% Highest 20%	0.95 (0.71–1.27) 1.00 1.13 (0.86–1.49)	1.38 (1.11–1.71) 1.00 0.98 (0.78–1.25)	1.13 (0.95–1.35) 1.00 1.01 (0.85–1.21)	1.16 (1.03–1.32) 1.01 (0.85–1.21)
Women					
Arch Height Left	Lowest 20% Middle 60% Highest 20%	0.97 (0.62–1.51) 1.00 0.98 (0.63–1.51)	1.61 (1.21–2.13) 1.00 0.97 (0.71–1.34)	1.11 (0.91–1.36) 1.00 1.04 (0.84–1.27)	1.22 (1.04–1.42) 1.01 (0.86–1.19)
Arch Height Right	Lowest 20% Middle 60% Highest 20%	0.98 (0.63–1.53) 1.00 0.91 (0.58–1.42)	1.41 (1.07–1.89) 1.00 0.91 (0.66–1.26)	0.99 (0.81–1.22) 1.00 1.05 (0.86–1.29)	1.10 (0.95–1.28) 0.99 (0.85–1.17)
Arch Index Left	Lowest 20% Middle 60% Highest 20%	1.04 (0.67–1.61) 1.00 0.93 (0.60–1.45)	1.54 (1.17–2.04) 1.00 0.88 (0.64–1.21)	0.95 (0.77–1.16) 1.00 0.98 (0.80–1.21)	1.12 (0.96–1.31) 0.95 (0.81–1.11)
Arch Index Right	Lowest 20% Middle 60% Highest 20%	1.16 (0.75–1.78) 1.00 0.96 (0.61–1.50)	1.29 (0.97–1.72) 1.00 0.89 (0.63–1.18)	0.96 (0.78–1.19) 1.00 1.14 (0.93–1.39)	1.08 (0.92–1.26) 1.05 (0.90–1.24)
Bony Arch Index Left	Lowest 20% Middle 60% Highest 20%	1.11 (0.73–1.69) 1.00 0.77 (0.48–1.22)	1.55 (1.17–2.05) 1.00 0.88 (0.64–1.22)	1.02 (0.83–1.25) 1.00 1.06 (0.86–1.30)	1.17 (1.00–1.37) 0.97 (0.82–1.14)
Bony Arch Index Right	Lowest 20% Middle 60% Highest 20%	1.11 (0.72–1.71) 1.00 0.91 (0.58–1.43)	1.47 (1.11–1.95) 1.00 0.86 (0.62–1.19)	1.02 (0.83–1.26) 1.00 1.16 (0.95–1.41)	1.15 (0.99–1.35) 1.05 (0.89–1.23)

Legend:
CI=confidence interval

(2) One problem with the above analyses is that the ranges of scores for the percentile rankings (lowest 20 percent, middle 60 percent and highest 20 percent) differed somewhat for the Marine Corps, Air Force (8), and Army (55) studies. Table 26 shows the measurement ranges in all three investigations. The Marine Corps and Air Force measurement ranges were similar. The Army measurement ranges encompassed a wider range of scores at the lowest 20 percent, and higher values in the subsequent middle 60 percent and highest 20 percent. The largest differences in values were between the Army and Air Force investigations. Nonetheless, the Air Force and Army results were similar in showing that individuals with lower arches tended to be at highest injury risk and the meta-analyses supports this general observation.

Table 26. Ranges of Measurements for Various Distributions in Marine Corps, Air Force, and Army Studies

		Men			Women		
Variable	Distribution	Marine Corps Ranges	Air Force Ranges	Army Ranges	Marine Corps Ranges	Air Force Ranges	Army Ranges
Arch Height Left	Lowest 20%	11.6–29.7 mm	12.8–27.9 mm	9.3–32.7 mm	18.7–28.3 mm	8.8–26.7 mm	15.3–30.0 mm
	Middle 60%	29.8–42.8 mm	28.0–40.8 mm	32.8–46.1 mm	28.4–40.2 mm	26.8–38.0 mm	30.1–42.2 mm
	Highest 20%	42.9–70.7 mm	40.9–61.3 mm	46.2–69.0 mm	40.3–55.8 mm	38.1–53.1 mm	42.2–59.4 mm
Arch Height Right	Lowest 20%	12.2–30.3 mm	12.6–28.4 mm	13.8–34.9 mm	15.1–28.3 mm	15.5–27.4 mm	16.6–31.8 mm
	Middle 60%	30.4–42.2 mm	28.5–41.8 mm	35.0–47.7 mm	28.4–41.1 mm	27.5–38.5 mm	31.9–42.9 mm
	Highest 20%	42.3–61.6 mm	41.9–60.6 mm	47.8–69.0 mm	41.2–55.8 mm	38.6–57.6 mm	43.0–63.5 mm
Arch Index Left	Lowest 20%	0.0456–0.1094	0.0439–0.1030	0.0347–0.1222	0.0724–0.1167	0.0358–0.1104	0.0590–0.1233
	Middle 60%	0.1095–0.1587	0.1031–0.1539	0.1223–0.1746	0.1168–0.1664	0.1105–0.1577	0.1234–0.1758
	Highest 20%	0.1588–0.2526	0.1540–0.2428	0.1747–0.2659	0.1665–0.2335	0.1578–0.2395	0.1759–0.2517
Arch Index Right	Lowest 20%	0.0410–0.1128	0.0568–0.1125	0.0515–0.1301	0.0613–0.1173	0.0568–0.1125	0.0687–0.1288
	Middle 60%	0.1129–0.1579	0.1126–0.1616	0.1302–0.1792	0.1174–0.1718	0.1126–0.1616	0.1289–0.1791
	Highest 20%	0.1580–0.2505	0.1617–0.2417	0.1793–0.2640	0.1719–0.2417	0.1617–0.2417	0.1792–0.2669
Bony Arch Index Left	Lowest 20%	0.0647–0.1473	0.0489–0.1471	0.0456–0.1650	0.0973–0.1572	0.0489–0.1471	0.0778–0.1662
	Middle 60%	0.1474–0.2169	0.1472–0.2132	0.1651–0.2377	0.1573–0.2244	0.1472–0.2132	0.1663–0.2387
	Highest 20%	0.2170–0.3400	0.2132–0.3024	0.2378–0.3901	0.2245–0.3302	0.2133–0.3024	0.2388–0.3529
Bony Arch Index Right	Lowest 20%	0.0556–0.1511	0.0799–0.1511	0.0678–0.1756	0.0823–0.1567	0.0799–0.1511	0.0905–0.1753
	Middle 60%	0.1512–0.2136	0.1512–0.2180	0.1757–0.2450	0.1568–0.2321	0.1512–0.2180	0.1754–0.2461
	Highest 20%	0.2137–0.3522	0.2181–0.3213	0.2451–0.3939	0.2322–0.3285	0.2181–0.3213	0.2462–0.3671

(3) The results of the meta-analyses (Table 25) are not in accord with Cowan et al. (4), who showed higher injury risk among Army infantry recruits with high arches and lower risk among infantry recruits with low arches, compared with recruits in the middle 60 percent of arch height. Cowan et al. (4) took pictures of the right foot of 246 male Army infantry recruits while they stood with their weight on the foot that was examined. A calibration device was included in the picture frame and pictures were digitized to determine arch heights and foot lengths. After this evaluation, the recruits participated in the 12-week infantry 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. Compared with the current Marine Corps,

Air Force (8), and Army (55) studies, Cowan et al. (4) used a different subject population, different methods of arch measurement (pictures versus direct measurements), and a different definition of injury. These methodological differences might account for some of the discrepant findings.

(4) The results of the meta-analyses (Table 25) are in partial accord with those of Kaufmann et al. (3), whose data tended to show higher injury risk among Navy Sea, Air, and Land (SEAL) candidates with both high and low bony arch indices. Kaufmann et al. (3) collected bony arch index data on 423 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, those defined as either pes cavus or pes planus tended to have a higher incidence of stress fractures, Achilles tendonitis, and iliotibial band syndrome, although the differences were not statistically significant. The paucity of the methodological description makes direct comparisons with the meta-analyses difficult. As with Cowan et al. (4), differences in subject populations, length of training time, training environments, and injury definitions are likely to account for some of the differences.

(5) The arch height, arch index, and bony arch index values of the men in the Cowan et al. (4) study can be compared directly with those of the men in the Marine Corps, Air Force (8), and Army (55) investigations because the measures were obtained using the same anatomical landmarks. Comparisons of mean values and the selected percentile range values are shown in Table 27. Average values for all three measures of the right foot of the men in the Marine Corps and Air Force studies were 22 to 25 percent less than those of Cowan et al. (4). Mean values in the Army study (55) tended to be closer to those of Cowan et al. (4), but were still about 10 to 13 percent lower. Different measurement methods (described above) may account for some of the differences.

Table 27. Comparison of Arch Heights and Arch Indices (Right Foot, Men) from the Study of Cowan et al. (4) and from the Marine Corps, Air Force and Army Studies

Measure	Level of Measure	Cowen et al. (4)	Current Marine Corps Study	Air Force Study (8)	Army Study (55)
Arch Height (Navicular Height) (mm)	Mean ±SD	46.0 ± 6.1	36.1 ± 7.4	35.5 ± 7.8	41.4 ± 7.7
	20% Lowest	27.2–40.8	12.2–30.3	12.6–28.5	13.8–34.9
	60% Middle	40.9–50.8	30.4–42.2	28.6–41.8	35.0–47.7
	20% Highest	50.9–60.5	42.3–61.6	41.9–49.0	47.8–69.0
Arch Index	Mean ±SD	0.17 ± 0.02	0.13 ± 0.03	0.13 ± 0.03	0.15 ± 0.03
	20% Lowest	0.10–0.15	0.04–0.11	0.05–0.11	0.05–0.13
	60% Middle	0.15–0.19	0.11–0.16	0.11–0.16	0.13–0.18
	20% Highest	0.19–0.24	0.16–0.25	0.16–0.18	0.18–0.26
Bony Arch Index	Mean ±SD	0.24 ± 0.04	0.18 ± 0.04	0.18 ± 0.04	0.21 ± 0.04
	20% Lowest	0.14–0.21	0.06–0.15	0.06–0.14	0.07–0.18
	60% Middle	0.21–0.27	0.15–0.21	0.14–0.21	0.18–0.25
	20% Highest	0.27–0.34	0.21–0.35	0.21–0.25	0.25–0.39

d. Injury Rates in Marine Corps Recruit Training

(1) Table 28 compares injury incidence and injury rates in the current study with those of previous Marine Corps recruit investigations (10, 22, 23, 25, 61). Past studies indicate that cumulative injury incidence for men ranged from 23 to 40 percent while incidence for women ranged from 41 to 53 percent. Injury definitions differed in various studies, perhaps accounting for a portion of the varying rates. In the present study, cumulative injury incidence was about the same for men and women. Injury rates for men were similar to those reported by Almeida et al. (23) and injury rates for women were similar to those reported by Shaffer et al. (25) and Almeida et al. (22). Nonetheless, previous gender comparisons showed women to be 1.7 to 2.3 times more likely to have an injury compared with men (22, 61). Differences in injury definitions and training locations (Parris Island versus San Diego) should be considered in making comparisons between studies.

Table 28. Comparison of Injury Incidence and Injury Rate in Past and Current Studies of Marine Corps Recruits

<table>
<tr><th>Study</th><th>Year Data Collected</th><th>Gender</th><th>n</th><th>Location</th><th>Data Collection</th><th>Injury Definition</th><th>Cumulative Injury Incidence (%)</th><th>Injury Rate (injured recruits/ month)</th></tr>
<tr><td>Almeida et al., 1999 (23)</td><td>1993[a]</td><td>Men</td><td>1,143</td><td>San Diego CA</td><td>Medical records review</td><td>Musculoskeletal injuries (excludes skin)</td><td>39.6</td><td>14.4</td></tr>
<tr><td>Shaffer et al., 1999 (25)</td><td>1995–1996</td><td>Women</td><td>2,766</td><td>Parris Island SC</td><td>Surveillance system - clinic visits</td><td>Musculoskeletal injuries</td><td>44.0</td><td>14.7</td></tr>
<tr><td rowspan="2">Almeida et al., 1999 (22)</td><td rowspan="2">1993–1994[a]</td><td>Men</td><td>176</td><td>San Diego CA</td><td rowspan="2">Questionnaire</td><td rowspan="2">Lower extremity musculoskeletal injuries</td><td>25.6</td><td>9.3</td></tr>
<tr><td>Women</td><td>241</td><td>Parris Island SC</td><td>44.0</td><td>14.7</td></tr>
<tr><td rowspan="5">Jones et al., 1999 (61)</td><td rowspan="2">1993[b]</td><td>Men</td><td>434</td><td rowspan="2">Parris Island SC</td><td rowspan="5">Not clear</td><td rowspan="5">Not clear</td><td>22.8</td><td>8.3</td></tr>
<tr><td>Women</td><td>366</td><td>53.0</td><td>17.7</td></tr>
<tr><td rowspan="3">1995[c]</td><td>Men</td><td>2,546</td><td>San Diego CA</td><td>25</td><td>9.1</td></tr>
<tr><td>Men</td><td>396</td><td rowspan="2">Parris Island SC</td><td>29</td><td>10.5</td></tr>
<tr><td>Women</td><td>1,498</td><td>49</td><td>16.3</td></tr>
<tr><td>Rauh et al., 2006 (10)</td><td>1999</td><td>Women</td><td>824</td><td>Parris Island SC</td><td>Medical records review</td><td>Non-stress fracture overuse injury</td><td>48.5</td><td>16.2</td></tr>
<tr><td rowspan="2">Current[d]</td><td rowspan="2">2007</td><td>Men</td><td>840</td><td>San Diego CA</td><td rowspan="2">Surveillance system - clinic visits</td><td>All injuries[d]</td><td>41.7</td><td>15.2</td></tr>
<tr><td>Women</td><td>570</td><td>Parris Island SC</td><td>All injuries[d]</td><td>40.6</td><td>13.5</td></tr>
</table>

Notes:
[a] Includes only those completing training
[b] Secondary report from a doctoral dissertation (76)
[c] Secondary report from the Naval Health Research Center
[d] Injury index is the CII

e. Injury Risk Factors. While there were no differences in injury rates between the C and E groups, the study did identify a number of other injury risk factors. Many of these have been examined in previous studies but some have not.

(1) Height and Weight.

(a) The association between injuries and body height and weight has not been previously reported in Marine Corps basic training. The present study found little association between body weight and injury risk among men, in consonance with other Army basic training studies that have examined this relationship (8, 9, 55, 77). On the other hand, heavier women were at lower injury risk than lighter women. Future studies will need to confirm this finding and measures of body composition (densiometry or dual X-ray absorptometry) may be helpful. It may be that low body weight among women reflected insufficient muscle mass to perform some of the tasks required in Marine Corps basic training.

(b) In the present study, there was also little association between injury risk and height. Previous basic training studies examining associations between injury risk and height are conflicting. One study found that shorter Australian Air Force recruits were at higher injury risk (77), while a study of Army recruits found that shorter women, but not shorter men, were at higher risk (6). Other studies have found no relationship between injury risk and height in men or women in Army or Air Force basic training (8, 9). In one study that found a relationship between height and injury, height was not an independent injury risk factor in multivariate analysis (77). Height was collected only to the nearest inch in the present study and another (9) that found no relationship between height and injury: it has been suggested (8) that using finer graduations of height (centimeters (77) or tenths of centimeters (6) might allow more accurate classification of shorter individuals.

(2) Body Mass Index.

(a) In the current study, there was no relationship between BMI and injury risk among either men or women. The results of previous basic training studies conflict with regard to associations between BMI and injury. A previous Marine Corps basic training study showed that women with either high or low BMI were at higher risk of stress fractures (bimodal relationship), but no relationship was found for overuse injuries not involving stress fracture (78). Some Army and Air Force basic training studies have reported bimodal relationships (6, 55), but others have shown no relationship (7, 9) or increased risk with higher BMI (77). One study of Chinese Armed Forces Police found that those with low BMI were at higher injury risk (79).

(b) Generally, BMI shows a close relationship with body fat in military and civilian samples, demonstrating correlations on the order of 0.7 (67, 80, 81). However, this means that only about 50 percent of the variance in BMI is accounted for by body fat. The relationship between BMI and injury in basic training is likely to be complex because individuals can have a high BMI either because of higher body fat or because of higher fat-free mass. If high BMI reflects a larger percentage of body fat relative to height, injury risk might be increased because the additional fat burden would both 1) increase the intensity of physical activity (82) leading to more rapid fatigue and 2) impose additional repetitive stress on the musculoskeletal system because of the greater weight relative to height. However, body fat per se has not shown a consistent relationship with injuries in Army BCT (6, 9, 49). In contrast to high BMI, low BMI may reflect a paucity of either fat, fat-free mass, or both. Low BMI may make recruits more susceptible to injury if they lack the muscle mass or strength in the supportive structures (ligaments, bones) required to perform certain physical tasks and/or if they overexert or overuse the available muscle mass or supportive structures. Since a number of studies have shown that high, low, or both high and low BMI are associated with injury in basic training (6, 8, 49, 55, 77, 78), a bimodal relationship may be most plausible.

(3) Physical Fitness.

(a) In both men and women, higher injury risk was associated with lower aerobic fitness (i.e., slower 1.5-mile run times). This is in consonance with previous Marine Corp basic training studies (10, 11), as well as studies in the Army (6, 9, 48, 49, 54, 55, 62) and Air Force (8) and in basic training of other countries (83-85). Importantly, slower run time was an independent risk factor when considered in the multivariate model. Less fit individuals are likely to fatigue more rapidly for both cardiovascular and metabolic reasons (86, 87). Fatigue has been shown to result in changes in economy (88, 89) and gait (88-93), which may put more stress on body regions not accustomed to stress. Individuals with lower aerobic capacity may perceive long-term low intensity tasks as more difficult (94). The combined cardiovascular, metabolic, biomechanical, and perceptual stress could make injuries more likely in these less fit individuals.

(b) Higher injury risk was also associated with lower muscular endurance in the present study. Among the men, lower performance on either the pull-ups or the crunches was associated with higher injury risk. Among the women, lower performance on the crunches was associated with injury and lower performance on the flexed arm hang tended to be associated with injury. The injury and muscular endurance association was strongest when recruits in the quartiles with the highest performance were compared with recruits in the quartiles with the lowest performance. Associations between injury and muscular endurance have not been previously examined in Marine Corp basic training, but the findings of the present study are in consonance with those of previous Army (7, 9, 55) and Air Force (8) basic training investigations, which showed similar relationships. 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 recruit training that require this fitness component (e.g., obstacle courses, climbing). In a manner analogous to aerobic fatigue, individuals with lower muscular endurance may expereience a greater level of stress and need to recruit different muscle groups as the active muscle groups begin to fatigue (92, 95, 96). The unaccustomed stress and fatigue may make injuries more likely.

(4) Cigarette Smoking.

(a) In the present study, men who smoked cigarettes tended to have higher injury risk and cigarette smoking was an independent risk factor for injury in the multivariate analysis. On the other hand, women who smoked were only at modestly elevated injury risk. Cigarette smoking prior to basic training has consistently been associated with increased injury risk in Army and Air Force basic training (7-9, 55, 97, 98) and in army basic training in other countries (84, 99). Further, smoking was associated with injury in infantry soldiers (100) and in other occupational groups (101-108). Although past basic training studies (7-9, 55, 84, 97) have demonstrated a dose-response (i.e., progressively more cigarettes/day associated with progressively higher injury risk), this was only modestly evident in the present study with somewhat higher risk among recruits smoking 10 or more cigarettes per day compared with those smoking 1–9 cigarettes/day.

(b) 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 impairs wound healing (109-113), bone healing (114-118), tissue strength (119-124), and immune function. The immune system is important for tissue healing, since macrophages, leukocytes, and lymphocytes regulate various steps in the process and remove or assist in removal of damaged tissue (125-128). The macrophages of smokers have lower phagocytic activity, lower responsiveness to bacterial challenge, and reduced gene expression of the proinflammatory cytokines, which are important for tissue healing (129-131).

(c) Collagen deposition is a major factor in wound healing (132, 133). 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 (134). 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 (121-124). In one study, 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 (120). Human studies involving experimentally induced arm wounds showed that smokers produced less hydroxyproline, a marker of collagen production (135, 136), and synthesized less Type I and Type III collagen (137); noncollagen protein was apparently not affected (136). 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 (138).

(d) In Marine Corps basic training, all recruits ceased smoking at the beginning of training. Thus the mechanism accounting for the association between smoking and injuries must be active beyond cessation of smoking, into the basic training period. Evidence for the longer-term effects of smoking come from studies on collagen metabolism, skin damage, immune function, and possibly bone tissue. One study (139) 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 hydoxyproline/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 (140-142). Smoking reduction (by at least 50 percent) for 6 to 8 weeks prior to surgery has been shown to be associated with a reduction in postsurgical complications (at 10 days post-surgery) (143). Immune studies suggest that smoking-induced leukocytosis slowly decreases over time once smoking ceases (144-150). One day to 6 weeks after smoking cessation, the leukocyte count was still elevated (146, 150). Three months after smoking cessation, the neutrophil concentration tended to decrease (145). 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 (147). 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 (144).

(e) 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 greater rebelliousness, less seat belt use, more risky sex, more favorable views 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 (151). An overall measure of risk taking was also higher in the Air Force recruit smokers (151). In civilian studies, smokers had more motor vehicle accidents, had more traffic violations, used seat belts less often, participated in less physical activity, consumed more alcohol, and had lower intake of fruits and vegetables (152-154). Heavy smoking ($\geq$ 20 cigarettes/day) is much more likely to be associated with multiple risk behaviors (154). It is possible that this higher risk-taking behavior of smokers manifests itself in the activities of basic training and results in a higher injury rate among smokers.

(f) In the present study it was of interest that both Marine Corps men and women who had quit smoking for longer than 1 year were still at elevated injury risk and that this risk was greater than that of the current smokers. Table 29 compares injury risk among nonsmokers, smokers, and those who quit smoking at different times in the Marine Corps, Air Force (8), and Army (55). In the Air Force recruit investigation, there is some suggestion of reduced injury risk with longer smoking cessation among the women, but this was not seen among the male Air Force recruits. In the Army study, which provided the largest sample sizes, risk of injury was lower among recruits who reported that they had ceased smoking for more than 1 year, compared with those who reported that they had ceased smoking for less than 1 year. When the results were combined by meta-analysis (summary risk ratios, general variance-based method), injury risk was somewhat lower among those who quit smoking and, among women, this reduction was greater in those who had quit smoking for a longer period.

Table 29. Meta-Analyses Comparing Recruits Who Report Smoking and Quit Smoking in Marine Corps, Air Force and Army Studies

		Men			Women		
Study	Smoking Status	n	HR (95%CI)	SHR (95%CI)	n	HR (95%CI)	SHR (95%CI)
Marine Corps Study (Current)	Never Smoked	420	1.00	Smoker 1.43 (1.28–1.59)	585	1.00	Smoker 1.44 (1.25–1.65)
	Smoker	302	1.29 (1.02–1.62)		129	1.22 (0.90–1.66)	
	Quit 1–12 Months	61	1.33 (0.89–1.99)		32	1.07 (0.61–1.89)	
	Quit>12 months	33	1.73 (1.06–2.81)		20	2.59 (1.47–4.57)	
Air Force Study (8)	Never Smoked	893	1.00	Quit 1–12 Months 1.25 (1.05–1.51)	341	1.00	Quit 1–12 Months 1.34 (1.07–1.66)
	Smoker	386	1.43 (1.15–1.78)		114	1.29 (0.95–1.74)	
	Quit 1–12 Months	110	1.00 (0.68–1.49)		37	1.13 (0.70–1.85)	
	Quit>12 months	61	1.31 (0.82–2.09)		22	0.70 (0.34–1.42)	
Army Study (55)	Never	1157	1.00	Quit >12 Months 1.37 (1.10–1.71)	546	1.00	Quit >12 Months 1.30 (0.98–1.72)
	Smoker	671	1.49 (1.28–1.74)		254	1.57 (1.32–1.88)	
	Quit 1–12 Months	190	1.35 (1.06–1.72)		67	1.52 (1.14–2.04)	
	Quit>12 months	129	1.28 (0.95–1.71)		48	1.14 (0.79–1.65)	

Legend:
HR=hazard ratio
SHR=summary hazard ratio
CI=confidence interval

(5) Physical Activity. Six items on the questionnaire dealt with physical activity prior to Marine Corps basic training. Men and women who had a lower self-rating of physical activity were at higher risk of injury. Men and women who reported a lower frequency of physical activity (frequency of exercise/sports, running/jogging, weight training) prior to basic training were at higher injury risk, although this association was weaker among the men. Men who had not played high school sports were at higher injury risk, but this was not found among the women. Not playing high school sports was an independent injury risk factor in the multivariate analysis among men. Other studies of Army and Marine Corps recruits have shown that lower pre-basic training physical activity increases injury risk in training (6, 7, 9-11, 44, 55, 79, 84). In Marine Corps basic training, subjects perform weight-bearing physical activity primarily in the form of standing (in formation), walking, and running. It seems reasonable that a higher frequency of weight-bearing physical training prior to training would result in less susceptibility to injury because of the favorable influences of physical activity on the body. Physical activity of the proper intensity, frequency, and duration can increase aerobic fitness, muscle strength, connective tissue strength, and general health, and can reduce body fat (155-162). Bone mineral density is higher in physically active individuals (98, 163-167) and higher bone mineral density has been associated with greater weekly physical activity (165). These and other factors may contribute to reducing susceptibility to injury among the most physically active recruits (168).

(6) Abnormal Menses. In the current study, women reporting fewer menstrual periods in the last year were at higher injury risk; missing six or more menstrual cycles in a row in the last year was an independent injury risk factor in the multivariate Cox regression. Past Marine Corps studies (10, 169) have shown 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 overuse injuries other than stress fractures. In Army basic training, women who reported no menstrual cycles in the last year were at elevated injury risk (55). Surveys of young (average 26 years) active duty Army women (170) and women in Marine Corps Officer Candidate School (171) have also shown menstrual irregularities to be associated with higher stress fracture incidence. Besides military studies, investigations of female athletes have also suggested that those with menstrual irregularities have a higher overall injury incidence (172), take longer to recover from injuries (173), and specifically have a higher incidence of stress fractures and frank fractures (172, 174, 175). 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 likelihood of fracture (172, 173, 175, 176). Bennell et al. (177) 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 percent of the Military recommended daily allowance (54). One study found that amenorrheic women had lower bone mineral density even after controlling for calcium intake (175).

8. CONCLUSIONS

a. This prospective study demonstrated that assigning running shoes based on the static weight-bearing plantar foot surface shape had little influence on injury risk in Marine Corps basic training, even after controlling for other injury risk factors. There was little difference in injury rates among those who were assigned a different type of shoe (motion control, stability, or cushioned) based on plantar foot shape and those who received a stability shoe regardless of plantar foot shape.

b. Individuals in the lower 20th percentile of arch heights tended to be at higher risk of injury than individuals in the middle 60 percent of arch heights.

c. Plantar foot shapes judged as low, normal, and high did have progressively higher average arch heights. Despite the higher average values, there were a considerable number of mismatches when plantar shapes were matched with corresponding percentiles of arch heights. Plantar shape determinations matched corresponding percentiles of measured arch heights (right side) about 64 percent of the time, overall. Normal plantar shapes had the largest numbers of matches (over 80 percent), with high and low plantar shapes matching only 23 percent and 31 percent of the time, respectively.

d. In the present study, injury rates were about the same for men and women. Previous Marine Corps studies indicated that that women’s risk of injury was twice that of men. The reason for the difference between the present study and past studies is not clear but differences in the training location (Parris Island versus San Diego) and training programs should be considered to explain the between-study differences.

e. Risk factors for injuries identified in the present study were in consonance with those identified in other Marine Corps, Air Force, and Army investigations. Injury risk was higher among those who, on entry to training, were older, were less physically fit, were less physically active, were cigarette smokers, and (among women) had menstrual dysfunction.

9. RECOMMENDATION. If the goal is injury prevention, it is not necessary to provide running shoes to Marine Corps recruits based on a visual inspection of the static weight-bearing plantar shape. Providing running shoes to Marine Corps recruits on this basis was no more protective against injury than issuing a single shoe regardless of plantar shape. It is still recommended that recruits receive a new shoe on entry to recruit training, since older shoes have previously been shown to be associated with increase injury risk (44).

APPENDIX A. REFERENCES

1. Pritchard A.E. 2001. Running shoe design, selection and care: does it make a difference? *Army Medical Department Journal*, Apr/May/Jun:43-51.
2. Menz H.B. 1998. Alternative techniques for the alternative assessment of foot pronation. *Journal of the American Podiatric Medical Association*, 88:119-129.
3. Kaufman K.R., Brodine S.K., Shaffer R.A., Johnson C.W., and Cullison T.R. 1999. The effect of foot structure and range of motion on musculoskeletal overuse injury. *American Journal of Sports Medicine,* 27:585-593.
4. Cowan D.N., Jones B.H., and Robinson J.R. 1993. Foot morphologic characteristics and risk of exercise-related injuries. *Archives of Family Medicine*, 2:773-777.
5. Knapik J.J., Hauret K.G., and Jones B.H. Primary Prevention of Injuries in Initial Entry Training. In: *Textbook of Military Medicine. Recruit Medicine.* M.K. Lenhart, D.E. Lounsbury, and R.B. North (Eds.) Washington DC: Bordon Institute, 2006, pp. 125-146.
6. Jones B.H., Bovee M.W., Harris J.M., and Cowan D.N. 1993. Intrinsic risk factors for exercise-related injuries among male and female Army trainees. *American Journal of Sports Medicine,* 21:705-710.
7. Jones B.H., Cowan D.N., Tomlinson J.P., Robinson J.R., Polly D.W., and Frykman P.N. 1993. Epidemiology of injuries associated with physical training among young men in the Army. *Medicine and Science in Sports and Exercise,* 25:197-203.
8. Knapik J.J., Brosch L.C., Venuto M., Swedler D.I., Bullock S.H., Gaines L.S., Murphy R.J., Canada S.E., Hoedebecke E.L., Tobler S.K., Tchandja J., and Jones B.H. (2008). Injury reduction effectiveness of prescribing running shoes based on foot shape in Air Force Basic Military Training. Technical Report No. 12-MA-05SBA-08A, Aberdeen Proving Ground MD: Army Center for Health Promotion and Preventive Medicine.
9. Knapik J.J., Sharp M.A., Canham-Chervak M., Hauret K., Patton J.F., and Jones B.H. 2001. Risk factors for training-related injuries among men and women in Basic Combat Training. *Medicine and Science in Sports and Exercise,* 33:946-954.
10. Rauh M.J., Macera C.A., Trone D.W., Shaffer R.A., and Brodine S.K. 2006. Epidemiology of stress fractures and lower extremity overuse injuries in female recruits. *Medicine and Science in Sports and Exercise*, 38:1571-1577.
11. Shaffer R.A., Brodine S.K., Almeida S.A., Williams K.M., and Ronaghy S. 1999. Use of simple measures of physical activity to predict stress fractures in young men undergoing a rigorous physical training program. *American Journal of Epidemiology,* 149:236-242.
12. Preventive Medicine. Technical Report No. 40-5, Washington DC: Headquarters, Department of the Army.
13. Hodge J.G. 2005. An enhanced approach to distinguishing public health practice and human subjects research. *Journal of Law, Medicine and Ethics,* Spring:2-19.
14. Jones B.H., Amoroso P.J., Canham M.L., Weyandt M.B., and Schmitt J.B. 1999. Atlas of injuries in U.S. Armed Forces. *Military Medicine*, 164 (Supplement0:1-1 - 9-25.
15. Jones B.H., and Hansen B.C. (1996). Injuries in the military: a hidden epidemic. Technical Report No. 29-HA-4844-97, Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventive Medicine.

16. US Army Disability Agency. Department of the Army Inspector General's Report. Disability cost estimates. Technical Report No. Washington DC: US Army Physical Disability Agency, 1995.

17. Kaufman K.R., Brodine S., and Shafer R.A. 2000. Military training-related injuries. Surveillance, research and prevention. *American Journal of Preventive Medicine,* 18(Suppl):54-63.

18. Knapik J.J., Canham-Chervak M., Hauret K., Hoedebecke E., Laurin M.J., and Cuthie J. 2001. Discharges during US Army Basic Combat Training: injury rates and risk factors. *Military Medicine,* 166:641-647.

19. Trank T.V., Ryman D.H., Minagawa R.Y., Trone D.W., and Shaffer R.A. 2001. Running mileage, movement mileage, and fitness in male US Navy recruits. *Medicine and Science in Sports and Exercise*, 33:1033-1038.

20. Shaffer R.A. Musculoskeletal Injury Project. *In Proceedings of 43d Annual Meeting of the American College of Sports Medicine*. Cincinnati, OH, 1996.

21. Jones B.H. 1996. Injuries among men and women in gender-integrated BCT units. Ft Leonard Wood 1995. *Medical Surveillance Monthly Report,* 2:2-3,7-8.

22. Almeida S.A., Trone D.W., Leone D.M., Shaffer R.A., Patheal S.L., and Long K. 1999. Gender differences in musculoskeletal injury rates: a function of symptoms reporting? *Medicine and Science in Sports and Exercise,* 31:1807-1812.

23. Almeida S.A., Williams K.M., R.A. S., and Brodine S.K. 1999. Epidemiological patterns of musculoskeletal injuries and physical training. *Medicine and Science in Sports and Exercise,* 31:1176-1182.

24. Snedecor M.R., Boudreau C.F., Ellis B.E., Schulman J., Hite M., and Chambers B. 2000. U.S. Air Force recruit injury and health study. *American Journal of Preventive Medicine,* 18(3S):129-140.

25. Shaffer R.A., Brodine S.K., Ito S.I., and Le A.T. 1999. Epidemiology of illness and injury among U.S. Navy and Marine Corps female training populations. *Military Medicine,* 164:17-21.

26. Williams D.S., and McClay I.S. 2000. Measurements to characterize the foot and medial longitudinal arch: reliability and validity. *Physical Therapy,* 80:864-871.

27. Kernozek T.W., and Ricard M.D. 1990. Foot placement angle and arch type: effect on rearfoot motion. *Archives of Physical Medicine and Rehabilitation,* 71:988-991.

28. Nigg B.M., Cole G.K., and Nachbauer W. 1993. Effects of arch height on the foot ground reaction force in running. *Journal of Biomechanics,* 26:909-916.

29. Nachbauer W., and Nigg B.M. 1992. Effects of arch height on the foot on ground reaction forces in running. *Medicine and Science in Sports and Exercise,* 24:1264-1269.

30. Cowan D.N., Robinson J.R., Jones B.H., Polly D.W., and Berrey B.H. 1994. Consistency of visual assessments of arch height among clinicians. *Foot and Ankle,* 15:213-217.

31. Knapik J.J., Feltwell D., Canham-Chervak M., Arnold S., Hauret K., Renderio D., Wells J.D., and Rohde C. (2001). Evaluation of injury rates during implementation of the Fort Drum Running Shoe Injury Prevention Program. Technical Report No. 12-MA-6558-01, Aberdeen Proving Ground MD: US Army Center for Health Promotion and Preventive Medicine.

32. McPoil T.G. 2000. Athletic footwear: design, performance and selection issues. *Journal of Science and Medicine in Sports,* 3:260-267.

33. McPoil T.G. 1988. Footwear. *Physical Therapy,* 68:1857-1865.

34. Nigg B.M., and Segesser B. 1992. Biomechanical and orthopedic concepts in sports shoe construction. *Medicine and Science in Sports and Exercise,* 24:595-602.

35. Winter D.A., and Bishop P.J. 1992. Lower extremity injury. Biomechanical factors associated with chronic injury to the lower extremity. *Sports Medicine,* 14:149-156.

36. Jorgensen U. 1990. Body load in heel strike running: the effect of a firm heel counter. *American Journal of Sports Medicine,* 18:177-181.

37. Jorgensen U., and Ekstrand J. 1988. Significance of heel pad confinement for the shock absorption at heel strike. *International Journal of Sports Medicine,* 9:468-473.

38. DeClercq D., Aerts P., and Kunnen M. 1994. The mechanical characteristics of the human heel pads during foot strike in running: an in vivo cineradiographic study. *Journal of Biomechanics,* 27:1213-1222.

39. Wilk B.R., Fisher K.L., and Gutierrez W. 2000. Defective running shoe as a contributory factor in plantar fasciitis in a triathlete. *Journal of Orthopedic and Sports Physical Therapy,* 30:21-28.

40. Brody D.M. 1980. Running injuries. *CIBA Clinical Symposia,* 32:1-36.

41. James S.L., Bates B.T., and Osternig L.R. 1978. Injuries to runners. *American Journal of Sports Medicine,* 6:40-50.

42. Jacobs S.J., and Berson B.L. 1986. Injuries to runners: a study of entrants to a 10,000 meter race. *American Journal of Sports Medicine,* 14:151-155.

43. Burgess I., and Ryan M.D. 1985. Bilateral fatigue fractures of the distal fibulae caused by a change of running shoes. *Medical Journal of Australia,* 143:304-305.

44. Gardner L.I., Dziados J.E., Jones B.H., Brundage J.F., Harris J.M., Sullivan R., and Gill P. 1988. Prevention of lower extremity stress fractures: a controlled trial of a shock absorbent insole. *American Journal of Public Health,* 78:1563-1567.

45. Milgrom C., Finestone A., Shlamkovitch N., Wosk J., Laor A., Voloshin A., and Eldad A. 1992. Prevention of overuse injuries of the foot by improved shoe shock attenuation. *Clinical Orthopedics,* 281:189-192.

46. McKay G.D., Goldie P.A., and Oakes B.W. 2001. Ankle injuries in basketball: injury rate and risk factors. *British Journal of Sports Medicine,* 35:103-108.

47. Cook S.D., Kester M.A., and Brunet M.E. 1985. Shock absorption characteristics of running shoes. *American Journal of Sports Medicine,* 13:248-253.

48. Knapik J.J., Cuthie J., Canham M., Hewitson W., Laurin M.J., Nee M.A., Hoedebecke E., Hauret K., Carroll D., and Jones B.H. (1998). Injury incidence, injury risk factors, and physical fitness of U.S. Army basic trainees at Ft Jackson SC, 1997. Technical Report No. 29-HE-7513-98, Aberdeen Proving Ground, MD: U.S. Army Center for Health Promotion and Preventive Medicine.

49. Jones B.H., Bovee M.W., and Knapik J.J. Associations among body composition, physical fitness, and injuries in men and women Army trainees. In: *Body Composition and Physical Performance.* B.M. Marriott, and J. Grumstrup-Scott (Eds.) Washington, D.C.: National Academy Press, 1992, pp. 141-173.

50. Bensel C.K., and Kish R.N. (1983). Lower extremity disorders among men and women in Army basic training and effects of two types of boots. Technical Report No. TR-83/026, Natick, MA: U.S. Army Natick Research and Development Laboratories.

51. Kowal D.M. 1980. Nature and causes of injuries in women resulting from an endurance training program. *American Journal of Sports Medicine*, 8:265-269.

52. Knapik J.J., Hauret K.G., Arnold S., Canham-Chervak M., Mansfield A.J., Hoedebecke E.L., and McMillian D. 2003. Injury and fitness outcomes during implementation of Physical Readiness Training. *International Journal of Sports Medicine*, 24:372-381.

53. Knapik J.J., Darakjy S., Scott S., Hauret K.G., Canada S., Marin R., Palkoska F., VanCamp S., Piskator E., Rieger W., and Jones B.H. (2004). Evaluation of two Army fitness programs: the TRADOC Standardized Physical Training Program for Basic Combat Training and the Fitness Assessment Program. Technical Report No. 12-HF-5772B-04, Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventive Medicine.

54. Westphal K.A., Friedl K.E., Sharp M.A., King N., Kramer T.R., Reynolds K.L., and Marchitelli L.J. (1995). Health, performance and nutritional status of U.S. Army women during basic combat training. Technical Report No. T96-2, Natick, MA: U.S. Army Research Institute of Environmental Medicine.

55. Knapik J.J., Swedler D., Grier T., Hauret K.G., Bullock S., Williams K., Darakjy S., Lester M., Tobler S., Clemmons N., and Jones B.H. (2008). Injury reduction effectiveness of prescribing running shoes based on foot shape in basic combat training. Technical Report No. 12-MA-05SB-08, Aberdeen Proving Ground MD: US Army Center for Health Promotion and Preventive Medicine.

56. Bell N.S., Mangione T.W., Hemenway D., Amoroso P.J., and Jones B.H. 2000. High injury rates among female Army trainees. A function of gender? *American Journal of Preventive Medicine*, 18(Suppl. 3):141-146.

57. Canham-Chervak M., Knapik J.J., Hauret K., Cuthie J., Craig S., and Hoedebecke E. (2000). Determining physical fitness entry criteria for entry into Army Basic Combat Training: can these criteria be based on injury? Technical Report No. 29-HE-1395-00, Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventive Medicine.

58. Knapik J.J., Hauret K., Bednarek J.M., Arnold S., Canham-Chervak M., Mansfield A., Hoedebecke E., Mancuso J., Barker T.L., Duplessis D., Heckel H., Peterson J. (2001). The Victory Fitness Program. Influence of the US Army's emerging physical fitness doctrine on fitness and injuries in Basic Combat Training. Technical Report No. 12-MA-5762-01, Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventive Medicine.

59. Knapik J.J., Darakjy S., Scott S.J., Hauret K.G., Canada S., Marin R., Rieger W., and Jones B.H. 2005. Evaluation of a standardized physical training program for Basic Combat Training. *Journal of Strength and Conditioning Research,* 19:246-253.

60. Kowal D.M., Patton J.F., and Vogel J.A. 1978. Psychological states and aerobic fitness of male and female recruits before and after basic training. *Aviation, Space and Environmental Medicine,* 49:603-606.

61. Jones B.H., Shaffer R.A., and Snedecor M.R. 1999. Injuries treated in outpatient clinics: surveys and research data. *Military Medicine,* 164 (Suppl)

62. Knapik J.J., Sharp M.A., Canham M.L., Hauret K., Cuthie J., Hewitson W., Hoedebecke E., Laurin M.J., Polyak C., Carroll D., and Jones B. (1999). Injury incidence and injury risk factors among US Army Basic Trainees at Ft Jackson, SC (including fitness training unit personnel, discharges, and newstarts). Technical Report No. 29-HE-8370-99, Aberdeen Proving Ground MD: US Army Center for Health Promotion and Preventive Medicine.

63. Knapik J.J., Reynolds K.L., and Barson J. (1997). Influence of antiperspirants on foot blisters following road marching. Technical Report No. ARL-TR-1333, Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

64. Jones B.H., Cowan D.N., and Knapik J.J. 1994. Exercise, training and injuries. *Sports Medicine,* 18:202-214.

65. Knapik J.J., Canham-Chervak M., Hauret K., Laurin M.J., Hoedebecke E., Craig S., and Montain S. 2002. Seasonal variations in injury rates during US Army Basic Combat Training. *Annals of Occupational Hygiene,* 46:15-23.

66. Knapik J.J. 2001. Multivariate analysis of intrinsic injury risk factors in a cohort of US Army basic trainees. *Medicine and Science in Sports and Exercise,* 33:S6.

67. Knapik J.J., Burse R.L., and Vogel J.A. 1983. Height, weight, percent body fat and indices of adiposity for young men and women entering the U.S. Army. *Aviation, Space and Environmental Medicine,* 54:223-231.

68. Cohen J. 1977. *Statistical Power Analysis for the Behavioral Sciences*. New York: Academic Press.

69. Kahn H.A., and Sempos C.T. 1989. *Statistical Methods in Epidemiology*. New York: Oxford University Press.

70. Hosmer D.W., and Lemeshow S. 1989. *Applied Logistic Regression*. New York: John Wiley & Sons.

71. Knapik J.J., Swedler D., Grier T., Hauret K.G., Bullock S., Williams K., Darakjy S., Lester M., Tobler S., and Jones B.H. 2009. Injury reduction effectiveness of prescribing running shoes based on plantar shape. *Journal of Strength and Conditioning Research,* 23:685-697.

72. Petitti D.B. 2000. *Meta-Analysis, Decision Analysis and Cost-Effectiveness Analysis*. New York: Oxford University Press.

73. Greene W., and Fredericksen R. 2007. Fall Shoe Guide. *Runner's World,* September 101-114.

74. ASICS (2008). Shoe Fit Guide. On line at: http://www.asicsamerica.com/sports/running/shoeFitGuide.aspx, Accessed 16 June 2008

75. NewBalance (2008). Arch Types and Body Frames. On line at: http://www.nbwebexpress.com/siteLanding/foot_guide.asp and http://wwwnbwebexpress.com/achieve_more/running_gait.asp, Accessed 16 June 2008

76. Kimsey C.D. (1993). Epidemiology of lower extremity injuries in U.S. Marine Corps recruits. Technical Report No. Columbia SC: University of South Carolina School of Public Health.

77. Ross J., and Woodward A. 1994. Risk factors of injury during basic military training. *Journal of Occupational Medicine,* 10:1120-1126.

78. Rauh M.J., Koepsell T.D., Rivara F.P., Margherita A.J., and Rice S.G. 2006. Epidemiology of musculoskeletal injuries among high school cross-country runners. *American Journal of Epidemiology,* 163:151-159.

79. Wang X., Wang P.S., and Zhou W. 2003. Risk factors of military training-related injuries in recruits of Chinese People's Armed Police Force. *Chinese Journal of Traumatology,* 6:12-17.

80. Knapik J.J., Jones S.B., Sharp M.A., Darakjy S., Hauret K.G., Burrell L., Goddard D., Nevin R., and Jones B.H. (2006). A prospective study of injuries and injury risk factors among United States Army wheel vehicle mechanics. Technical Report No. 2-MA-7193B-06, Aberdeen Proving Ground MD: US Army Center for Health Promotion and Preventive Medicine.

81. Roche A.F., Siervogel R.M., Chumlea W.M., and Webb P. 1981. Grading body fatness from limited anthropometric data. *American Journal of Clinical Nutrition,* 34:2831-2838.

82. Cureton K.J. Effects of experimental alterations in excess weight on physiological responses to exercise and physical performance. In: *Body Composition and Physical Performance. Applications for Military Services.* B.M. Marriott, and J. Grumstrup-Scott (Eds.) Washington, D.C.: National Academy Press, 1992.

83. Pope R.P., Herbert R.D., Kirwan J.D., and Graham B.J. 2000. A randomized trial of preexercise stretching for prevention of lower-limb injury. *Medicine and Science in Sports and Exercise,* 32:271-277.

84. Heir T., and Eide G. 1997. Injury proneness in infantry conscripts undergoing a physical training programme: smokeless tobacco use, higher age, and low levels of physical fitness are risk factors. *Scandinavian Journal of Medicine and Science in Sports,* 7:304-311.

85. Rayson M., and Wilkinson D. (2003). Potential risk modifiers for training outcomes and injury in single entry recruits: body mass, composition and aerobic fitness. Technical Report No. 22APR03, Farnham, Surry, England: Optimal Performance.

86. Hickson R.C., Foster C., Pollock M.L., Galassi T.M., and Rich S. 1985. Reduced training intensities and loss of aerobic power, endurance, and cardiac growth. *Journal of Applied Physiology,* 58:492-499.

87. Katch F.I. 1973. Optimal duration of endurance performance on the cycle ergometer in relation to maximal oxygen intake. *Ergonomics,* 16:227-235.

88. Candau R., Belli A., Millet G.Y., George D., Barbier B., and Rouillon J.D. 1998. Energy cost and running mechanics during a treadmill run to voluntary exhaustion in humans. *European Journal of Applied Physiology,* 77:479-485.

89. Mercer J.A., Bates B.T., Dufek J.S., and Hreljac A. 2003. Characteristics of shock attenuation during fatigued running. *Journal of Sports Sciences,* 21:911-919.

90. Derrick T.R., Dereu D., and Mclean S.P. 2002. Impacts and kinematic adjustments during an exhaustive run. *Medicine and Science in Sports and Exercise,* 34:998-1002.

91. Dutto D.J., and Smith G.A. 2002. Changes in spring-mass characteristics during treadmill running to exhaustion. *Medicine and Science in Sports and Exercise,* 34:1324-1331.

92. Enoka R.M., and Stuart D.G. 1992. Neurobiology of muscle fatigue. *Journal of Applied Physiology,* 72:1631-1648.

93. Mizrahi J., Verbitsky O., Isakov E., and Daly D. 2000. Effect of fatigue on leg kinematics and impact acceleration in long distance running. *Human Movement Science,* 19:139-151.

94. Garcin M., Vautier J.F., Vandewalle H., and Monod H. 1988. Rating of perceived exertion (RPE) as an index of aerobic endurance during local and general exercise. *Ergonomics,* 41:105-114.

95. Gleeson N.P., Reilly T., Mercer T.H., Rakowski S., and Rees D. 1998. Influence of acute endurance activity on leg neuromuscular and musculoskeletal performance. *Medicine and Science in Sports and Exercise,* 30:596-608.

96. Gandevia S.C. 1992. Some central and peripheral factors effecting human motoneuronal output in neuromuscular fatigue. *Sports Medicine,* 13:93-98.

97. Altarac M., Gardner J.W., Popovich R.M., Potter R., Knapik J.J., and Jones B.H. 2000. Cigarette smoking and exercise-related injuries among young men and women. *American Journal of Preventive Medicine,* 18 (Suppl 3S):96-102.

98. Lappe J.M., Stegman M.R., and Recker R.R. 2001. The impact of lifestyle factors on stress fractures in female Army recruits. *Osteoporosis International,* 12:35-42.

99. Valimaki M.J., Alhava E., Lehmuskallio E., Loyttyniemi E., Sah T., Suominen H., and Valimakii M.J. 2005. Risk factors for clinical stress fractures in male military recruits: a prospective cohort study. *Bone,* 37:267-273.

100. Reynolds K.L., Heckel H.A., Witt C.E., Martin J.W., Pollard J.A., Knapik J.J., and Jones B.H. 1994. Cigarette smoking, physical fitness, and injuries in infantry soldiers. *American Journal of Preventive Medicine,* 10:145-150.

101. Cady L.D., Bischoff D.P., O'Connell E.R., Thomas P.C., and Allen J.H. 1979. Strength and fitness and subsequent back injuries in firefighters. *Journal of Occupational Medicine,* 21:269-272.

102. Chau N., Bourgkard E., Bhattacherjee A., Ravaud J.F., Choquet M., and Mur J.M. 2008. Associations of job, living conditions and lifestyle with occupational injury in working population: a population-based study. *International Archives of Occupational and Environmental Health,* 81:379-389.

103. McSweeney K.P., Congleton J.J., Kerk C.J., Jenkins O., and Craig B.N. 1999. Correlation of recorded injury and illness data with smoking, exercise, and absolute aerobic capacity. *International Journal of Industrial Ergonomics,* 24:193-200.

104. Craig B.N., Congleton J.J., Kerk C.J., Amendola A.A., and Gaines W.G. 2006. Personal and non-occupational risk factors and occupational injury/illness. *American Journal of Industrial Medicine,* 49:249-260.

105. Mudr D., Naus A., Hetychova V., and Vavreckova O. 1966. Work injuries and smoking. *Industrial Medicine and Surgery,* 35:880-881.

106. Ryan J., Zwerling C., and Orav E.J. 1992. Occupational risk associated with cigarette smoking: a prospective study. *American Journal of Public Health,* 82:29-32.

107. Sacks J.J., and Nelson D.E. 1994. Smoking and injuries: an overview. *Preventive Medicine*, 23:515-520.

108. Tsai S.P., Gilstrap E.L., Cowles S.R., Waddell L.C., and Ross C.E. 1992. Personal and job characteristics of musculoskeletal injuries in an industrial population. *Journal of Occupational Medicine,* 34:606-612.

109. Jones J.K., and Triplett R.G. 1992. The relationship of cigarette smoking to impaired intraoral wound healing. *Journal of Oral and Maxillofacial Surgery,* 50:237-239.

110. Mosely L.H., Finseth F., and Goody M. 1978. Nicotine and its effect on wound healing. *Plastic and Reconstructive Surgery,* 61:570-575.

111. Reus W.F., Robson M.C., Zachary L., and Heggers J.P. 1984. Acute effects of tobacco smoking in the cutaneous micro-circulation. *British Journal of Plastic Surgery,* 37:213-215.

112. Riefkohl R., Wolfe J.A., Cox E.B., and McCarthy K.S. 1986. Association between cutaneous occlusive vascular disease, cigarette smoking, and skin slough after rhytidectomy. *Plastic and Reconstructive Surgery,* 77:592-595.

113. Siana J.E., Rex S., and Gottrup F. 1989. The effect of cigarette smoking on wound healing. *Scandinavian Journal of Plastic and Reconstructive Surgery,* 23:207-209.

114. Castillo R.C., Bosse M.J., MacKenzie E.J., and Patterson B.M. 2005. Impact of smoking of fracture healing and risk of complications in limb-threatening open tibia fractures. *Journal of Orthopaedic Trauma,* 19:151-157.

115. Riebel G.D., Boden S.D., Whitesides T.E., and Hutton W.C. 1995. The effects of nicotine on incorporation of cancellous bone graft in an animal model. *Spine,* 20:2198-2202.

116. Raikin S.M., Landsman J.C., Alexander V.A., Froimson M.I., and Plaxton N.A. 1998. Effect of nicotine on the rate and strength of long bone fracture healing. *Clinical Orthopedics,* 353:231-237.

117. Silcox D.H., Daftari T., Boden S.D., Schimandle J.H., Hutton W.C., and Whitesides T.E. 1995. The effect of nicotine on spinal fusion. *Spine*, 14:1549-1553.

118. Chen F., Osterman L., and Mahony K. 2001. Smoking and bony union after ulna-shorting osteotomy. *American Journal of Orthopedics* 30:486-489.

119. Karim A., Pandit H., Murray J., Wandless F., and Thomas N.P. 2006. Smoking and reconstruction of the anterior cruciate ligament *Journal of Bone and Joint Surgery. British Volume*, 88:1027-1031.

120. Gill C.S., Sandell L.J., El-Zawawy H.B., and Wright R.W. 2006. Effects of cigarette smoking on early medial collateral ligament healing in a mouse model. *Journal of Orthopaedic Research*, 24:2141-2149.

121. Wong L.S., Green H.M., Feugate J.E., Yadav M., Nothnagel E.A., and Martins-Green M. 2004. Effects of "second hand" smoke on structure and function of fibroblasts, cells that are critical for tissue repair and remodeling. *BMC Cell Biology,* 5:13.

122. Carnevali S., Nakamura Y., Mio T., Liu X., Takigawa K., Romberger D.J., Spurzem J.R., and Rennard S.I. 1998. Cigarette smoke extract inhibits fibroblast-mediated collagen gel contraction. *American Journal of Physiology,* 274:L591-L598.
123. Nakamura Y., Romberger D.J., Tate L., Ertl R.F., Kawamoto M., Adachi Y., Sisson J.H., Spurzem J.B., and Rennard S.I. 1995. Cigarette smoke inhibits fibroblast proliferation and chemotaxis. *American Journal of Respiratory Critical Care Medicine,* 151:1497-1503.
124. Raveendran M., Senthil D., Utama B., Shen Y., Dudley D., Wang J., Zhang Y., and Wang X.L. 2004. Cigarette suppresses the expression of P4Halpha and vascular collagen production. *Biochemical and Biophysical Research Communications,* 323:592-598.
125. Schaffer M., and Barbul A. 1998. Lymphocyte function in wound healing and following injury. *British Journal of Surgery,* 85:444-460.
126. Barbul A., and Regan M.C. 1995. Immune involvement in wound healing. *Otolaryngologic Clinics of North America,* 28:955-968.
127. DiPietro L.A. 1995. Wound healing: the role of macrophages and other immune cells. *Shock,* 4:233-240.
128. Park J.E., and Barbul A. 2004. Understanding the role of immune regulation in wound healing. *American Journal of Surgery,* 187 (Suppl 1):11S-16S.
129. Sopori M.L., and Kozak W. 1998. Immunomodulatory effects of cigarette smoke. *Journal of Neuroimmunology,* 83:148-156.
130. Chen H., Cowan M.J., Hasday J.D., Vogel S.N., and Medvedev A.E. 2007. Tobacco smoke inhibits expression of proinflammatory cytokines and activation of IL-1R-associated kinase, p38, and NF-kappa-B in aveolar macrophages stimulated with TLR2 and TLR4 angonists. *Journal of Immunology,* 179:6097-6106.
131. McCrea K.A., Ensor J.E., Nall K., Bleeker E.R., and Hasday J.D. 1994. Altered cytokine regulation in the lungs of cigarette smokers. *American Journal of Respiratory and Critical Care Medicine,* 150:696-703.
132. Viljanto J. 1964. Biochemical basis of tensile strength in wound healing. An experimental study with viscose cellulose sponges on rats. *Acta Chirurgica Scandinavica,* Suppl 333:1-101.
133. Madden J.W., and Peacock E.E. 1968. Studies on the biology of collagen during wound healing. I: Rate of collagen synthesis and deposition in cutaneous wounds of the rat *Surgery,* 64:228-294.
134. Clark R.F. 1996. *The Molecular and Cellular Biology of Wound Repair*. New York: Plenum Press.
135. Goodson W.H., and Hunt T.K. 1984. Wound healing in well-controlled diabetic men. *Surgical Forum,* 35:614-616.
136. Jorgensen L.N., Kallehave F., Christensen E., Siana J.E., and Gottrup F. 1998. Less collagen production in smokers. *Surgery,* 123:450-455.
137. Knuutinen A., Kokkonen N., Risteli J., Vahakangas K., Kallioinen M., Salo T., and Oikarinen A. 2002. Smoking affects collagen synthesis and extracellular matrix turnover in human skin. *British Journal of Dermatology,* 146:588-594.

138. Jonsson K., Jensen J.A., and Goodson W.H. 1991. Tissue oxygenation, anemia, and perfusion in relation to wound healing in surgical patients. *Annals of Surgery,* 214:605-613.
139. Suchi M., Matsuki H., Misawa K., Kasuga H., and Yanagisawa Y. 1989. The effect of abstinence from smoking on urinary excretion of hydroproline. *Tokai Journal of Experimental and Clinical Medicine,* 14:401-407.
140. Ernster V.L., Grady D., Miike R., Black D., Selby J., and Kerlikowske K. 1995. Facial wrinkling in men and women by smoking status. *American Journal of Public Health,* 85:78-82.
141. Model D. 1985. Smoker's face: an underrated clinical sign? *British Medical Journal,* 291:1760-1762.
142. Kadunce D.P., Burr R., Gress R., Kanner R., Lyon J.L., and Zone J.J. 1991. Cigarette smoking: risk factor for premature facial wrinkling. *Annals of Internal Medicine,* 114:840-844.
143. Moller A.M., Villebro N., Pedersen T., and Tonnesen H. 2002. Effect of peoperative smoking intervention on postoperative complications: a randomized clinical trial. *Lancet,* 359:114-117.
144. Tollerud D.J., Clarke J.W., Brown L.M., Neuland C.Y., Mann D.L., Pankiw-Trost L.K., Blattner W.A., and Hoover R.N. 1989. Association of cigarette smoking with decreased numbers of circulating natural killer cells. *American Review of Respiratory Diseases,* 139:194-198.
145. Hersey P., Prendergast D., and Edwards A. 1983. Effects of cigarette smoking on the immune system. *Medical Journal of Australia,* 2:425-429.
146. Miller L.G., Goldstein G., Murphy M., and Ginns L.C. 1982. Reversible alterations in immunoregulatory T Cells in smoking. *Chest,* 82:526-529.
147. Yarnell J.W.G., Sweetnam P.M., Rogers S., Elwood P.C., Bainton D., Baker I.A., Esatham R., and Etherington M.D. 1987. Some long term effects of smoking from the Caerphilly and Speedwell Collaborative Surveys. *Journal of Clinical Pathology,* 40:909-913.
148. Friedman G.D., Siegelaub A.B., Seltzer C.C., Feldman R., and Collen M.F. 1973. Smoking habits and the leukocyte count. *Archives of Environmental Health,* 26:137-143.
149. Hughes D.A., Haslam P.L., Townsend P.J., and Turner-Warwick M. 1985. Numerical and functional alterations in circulatory lymphocytes in cigarette smokers. *Clinical and Experimental Immunology,* 61:459-466.
150. Nobel R.C., and Penny B.B. 1975. Comparison of leukocyte count and function in smoking and nonsmoking men. *Infection and Immunity,* 12:550-555.
151. Lando H.A., Haddock C.K., Klesges R.C., Talcott G.W., and Jensen J. 1999. Smokeless tobacco use in a population of young adults. *Addictive Behaviors,* 24:431-447.
152. DiFranza J.R., Winters T.H., Goldberg R.J., Cirillo L., and Biliouris T. 1986. The relationship of smoking to motor vehicle accidents and traffic violations. *New York State Journal of Medicine,* 86:464-467.
153. Eiser J.R., and Sutton S.R. 1979. Smoking, seat belts, and beliefs about health. *Addictive Behaviors,* 4:331-338.

154. Chiolero A., Wietlisbach V., Ruffieux C., Paccaud F., and Cornuz J. 2006. Clustering of risk behaviors with cigarette consumption: a population-based survey. *Preventive Medicine,* 42:348-353.
155. Kohrt M., Bloomfield S.A., Little K.D., Nelson M.E., and Yingling V.R. 2004. Physical activity and bone health. Position stand of the American College of Sports Medicine. *Medicine and Science in Sports and Exercise,* 36:1985-1996.
156. Layne J.E., and Nelson M.E. 1999. The effects of progressive resistance training on bone density: a review. *Medicine and Science in Sports and Exercise,* 31:25-30.
157. American College of Sports Medicine. 1998. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Medicine and Science in Sports and Exercise,* 30:975-991.
158. Fleck S.J., and Kraemer W.J. 1987. *Designing Resistance Training Programs*. Champaign IL: Human Kinetic Publishers.
159. Maffulli N., and King J.B. 1992. The effects of physical activity on some components of the skeletal system. *Sports Medicine,* 13:393-407.
160. Blair S.N., Cheng Y., and Holder S. 2001. Is physical activity or physical fitness more important in defining health benefits? *Medicine and Science in Sports and Exercise,* 33:S379-S399.
161. Kell R.T., Bell G., and Quinney A. 2001. Musculoskeletal fitness, health outcomes and quality of life. *Sports Medicine,* 31:863-873.
162. Ross R., and Janssen I. 2001. Physical activity, total and regional obesity: dose-response considerations. *Medicine and Science in Sports and Exercise,* 33:S521-S527.
163. Pettersson U., Nordstrom P., and Lorentzon R. 1999. A comparison of bone mineral density and muscle strength in young male adults with different exercise level. *Calcified Tissue International,* 64:490-498.
164. Elgan C., Dykes A.K., and Samsioe G. 2002. Bone mineral density and lifestyle among female students aged 16-24 years. *Gynecological Endocrinology,* 16:91-98.
165. Babroutsi E., Magkos F., Manios Y., and Sidossis L.S. 2005. Lifestyle factors affecting heel ultrasound in Greek females across different life stages. *Osteoporosis International,* 16:552-561.
166. Valimaki M.J., Karkkainen M., Lamberg-Allardt C., Laitinen K., Alhava E., Heikkinen J., Impivaara O., Makela P., Palmgren J., and Seppanen R. 1994. Exercise, smoking, and calcium intake during adolescence and early adulthood as determinants of peak bone mass. Cardiovascular Risk in Young Finns Study Group. *British Medical Journal,* 309:230-235.
167. Afghani A., Xie B., Wiswell R.A., Gong J., Li Y., and Johnson C.A. 2003. Bone mass of Asian adolescents in China: influence of physical activity and smoking. *Medicine and Science in Sports and Exercise,* 35:720-729.
168. Knapik J.J., Darakjy S., Hauret K.G., Canada S., Scott S., Rieger W., Marin R., and Jones B.H. 2006. Increasing the physical fitness of low fit recruits prior to Basic Combat Training: an evaluation of fitness, injuries and training outcomes. *Military Medicine,* 171:45-54.

169. Shaffer R.A., Rauh M.J., Brodine S.K., Trone D.W., and Macera C.A. 2006. Predictors of stress fractures in young female recruits. *American Journal of Sports Medicine,* 34:108-115.
170. Friedl K.E., Nuovo J.A., Patience T.H., and Dettori J.R. 1992. Factors associated with stress fractures in Army women: indications for further research. *Military Medicine,* 157:334-338.
171. Winfield A.C., Moore J., Bracker M., and Johnson C.W. 1997. Risk factors associated with stress reactions in female Marines. *Military Medicine,* 162:698-702.
172. Lloyd T., Triantafyllou S.J., Baker E.R., Houts P.S., Whiteside J.A., Kalenak A., and Stumpf P.G. 1986. Women athletes with menstrual irregularity have increased musculoskeletal injuries. *Medicine and Science in Sports and Exercise,* 18:374-379.
173. Beckvid-Henriksson G., Schnell C., and Linden-Hirschberg A. 2000. Women endurance runners with menstrual dysfunction have prolonged interruption of training due to injury. *Gynecologic and Obstetric Investigation,* 49:41-46.
174. Bennell K.L., Malcom S.A., Thomas S.A., Reid S.J., Brukner P.D., Ebeling P.R., and Ward J.D. 1996. Risk factors for stress fractures in track and field athletes. A twelve-month prospective study. *American Journal of Sports Medicine,* 24:810-818.
175. Davis M.C., Hall M.L., and Jacobs H.S. 1990. Bone mineral loss in young women with amenorrhoea. *British Medical Journal,* 301:790-793.
176. Feingold D., and Hame S.L. 2006. Female athletic triad and stress fractures. *Orthopedic Clinics of North America,* 37:575-583.
177. Bennell K., Matheson G., Meeuwisse W., and Brukner P. 1999. Risk factors for stress fractures. *Sports Medicine,* 28:91-122.

APPENDIX B.

REQUEST LETTER

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, DC 20301

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Support for Military Training Footwear Study

I solicit your support as we begin the Defense Safety Oversight Council (DSOC) sponsored project on the Military Training Footwear Study. This study is directed at reducing the impact of injuries on combat readiness and attrition during Initial Entry Training. It is a quad-service initiative to: 1) determine if prescribing footwear to basic trainees on the based on measured foot type will reduce attrition and training-related injuries among military recruits, 2) directly compare basic training injury rates across the services using the same metrics; and 3) make recommendations for cross-cutting injury preventions efforts. After the study's conclusion, there will be briefings for each Service's leadership on results and recommendations as well as to the DSOC.

The organizing agency for the study is the Naval Health Research Center (NHRC). Mr. Daniel Trone, NHRC, will serve as the principal investigator, overall project coordinator, and POC (619-767-4772; trone@nhrc.navy.mil). Your support for this study and to Mr. Trone will be greatly appreciated.

James B. Gunlicks
Chair, Military Training Task Force
Defense Safety Oversight Council

APPENDIX C.

LIFESTYLE QUESTIONNAIRE (EXAMPLE)

Physical Training Footwear & Musculoskeletal Injuries: **Trainee Survey**

READ ALL DIRECTIONS AND QUESTIONS CAREFULLY

- **In this questionnaire, you will be asked about yourself and your lifestyle before coming to basic training.**
- **Answer each question to the best of your ability.**

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 Athletic shoes
     Name or type, ______________________
   - ☐6 Sandals
     Name or type, ______________________
   - ☐7 Other
     Please specify, ______________________

For Office Use Only: Coded by: _____ Entered by: _____ Verified by: _____

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 or more times per week
- ☐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

22. Were any of these injuries due to participation in a sport played during high school?

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

Physical Fitness

23. How would you rate your current physical fitness?

☐1 Poor
☐2 Fair
☐3 Good
☐4 Very Good
☐5 Excellent

24. Indicate which of the following sports you participated in during high school and the number of seasons you played that sport.

☐0 Does not apply, I did not play sports

☐1 Basketball	|___|___| Seasons		☐6 Volleyball	|___|___| Seasons
☐2 Football	|___|___| Seasons		☐7 Soccer	|___|___| Seasons
☐3 Baseball/Softball	|___|___| Seasons		☐8 Lacrosse	|___|___| Seasons
☐4 Field Hockey	|___|___| Seasons		☐9 Cross Country	|___|___| Seasons
☐5 Track (running events)	|___|___| Seasons		☐10 Other, _______________,	|___|___| Seasons

Menstrual History

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

|___|___| Years

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

|___|___| Menstrual Periods

27. 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

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

☐ 1 YES
☐ 2 NO

29. 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.

APPENDIX D

RECORDING SHEET FOR FOOT MEASUREMENTS (EXAMPLE)

Physical Training Footwear & Musculoskeletal Injury
Foot Measurement Data Recording Sheet

Date: |___|___| / |___|___| / 2007
MM DD

RECRUIT'S NAME & SSN

Last Name: ______________________ First Name: ______________________

SSN: |___|___|___| - |___|___| - |___|___|___|___|

FOOT SHAPE

RA #1 initials: _____ RA #2 initials: _____

	RA #1			RA #2		
Right Foot Arch:	High	Low	Normal	High	Low	Normal
Left Foot Arch:	High	Low	Normal	High	Low	Normal

Foot Shape Final Determination

Right Foot Arch: High Low Normal

Left Foot Arch: High Low Normal

SHOE PRESCRIPTION - RA initials: _____

Shoe Model: 587 767 881

Shoe Size: |___|___|.|___|

Shoe Width: B D EE EEEE

FOOT LENGTH & ARCH HEIGHT

RA initials: _____

Device #: _____

Foot Length 1 (Total): Right |___|___|.|___|___| cm Left |___|___|.|___|___| cm

Foot Length 2 (MPJ): Right |___|___|.|___|___| cm Left |___|___|.|___|___| cm

Foot Arch Height: Right |___|___|.|___|___| mm Left |___|___|.|___|___| mm

FINAL SHOE SELECTION

Shoe Model: 587 767 881

Shoe Size: |___|___|.|___|

Shoe Width: B D EE EEEE

For Office Use Only: Coded by: _____ Entered by: _____ Verified by: _____

APPENDIX E.

ICD-9 CODES FOR THE MODIFIED OVERUSE INJURY INDEX

354.0
715.04
715.09
715.10
715.11
715.12
715.13
715.14
715.15
715.16
715.17
715.18
715.20
715.21
715.22
715.23
715.24
715.24
715.25
715.26
715.27
715.28
715.30
715.31
715.32
715.33
715.34
715.35
715.36
715.37
715.38
715.80
715.81
715.82
715.83
715.84
715.85
715.86
715.87
715.88
715.89
715.90
715.91
715.92
715.93
715.94
715.95
715.96
715.97
715.98
716.80
716.81
716.82
716.83
716.84
716.85
716.86
716.87
716.88
716.89
716.90
716.91
716.92
716.93
716.94
716.95
716.96
716.97
716.98
716.99
717.7
719.40
719.41
719.42
719.43
719.44
719.45
719.46
719.47
719.48
719.49
719.50
719.51
719.52
719.53
719.54
719.55
719.56
719.57
719.58
719.59
719.60
719.61
719.62
719.63
719.64
719.65
719.66
719.67
719.68
719.69
720.2
721.0
721.1
721.2
721.3
721.4
721.41
721.42
721.90
721.91
722.4
722.5
722.51
722.52
722.60
722.70
722.71
722.72
722.73
723.0
723.1
723.3
723.4
723.5
723.9
724.00
724.01
724.02
724.09
724.2
724.3
724.4
724.5
724.60
724.70
724.71
724.79
724.8
726.10
726.11
726.12
726.19
726.2
726.30
726.31
726.32
726.33

726.39	727.66	735.2	736.89
726.4	727.67	735.3	736.9
726.5	727.68	735.4	737.0
726.60	727.69	735.5	737.10
726.61	727.82	735.8	737.19
726.62	727.83	735.9	737.20
726.63	727.9	736.00	737.21
726.64	728.9	736.01	737.22
726.65	728.71	736.02	737.29
726.69	728.83	736.03	737.30
726.70	728.85	736.04	737.31
726.71	729.1	736.05	737.32
726.72	729.2	736.06	737.33
726.73	729.4	736.07’	737.34
726.79	729.5	736.1	737.39
726.90	729.81	736.20	737.8
726.91	729.82	736.21	737.9
727.00	729.89	736.22	738.4
727.03	729.9	736.29	738.7
727.04	733.10	736.41	738.8
727.05	733.11	736.42	738.9
727.06	733.13	736.5	739.1
727.09	733.14	736.60	739.2
727.1	733.15	736.70	739.3
727.2	733.16	736.71	739.4
727.3	733.19	736.72	739.5
727.59	733.93	736.73	739.60
727.60	733.94	736.74	739.7
727.62	733.95	736.75	739.8
727.63	734	736.76	843
727.64	735.0	736.79	
727.65	735.1	736.81	