Injury Reduction Effectiveness of Selecting Running Shoes Based on Plantar Shape

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Abstract

Knapik, JJ, Swedler, DI, Grier, TL, Hauret, KG, Bullock, SH, Williams, KW, Darakjy, SS, Lester, ME, Tobler, SK, and Jones, BH. Injury reduction effectiveness of selecting running shoes based on plantar shape. *J Strength Cond Res* 23(3): 685–697, 2009—Popular running magazines and running shoe companies suggest that imprints of the bottom of the feet (plantar shape) can be used as an indication of the height of the medial longitudinal foot arch and that this can be used to select individually appropriate types of running shoes. This study examined whether or not this selection technique influenced injury risk during United States Army Basic Combat Training (BCT). After foot examinations, BCT recruits in an experimental group (E: $n = 1{,}079$ men and 451 women) selected motion control, stability, or cushioned shoes for plantar shapes judged to represent low, medium, or high foot arches, respectively. A control group (C: $n = 1{,}068$ men and 464 women) received a stability shoe regardless of plantar shape. Injuries during BCT were determined from outpatient medical records. Other previously known injury risk factors (e.g., age, fitness, and smoking) were obtained from a questionnaire and existing databases. Multivariate Cox regression controlling for other injury risk factors showed little difference in injury risk between the E and C groups among men (risk ratio (E/C) = 1.01; 95% confidence interval = 0.88–1.16; $p = 0.87$) or women (risk ratio (E/C) = 1.07; 95% confidence interval = 0.91–1.25; $p = 0.44$). In practical application, this prospective study demonstrated that selecting shoes based on plantar shape had little influence on injury risk in BCT. Thus, if the goal is injury prevention, this selection technique is not necessary in BCT.

Key Words age, physical activity, physical fitness, smoking

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Introduction

Popular running magazines, running shoe companies, and other publications suggest that imprints of the bottom of the feet (i.e., plantar shape) can be used as an indication of the height of the medial longitudinal foot arch and that this can be used to select individually appropriate types of running shoes (5,10–12,34,38). Individuals with plantar shapes reflecting low arches are presumed to have greater rear foot and midfoot mobility that allows the foot to pronate excessively during the stance phase of running. Motion control shoes are recommended for low-arched individuals because such shoes presumably control this excessive pronation. Individuals with plantar shapes reflecting high arches are presumed to have rigid or inflexible feet that underpronate and impact the ground with greater force. Cushioned shoes are recommended for high-arched individuals to presumably allow for more pronation and provide more shock absorbency to reduce ground impact forces. Individuals with plantar shapes reflecting average arch heights are assumed to impact the ground with less force and have an appropriate amount of pronation during the stance phase of running. Stability shoes are recommended for average-arched individuals, and these shoes presumably have moderate cushioning and motion control characteristics (38).

There are a large number of biomechanical studies involving running shoes, and these studies frequently hypothesize that specific changes in body mechanics induced by running shoes can influence injury rates (7,17,18,31,32,35,45). However, the data linking shoes to actual cases of injuries are sparse. Two case studies (6,44) and several epidemiological investigations (9,30,33) provide some evidence that ill-fitting and older shoes may result in higher injury rates. Only one retrospective cohort study has specifically tested the hypothesis that selecting running shoes on the basis of foot arch height might reduce injuries, and this study noted several major methodological problems (25).

The current practice in the United States (U.S.) Army is to prescribe running shoes to recruits entering Basic Combat

Training (BCT) based on their plantar shape during full weight bearing. Because the question of whether or not this technique reduced injuries had not been adequately addressed, the U.S. Department of Defense Safety Oversight Council requested that the issue be studied. This paper reports the results of an investigation to determine whether or not injury risk can be reduced by selecting running shoes based on plantar shape.

Methods

Experimental Approach to the Problem

Subjects were randomized into a control (C) or experimental (E) group in sequential order (alternately in order of arrival for testing). All C group subjects were assigned a single stability-type running shoe. E group subjects were prescribed a type of running shoes based on their plantar shape. If the subject in the E group was classified as having a plantar shape indicative of a low arch, a motion control type shoe was prescribed. If the subject in the E group was classified as having a plantar shape indicative of a high arch, a cushion type shoe was prescribed. If the subject in the E group was classified as having a plantar shape indicative of a normal arch, a stability type shoe was prescribed. If the plantar shape was classified differently for an E subject's right foot and left foot, the raters prescribed a shoe type that most closely fit the average of the two feet. For example, a subject with a plantar shape indicative of a moderately high left foot and a normal right foot would be prescribed a stability shoe because the left foot was not judged extremely high.

Subjects

Subjects were new U.S. Army recruits participating in BCT at Fort Jackson, S.C. They were briefed on the purposes and risks of the study and voluntarily agreed to participate by signing an informed consent statement. The study protocol was approved by the institutional review committee of the U.S. Army Medical Research and Development Command, Fort Detrick, Md.

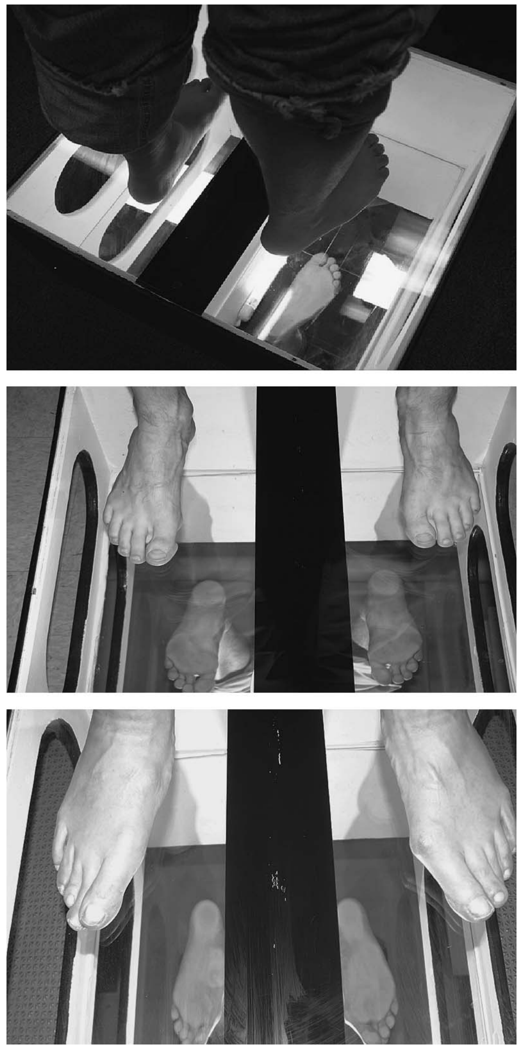

Figure 1. Plantar shape device with normal (top figure), high arched (middle figure), and low arched (bottom figure) individuals.

Initial Testing

Volunteers were administered a questionnaire that asked about tobacco use, physical activity, injury history, and (for women) menstrual history. To determine the shape of the plantar surface, the barefoot volunteer mounted the acrylic platform of the device shown in Figure 1. Subjects were instructed to stand with equal weight on each foot. The device contained a mirror that reflected the underside of the foot, thus providing a visual image of the footprint and the amount of plantar surface contact. The footprint was examined by two testers who were side by side. The testers made independent determinations of the plantar shapes, classifying each subject's arch height as either high, normal, or low based on a template (38): more area in the middle third of the plantar shape indicated a low arch and less area a high arch (Figure 1). If the raters' assessments differed, they discussed the assessment and reached consensus. Both the independent assessments and the final consensus were recorded.

Running Shoes

The day after the initial testing, subjects were escorted to the Post Exchange (PX), where they obtained their prescribed type of running shoe. A member of the study team assured that each person selected the prescribed shoe type and was fitted with the proper shoe size. All C group subjects received a standard stability running shoe (New Balance 767ST; New Balance, Boston, Mass.). E subjects could select any shoe within their assigned types. The 19 shoe models available for purchase at the PX are listed in Table 1 along with the shoe types and the number of E group subjects selecting each shoe. The Army and Air Force Exchange System (AAFES)

TABLE 1. Distribution of shoes by type and shoes selected by E group subjects.

PX classification	Manufacturer classification	Runner's World classification	Shoe (brand and model)	E men (n)	E women (n)
Motion control	Motion control	Motion control	Asics Gel Foundation 7	21	13
Motion control	Motion control	Motion control	Brooks Addiction 7	29	9
Motion control	Motion control	Motion control	Saucony Grid Stabil 6	33	21
Motion control	Stability	Stability	New Balance 857*	37	1
Stability	Stability	Stability	New Balance 767ST	328	143
Stability	Stability	Stability	Asics Gel 1120	3	0
Stability	Stability	Stability	Asics Gel 2120	118	65
Stability	Stability	Stability	Brooks Adrenaline GTS6	42	16
Stability	Stability	Stability	Brooks Adrenaline GTS7	108	46
Stability	Stability	Stability	Nike Structure Triax	124	3
Stability	Stability	Stability	Saucony Grid Omni 5	43	21
Stability	Stability	Not rated	New Balance 717G4‡	2	1
Stability	Cushion	Cushion	Nike Air Max Moto†	22	43
Cushion	Cushion	Cushion	New Balance 755	24	1
Cushion	Cushion	Cushion	Asics Gel Cumulus	30	22
Cushion	Cushion	Cushion	Brooks Radius 6	45	28
Cushion	Cushion	Cushion	Nike Air Pegasus	70	26
Cushion	Cushion	Cushion	Saucony Grid Trigon 4	8	9
Cushion	Cushion	Not rated	New Balance 644‡	2	0

*This shoe was classified stability by the manufacturer and Runner's World but as motion control by the PX.
†This shoe was classified cushion by manufacturer and Runner's World but stability by the PX.
‡These shoes were not classified by Runner's World.

determined which shoes were available in the PX and informed us that the vendors had indicated the shoe types.

To verify the PX shoe types, we examined the *Runner's World* magazine shoe ratings (10–12) and the *Runner's World* Running Shoe Finder (www.runnersworld.com/channel/0,7119,s6-240-0-0-0,00.html). We also examined websites for the various shoe manufactures and, in some cases, called company representatives to verify the shoe types. For 2 shoes, the PX classification differed from those of the *Runner's World* and the manufacturer. The PX classification listed the New Balance 857 as a motion control shoe, but *Runner's World* and the manufacturer listed it as a stability shoe. The Nike Air Max Moto (Nike, Beaverton, Ore.) was listed in the PX classification as a stability shoe but by *Runner's World* and the manufacturer as a cushioned shoe. Two shoes, the New Balance 644 and 717, could not be found in the *Runner's World* sources.

Basic Combat Training

After the subjects received their shoes, they continued in-processing at the Reception Station for 3 to 7 days to complete paperwork, receive vaccinations, undergo medical examinations, and complete other activities. They then relocated to their training companies where they began their 9-week BCT cycle. Cycles in the current study ran between March and July 2007.

BCT is described in U.S. Army Training and Doctrine Command Regulation 350-6 (3). Briefly, physical training (PT) sessions were performed in the early morning for 1–1.5 hours, 4–6 days per week. PT sessions generally alternated between "cardiorespiratory days" and "muscle strength days." Cardiorespiratory days involved distance running (0.5–3 miles) and/or sprinting, with some push-ups and sit-ups. Four running ability groups were formed in each company based on the distribution of run scores on the first fitness test (25% in each group). Muscle strength days involved different types of push-ups and sit-ups, in addition to a wide variety of other training drills, as described in Army training manuals (2,4). Soldiers also participated in classroom instruction and operational field training (3). No effort was made to restrict the wearing of running shoes to PT, and no system was in place to account for the amount of time subjects wore their running shoes during their limited discretionary time.

Attrition from Training and Withdrawal from Study During BCT

Some subjects attrited from BCT, not completing the entire 9-week program. Reasons for attrition included (a) discharge from the Army, (b) reassignment to a new unit (recycle), (c) return to National Guard Unit and release from active duty (REFRAD), and (d) absent without leave (AWOL). Discharges and recycles were obtained from a local data system maintained at Fort Jackson and cross checked with 2 Army-wide databases: the Resident Individual Training Management System and the Automated Instructional Management

Table 2. Volunteers excluded and retained in the study.

	Volunteers (*n*)				Proportion of volunteers (%)			
	Men		Women		Men		Women	
	C	E	C	E	C	E	C	E
Volunteers	1,343	1,346	630	633	100	100	100	100
Prescription not obtained in PX	140	127	41	51	10	9	7	8
Changed shoes during BCT	124	130	106	114	9	10	17	18
Total retained*	1,079	1,089	483	468	80	81	77	74
Total excluded†	264	257	147	165	20	19	23	26
p-value (retained/excluded)	0.34		0.13					

C = control; E = experimental; PX = Post Exchange; BCT = basic combat training.
*Retained = volunteers (prescription not obtained in PX + changed shoes during BCT).
†Excluded = prescription not obtained in PX + changed shoes during BCT.

System-Personal Computer. REFRADs were obtained from the senior Army Reserve/National Guard liaison at Fort Jackson, who maintains a database of these cases. AWOLs were obtained from a local list maintained by the Trainee/Student Work Division at Fort Jackson.

Just before graduation, subjects were assembled in their BCT companies. Individuals who had changed their running shoes during the course of BCT were identified and considered study withdrawals.

Physical Characteristics, Demographics, and Physical Fitness

Subjects' height and weight on entry to service were obtained from the Reception Battalion Automated Support System database. Subjects' educational level, marital status, race, and component (active, reserve, or National Guard) were obtained from the Defense Manpower Data Center (DMDC) database.

Within 2 to 4 days of subjects entering their training companies, drill sergeants administered the Army Physical Fitness Test (APFT), using well-standardized techniques (36). The APFT consisted of 3 events: a 2-minute maximal effort push-up event, a 2-minute maximal effort sit-up event, and a 2-mile run for time administered in that order. APFT scores were obtained from the BCT companies. Some of the companies did not retain their initial APFT scores, so the number of subjects with APFT scores was limited.

Injury Outcomes

The Defense Medical Surveillance System (DMSS) regularly incorporates data on ambulatory (outpatient) encounters that occur within military treatment facilities, as well as those at outside facilities that are paid for by the Department of Defense. The DMSS provided visit dates and International Classification of Disease, Ninth Revision, Clinical Modification (ICD-9-CM) codes for all outpatient medical visits that occurred during the 9-week BCT cycle of each subject. The first 4 diagnoses for each visit were considered in the analysis, although a single visit usually included only 1 diagnosis. Five

Table 3. Comparisons of control (C) and experimental (E) groups on reasons for attrition.

	Male attrition					Female attrition				
	C (*n*)		E (*n*)			C (*n*)		E (*n*)		
Reasons for attrition	No	Yes	No	Yes	*p*-value*	No	Yes	No	Yes	*p*-value*
Discharges	1,030	49	1,038	51	0.37	416	67	405	63	0.85
Recycles	1,052	27	1,072	17	0.12	455	28	443	25	0.76
AWOL	1,072	7	1,084	5	0.55	482	1	467	1	0.98
REFRAD	1,079	0	1,089	0	–	481	2	467	1	0.58

AWOL = Absent without leave; REFRAD = Recalled from active duty (National Guard).
*From chi-square statistic.

Table 4. Comparison of control (C) and experimental (E) groups on injury incidence rates.

Index	Men: Injury incidence rate (injuries/1,000 person-days) C	Men: Injury incidence rate (injuries/1,000 person-days) E	Men: Rate ratio-C/E (95% confidence interval)	Men: *p*-value*	Women: Injury incidence rate (injuries/1,000 person-days) C	Women: Injury incidence rate (injuries/1,000 person-days) E	Women: Rate ratio-C/E (95% confidence interval)	Women: *p*-value*
Installation injury index	5.49	5.48	1.00 (0.86–1.16)	0.99	10.30	10.67	0.97 (0.82–1.14)	0.67
Modified installation injury index	5.89	5.87	1.00 (0.87–1.15)	0.96	10.86	10.93	0.96 (0.82–1.12)	0.61
Overuse injury index	4.37	4.55	0.96 (0.82–1.13)	0.63	8.87	9.16	0.94 (0.79–1.11)	0.45
Training-related injury index	3.99	4.38	0.91 (0.77–1.08)	0.13	8.80	8.59	0.99 (0.83–1.18)	0.90
Comprehensive injury index	5.95	6.04	0.99 (0.86–1.13)	0.85	10.87	11.37	0.96 (0.82–1.12)	0.58

*Chi-square for rates (19).

injury indices were calculated: the Installation Injury Index (III), the Modified Installation Injury Index (MIII), the Training Injury Index (TII), the Comprehensive Injury Index (CII), and the Overuse Injury Index (OII). All indices include specific ICD-9-CM codes, as described previously (24).

Statistical Analyses

Age was calculated from the date of birth on the questionnaire to the date of the informed consent briefing. Body mass index (BMI) was calculated as weight/height^2 (21). Between-rater reliability of plantar shape determinations was assessed with the kappa coefficient.

For all 5 injury indices, person-time injury incidence rates (injured subjects per 1,000 person-days) were calculated as:

(Subjects with $\geq$1 injury) $\div$ (total time in BCT $\times$ 1,000)

The total time in BCT was 63 days for subjects who completed BCT and less for those who attrited from training. Comparisons between the E and C groups were made using a chi-square for person-time (19).

Cox regression was used to examine the associations between potential risk factors (including group membership) and time to first CII injury. For each analysis, once a subject had an injury, his or her contribution to time in BCT was terminated. Those who attrited from training had their time terminated (censored) at the day they left their original training company. All potential injury 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 converted to four equal-sized groups based on the distribution of the scores. Age was partitioned into four groups (17–19, 20–24, 25–29, and $\geq$30 years). Univariate Cox regressions established the association between time to first injury and each potential risk factor in isolation. Backward-stepping multivariate Cox regressions established the effect of multiple risk factors (including group membership) on injury risk. Risk factors were included in the multivariate model if they achieved $p < 0.10$ in the univariate analyses (15). In all Cox regressions, simple contrasts were used by establishing a baseline level of each variable (risk ratio = 1.00) and then comparing the baseline risk to the risk at the other levels of the variable.

Results

Participants and Study Exclusions

Volunteers for the study included 2,689 men and 1,263 women. Individuals entering the U.S. Army are broadly representative of the U.S. population and enter BCT with a wide variety of demographics, physical characteristics, physical activity, and physical fitness levels, as described below. Subjects participated in BCT in 38 separate companies conducting training between March and July 2007.

Subjects were excluded from analysis if (a) they did not, or could not, obtain the prescribed shoe in the PX or (b) if they

Table 5. Injury hazard ratios for each potential risk factor (univariate Cox regression).

	Men				Women			
Variable (Mean ± SD)*	Level of variable	*n*	Hazard ratio (95% CI)	*p*-value	Level of variable	*n*	Hazard ratio (95% CI)	*p*-value
Group	C	1,068	1.00	–	C	464	1.00	–
	E	1,079	1.02 (0.89–1.17)	0.80	E	451	1.06 (0.90–1.24)	0.48
Age (men = 23 ± 5;	17.0–19.9 y	692	1.00	–	17.0–19.9 y	328	1.00	–
women = 23 ± 6)	20.0–24.9 y	945	1.07 (0.90–1.26)	0.45	20.0–24.9 y	355	1.02 (0.85–1.23)	0.84
	25.0–29.9 y	305	1.36 (1.10–1.68)	<0.01	25.0–29.9 y	118	1.30 (1.01–1.66)	0.04
	≥30 y	205	1.37 (1.06–1.73)	0.02	≥30 y	114	1.43 (1.12–1.84)	<0.01
Body mass index	15.20–22.12 kg·m^{-2}	538	1.00	–	14.15–21.29 kg·m^{-2}	230	1.00	–
(men = 25.5 ± 4.3;	22.13–25.06 kg·m^{-2}	542	0.89 (0.73–1.08)	0.23	21.30–23.80 kg·m^{-2}	228	0.89 (0.71–1.11)	0.30
women = 23.7 ± 3.3)	25.07–28.36 kg·m^{-2}	534	1.06 (0.87–1.28)	0.56	23.81–25.97 kg·m^{-2}	228	0.91 (0.73–1.13)	0.40
	28.37–39.56 kg·m^{-2}	533	0.97 (0.79–1.18)	0.74	25.98–34.02 kg·m^{-2}	229	0.89 (0.71–1.11)	0.28
Push-ups	0–25 reps per 2 min	359	1.38 (1.08–1.78)	0.01	0–4 reps per 2 min	132	1.92 (1.41–2.59)	<0.01
(men = 35 ± 15;	26–34 reps per 2 min	309	1.19 (0.91–1.54)	0.21	5–13 reps per 2 min	134	1.36 (0.99–1.86)	0.06
women = 15 ± 12)	25–44 reps per 2 min	331	1.01 (0.77–1.32)	0.95	14–22 reps per 2 min	128	1.20 (0.87–1.65)	0.27
	45–83 reps per 2 min	331	1.00	–	23–62 reps per 2 min	122	1.00	–
Sit-ups	0–33 reps per 2 min	333	1.24 (0.96–1.61)	0.10	0–20 reps per 2 min	139	1.75 (1.29–2.37)	<0.01
(men = 41 ± 15;	31–40 reps per 2 min	336	1.19 (0.92–1.55)	0.19	21–33 reps per 2 min	130	1.34 (0.98–1.83)	0.07
women = 33 ± 17)	41–51 reps per 2 min	349	1.01 (0.78–1.32)	0.92	34–46 reps per 2 min	127	1.10 (0.79–1.51)	0.58
	52–92 reps per 2 min	312	1.00	–	47–89 reps per 2 min	120	1.00	–
2-Mile run	11.7–16.0 min	310	1.00	–	12.3–19.4 min	118	1.00	–
(men = 18.3 ± 3.1;	16.1–17.4 min	315	1.11 (0.84–1.47)	0.46	19.5–22.1 min	116	0.99 (0.71–1.38)	0.94
women = 22.1 ± 3.5)	17.5–20.2 min	305	1.24 (0.94–1.64)	0.13	22.2–24.7 min	117	1.14 (0.82–1.59)	0.43
	20.3–32.2 min	310	1.52 (1.16–1.99)	<0.01	24.8–31.3 min	116	2.18 (1.60–2.98)	<0.01
Cigarettes per day in	None	1,095	1.00	–	None	533	1.00	–
last 30 d	1–9 cigarettes per day	559	1.20 (1.01–1.42)	0.04	1–9 cigarettes per day	224	1.44 (1.19–1.73)	<0.01
(men = 9 ± 7;	10–19 cigarettes per day	333	1.24 (1.01–1.42)	0.04	10–19 cigarettes per day	114	1.49 (1.17–1.89)	<0.01
women = 8 ± 6)	≥20 cigarettes per day	160	1.67 (1.31–2.13)	<0.01	≥20 cigarettes per day	44	1.90 (1.34–2.68)	<0.01
Days smoked cigarettes	None	1,092	1.00	–	None	531	1.00	–
in last 30 d	1–9 d	217	0.97 (0.76–1.25)	0.83	1–9 d	79	1.21 (0.91–1.61)	0.18
(men = 21 ± 11;	10–19 d	167	1.14 (0.87–1.50)	0.34	10–19 d	51	1.57 (1.12–2.20)	<0.01
women = 22 ± 11)	≥20 d	671	1.42 (1.22–1.65)	<0.01	≥20 d	254	1.58 (1.32–1.88)	<0.01
Self-rating of physical activity	Much less active	191	1.72 (1.23–2.41)	<0.01	Much less active	152	1.47 (0.92–2.34)	0.11
compared with others of	Somewhat less active	528	1.18 (0.87–1.59)	0.28	Somewhat less active	285	1.47 (0.94–2.03)	0.09
same age and sex	About the same	709	1.11 (0.84–1.49)	0.47	About the same	245	1.16 (0.73–1.82)	0.54
	Somewhat more active	559	0.96 (0.71–1.30)	0.78	Somewhat more active	200	1.06 (0.67–1.69)	0.80
	Much more active	157	1.00	–	Much more active	33	1.00	–

Frequency of exercise or sports before BCT	≤1 time per week	591	1.26 (1.02–1.55)	0.03	≤1 time per week	336	1.41 (1.09–1.82)	<0.01
	2–4 times per week	1,167	1.04 (0.86–1.27)	0.66	2–4 times per week	455	1.11 (0.86–1.43)	0.42
	≥5 times per week	386	1.00	–	≥5 times per week	124	1.00	–
Frequency of running/jogging before BCT	≤1 time per week	988	1.28 (0.98–1.68)	0.07	≤1 time per week	459	1.62 (1.16–2.27)	<0.01
	2–4 times per week	973	1.03 (0.78–1.34)	0.86	2–4 times per week	385	1.32 (0.94–1.86)	0.11
	≥5 times per week	184	1.00	–	≥5 times per week	70	1.00	–
Length of time running/jogging before BCT	Did not run or jog	310	1.58 (1.17–2.14)	<0.01	Did not run or jog	167	1.34 (0.96–1.85)	0.08
	≤1 mo	885	1.11 (0.84–1.47)	0.45	≤1 mo	310	1.18 (0.87–1.59)	0.29
	2–3 mo	612	1.13 (0.85–1.51)	0.39	2–3 mo	239	0.92 (0.67–1.26)	0.61
	4–6 mo	154	1.24 (0.87–1.78)	0.24	4–6 mo	69	1.10 (0.74–1.63)	0.66
	≥7 mo	183	1.00	–	≥7 mo	80	1.00	–
Previous lower extremity injury	No	1,830	1.00	–	No	793	1.00	–
	Yes	316	1.01 (0.60–1.22)	0.95	Yes	122	1.41 (1.13–1.75)	<0.01
Menstrual periods in last year					0	30	1.83 (1.22–2.76)	<0.01
					1–3	28	1.05 (0.66–1.68)	0.84
					4–6	36	1.25 (0.85–1.86)	0.26
					7–9	39	1.23 (0.84–1.80)	0.29
					10–12	750	1.00	–
					≥13	28	1.05 (0.65–1.68)	0.85
Component	Active Army	1,075	1.00	–	Active Army	454	1.00	–
	National Guard	807	0.87 (0.75–1.01)	0.06	National Guard	326	0.85 (0.71–1.01)	0.06
	Reserve	245	0.81 (0.64–1.03)	0.08	Reserve	122	0.78 (0.61–1.00)	0.05
Educational level	<HS graduate	98	1.00	–	<HS graduate	37	1.00	–
	HS graduate	1,653	0.99 (0.71–1.36)	0.94	HS graduate	664	0.91 (0.63–1.33)	0.63
	Some college	135	1.05 (0.70–1.59)	0.81	Some college	74	0.83 (0.52–1.31)	0.42
	College graduate	69	0.65 (0.38–1.13)	0.13	College graduate	49	0.77 (0.46–1.26)	0.29
	Unknown	172	0.71 (0.47–1.08)	0.11	Unknown	78	0.81 (0.51–1.28)	0.36
Race	Caucasian	1,401	1.00	–	Caucasian	494	1.00	–
	African-American	364	0.95 (0.78–1.15)	0.58	African-American	263	0.75 (0.62–0.90)	<0.01
	Hispanic	266	1.01 (0.81–1.24)	0.97	Hispanic	96	0.82 (0.64–1.07)	0.15
	Asian	66	0.63 (0.39–1.02)	0.06	Asian	32	0.59 (0.37–0.94)	0.03
	American Indian	21	0.67 (0.30–1.50)	0.33	American Indian	12	0.95 (0.47–1.92)	0.89
	Unknown	9	1.11 (0.42–2.98)	0.83	Unknown	5	0.40 (0.10–1.59)	0.19
	Never married	1,628	1.00	–	Never married	639	1.00	–
Marital status	Married	423	1.09 (0.92–1.30)	0.33	Married	203	1.28 (1.07–1.55)	<0.01
	Other	68	1.47 (1.03–2.10)	0.03	Other	60	1.97 (1.39–2.53)	<0.01
	Unknown	8	1.36 (0.51–3.64)	0.54	Unknown	0	–	–

BCT = basic combat training; HS = high school.
*For continuous variables.

Table 6. Injury hazard ratios for study variables with the fitness variable excluded (multivariate Cox regression).

Variable	Level of variable	*n*	Hazard ratio (95% CI)	*p*-value
Men				
Group	C	1,054	1.00	–
	E	1,070	1.01 (0.88–1.16)	0.87
Age	17.0–19.9 y	679	1.00	–
	20.0–24.9 y	940	1.06 (0.89–1.25)	0.51
	25.0–29.9 y	301	1.41 (1.14–1.75)	<0.01
	≥30 y	204	1.43 (1.11–1.83)	<0.01
Self-rating of physical activity compared with others of same age and sex	Much less active	189	1.63 (1.16–2.30)	<0.01
	Somewhat less active	523	1.15 (0.85–1.55)	0.38
	About the same	705	1.08 (0.81–1.46)	0.60
	Somewhat more active	552	0.97 (0.72–1.32)	0.97
	Much more active	155	1.00	–
Component	Active Army	1,074	1.00	–
	National Guard	806	0.88 (0.75–1.01)	0.07
	Army Reserve	244	0.85 (0.67–1.08)	0.18
Number of days smoked in 30 d before BCT	None	1,082	1.00	–
	1–9 d	214	0.98 (0.76–1.26)	0.89
	10–19 d	166	1.16 (0.88–1.52)	0.28
	≥20 d	661	1.36 (1.16–1.59)	<0.01
Women				
Group	C	458	1.00	–
	E	444	1.07 (0.91–1.25)	0.44
Age	17.0–19.9 y	325	1.00	–
	20.0–24.9 y	349	1.00 (0.83–1.21)	0.97
	25.0–29.9 y	115	1.28 (1.00–1.65)	0.05
	≥30 y	113	1.52 (1.18–1.96)	<0.01
Self rating of physical activity compared with others of same age and sex	Much Less Active	152	1.47 (0.92–2.36)	0.11
	Somewhat Less Active	281	1.48 (0.l94–2.32)	0.09
	About the Same	241	1.20 (0.76–1.90)	0.43
	Somewhat more Active	195	1.13 (0.70–1.80)	0.62
	Much More Active	33	1.00	–
Component	Active Army	454	1.00	–
	National Guard	326	0.81 (0.74–1.05)	0.14
	Army Reserve	122	0.81 (0.63–1.04)	0.09
Number of days smoked in 30 d before BCT	None	525	1.00	–
	1–9 d	76	1.21 (0.91–1.61)	0.20
	10–19 d	50	1.60 (1.14–2.24)	<0.01
	≥20 d	251	1.54 (1.29–1.85)	<0.01

C = control; E = experimental; BCT = basic combat training; CI = confidence interval.

did not wear the prescribed shoe for all physical training while in BCT. Thus, the cohort for the study was defined as those volunteers who had obtained the prescribed shoe and wore it throughout BCT. The major reason for not obtaining the prescribed shoe in the PX was that it was not available when the subject arrived. The number of new Soldiers processing through the PX daily made it difficult to keep all the shoe types and sizes in stock. Some subjects voluntarily withdrew from the study because they found the prescribed shoe uncomfortable during the fitting process or because they did not like the shoe style. Volunteers excluded and retained for analysis are shown in Table 2.

Attrition from Training

Table 3 compares the two groups on reasons for attrition. Differences in attrition between E and C groups were small among both men and women. When all training attrition was considered together, the C men had slightly more attrition than the E men (C = 9%; E = 7%; chi-square, $p = 0.08$); there was no significant group difference in attrition between the C and E women (C = 22%; E = 23%; chi-square, $p = 0.26$).

TABLE 7. Injury hazard ratios for study variables with fitness variable included (multivariate Cox regression).

Variable	Level of variable	*n*	Hazard ratio (95% CI)	*p*-value
Men				
Group	C	623	1.00	–
	E	616	1.09 (0.92–1.32)	0.37
2-mile run	11.7–16.0 min	310	1.00	–
	16.1–17.4 min	315	1.06 (0.80–1.41)	0.69
	17.5–20.2 min	305	1.19 (0.90–1.59)	0.23
	20.3–32.2 min	309	1.42 (1.07–1.88)	0.02
Number of days smoked in 30 d before BCT	None	629	1.00	–
	1–9 d	324	1.15 (0.90–1.45)	0.26
	10–19 d	192	1.39 (1.06–1.81)	0.02
	≥20 d	94	1.80 (1.30–2.49)	<0.01
Self-rating of physical activity compared with others of same age and sex	Much less active	109	1.67 (1.05–2.65)	0.03
	Somewhat less active	292	0.98 (0.64–1.50)	0.93
	About the same	414	0.96 (0.64–1.45)	0.85
	Somewhat more active	334	0.90 (0.59–1.36)	0.61
	Much more active	90	1.00	–
Women				
Group	C	245	1.00	–
	E	222	1.18 (0.93–1.48)	0.17
2-mile run	12.3–19.4 min	118	1.00	–
	19.5–22.1 min	116	0.91 (0.65–1.28)	0.60
	22.2–24.7 min	117	1.14 (0.82–1.58)	0.43
	24.8–31.3 min	116	2.18 (1.59–2.97)	<0.01
Number of days smoked in 30 d before BCT	None	269	1.00	–
	1–9 d	50	1.37 (0.94–1.98)	0.10
	10–19 d	23	1.72 (1.07–2.79)	0.03
	≥20 d	125	1.42 (1.10–1.84)	<0.01
Previous lower-extremity injury	No	399	1.00	–
	Yes	68	1.53 (1.13–2.07)	<0.01

C = control; E = experimental; BCT = basic combat training; CI = confidence interval.

Injury Rates and Injury Risk Factors

The DMSS returned medical data on 98% of subjects (3,062 of 3,119), and the DMDC returned demographic data on 97% of subjects (3,029 of 3,119). Table 4 shows the person-time injury incidence rates for the various injury indices and compares the rates in the C and E groups. Injury risk was almost identical in the C and E groups, regardless of the injury index examined.

TABLE 8. Injury hazard ratios by group and plantar shape (univariate Cox regression).

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

C = control; E = experimental; CI = confidence interval.

TABLE 9. Injury hazard ratios by group with and without particular shoe models (univariate Cox regression).

Group	Men *n*	Men Hazard ratio (95% CI)	Men *p*-value	Women *n*	Women Hazard ratio (95% CI)	Women *p*-value
C	1,068	1.00	–	464	1.00	–
E (wearing either Nike Air Max Moto or New Balance 857)	58	1.08 (0.71–1.64)	0.72	43	1.04 (0.71–1.52)	0.85
C	1,068	1.00	–	464	1.00	–
E (not wearing Nike Air Max Moto or New Balance 857)	1,021	1.02 (0.88–1.34)	0.84	408	1.06 (0.90–1.26)	0.48

C = control; E = experimental; CI = confidence interval.

Table 5 shows the results of the univariate Cox regression examining the association of time to first injury with group membership (C and E groups) and the other covariates. Differences in injury risk between the C and E groups were small. For both men and women, time to first injury was associated with older age; lower performance on push-ups, sit-ups, or the 2-mile run; a greater number of cigarettes or a greater number of days smoking cigarettes in the last 30 days; a lower perception of physical activity; and less frequent physical activity. Among women, those with previous lower-extremity injury were at higher injury risk. Active Army subjects tended to have higher injury risk than subjects in the National Guard or Army Reserve. Subjects of Asian descent were at lower risk of injury than those of Caucasian descent; women of African-American descent were at lower risk of injury than women of Caucasian descent. Men and women classified as "other" marital status (primarily those divorced or widowed) were at higher risk of injury than those who had never been married; among women, those who were married were also at higher risk than those who never married.

Because much of the APFT data were missing, 2 multivariate Cox regression models were run for both men and women. The first model excluded the APFT variables, whereas the second model included the APFT variables that met the inclusion criteria (i.e., $p < 0.10$ in the univariate Cox regression). Table 6 shows the results of the backward-stepping multivariate Cox regression model that excluded the fitness variables and with the group membership (C or E) forced into the model. Those with complete data included 2,157 men (98% of the entire male sample) and 902 women (99% of the entire female sample). For both men and women, group membership (E or C) was not significantly associated with injury risk. Older age, less self-rated physical activity, active Army component, and more days of cigarette smoking were independent injury risk factors.

Table 7 shows the results of the multivariate Cox regression that included the APFT variables. Those with complete data included 1,239 men (57% of the male sample) and 467 women (51% of the female sample). Group membership (E or C) was not significantly associated with injury risk. For both men and women, injury risk was associated with slower 2-mile run time and more days of cigarette smoking. For men, less self-rated physical activity was associated with higher injury risk; for women, a previous lower-extremity injury was associated with higher injury risk.

Injury risk was examined for the 3 plantar shapes within the C and E groups independently. Table 8 shows univariate Cox regression results for these analyses. Among the C subjects (all whom wore the stability shoe regardless of foot type), there were very minor differences in injury risk by plantar shape. Among the E group, men with plantar shapes indicative of high arches who wore the cushioned shoe were at higher risk of injury than men with plantar shapes indicative of normal arches who wore the stability shoe; this increased injury risk was not seen among the E group women with plantar shapes indicative of high arches who wore cushioned shoes. A separate univariate Cox regression was performed comparing injury risk in only high- and low-arched individuals in the E and C groups (i.e., not including the normal arch individuals in the analysis). Among the men, injury risk was 1.23 (95% confidence interval [CI], 0.96–1.59; $p = 0.11$) times higher in the E group compared with the C group. Among the women, injury risk was 1.16 (95% CI, 0.85–1.58; $p = 0.35$) times higher in the E group compared with the C group.

Because 2 of the shoes (New Balance 857 and Nike Air Max Moto) worn by subjects were classified differently by the PX versus *Runner's World* and the manufacturers, E group subjects wearing these 2 shoe models were analyzed separately. Two analyses were performed, and these are shown in Table 9. The first analysis compared the C group with the subjects in the E group who wore the New Balance 857 and Nike Air Max Moto. Injury risk was similar in these 2 groups. The second analysis removed the subjects wearing the New Balance 857 or Nike Air Max Moto from the E group and compared the remaining E group subjects with the C group. Differences in injury risk were small between C and E subjects without the shoes in question.

Discussion

In this study, the E group was prescribed a type of running shoe based on their plantar shape because this method was used in BCT at the time of the study and because it was similar to the common self-evaluation technique (the "wet test") recommended by running magazines, shoe companies, and other publications (5,12,38). The present study demonstrated that selecting running shoes based on plantar shape did not reduce injury risk during U.S. Army BCT. Even after controlling for known risk factors, such as physical fitness, age, physical activity before BCT, cigarette smoking, and menstrual status (26,39), there were no significant differences in injury risk between the C and E groups.

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 allow for more foot pronation (31,32,35,45). All C group subjects wore a stability shoe regardless of plantar shape, and injury risk was very similar among the 3 foot types (high, normal, and low) within this group (Table 8). Stability shoes presumably offer some cushioning with some motion control characteristics (38). When E group subjects were examined separately (Table 8), men with plantar shapes indicative of high arches who wore the cushioned shoe were, contrary to expectation, at higher injury risk. This increased injury risk was not seen among E group women with plantar shapes indicative of high arches who wore the cushioned shoe. It is possible that under some circumstances, high levels of cushioning may attenuate plantar feedback (40) and result in gait alterations (8,20) that increase the likelihood of injury.

If injury risk could be reduced by selecting running shoes based on the plantar shape, that reduced risk might be best seen by comparing C and E subjects at the extremes, that is, those with plantar shapes indicative of high and low arches. This is because E subjects wore shoes specifically designed for their foot type (motion control and cushion), whereas C subjects wore a stability shoe designed for another foot type. Contrary to expectation, comparing E and C subjects in this manner indicated that injury risk was slightly higher in the E group. This indicated that even with extreme foot shapes, selecting running shoes on the basis of plantar shape did not reduce injury risk and may have increased it slightly in this study.

Two shoes (New Balance 857 and the Nike Air Max Moto) were classified differently in the PX system compared with the *Runner's World* or manufacturer typing. Nonetheless, when the subjects in the E group who wore these 2 shoes were compared with all the C subjects, injury risks differed little. Further, when subjects wearing these 2 shoes were eliminated from the E group and the remaining E group subjects compared with the C group, injury risk still differed little between the 2 groups (Table 9).

The current study is not in consonance with a previous investigation (25) that showed a postwide decrease in serious injuries among soldiers at Fort Drum, N.Y., after initiation of a running shoe prescription program. However, there were many methodological differences between the current study and the earlier one. The current study involved only a prescription based on the plantar shape; the earlier study involved a prescription based on an evaluation of foot arch height and foot flexibility. The current study involved a population of recruits in a situation where it was assured that the prescribed shoe type was obtained and there was follow-up to guarantee that the prescribed shoe type was worn during the entire course of the study. In the earlier study, soldiers were given the shoe prescription, but there was no follow-up to determine whether they made the recommended purchase and no knowledge of when or how often the shoes were used for training. In fact, in a survey involving a convenience sample of 122 Fort Drum soldiers (out of an average 9,752 estimated to be on post), only 11% said that they had followed the shoe prescription advice. The current study involved an initial shoe prescription with follow-up for any injury occurring in a subsequent 9-week period of a standardized training program. The earlier study involved a retrospective examination of medical visits to a physical therapy clinic before and after the shoe program was initiated. A number of temporal factors were potential confounders in the earlier study, and these were discussed at length in the technical report (25). The major potential confounder was the change in the surveillance system used to track injuries, which occurred during the months when injuries began to decrease. The current study was prospective in design and involved two groups training side by side in a well-regulated BCT setting. Thus, the current study involved manipulation of only 1 variable (running shoe selection based on plantar shape), considerably better knowledge about the shoe actually worn during training, and a more controlled training environment.

The present study found a number of risk factors that confirmed previous work in BCT. Higher injury risk progressively increased with progressively lower aerobic fitness, lower muscular endurance, older age, less physical activity, and more cigarette smoking, similar to results in much of the BCT literature (1,9,14,16,22,28,29,37,41,43). Of particular interest was the finding that subjects entering service as active Army recruits tended to have a higher injury rate than National Guard or Reserve recruits. This was not found in an earlier study (29), but the current finding might be associated with recent National Guard/Reserve policy changes. Reserve and National Guard units were experiencing recruiting challenges, presumably because units could be expected to deploy more often, and deployments may have a perceived negative effect on the lifestyles of personnel (42). In an effort to reduce attrition among those who sign up for duty, units have initiated programs that prepare new recruits for BCT by providing them with physical training, military knowledge, and prescreening to assure they have no physical, criminal, or other types of problems before BCT (13,27). Recruits are given a fitness test several times before BCT and perform physical training during scheduled drills. They are provided information on physical training to improve their fitness outside of scheduled weekend drills, and they keep physical training logs. Smoking is prohibited at all drills and there is an emphasis on smoking cessation. These programs may have been successful in reducing injury rates in BCT, especially because increasing physical fitness before BCT has been shown to reduce injury risk (23). Further support for this idea comes from the fact that Component was an independent injury risk factor when the fitness variables were excluded from the multivariate analysis, but Component was not an independent risk factor when the fitness variables were included in the multivariate analysis.

Practical Application

The present study indicated that prescribing running shoes to BCT recruits based on static, weight-bearing plantar shape is not effective for injury prevention. This procedure did not protect against injury any more than the prescription of a single shoe, regardless of plantar shape. It was recommended to the U.S. Army Training and Doctrine Command that the current practice of prescribing shoes in this manner in BCT be discontinued. It was still recommended that recruits receive a new pair of running shoes on entry to BCT, because older running shoes have been shown to increase injury risk (9).

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