REVIEW ARTICLE

Sports Med 1999 Feb; 27 (2): 111-125
0112-1642/99/0002-0111/$07.50/0

Physical Training and Exercise-Related Injuries

Surveillance, Research and Injury Prevention in Military Populations

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Abstract

Athletes and soldiers must both develop and maintain high levels of physical fitness for the physically demanding tasks they perform; however, the routine physical activity necessary to achieve and sustain fitness can result in training-related injuries. This article reviews data from a systematic injury control programme developed by the US Army. Injury control requires 5 major steps: (i) surveillance to determine the size of the injury problem; (ii) studies to determine causes and risk factors for these injuries; (iii) studies to ascertain whether proposed interventions actually reduce injuries; (iv) implementation of effective interventions; and (v) monitoring to see whether interventions retain their effectiveness.

Medical surveillance data from the US Army indicate that unintentional (accidental) injuries cause about 50% of deaths, 50% of disabilities, 30% of hospitalisations and 40 to 60% of outpatient visits. Epidemiological surveys show that the cumulative incidence of injuries (requiring an outpatient visit) in the

8 weeks of US Army basic training is about 25% for men and 55% for women; incidence rates for operational infantry, special forces and ranger units are about 10 to 12 injuries/100 soldier-months. Of the limited-duty days accrued by trainees and infantry soldiers who were treated in outpatient clinics, 80 to 90% were the result of training-related injuries.

US Army studies document a number of potentially modifiable risk factors for these injuries, which include high amounts of running, low levels of physical fitness, high and low levels of flexibility, sedentary lifestyle and tobacco use, amongst others. Studies directed at interventions showed that limiting running distance can reduce the risk for stress fractures, that the use of ankle braces can reduce the likelihood of ankle sprains during airborne operations and that the use of shock-absorbing insoles does not reduce stress fractures during training.

The US Army continues to develop a comprehensive injury prevention programme encompassing surveillance, research, programme implementation and monitoring. The findings from this programme, and the general principles of injury control therein, have a wide application in civilian sports and exercise programmes.

Soldiers must develop and maintain high levels of physical fitness in preparation for military missions, in similar ways to athletes preparing for competition. The potential demands of combat and other duties require military personnel (particularly the US Army and Marine Corps) to routinely engage in vigorous physical and operational training to sustain a high level of readiness. Typical training activities include running, marching, calisthenics, climbing, hurdling, crawling, jumping, digging, lifting and carrying loads while hiking.

As with other groups engaged in vigorous physical activity and training,[1-4] injuries frequently occur in military populations.[5-8] These injuries concern the military not only because of their frequency but because they result in significant loss of personnel resources and can compromise operational readiness. To reduce the incidence of injuries and their effect on individuals and military objectives, a systematic programme of injury prevention was considered necessary by the US Army.

Table I lists the 5 key public health steps to injury control (surveillance, research, intervention, programme implementation and programme monitoring). These 5 steps of systematic injury control require that 5 primary questions be answered [personal communications, M. Rosenberg, Centers for Disease Control and Prevention, Atlanta (GA)]:

(i) Does a problem exist?
(ii) What causes the problem?
(iii) What works to prevent the problem?
(iv) Who needs to know and what do they need to do?
(v) How effective are the preventive measures put in place?

Successful prevention/control requires information from surveillance and research at all steps in this process.

The foundation of a systematic approach to the prevention and control of injuries is medical surveillance. Unlike research, medical surveillance implies a linkage between health information and preventive action.[9,10] Routine surveillance provides the information necessary to determine the magnitude of problems affecting the health of populations and provides the basis for prioritising and targeting injuries and diseases for prevention or research. Research is necessary to determine the underlying risk factors for and causes of injuries and diseases. Prevention of injuries requires identification of modifiable risk factors and causes.[11] Once a strategy for prevention has been devised, research may also be necessary to determine whether the interventions work. Following implementation of a prevention strategy, surveillance of the ongoing effectiveness of that strategy is necessary.[9,10]

This article primarily reviews data from the first

3 elements of the US Army injury prevention programme – surveillance, research and intervention. We examined data from surveillance sources and epidemiological surveys which define the magnitude of the problem of injuries in the US Army and Marine Corps. We further reviewed the results of epidemiological research that identifies causes and risk factors for training- and operations-related injuries. Some of the prevention programmes that were implemented are also discussed. The findings from US Army research are used to demonstrate the power of simple screening and survey methodologies in exercise and training injury research. Finally, we use the data discussed to illustrate the contributions of surveillance and epidemiological research to a comprehensive injury prevention programme such as that outlined in table I.

Table I. Key steps in the injury control process and the role of surveillance, research and intervention

Step 1: Surveillance	Document the existence of a problem and its magnitude
	frequency and distribution
	rates and trends
Step 2: Research	Identify the cause and risk factors for a problem
	epidemiology
	pathophysiology
	biomechanics
	ergonomics
Step 3: Intervention	Determine what measures are effective in preventing the problem
	training
	testing/trials
	development of safer products and equipment
	engineering changes
Step 4: Programme implementation	Disseminate information to those who need to know and act
	education
	regulations, rules and laws
	safety guidelines and policies
	equipment
Step 5: Programme monitoring	Determine effectiveness of injury prevention programmes

1. Surveillance and Survey Data on Injuries

The first step of the public health process of injury control/prevention is to determine whether a problem exists. This can be accomplished for military populations because comprehensive medical and fatality records are maintained for all military personnel on active duty. The sizes of unit populations are known at all times, copies of all military hospital discharge summaries are filed in individual medical records and demographic, occupational and medical information from hospital discharge summaries is coded and entered into central computerised files. Injury diagnoses are coded using International Classification of Disease Codes (ICD-9 Codes); all acute injury diagnoses receive an external cause code using North Atlantic Treaty Organization codes which are similar to the cause codes in ICD-9 (E-Codes). Hospitalisation rates and trends are now routinely reviewed and published. Computerised databases of disability discharges and deaths are also maintained. Virtually all outpatient visits to military medical treatment facilities are documented in the records of individual personnel. Because computerised military-wide databases were unavailable for 'sick call' (outpatient) visits until recently, the primary source of data on the incidence of injuries requiring only outpatient management is focal periodic surveys of individual medical records for entire targeted unit populations.

1.1 Incidences of Injury-Related Hospitalisation, Disability and Death

Surveillance of hospital records, patients with disability and fatalities provides perspective on how injuries of varying degrees of severity affect the US Army in terms of personnel resources and readiness. Direct comparisons of incidence rates and frequencies across levels of injury severity are complicated by differences in categorisation of information and how specific diagnoses are defined. Nevertheless, data on hospitalisations, disabilities and deaths provide a valuable perspective on the magnitude of the problem.

Since 1989, the Standard Inpatient Data Record has provided a common register of hospitalisations

Table II. Cumulative incidence of all injuries among US Army trainees during the 8-week basic combat training cycle

Study	Year data collected	Incidence (%)	
		men[a]	women[a]
Kowal[14]	1978	26	54
Bensel & Kish[15]	1982	23	42
Jones et al.[16]	1984	28	50
Bell et al.[17]	1988	27	57
Westphal et al.[18]	1994	ND	67

ND = no data.

in all US military hospitals regardless of service (i.e. Army, Navy or Air Force). In 1994, musculoskeletal conditions and injuries accounted for 28% of hospitalisations in US Army personnel.[12] The next most common category was digestive diseases, at 12%. Information from this Record indicates that acute injuries associated with physical activity, training and athletics are potentially serious, as well as frequent, in the US Army. In 1994, the rate of hospitalisation for injury in US Army personnel was estimated at 45 hospitalisations/1000 person-years.[12] Athletics- and sports-related injuries accounted for 12% of the cases where an external cause of injury was recorded, and other potential training injuries accounted for an additional 14%.[12] Days lost ('noneffective days') due to hospitalisation for injuries caused by sports and athletics alone were 26 days/1000 soldiers per year.[12]

Tracking of patients with disability is performed by the Army Physical Disability Agency (APDA) which keeps a computerised list of reviewed patients.[13] In 1994, the rates of disability were about 15 cases/1000 person-years, with about 53% of these being due to injury. The coding scheme used by the APDA does not allow determination of the contribution of physical training–related injuries to disability; however, a pilot study in an infantry division suggested that the injuries sustained by 28% of personnel requiring disability evaluations may be attributable to athletics.[12]

Deaths in the military are routinely reported by the Military Services' Casualty Offices to the Department of Defense Directorate of Information and Operations Reports (DIOR). DIOR publishes the *Worldwide Casualty Report* which provides mortality data, broken down into 5 categories: accidents, suicides, homicides, illness and combat (hostile action), for all of the services. In 1994, the US Army fatality rate was 87 deaths per 100 000 person-years, with unintentional injuries (accidents) accounting for 49% of all deaths. All illnesses and diseases accounted for only 18% of deaths in the US Army.

1.2 Incidence of Outpatient Injury Visits

Episodic surveys of outpatient medical records ('sick call' visits) have also documented the incidence of injuries among military trainees and

Table III. Injury incidence rates among soldiers in operational US Army units

Study	Year data collected	Type of unit	Incidence rate (events/100 soldier-months)	
			new injuries	clinic visits for injuries
Tomlinson et al.[5]a	1984-1985	Infantry	11.2	ND
		Special forces	12.1	ND
		Rangers	10.1	ND
		Artillery and aviation	4.5	ND
Knapik et al.[6]b	1989	Infantry	11.8	18.3
Reynolds et al.[21]	1989-1990	Infantry	ND	15.1
Reynolds et al.c	1996	Artillery	10.7	18.8

a Annualised data based on 8 weeks of data collection.
b Annualised rate based on 6 months of data collection.
c Reynolds et al., unpublished data (n = 189, 1-year follow-up).
ND = no data.

Table IV. Relative rates of injury and illness among US Army trainees[23] and infantry soldiers[a]

Category	Sample	Injury rate (cases/100 soldier-months)	Illness rate (cases/100 soldier-months)	Rate ratio (injury rate/illness rate)
Soldiers with 1 or more ‘sick call’ visits	Male trainees	13.7	17.7	0.8
	Female trainees	25.2	24.2	1.0
	Male infantry	12.8	12.0	1.3
Total ‘sick call’ visits	Male trainees	22.1	26.4	0.8
	Female trainees	39.6	37.2	1.0
	Male infantry	19.6	12.0	1.6
Days of limited duty	Male trainees	40	8	5.0
	Female trainees	129	6	21.5
	Male infantry	113	11	10.3

a Reynolds K, unpublished data on US Army infantry soldiers, Fort Drum (NY), 1989 (n = 351, 72-day follow-up).

soldiers. The greatest amount of documentation exists for US Army basic training. As shown in table II, the cumulative incidence of male trainees seeking medical care for 1 or more injuries during the 8 weeks of basic training varied between 23 and 28%; injuries for women ranged from 42 to 67%.[14-18] The estimated injury rates are 12 to 14 and 21 to 29 injuries per 100 person-months for male and female trainees, respectively. Male US Army Infantry trainees undergoing a 12-week period of basic training experience a cumulative incidence of injury of 46%,[7] about 15 injuries per 100 person-months. Rates of this magnitude have also been observed for US Marine Corps recruits.[19]

In contrast to trainees, injury rates in operational military units can vary more widely, probably because of the varied nature of the occupational tasks performed (the US Army has 277 occupational specialities).[20] As shown in table III, male soldiers in infantry, special forces and ranger units have documented injury rates of between 10.1 and 12.1 injuries per 100 soldier-months,[5,6,21] similar to those of US Army trainees. Artillery and aviation units have lower rates.[5] Injury rates among military trainees, infantry soldiers and special forces and ranger units are comparable with those experienced by high school and collegiate athletes participating in endurance events; however, rates are generally lower than for those involved in contact sports.[3,22]

1.3 Causes of Morbidity: Injury Versus Illness

Comparisons of the number of limited duty days resulting from injuries versus those resulting from illnesses provide another perspective on the importance of injuries to overall US military physical readiness. Table IV contains data on the relative rates of morbidity from injury and illness and the rates of limited duty days. For male and female US Army trainees, the ratio of the rates of injury and illness (soldiers with 1 or more ‘sick call’ visits) is about 1 : 1; however, for injury, the rates of limited duty days are much higher than for illness. Among infantry soldiers, the rates for injury are slightly higher than those for illness but the rates of limited duty days are roughly 10 times higher. Injuries requiring outpatient care clearly cause significantly more temporary disability than do illnesses.

1.4 Overview of Injury Impact

Data on morbidity and mortality across the spectrum of health indicate that injuries are an important problem both in terms of absolute rates and also relative to disease and illness. Based on these data, the relative numbers of injuries from each category of injury (death, disability, hospitalisation and outpatient) can be estimated. The frequency data presented in table V show clearly that outpatient sick call visits account for the largest number of injuries – almost 2000 for every death that occurs. Consequently, although the injuries in this category are less severe than those in other

Table V. Frequency of injuries requiring different levels of care and ratios of less severe injuries to deaths, based on US Army–wide data for 1994

Patient category	Estimated injuries (cases/year)		Ratio of other injuries to accidental deaths[a]
	total	training- or athletics-related	
Accidental death	230	60	1
Disability	4500	2400	20
Hospitalisation	23 000	6000	100
Outpatient 'sick call'[b]	440 000	240 000	1900

a Calculated as source of injury/total accidental deaths.

b Estimated from data of Tomlinson et al.[5]

categories, injuries treated on an outpatient basis have the largest impact in terms of personnel resources and military readiness. Sports and physical training–related injuries account for a large percentage of the total injuries in all categories (table V). Furthermore, most injuries treated in US Army outpatient clinics are lower extremity training-related injuries.[6,16,21] The sheer number of training-related injuries warrants investment in research and prevention programmes to reduce the incidence of such events.

For vigorously active US Army populations, the data clearly indicate that physical training–related injuries cause more limited duty days than all of the other outpatient conditions combined. The relative magnitude of the injury problem, compared with illnesses, is a strong argument for a systematically coordinated training injury prevention programme. While surveys and surveillance indicate that injuries are an important problem, these tools alone do not provide the information necessary to prevent injuries. The foundation of an effective injury prevention programme is detailed knowledge of injury risk factors and the causes of injury, which requires focused research.

2. Research on Risk Factors for Training Injuries

When a problem such as training injuries has been identified, the next step in the control process (see table I) is to identify causes and risk factors. Table VI lists some risk factors for training injuries which have been identified by military and civilian sports medicine studies.[25,26] These risk factors may be categorised as either intrinsic or extrinsic in nature. Intrinsic factors are inherent characteristics of individuals, for example age, race, gender, anatomical characteristics or physical fitness. Extrinsic factors are variables that are external to the individual, such as physical training programmes, equipment, terrain and weather conditions, which influence the risk of injury. Sections 2.1 to 2.6 highlight some of the key risk factors for training-related injuries in military populations and illustrate the use of simple survey and research methods to identify these risk factors.

Table VI. Risk factors for physical training injuries in military populations

Intrinsic factors
Demographic characteristics
age
race
gender
other
Anatomical factors
high arches (pes cavus)
'knock knees' (genu valgus)
excessive Q-angle
other
Physical fitness level
low cardiorespiratory endurance (slow run times)
low muscle endurance (low number of push-ups and sit-ups)
high and low flexibility (toe-touching ability)
other
Behavioural traits
sedentary (inactive) lifestyle
tobacco use
other
Past injury
Extrinsic Factors
Training parameters
high running mileage
frequent marching and running
other
Equipment factors
boots not 'broken in'[24]
ankle braces
other

2.1 Demographic Characteristics

Demographic data (i.e. age, race and gender) is routinely maintained in administrative and medical records for all military personnel. Data on US Army basic trainees indicate that older individuals are more likely to sustain injuries.[7,27,28] In contrast, infantry soldiers[6] and mixed groups of soldiers with many different occupational specialities[5] show a declining trend for injuries with increasing age. This discrepancy between trainees and soldiers may be explained by the fact that trainees all engage in the same type of physical training. However, in operational US Army units, older soldiers tend to be of higher rank and are, consequently, in staff or supervisory positions; they may have less exposure to occupational physical hazards compared with younger soldiers. The decline in injuries with increasing age in operational US Army personnel is in consonance with data from civilian populations.[29]

Ethnicity[30] and gender[29] also appear to influence injury incidence. Several reports suggest that White trainees experience more stress fractures and other training injuries than Black trainees and those of other non-White ethnic origins.[7,27,28] Black soldiers also experience fewer blisters on the foot compared with individuals of other ethnic origin.[31] Regarding gender, studies of US Army basic trainees consistently report injury rates among female trainees that are 1.5 to 2.0 times higher than those for male trainees.[7,8,14-16] Interestingly, multivariate analyses which control for physical fitness indicate that men and women with similar cardiorespiratory endurance (run times) experience the same risks for injury.[8] While age, race, and gender themselves are not modifiable risk factors, altering training programmes and modifying other risk factors, such as improving individuals' physical fitness levels, may reduce the risk of injury for some of these higher risk demographic groups.

2.2 Anatomical Factors

Mass population screening techniques have been employed to study the possible association between injury risk and anatomical variables, such as 'flat feet', bowed legs and leg length discrepancies.[32-35] Observations from a study of computer-digitised photographs of the feet of male US Army infantry trainees indicated that recruits with flatter feet are at a lower risk of lower extremity injuries during training than those with 'normal' and high arches (fig. 1).[33] This study adds support to the conclusions of a study of lower extremity stress fractures among soldiers of the Israeli Defense Force, which demonstrated that individuals with the flattest feet had the lowest injury incidence.[35]

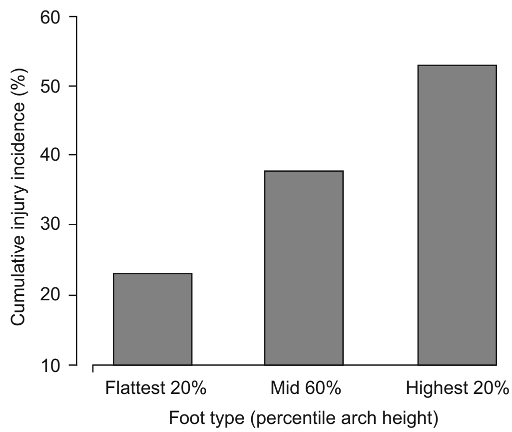

Fig. 1. Relationship between foot arch height and risk of lower extremity injuries among male US Army infantry trainees. Arch height is the ratio of navicular height to medial metatarsal phalangeal joint length. For the flattest 20% compared with the highest 20%, relative risk = 2.3, $p < 0.05$.[33]

Besides high foot arches, excessive Q-angle (>15°) of the knee has been shown to be associated with higher risk of lower extremity stress fractures and other injuries (fig. 2). Genu valgus ('knock knee') was also found to be related to risk of overuse injuries (fig. 3).[34] Some of these findings are contrary to commonly held beliefs[36] and indicate the need to examine generally accepted but unproven hypotheses regarding the association of anatomical and other factors with injuries.

2.3 Physical Fitness

Important components of health-related physical fitness include cardiorespiratory endurance,

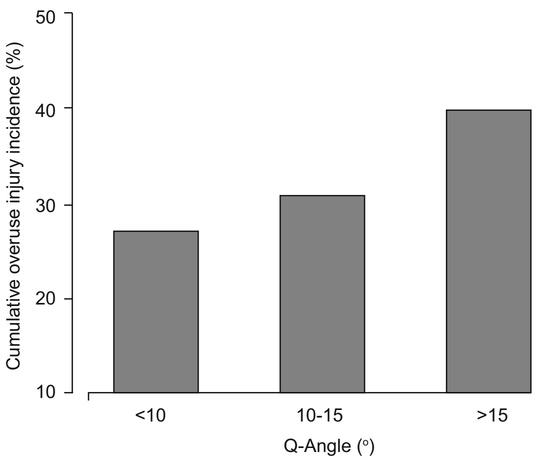

Fig. 2. Relationship between Q-angle and the risk of overuse injury in US Army male infantry trainees. Q-angle is the angle formed by 2 lines, one drawn from the midpoint of the patella to the tibial tuberosity and the other from the midpoint of the patella to the anterior superior iliac spine. For trainees with Q-angles <10° compared with those with Q-angles >15°, relative risk = 1.5, p = 0.10.[34]

muscle strength, muscle endurance, flexibility and body composition.[37,38] The US Army and other military populations routinely measure and record information related to these fitness components. The US Army Physical Fitness Test (APFT) is performed twice yearly by all soldiers and consists of tests related to cardiorespiratory endurance [3.2-kilometre (2-mile) run times], muscle endurance (push-ups and sit-ups) and surrogate measurements for body composition (height and weight). For other fitness factors not routinely assessed by the military services, suitable methods for mass screening have been devised and employed in military research. These include toe touching and joint range of motion to evaluate flexibility,[39,40] maximum voluntary force exertion to assess strength,[41,42] and circumferential measurements to estimate body fat.[43]

The most consistently documented risk factor for injuries in US Army populations is low cardiorespiratory endurance, measured by running performance. Figure 4 depicts the association between 1.6-kilometre (1-mile) run times and cumulative incidence of injuries during 8 weeks of basic training. Trends for both men and women indicate increasing risk of injury for groups with increasingly slow run times.[8,16] Similar trends have been documented in active duty infantry and combat engineer populations.[6,44] This observation makes sense given the ubiquitous nature of weight-bearing training (running and marching) in the US Army. Individuals with low aerobic capacity will experience greater physiological stress relative to their maximum capacity at any given absolute level of performance.

Flexibility is another component of physical fitness associated with risk of injury in military populations. Prospective measurements of toe touching ability indicate that US Army trainees at both the high and low extremes of back and hamstring flexibility experience more injuries (fig. 5).[7] This bimodal association with higher injury risk in individuals at the extremes of flexibility is similar to observations reported for female collegiate athletes in a study that employed goniometric techniques to measure hip range of motion.[45,46] These data suggest a need to re-examine the widely held belief that greater flexibility protects against injury.[47]

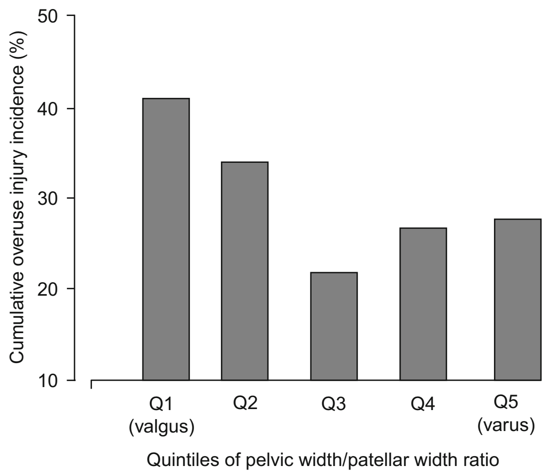

Fig. 3. Relationship between genu valgus/genu varus and risk of overuse injury in US Army male infantry trainees. Genu valgus/genu varus was measured as the ratio of pelvic width to patellar width with large values indicative of valgum and small values indicative of varum. For quintile 1 compared with 3, relative risk = 1.9, p = 0.02.[34]

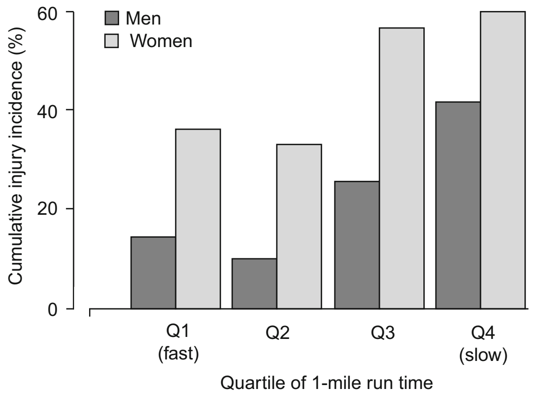

Fig. 4. Relationship between 1.6-kilometre (1-mile) run times and the cumulative incidence of injuries during 8 weeks of basic training among male and female US Army trainees. For men, the relative risk (quartile 2 compared with 4) = 4.2, $p < 0.10$; for women, the relative risk (quartile 2 compared with 4) = 1.7, $p < 0.10$; for trends in men and women, $p < 0.05$.[8]

US Army studies have also found less consistent and less significant associations between other physical fitness measures and risk of injury.[6-8,16,21] These include the ability to perform only low numbers of push-ups and sit-ups and higher percentages of body fat (estimated from skinfold thickness or circumference measurements). This type of data emphasises the need to systematically investigate the association of suspected physical fitness components and other risk factors with the occurrence of injuries.

2.4 Lifestyle and Behavioural Characteristics

Questionnaires have been used to study associations of injury risks with lifestyles and habits (e.g. physical activity and smoking) among US Army trainees and soldiers. Simple questions about the level of physical activity prior to entering the service and frequency of running, for example, have provided important clues about the effect of past activity on current risks of physical training–related injuries. Outcomes from these questionnaires demonstrate the value of asking individuals for information on specific behavioural characteristics.

Several prospective studies of US Army trainees and US Marine Corps recruits have reported that sedentary lifestyle prior to entering the service is associated with higher risk of injury during initial entry training.[7,8,16,28] Figure 6 depicts the association of self-assessed past activity level with risk of injury during US Army basic training. The trend of decreasing risk for those trainees who were previously more active than other individuals of the same age and gender is a consistent finding among male trainees[7,8,16,28] but not among female trainees.[8,16] Also, male infantry trainees who run more frequently prior to entering the US Army experience fewer injuries during basic training[7] (fig. 7). These observations suggest that past physical activity is protective against future injuries associated with physical training, at least among men.

Tobacco smoking is another behavioral health risk factor reported to be associated with higher risk of injury among US Army trainees and soldiers. Figure 8 demonstrates the relationship between the amount of smoking and cumulative incidences of injury in male infantry trainees.[7] Similarly, higher injury risk has also been associated with increased smoking by infantry soldiers (fig. 9).[21] In addition, the use of smokeless tobacco has been associated with risk of foot blisters during military road marching.[31] Whether the association between injury risk and tobacco use is

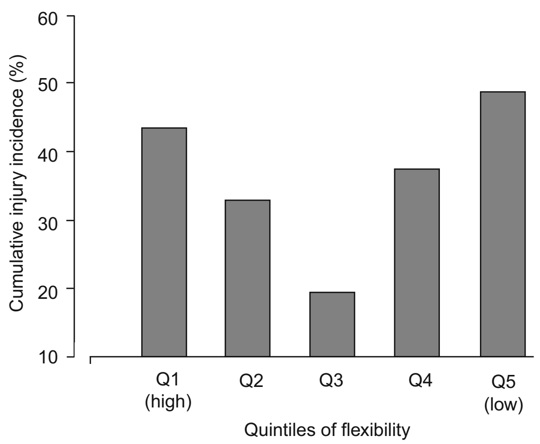

Fig. 5. Relationship between flexibility and the cumulative incidence of lower extremity injuries in male US Army infantry basic trainees. For quintile 1 compared with 3, relative risk = 2.2, $p < 0.05$.[7]

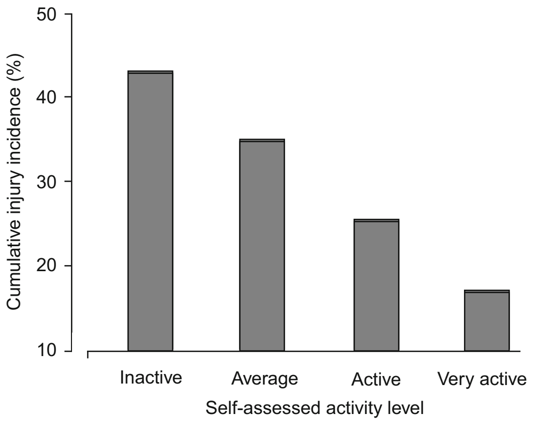

Fig. 6. Relationship between self-assessed past activity level and risk of injury in male US Army trainees. For inactive compared with very active trainees, relative risk = 2.5, $p = 0.06$ (for trend).[8]

behavioural or physiological remains to be demonstrated. Psychosocial factors such as greater risk taking behaviour and specific cognitive deficits have been reported in smokers.[48] Physiological factors such as delayed wound healing, increased bone demineralisation and immune suppression are also more frequently present in tobacco users than nonusers.[31,48] Determination of the underlying mechanism of the association between tobacco use and injuries will certainly require experimental as well as epidemiological investigation.

2.5 Training Factors

For US Army infantry trainees, risk of injury is higher in units whose members run a greater total distance. Daily log books completed by training company staff and direct observations have been used to document training. One study[49] observed that infantry trainees running an average of 17.6 kilometres (11 miles) per week experienced 27% more lower extremity injuries than those running 8 kilometres (5 miles) per week (42 versus 33%, respectively). Ironically, individuals in the 2 training units in this study ran about the same average times on the 3.2-kilometre (2-mile) run test at the conclusion of basic training (13.8 versus 13.5 minutes, respectively, for the high- and low-mileage groups; $p = 0.37$), indicating the achievement of similar final levels of cardiorespiratory fitness. Survival analysis of these data indicated that trainees in the high mileage unit experienced significantly more injuries at all points in time; however, no differences existed in the cumulative incidence of injury per cumulative distance run. These data suggest that there may be a finite risk of injury per mile run (or perhaps per running stride). These findings are consistent with the literature on civilian distance runners, which indicate higher risks of injury with greater distances run per week.[1,50,51]

Undoubtedly, training factors other than the amount of running and marching influence the risks of injury to recruits and trained soldiers. Documentation of these factors will require more detailed studies and the use and development of better, more quantitative, methods of measuring exercise and training.

2.6 Multivariate Models of Injury Risk

Factors determining risk of injury are clearly multifactorial and complex. For this reason, multivariate analytical techniques are necessary to determine which constellations of intrinsic and extrinsic risk factors are most associated with risk of injury and to control interrelationships between

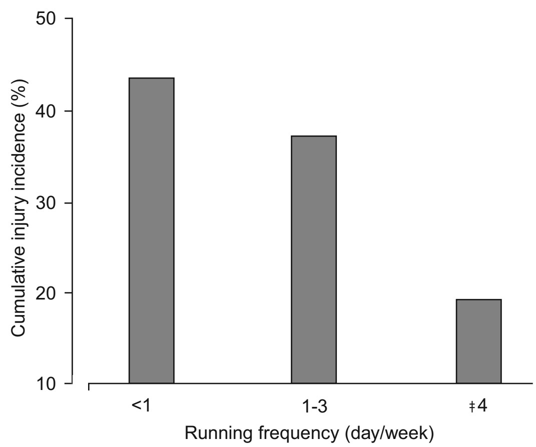

Fig. 7. Relationship between self-reported frequency of running in the month prior to beginning service and risk of injury in US Army trainees. For running on <1 day/week compared with ≥4 days/week, relative risk = 2.2, $p < 0.05$.[7]

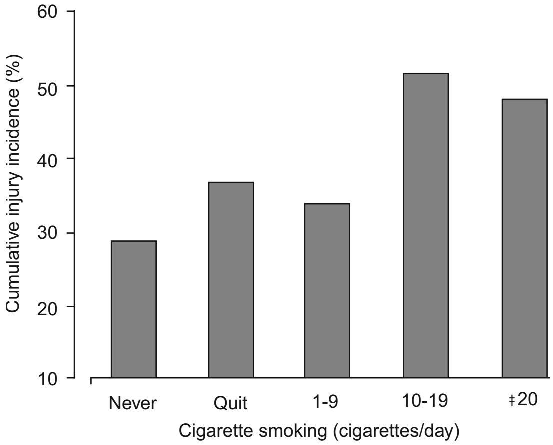

Fig. 8. Relationship between cigarette smoking and risk of injury among US Army male infantry trainees. For never having smoked compared with >20 cigarettes/day, relative risk = 1.7, $p < 0.05$.[7]

these factors. Methods employed in studies of risk factors for exercise-related injuries include Mantel-Haenzsel stratified χ^2 tests,[8] logistic regression analysis,[7,21,28,31] survival analysis[49] and proportionate hazard models.[52]

Multivariate analysis of data on male infantry trainees identifies the most significant risk factors for overuse injuries of the lower extremities (i.e. stress fractures, Achilles tendinitis, plantar fasciitis and overuse knee syndromes) occurring during 12 weeks of infantry basic training. Table VII summarises the risk factors for overuse injuries identified among infantry trainees.[7] These factors include older age, White race, history of an ankle sprain, lower amounts of running and physical activity prior to entering the army, and higher unit training mileage during basic military training. Variants of analyses such as these can also be employed to identify combinations of risk factors that place soldiers and others at particularly high risk.

Studies of US Army recruits also illustrate the need to control for confounding factors. For example, in all studies of US Army trainees reported in the literature, women experience more injuries than men;[14-16,27] however, a number of these studies also indicate that the physical fitness of the female trainees is lower than that of the male trainees entering the army. When the effect of aerobic fitness (measured by maximal effort run times) is controlled for by either stratified analysis or logistic regression analysis, gender ceases to be a risk factor.[8] In other words, the risk of injury is similar among men and women of the same relative level of aerobic fitness. Observations such as this illustrate the need to explore not only the associations of single risk factors with injury but also the effects that multiple variables exert on risks and on each other. Analysis should begin with a thorough exploration of univariate associations but should progress to multivariate models to control for confounding and to illuminate interactions.

In summary, the results of US Army training injury research illustrate the need to systematically study risk factors for injury. In some reports, the results of military research confirm and extend the findings of studies of civilian populations. For example, higher training mileage[1,2,50,51] and past injuries[2,51] are risk factors among civilian runners and exercise participants as well as military trainees. In other reports, Army research appears to contradict or only partially support commonly held beliefs about the causes of injury.[7,33,35] For example, 'flat feet' and lower flexibility are widely believed to increase injury risk, but these beliefs are

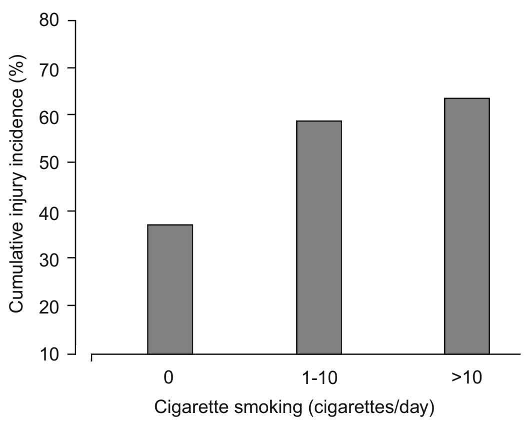

Fig. 9. Relationship between cigarette smoking and risk of injury among infantry soldiers. For nonsmokers compared with those smoking >10 cigarettes/day, relative risk = 1.7, $p < 0.01$.[21]

Table VII. Risk factors for lower extremity overuse injuries among 303 US Army infantry trainees followed for >12 weeks of initial training, with adjusted odds ratios (OR) from logistic regression and 95% confidence intervals (CI) [Jones BH, et al., previously unpublished data]

Risk factor	Injury OR	95% CI for OR
Age (years)		
<24	1.0	
≥24	2.5	1.2-5.2*
Ethnic group		
Black	1.0	
Other	2.3	0.5-9.4
White	3.7	1.2-11.7*
Previous ankle injury		
None	1.0	
Sprain	2.0	1.1-3.8*
Previous physical activity at work		
Moderate-heavy	1.0	
Light	2.0	1.1-3.7*
Previous physical activity		
Above average	1.0	
Average or below	2.0	1.1-3.5*
Running in last month		
>4 days/week	1.0	
<4 days/week	3.1	1.2-8.7*
Unit training distance (miles/week)		
Low (5)	1.0	
High (11)	2.0	1.0-3.5*

* p < 0.05.

founded primarily on clinical suspicions; little systematic epidemiological research has been performed prior to these military studies. More civilian and military research is needed to validate the risk factors discussed and to discover others.

3. Injury Prevention Strategies

Simply identifying risk factors is only part of a systematic, comprehensive injury prevention programme. Once risk factors have been identified, it is important to devise and test promising prevention strategies – the third step of the injury control process. Findings from the implementation of these strategies can prove to be more complex than the simple hypothesis from which the strategies were originally generated.

3.1 Modifications of Training Programmes

A study conducted by the US Naval Health Research Center provides an example of a successful prevention strategy that was adequately tested prior to implementation. The study examined the effectiveness of reducing running activity to reduce the incidence of stress fractures. As noted in section 2.5, an observational study indicated that training mileage was associated with a high cumulative incidence of injuries.[49] Naval research personnel studied 3 groups (1 control and 2 test groups) with more than 1000 marine recruits in each. The groups performed different amounts of organised running during their 12-week boot camp. Individuals with stress fractures were tracked during the 11-week training cycle and trainees' final 4.8 kilometre (3-mile) run times were obtained (table VIII). Comparing the highest and lowest mileage groups shows that a 40% reduction in running distance resulted in a 54% reduction in stress fractures with only slightly slower (2.5%) run times at the end of boot camp. Thus, stress fractures could be reduced with minimal losses in cardiorespiratory endurance.[53]

3.2 Modifications of Equipment

Use of an ankle brace to prevent parachute jump–related injuries provides another example of a successful prevention trial. Military parachuting injuries have been reported to be 8 to 14 injuries/1000 aircraft exits, with ankle injuries accounting for about 30 to 60% of the total.[54-56] Studies in the sports medicine literature strongly suggest that ankle bracing can reduce the incidence of ankle injuries.[57,58] An experimental study was conducted on 745 military airborne students who performed a total of 3725 aircraft exits for which about half of the students wore ankle braces and half did not.[55] Ankle sprain incidence was 1.9% in nonbraced students and 0.3% in brace wearers (relative risk 6.3, $p < 0.04$). For all injuries, the braced group had a 4.3% incidence whereas the nonbraced group had a 5.1% incidence (relative risk 1.2, p = 0.92).[55] The brace did not influence other types of injuries.

While investigating the effect of footwear choice, a study of Israeli Defense Force trainees revealed that a high-top athletic shoe worn during training prevented foot injuries compared with the standard combat boot;[59] however, the overall lower extremity injury rates for the 2 groups were the same.

These latter 2 studies[55,59] suggest that the incidence of specific injuries can be reduced without influencing the incidence of total injury. It may be prudent to balance the injury reduction capability of a specific intervention against the total injury picture before costly interventions are instituted.

Even unsuccessful prevention trials are valuable since they save further expenditure of resources on strategies that may not work. In the mid-1980s, the US Marine Corps was prepared to purchase shock-absorbent boot insoles for issue to all incoming recruits in order to reduce the incidence of stress fractures. The sports medicine literature suggested that such an intervention could reduce the likelihood of some injuries.[60,61] Before committing funds, however, a study was commissioned to determine the efficacy of the insoles. Gardner et al.[28] followed more than 3000 US Marine recruits who were randomly assigned to wear a shock-absorbent insole or a non–shock-absorbent insole. The incidence of stress fractures did not differ between the 2 groups, indicating that the shock-absorbent boot insoles under consideration did not prevent stress fractures in this population. This study saved the US Marine Corps considerable expense and demonstrated the cost-efficiency of such testing.

Table VIII. Total running distance, stress fracture incidence and final 4.8-km (3-mile) run times among 3 groups of male US Marine Corps recruits during a 12-week boot camp[48]

Number in group	Total running distance (km) [miles]	Stress fracture incidence (number/100 recruits)	Final run time (min)
1136	89 (55)	3.7	20.3
1117	66 (41)	2.7	20.7
1097	53 (33)	1.7	20.9

4. Conclusions

The first step of the injury control process (see table I) is to determine whether a problem exists. Medical surveillance data indicates that injuries are an important problem for the US Army. Unintentional (accidental) injuries cause about 50% of deaths, 50% of disabilities, 30% of hospitalisations and 40 to 60% of outpatient visits. For every unintentional injury death, there are about 20 injury disabilities, 100 hospitalisations and 1900 outpatient visits. Furthermore, epidemiological surveys[5-8,14-16,19,21] and surveillance data indicate that physical training–related injuries in the US Army result in significant, usually temporary, losses of personnel resources. 80 to 90% of limited duty days for trainees and infantry soldiers who visited outpatient clinics result from training injuries. Medical surveillance data further helps to prioritise the allocation of resources for prevention and research. As a result of data such as those presented, greater emphasis is being given to injury surveillance, prevention and research. For this reason, US Army and Navy research programmes have been developed to study training-related injuries.

The second step of the injury control process is identification of modifiable causes and risk factors. US Army research documents a number of potentially modifiable risk factors for these injuries,[6,7,16,31] including:

- high volumes of running
- low levels of physical fitness
- high and low levels of flexibility
- sedentary lifestyle
- tobacco use.

Some risk factors, such as body morphology, flexibility and smoking, warrant further study.

Demonstrating that a problem exists and identifying risk factors for injury is not sufficient to prevent the occurrence of injury. Knowledge of injury rates and risk factors provided by surveillance and research are of limited value unless they are integrated with other essential elements of an injury prevention programme. The ultimate goal of injury surveillance and research is injury prevention. The third step of the control process is the determination of what is effective in preventing injuries. Prevention strategies should be tested prior to programme implementation.

The fourth step of the injury control process, dissemination of information from surveillance and research programmes directly to those who can use it to prevent injuries (military commanders, soldiers, policy makers, etc.), is the key to successful prevention of injuries in the US Army. Once programmes are in place, programme effectiveness should be monitored. This is the fifth and final step of the injury control process.

In the US military services, the infrastructure for a comprehensive injury prevention programme, integrating surveillance, research, intervention, programme implementation, and programme monitoring, has been developed. The same general principles of injury prevention and control apply to civilian sports and exercise.

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