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Is High Intensity Functional Training (HIFT)/CrossFit® Safe for Military Fitness Training?

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Abstract

High-intensity functional training (HIFT) is a promising fitness paradigm that gained popularity among military populations. Rather than biasing workouts toward maximizing fitness domains such as aerobic endurance, HIFT workouts are designed to promote general physical preparedness. HIFT programs have proliferated due to concerns about the relevance of traditional physical training (PT), which historically focused on aerobic condition via running. Other concerns about traditional PT include: 1) the relevance of service fitness tests given current combat demands; 2) the perception that military PT is geared toward passing service fitness tests; and 3) that training for combat requires more than just aerobic endurance. Despite its' popularity in the military, concerns have been raised about HIFT's injury potential, leading to some approaches being labeled as "extreme conditioning programs" by several military and civilian experts. Given HIFT programs' popularity in the military and concerns about injury, a review of data on HIFT injury potential is needed to inform military policy. The purpose of this review is to: 1) provide an overview of scientific methods used to appropriately compare injury rates among fitness activities; and 2) evaluate scientific data regarding HIFT injury risk compared to traditional military PT and other accepted fitness activities

Keywords

military; high-intensity; functional; physical training; injury

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I. INTRODUCTION

High-intensity functional training (HIFT) is a promising fitness paradigm that has gained popularity among military populations. HIFT programs emphasize varied functional movements (i.e., movements requiring universal motor-recruitment patterns in multiple movement planes such as lifting, pulling, throwing, etc.) done at relatively high intensity[1,2]. Rather than biasing workouts toward maximizing a specific fitness domain (e.g., running programs for aerobic endurance), HIFT workouts are designed to promote general physical preparedness. This is particularly important for military populations who need to have superior physical conditioning to respond to occupational and warfare specific tasks[3].

HIFT stresses both aerobic and anaerobic energy pathways and is balanced in addressing power, strength, flexibility, speed, endurance, agility and coordination[1,2,4]. Workouts are highly varied and often "scored" (e.g., time required to complete tasks), which is common in many occupational fitness tests, in order to assess and document improvements. HIFT workouts can be scaled to accommodate varying levels of fitness or preexisting physical limitations and be designed for environments where exercise equipment is available or in austere environments where only body weight movements and the incorporation of available objects (e.g., ammo cans, sand bags) is possible. In addition to its impact on fitness, evidence suggests that HIFT training is uniquely effective in improving body composition, an important issue given recent increases in overweight and obesity among active duty military personnel[5–7].

The popularity of HIFT-related fitness programs in the military continues to increase. For example, in 2014 there were 281 non-profit CrossFit® gym affiliates on both Continental United States (CONUS) and overseas military installations (Personnel communication with Nicole Carroll, CrossFit Headquarters, Director of Certification and Training, 31 October 2014). Among the 146 CONUS affiliates, 50 (34.2%) were associated with US Army posts, 6 (4.1%) with Army National Guard units, 37 (25.3%) with US Air Force (USAF) bases, 6 (2.1%) with Air National Guard units, 12 (8.2%) with US Coast Guard stations, 16 (11.0%) with US Navy installations, 17 (11.6%) with US Marine Corps (USMC) bases, and 5 (3.4%) with Joint Base installations. In addition, a number of HIFT-related fitness programs have been tailored to the needs of military personnel including the Ranger Athlete Warrior program (Ranger-Athlete-Warrior Manual v4.0, press release, 2015), the USMC High Intensity Tactical Training Program[8], the Mission Essential Fitness program[9], and the CrossFit®-based Canadian Army's Combat Fitness Program[10].

HIFT-related fitness programs have proliferated in the military due to concerns about the relevance and benefits of traditional military physical training (PT), which historically focused primarily on aerobic conditioning[11]. Other concerns about traditional military PT include: 1) the relevance of service fitness tests given current combat demands; 2) the perception that military PT is geared toward passing service fitness tests[3]; and 3) that training for combat requires more than just aerobic endurance[12–16]. For example, CPT Nathan Showman (US Army), a combatives and fitness instructor with an advanced degree in Kinesiology, argues that traditional military PT has a high potential for injury and lacks applicability to relevant combat demands[13].

The large number of CrossFit® military affiliates also attests to a "grassroots" interest in HIFT. In fact, LTG Robert B. Abrams, Senior Military Assistant to the Secretary of Defense, implemented CrossFit® in 2012 for soldiers in the 3rd Infantry Division when he was the commanding general. His stated rationale for implementing CrossFit® for PT was that it was "*a functional approach to PT in order to prevent injuries performing daily duties*"[17]. Similarly, CrossFit® was used as the template for the Canadian Army's infantry Combat Conditioning Program and was suggested as a model for the Australian Army to revamp their combat physical fitness program[10,18].

Despite the popularity of HIFT, a frequently raised concern is the potential for injury risk compared to traditional military PT. Injuries are costly for the military, with musculoskeletal conditions costing the Army nearly $125 million yearly for disability compensation[3]. Showman and Henson[13] note the latest Army doctrine for physical readiness training (FM 7–22)[3] is designed to reduce injuries, implement phased training, and include multiple combat-relevant fitness domains (e.g., mobility, flexibility, agility). However, the complexity of the document has limited real-world application after which is further impacted by leader turnover[13]. Bergeron and colleagues[19], in a commentary on popular HIFT programs such as CrossFit® (labeled "extreme conditioning programs"), claimed that "there is an apparent disproportionate musculoskeletal injury risk from these demanding programs, particularly for novices, resulting in lost duty time, medical treatment, and extensive rehabilitation". Unfortunately, as we will discuss in this paper, the evidence offered for this assertion is based primarily on isolated cases or research not directly relevant to HIFT programs.

Given the popularity of HIFT programs in the military and concerns about injury risk, a review of published data on HIFT injury potential is needed to inform military policy. The purpose of this review is twofold: 1) to provide an overview of scientific methods used to appropriately compare injury rates among fitness activities; and 2) evaluate scientific data regarding potential injury risk of HIFT fitness programs compared to traditional military PT and other fitness activities.

II. MEASURES OF INJURY RISK AND RATES

When evaluating the risk potential of exercise programs, it is critical to ensure clarity about the nature of the programs evaluated and the metrics used to compare risks. According to current Army doctrine[3], "injuries are defined as any intentional or unintentional damage to the body resulting from acute or chronic exposure to mechanical, thermal, electrical, or chemical energy, and from the absence of such essentials as heat or oxygen" with musculoskeletal injuries seen as resulting primarily from PT programs.

One common way of defining injury risk is by presenting ***Injury Prevalence*** (see Box 1A for computation), the ratio of the number of people injured to the number of people at risk for injury in a given time period[20–22].

Injury prevalence typically is computed based on cross-sectional data, and the sample used to compute it can be an open population (e.g., the population of active duty service members at a particular military installation, which changes regularly) or a closed cohort (i.e., where no new individuals are included once the cohort is developed). For comparative purposes, it is important to know whether the sample was from an open or closed group. For instance, to determine the injury prevalence among personnel at a specific military installation in 2013, one would survey all military personnel on the installation and determine how many reported any injury and divide that number by the total number of military personnel on installation at that same time period in 2013. However, some military personnel may have moved to another installation sometime during the year, which makes this estimate from an open group. Thus, injury prevalence quantifies the number of military personnel who reported an injury relative to the total population at risk at our hypothetical military installation.

Injury Incidence Proportion (also referred to as ***Injury Cumulative Incidence***; see Box 1B for formula) is another way of expressing injury risk. Injury incidence proportion measures the average risk of injury occurrence and reflects the average probability of injury among people participating in an activity[21,22]. Injury incidence proportion is measured in a closed sample and only new cases of injured persons are counted. The incidence proportion provides an intuitive measure of injury risk because it tells us the percentage of newly injured Soldiers relative to the Soldier population at risk over a defined period of time.

Finally, injury risk can be described using ***Injury Incidence Rate*** (also referred to as the ***Injury Incidence Density***; see Box 1C for formula). Injury incidence rates use the number of new injuries in a closed group rather than the number of injured persons for the numerator and uses exposure time that an individual is involved in the activity of interest as the denominator (i.e., Person-time at risk, which is the time each person is followed until an injury occurs or if no injury occurs, it is just the total time they are observed)[21,22]. Injury incidence rate is useful because it more precisely quantifies injury frequency as a function of exposure time. It also allows for comparison of injury incidence rates with a common metric across activities because the injury count is corrected for the exposure time involved [21,22]. It is not appropriate to compare injury prevalence or incidence proportions across sports if their time requirements substantially differ, because activities with greater training or competition times would be disadvantaged due to having greater time at risk. For instance, if one wanted to compare whether Army or Marine Corps Basic Training resulted in more injuries, it would be improper to compute injury prevalence or incidence proportions for groups undergoing basic training because Marine basic training is longer than Army basic training. It would be more accurate to compute the injury incidence rate accounting for the time at risk.

III. INJURY RISK IN THE MILITARY AND ASSOCIATION WITH HIFT-RELATED PROGRAMS

It is important to be clear about how injury rates are calculated when examining the data on injuries in the military attributable to fitness programs. If different definitions of injury risk are used to compare programs, that comparison is flawed. If comparable measures of injury risk demonstrate that HIFT incurs no higher injury risk than traditional military PT, it is reasonable to conclude that HIFT confers no greater injury risk for military personnel.

Military Physical Training and Injury

Injuries due to PT are a problem among military personnel[23]. However, often it is argued that an injury-free fitness program is, by definition, an ineffective fitness program. Among all injuries incurred by military personnel, the largest proportion (ranging from 32%–63%) are associated with engaging PT and sports, and substandard fitness and body composition are consistent PT injury predictors[24–27]. Previous reviews have examined injury incidence proportions attributable to PT in the military, with incidence proportions ranging from 16.3%–61.7% for women and 7.5%–50.7% for men in a variety of training contexts such as basic training, infantry, special warfare, and officer candidate schools[23]. Figure 1 presents data from 1994–2003 reported by the Department of the Army[25] and Knapik and colleagues[28] documenting training-related injury incidence proportions.

Among male Army trainees, the most commonly reported injuries were low back pain, tendinitis, sprains, strains, and stress fractures, while among women the most common were muscle strains, stress fractures, sprains, tendinitis, and overuse knee injuries[29].

Critical Analysis of Existing Literature

When evaluating fitness-related injury risk, it is important that the literature used: 1) accurately identifies the program producing the injury data; 2) is based on systematically collected data with appropriate metrics for assessing the relative risk of injury; and, 3) is not reliant on anecdotal cases.

A commonly cited document detailing concerns about HIFT-related fitness programs in the military is titled "*Consortium for Health and Military Performance and American College of Sports Medicine consensus paper on extreme conditioning programs in military personnel*", published by Bergeron and colleagues[19]. However, the article bases concerns about "extreme conditioning programs" (ECPs) largely on sources not focused on ECPs or that do not discuss ECPs at all. For example, Bergeron et al.[19] state "muscle strains, torn ligaments, stress fractures, and mild to severe cases of potentially life threatening exertional rhabdomyolysis are reportedly occurring at increasing rates as the popularity of ECPs grows (4,27)." The first paper cited (reference 4) is a surveillance paper about the incidence of rhabdomyolysis in the military in 2009; it concludes that the majority of rhabdomyolysis cases and training injuries are linked to lower fit individuals rapidly increasing their physical activity during recruit training, often in locations characterized by high heat and humidity[30]. ECPs are not mentioned at all in this reference.

The second paper cited (reference 27) is a story in the *Air Force Times* magazine[31] that discusses the conference about ECPs upon which the Bergeron paper[19] was based, and that anecdotal reports of injury were why the conference was convened. The *Air Force Times* article quotes one of the other Bergeron[19] paper's authors (Dr. Francis O'Connor) as saying "the reason we are here is because of all of the anecdotal reports of injuries."[31] However, anecdotal cases are inferior to systematic evaluations of injury risk with respect to more accurately characterizing the injury potential for sports and fitness activities.[23–24]

Rhabdomyolysis Risk

Bergeron et al.[19] discuss potential negative outcomes from ECPs, including rhabdomyolysis; a rare condition whose symptoms include muscle pain, stiffness, weakness, darkening of the urine, decreased urine output, and swelling of the body part involved with or without pain[32]. The primary evidence offered by the authors that ECP's raised the risk of rhabdomyolysis was a single case which occurred in a Navy member; however, case studies do not establish elevated risks of negative outcomes.

HIFT-related fitness programs, including CrossFit®, do not appear to confer greater risk of rhabdomyolysis than other fitness activities encouraged by the military. A number of factors are associated with rhabdomyolysis risk which are not specific to any particular fitness activity, including age, hydration, low fitness levels, use of illicit drugs and alcohol, heat stroke, crush injuries, altitude, ambient temperature, and humidity[32]. Cases of rhabdomyolysis have been documented as occurring in a large variety of fitness activities (e.g., running, military basic training, etc.) and in several occupational groups (e.g., law enforcement, military, and firefighter trainees[32,33]). For example, 39.2% of Marine recruits were found to have elevated urinary markers of potential rhabdomyolysis during basic training[34].

Risk of rhabdomyolysis is arguably particularly common in marathons, which are frequently promoted by the military[35]. In contrast, recent systematic studies evaluating injury and other adverse events associated with HIFT-related fitness programs including CrossFit® in both civilian and military samples have reported no incidents of exertional rhabdomyolysis[9,36–40]. Thus, based on studies from systematic data (as opposed to single case studies), one would conclude that the risk of rhabdomyolysis for HIFT is low compared to distance running or military PT.

HIFT-related Fitness Programs vs. Traditional Military Physical Training

The most useful data for evaluating HIFT injury risk potential comes from direct evaluations of HIFT and/or comparisons to other fitness activities in military personnel. The most recent and relevant data were published by Grier and colleagues[41]. The authors followed two groups of Soldiers in a US Army Brigade Combat Team in 2010 before and after implementation of the Advanced Tactical Athlete Conditioning (ATAC) program, along with CrossFit® and the Ranger Athlete Warrior (RAW) program, with 1,032 Soldiers engaging in ATAC/CrossFit®/RAW and 340 engaging in traditional Army Physical Readiness Training (APRT), providing a direct comparison between the programs with respect to injury risk.

The ATAC/CrossFit®/RAW programs incorporated key aspects of HIFT including emphasis on functional movements focused on power and explosiveness, using multi-joint movements performed at higher intensities, interval training, and reduced training volumes, particularly for running. Workouts included but were not limited to the use of plyometrics, agility drills, speed interval training, strongman activities, use of kettlebells, and weightlifting[41].

Injury incidence proportions were computed based on data from medical records recorded by the Defense Medical Surveillance System for six months prior to and after full implementation of the ATAC/CrossFit®/RAW program. They found that injury incidence proportions for both groups increased a small amount between the two assessment periods, with a five percentage point increase in overall injuries for the ATAC/CrossFit®/RAW program Soldiers and a seven percentage point increase for Soldiers performing APRT. Figure 2 illustrates the pre- and post- ATAC/CrossFit®/RAW program implementation and APRT injury incidence proportions.

They reported no significant differences in injury incidence proportions between both groups. The authors concluded that no recommendations could be made against the use of these programs in the Army given they did not increase injury risk relative to APRT[41].

In another directly relevant HIFT program study in the Army, Paine and colleagues[38] published a detailed analysis of fitness improvements found in a pilot study of 14 officers attending the US Army Command and General Staff College at Ft. Leavenworth. Participants underwent eight-weeks of CrossFit® training and demonstrated significant improvements in a variety of fitness outcomes. No injuries were reported over the eight week training period, but there was no comparison group.

Heinrich and colleagues[9] conducted an eight-week randomized trial comparing APRT with a HIFT program called Mission Essential Fitness (MEF) in a sample of 67 young active duty Army personnel. MEF consisted of circuits involving functional movements requiring multiple joints and the use of intervals[38,41]. MEF participants demonstrated significant improvements on components of the APFT test compared to those doing APRT and no injuries were reported for either group.

The Naval Health Research Center conducted a 12-week HIFT study comparing a new Combat Conditioning Trial Program (CCTP) with traditional USMC combat PT in two battalions[42]. CCTP emphasized functional movements performed at sustained levels of high-intensity. CCTP workouts pushed Marines to perform “as many rounds as possible” of a set of functional movements in a fixed period of time[42]. They reported that Marines in CCTP experienced a 21% lower injury rate than Marines engaging in traditional combat PT.

A final eight-week HIFT study was conducted among 119 USAF Combat Controller trainees[43]. They evaluated the benefits of a revised fitness program for Combat Controller trainees because attrition exceeded 70%, with overuse injuries playing a significant role[43]. The original PT program was revised by reducing running volume by 50% and incorporating higher intensity functional movements and intervals focused on power development and use of multi-joint exercises. As with previous studies, Combat Controller trainees experienced significant improvements in a number of fitness metrics but, most relevant to this review, there was a 67% reduction in the overuse injury incidence proportion compared to traditional PT. Based on studies evaluating and/or comparing training approaches, HIFT-related fitness programs including CrossFit® had similar or fewer injuries than traditional military fitness approaches.

IV. INJURY INCIDENCE RATES ASSOCIATED WITH HIFT-RELATED FITNESS PROGRAMS

As was noted above, computing injury incidence rates requires more information than is typically reported in published studies[21,22]. In addition, it often is difficult to make comparisons of injury risk across studies because samples may be dissimilar with regard to important factors that also influence injury risk. Ideally when comparing rates across studies, one would directly standardize them so that potential confounding factors, such as the samples having different age distributions, can be corrected, but this is rarely possible because of limited available data[44].

Despite these limitations, it is still informative to examine injury incidence rates across a number of sports or activities that have different training volumes as long as the estimate is corrected for time at risk. Table 1 summarizes injury incidence rates per 1000 hours of training (or similar metric) for HIFT-related fitness programs and a number of other fitness activities and sports that have been reported in the scientific literature.

Data from the summarized studies provides strong evidence that HIFT programs, including CrossFit®, do not pose greater risk for injury than other military training programs or the majority of fitness activities encouraged at military installation fitness centers when a common metric is used. Injury incidence rates for HIFT programs ranged from 0.0/1000 hours to 3.1/1000 hours of training. Estimates were substantially lower than those reported for running, which is one of the primary activities emphasized in traditional military PT, and many other activities commonly conducted in military gyms including racquetball, tennis, basketball, volleyball, cycling, and rowing[45,46].

V. INJURY RISK AND DISTANCE RUNNING

Distance running has long been a core training and assessment method for the military[47]. For instance, all military fitness tests involve distance runs of either 1.5 (Air Force, Navy, and Coast Guard), 2 (Army), or 3 miles (Marine Corps). To prepare for Marine Corps Officer Candidates School, candidates are encouraged to engage in “weekly workouts of 1 long run 5–8 miles, 1 day 3–4 miles, 1 day sprints”[48]. The Navy Seals BUD/S Warning Order instructs candidates that “the majority of the physical activities you will be required to perform during your six months of training at BUD/S will involve running.”[49]. In addition to the significant volume of distance running required as part of training, each of the services sponsors and promotes participation in long distance runs, such as the Air Force Marathon, Army Ten-Miler, All Army Triathlon, Marine Corps Marathon, and Navy-Air Force Half Marathon.

Although distance running can promote aerobic endurance, its prominence in military PT has been questioned [1,12–16,50]. For instance, GEN James Amos, the 35th Commandant of the USMC notes that the USMC Fitness Program “over-emphasizes aerobic training (long distance running) and gives very little attention to strength training”[1]. Similarly, Showman and Henson state that, for the Army, the soldier who uses programs such as CrossFit® “is fitter and more combat-ready than a soldier who exclusively runs 50 miles per week and performs some push-ups"[13]. Supporting these criticisms, running has been found to negatively impact fitness domains like muscular strength[51] and, in the case of long distance running, is linked to decreased cardiovascular health, exertional rhabdomyolysis[52], and even premature death [53–56].

A key negative impact of distance running is its relatively strong association with training injuries. As demonstrated in Table 1, running has one of the highest injury incidence rates (per 1,000 training hours), especially for novice runners. Furthermore, research conducted among military populations has found running volume to be one of the most potent risk factors for training injury [23,25,29,57–59]. For instance, Abt and colleagues found running to be the most frequent cause of all injuries (23.1%) and preventable injuries (30%) among US Army Special Operations forces [59]. Similarly, a study of US Army infantry trainees found that those running an average of 11 miles per week experienced a 27% higher rate of lower extremity injuries than those running 5 miles per week, and the 2-mile run test times for the two groups were similar at the end of training [58]. Studies have demonstrated that when running volume is significantly reduced, recruits reduce their injury risk substantially without negatively impacting fitness[57]. Given the relatively low HIFT injury incidence rates compared to running and the positive impact on fitness domains important for readiness, it is puzzling how these popular exercise programs among military members could be discouraged with warnings of potential injury risk while distance running is encouraged.

VI. CONCLUSION: RISK ANALYSIS OF HIFT-RELATED FITNESS PROGRAMS INCLUDING CROSSFIT®

PT-related injuries are considered one of the leading threats to the health and readiness of military members. However, injuries also are viewed as part of the cost of being in the military because regular PT is critical for members to maintain their fitness for arduous deployments and missions[23,28,29,57,58]. Injuries are the leading cause of outpatient medical visits, hospitalizations, and discharges that result in 25 million limited duty days each year across the services and it has been estimated that stress fractures alone result in medical visits and lost training days that cost the military approximately $100 million annually[29,57]. Despite this, the military expects its personnel to regularly engage in fitness training activities.

A large scientific literature has convincingly demonstrated that high training volumes, particularly high running volumes, are one of the most significant and consistent predictors of training injuries[23,25,28,29,57,58,60,61]. Accordingly, US Army researchers have noted that one of the best interventions for decreasing injuries is reducing running volumes[26,28]. Despite these data, the military continues to support models of training that Kraemer and associates[11] characterize as being "…grounded in the old boxing concepts of training for 'roadwork'". Conversely, time spent in HIFT typically is 25%–80% less than traditional PT and has minimal inclusion of long distance running[9,62].

In conclusion, HIFT programming appears to be effective in improving fitness domains that are important for military members[1,4,63] while also reducing training volumes, especially for running, a primary risk factor for injuries and the most recommended strategy for injury prevention [23,25,28,29,57,58,60,61]. Current research evidence indicates that HIFT programs, including CrossFit®, pose similar or lower potential for injury than many traditional PT activities, while resulting in similar or better gains in overall fitness and body composition.

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Box 1A. Injury Prevalence Formula

$$\textit{Injury Prevalence} = \frac{\textit{Number of injured persons}}{\textit{Total populaton of interest}}\ \textit{at at given point in time}$$

Box 1B. Injury Incidence Proportion Formula

$$\textit{Injury Incidence Proportion} = \frac{\textit{Number of newly injured persons in a given time period}}{\textit{Number of persons at risk}}$$

Box 1C. Injury Incidence Rate

$$\textit{Injury Incidence Rate} = \frac{\textit{Number of new injuries in a given time period}}{\textit{Sum of person} - \textit{time at risk}}$$

Figure 1.

Computational Formulas for Injury Indices.

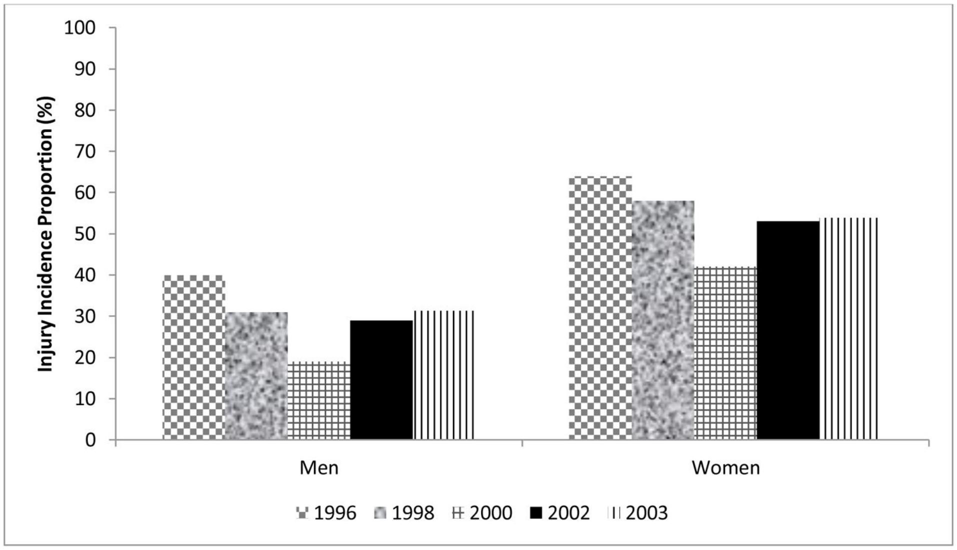

Figure 2.

Injury Incidence Proportions for Army Trainees*.

*Figure adapted from data provided in the Department of the Army report[25] and Knapik and colleagues[28].

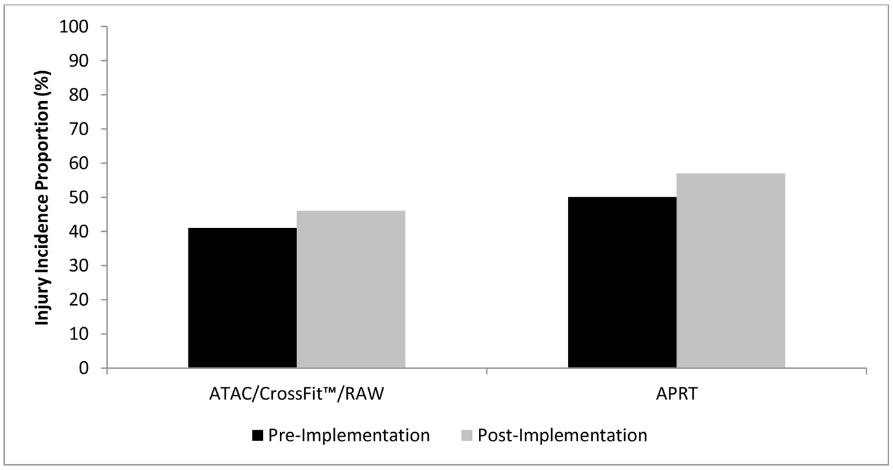

Figure 3.

Injury Incidence Proportions Among Army Personnel Before and After Implementation of ATAC/CrossFit/RAW as compared to Army Physical Readiness Training (APRT)*.

*Figure adapted from data provided by Grier and colleagues[41].

Table 1

Injury incidence rates for HIFT-related fitness programs and other sports that adjust for training exposure time using injuries/1000 hours (or similar incidence density metric).

Study	Study Population	Activity	Injury Incidence Rate/1000 hours of training (or similar incidence density metric)
HIFT-Related Fitness Program Studies			
Feito et al. (2014)[64]	Anonymous online survey of participants (N=737) from national and international CrossFit® online forums between Dec. 2011–Mar. 2012.	CrossFit® training	2.9 injuries/1000 hours of CrossFit® training (rate provided by Feito Y. Personal Communication. October 31, 2014)
Weisenthal et al. (2014)/ Giordano et al. (2014)[40,65]	Anonymous online survey of participants (N=386) from Northeastern US CrossFit® Gyms and the main CrossFit® website (www.crossfit.com) conducted from Oct. 2012–Feb. 2013.	CrossFit® training	2.4 injuries/1000 hours of CrossFit® training
Hak et al. (2013)[36]	Anonymous online survey of participants (N=132) from national and international CrossFit® online forums conducted from Feb.–May 2012.	CrossFit® training	3.1 injuries/1000 hours of CrossFit® training
Heinrich et al. (2012)[9]	Randomized 8-week pilot trial comparing HIFT (Mission Essential Fitness; MEF) (n=34) with Army Physical Readiness Training (n=33) in active duty US Army personnel.	Functional and interval circuit training	0.0 injuries/1000 hours of MEF training
Study of Military Physical Training Activities			
Piantanida et al. (2000)[66]*	Male and female USMC officer candidates (N=489) who were prospectively followed for 6-weeks while undergoing training in the summer of 1997.	Military physical training conducted at USMC Officers Candidate School	3.9 injuries/1000 hours of military physical training
Studies of other fitness activities			
Parkkari et al. (2004)[45]	Large cohort study (N=3,657) of individuals selected from the Finnish population ages 15–74 determining injury incidence in a variety of recreational sports activities. Prospective study with 92% follow-up at one year.	Activities ranging from categories including commuting (e.g., walking, biking), lifestyle (e.g., gardening, home repair), and recreational & competitive sports activities (e.g., martial arts, soccer, basketball, wrestling, running, swimming, etc.).	Examples reported from recreational and sports activities: 16.3 injuries/1000 hours of judo training 9.1 injuries/1000 hours of wrestling training 7.8 injuries/1000 hours of soccer training 7.0 injuries/1000 hours of volleyball training 4.7 injuries/1000 hours of tennis training 3.8 injuries/1000 hours of track and field training 3.6 injuries/1000 hours of running training 3.1 injuries/1000 hours of gym training 0.3 injuries/1000 hours of golf training
Requa et al. (1993)[46]	Review of studies determining injury incidence rates in a variety of recreational sports activities.	Activities including aerobic dance, yoga, rowing, roller skating, tennis, etc.	7.8 injuries/1000 hours of activity overall 19.5 injuries/1000 hours of aerobic dance activity (highest) 2.5 injuries/1000 hours of stationary biking activity (lowest)
Hespanhol et al. (2013)[67]	Online survey of recreational runners (N=200) who completed baseline and follow-up surveys over a 12 week period.	Running	10.0 injuries/1000 hours of running

Study	Study Population	Activity	Injury Incidence Rate/1000 hours of training (or similar incidence density metric)
Nielson et al., 2012[68]	Review of studies examining injury incidence rates among runners including healthy untrained volunteers, healthy novice runners, recreational distance runners, cross-country runners, and competitive runners.	Running	2.5–7.4 injuries/1000 hours of running among marathoners 33.0 injuries/1000 hours of running among novices
Winwood et al. (2014)[69]	One year retrospective survey of male Strongman athletes (N=213) from 19 countries.	Strongman events (e.g., stone lift, yoke walk, tire flip, etc.)	5.5 injuries/1000 hours of Strongman training
Raske et al., (2002)[70]	Questionnaire administered to male and female elite weight lifters (n=110; Olympic and Powerlifting) and randomly selected non-elite lifters (n=50) conducted in 1995 and 2000.	Olympic lifting (i.e., snatch; clean and jerk) and Powerlifting (i.e., bench press, deadlift, and back squat)	2.6 injuries/1000 hours of lifting training for elite lifters from 1993–1995 2.9 injuries/1000 hours of lifting training for non-elite lifters from 1993–1995 2.5 injuries/1000 hours of lifting training for elite lifters from 2000
Calhoun et al. (1999)[71]	Athletes (N=27) in residence at the USOC Olympic lifting training center from 1990–1995.	Olympic lifting (i.e., snatch; clean and jerk)	3.3 injuries/1000 hours of lifting training
Korkia et al. (1994)[72]	British triathletes (N=155) who varied in level from sprint to full ironman and experience from recreational to elite completed injury surveys weekly for eight weeks in 1990.	Triathlon events (i.e., swimming, running, and cycling)	5.4 injuries/1000 hours of triathlon training 17.4 injuries/1000 hours of triathlon competition
Zwingenberger et al. (2014)[73]	Triathletes (n=212) completed an injury survey about their training and competing for the previous 12 months while some (n=49) from this group were followed prospectively for 12 months.	Triathlon events (i.e., swimming, running, and cycling)	0.7 injuries/1000 hours of triathlon training (retrospective) 9.2 injuries/1000 hours of triathlon competition (retrospective) 1.4 injuries/1000 hours of triathlon training (prospective) 18.5 injuries/1000 hours of triathlon competition (prospective)
Reynolds et al. (2001)[74]	Women (N=45) who completed a 24-week strength and conditioning program developed to improve lifting and running performance in women in the Army. The injury incidence rate was computed only for injuries that resulted in at least one day of lost training time.	Strength training and running	2.8 injuries associated with lost training time/1000 hours of training
Tegnander et al. (2007)[75]	Female soccer players (N=181) representing all teams participating in the 2001 elite division season followed prospectively.	Soccer	3.1 acute injuries/1000 hours of training 23.6 acute injuries/1000 game hours
Brito et al. (2011)[76]	Male youths (N=912) ages 12–19 years were followed prospectively from 40 randomly selected sub-elite Portuguese youth soccer teams from 2009–2010..	Soccer	2.5 injuries/1000 hours of soccer exposure total 1.8 injuries/1000 training hours 6.8 injuries/1000 game hours
Verhagen et al. (2004)[77]	Male and female athletes (N=486) from 50 teams in the 2nd and 3rd Dutch national volleyball divisions were followed prospectively from 2001–2002.	Volleyball	3.0 injuries/1000 volleyball exposure total (games and training) for men 2.4 injuries/1000 volleyball exposure total (games and training) for women 2.3 injuries/1000 hours training for men 1.5 injuries/1000 hours training for women
Cumps et al. (2007)[78]	Male and female basketball players (N=164) from 14 different teams playing at the senior competitive, national, and regional level in the Netherlands were followed prospectively.	Basketball	8.0 injuries/1000 basketball exposure total (games and training) for men 13.9 injuries/1000 basketball exposure total (games and training) for women 2.0 injuries/1000 hours training for men 2.4 injuries/1000 hours training for women

*Note: Two other studies examined injury risk during military training and computed injury incidence rates, but used a different denominator than person-hours of training time (injuries/1,000 hours of training). O'Connor and colleagues[79] evaluated 874 male USMC officer candidates who underwent training in the summer of 2009 and were followed prospectively in either a short cycle (6-week) or long cycle (10-week) program. They reported *7.9 injuries/1000 person-days* of training in the short cycle program and *6.2 injuries/1000 person-days* of training in the long cycle program. Rosendal et al.[80] examined injuries among 330 male Danish military conscripts who were prospectively followed for 12 weeks of basic military training and reported *3.5 injuries/1000 recruit days*.