



## Original Contribution

# The Association of Aerobic Fitness With Injuries in the Fire Service

Gerald S. Poplin\*, Denise J. Roe, Wayne Peate, Robin B. Harris, and Jefferey L. Burgess

\* Correspondence to Dr. Gerald S. Poplin, University of Virginia, Center for Applied Biomechanics, Department of Mechanical and Aerospace Engineering School of Engineering and Applied Science, 4040 Lewis and Clark Drive, Charlottesville, VA 22911 (e-mail: poplin@virginia.edu).

Initially submitted April 24, 2013; accepted for publication August 6, 2013.

The aim of the present study was to understand the risk of injury in relation to fitness in a retrospective occupational cohort of firefighters in Tucson, Arizona, from 2005 to 2009. Annual medical evaluations and injury surveillance data were linked to compare levels of aerobic fitness in injured employees with those in noninjured employees. The individual outcomes evaluated included all injuries, exercise-related injuries, and sprains and strains. Time-to-event analyses were conducted to determine the association between levels of fitness and injury likelihood. Fitness, defined by relative aerobic capacity ( $VO_{2max}$ ), was associated with injury risk. Persons in the lowest fitness level category ( $VO_{2max} < 43$  mL/kg/minute) were 2.2 times more likely (95% confidence interval: 1.72, 2.88) to sustain injury than were those in the highest fitness level category ( $VO_{2max} > 48$  mL/kg/minute). Those with a  $VO_{2max}$  between 43 and 48 mL/kg/minute were 1.38 times (95% confidence interval: 1.06, 1.78) more likely to incur injury. Hazard ratios were found to be greater for sprains and strains. Our results suggest that improving relative aerobic capacity by 1 metabolic equivalent of task (approximately 3.5 mL/kg/minute) reduces the risk of any injury by 14%. These findings illustrate the importance of fitness in reducing the risk of injury in physically demanding occupations, such as the fire service, and support the need to provide dedicated resources for structured fitness programming and the promotion of injury prevention strategies to people in those fields.

aerobic capacity; fire service; injury

Abbreviation:  $VO_{2max}$ , relative aerobic capacity.

The work demands for fire service employees are well documented as requiring considerable physical abilities. In 1992, Sothmann et al. (1) recommended that these workers have a relative aerobic capacity ( $VO_{2max}$ ) between 38 and 42 mL/kg/minute in order to meet the measured workload demand for firefighters while also maintaining a reserve capacity to respond to other unanticipated events. Since then, most fire departments have adopted minimum fitness standards, often emphasizing aerobic capacity as a definitive measure of overall fitness. Standard fitness assessments for the general population typically have a set of norms that are scaled to age and sex, and results can range from poor to superior (2).

Opportunities for injury in the fire service are diverse. Persons with higher aerobic capacities should be able to consume more oxygen than those with lower aerobic capacities, and their bodies are likely to be more efficient at circulating oxygen

to all systems and producing energy. Persons in the top levels of a fitness spectrum may not be as susceptible to microtraumas and may recover better from injury than their less-fit counterparts (3–9). Hence, those with higher  $VO_{2max}$  should have a lower potential for fatigue and subsequent injury. Conversely, a high fitness level may also be an indicator that a person has an increased risk of injury, as these persons likely have greater exposure time to exercising hazards. In some fire departments, exercise has been shown to be the leading activity associated with on-duty injuries (10).

The objectives of the present study were to establish and understand the relationship between fitness status and the risk of injury in a 5-year occupational cohort of career fire service members. We hypothesized that firefighters deemed to be on the lower end of the fitness spectrum would be more susceptible to injury than their more fit colleagues.

## MATERIALS AND METHODS

### Population description, data sources, and years

As previously described (10), the present study includes data from commissioned employees of a medium-sized metropolitan fire department in the southwestern United States. Briefly, the fire department operates 21 fire stations and responds to nearly 520,000 permanent residents (with seasonal increases nearing 720,000 residents). Like many other municipal fire departments, this fire department requires an annual physical examination to assess fitness levels and provide medical clearance for each commissioned employee. Between 2005 and 2009, data for this study were obtained from 2 sources: physical assessments from annual clinic visits and department injury surveillance reports. The present study included all commissioned (noncivilian) employees of the fire department who were employed at some point in time during the study period. Approval for and oversight of the use of human subjects was provided by the University of Arizona's Institutional Review Board.

### Physical fitness measures

Information collected from annual exams included anthropometric measures (e.g., height, weight, body fat percentage),  $VO_{2max}$ , muscular strength, muscular endurance, and flexibility. Aerobic capacity can be defined as the highest rate at which oxygen can be taken up and utilized by the body during rigorous exercise (11). Aerobic capacity is expressed as a rate that is referenced in either absolute terms (L/minute) or by relative measures (mL/kg/minute) to account for individual size variations. In this study, we refer to studied relative aerobic capacity.  $VO_{2max}$  was categorized into 3 levels of fitness, using the 25th and 50th percentiles as the cutoff points between the "less fit" (<43 mL/kg/minute) and "high fit" (>48 mL/kg/minute) aerobic capacity categories, respectively. The use of a percentile as the cutoff was also used in 1999 by Lee et al. (12), who studied the relationship between cardiorespiratory fitness and cardiovascular disease in a large observational cohort of men. In addition, the 25th percentile closely relates to the recommended minimum level of aerobic capacity (42 mL/kg/minute) suggested by Sothmann et al. (1) that has been adopted by the National Fire Protection Association and most municipal fire departments in the United States (including those in this study's population). The 50th percentile was chosen as the cut off for the high fit designation because of the distributional characteristics of the population's data and to remain in accordance with current annual physical assessment methods used by the department. Neither age nor sex was directly considered when assigning aerobic fitness levels, as fire departments institute a minimum standard for aerobic fitness to help ensure that all commissioned fire personnel are capable of performing the myriad of critical job tasks and responses regardless of age or sex. Maximum aerobic capacity was estimated using the submaximal incremental treadmill protocol developed by Gerkin et al. (13) and guidelines suggested by the Wellness Fitness Initiative of the International Association of Fire Fighters and the International Association of Fire Chiefs

(14). In brief, each participant is hooked up to a heart rate monitor and made to walk on a standard treadmill. The treadmill's speed and incline are increased at prespecified time points until the subject's target heart rate is reached and  $VO_{2max}$  can be estimated. Direct measurement of  $VO_{2max}$  using oxygen and carbon dioxide analyzers and monitoring of electrocardiogram output is generally limited to specific indications because of its higher cost.

### Injury defined

Injuries that occurred on the job were recorded either if they were reportable to the Occupational Safety and Health Administration or if they were deemed nonreportable but were documented internally because of the potential for the injury to progress to the point of requiring an insurance claim (e.g., due to cumulative or repeated trauma). It should be noted that field personnel work 24-hour shifts. For the purposes of these analyses, reported injuries known to be only internally documented incidents with no loss of function or ability to perform duties (by review of injury report details) were excluded. In addition, cardiac events (e.g., stroke, heart attack), along with heat exhaustion, stress, and other medical issues, were excluded from injury analysis. These events were considered more likely to be indicative of an underlying set of symptoms, conditions, or diseases than to be related to an injury sustained on the job.

### Statistical analyses

Data from annual physical examinations and injury surveillance reports were merged utilizing unique identifiers, which enabled a direct comparison of persons with and without injury. Quantitative methods, notably time-to-event regression models, were used to evaluate the relationship between aerobic fitness and injury. Analyses were conducted for 3 separate injury outcomes: 1) any recorded injury; 2) injuries resulting from physical exercise; and 3) any reported sprain or strain.

For time-to-event (i.e., first injury) analyses, cumulative incidence was estimated using the life table and Kaplan-Meier methods, which allow for censoring (i.e., no injury). Incidence rates were assessed with respect to established fitness measures. These levels were set using methods similar to those used for establishing aerobic fitness levels (as previously explained); however, in this case, sex was taken into account for measures of body fat percentage, grip strength, and flexibility. The time-to-event analysis utilized repeated measures in which each time point (observation) corresponded to a person's annual medical examination until the occurrence of injury or censoring. This method accounted for variable observation periods because some employees were introduced later in the study period (e.g., new employees), whereas others dropped out (e.g., retired, transferred), and it enabled a single person to contribute time at risk to each of the fitness levels based on his or her most recent physical assessment. Survival analyses were completed using Cox proportional hazard regression models. Statistical analyses were conducted using Stata software, version 11.2 (StataCorp LP, College Station, Texas).

**Table 1.** Mean Values of Person-Level Descriptive Statistics, Tucson, Arizona, 2005–2009

Variable	No.	Mean	Minimum Mean	Maximum Mean	Mean Difference
VO <sub>2max</sub> , mL/kg/minute	782	49.6	43.6	55.8	12.2
Resting heart rate, beats per minute	797	62.9	57.2	69.2	12.0
Total grip strength, lbs <sup>a</sup>	797	229.5	211.4	247.5	36.1
Flexibility, inches <sup>b</sup>	782	5.8	4.5	7.0	2.5
% body fat	790	18.3	15.4	20.9	5.5

Abbreviation: VO<sub>2max</sub>, relative aerobic capacity.

<sup>a</sup> 1 lb = 0.45 kg.

<sup>b</sup> 1 inch = 2.54 cm.

## RESULTS

At the end of each calendar year from 2005 to 2009, there were between 577 to 694 commissioned employees within this metropolitan fire service. During that time period, 799 employees underwent at least 1 physical examination and follow-up until their first injury event or censoring. On average, the clinic database accounted for approximately 87% of the workforce population, and the mean age was 39.2 (standard deviation, 9.6) years. Table 1 displays select summary fitness measures of the study population across the study period. The mean for VO<sub>2max</sub> for the overall population across time was 49.6 mL/kg/minute, with a 12.2-unit difference between the minimum and maximum mean values. In total, 773 injuries were reported (Table 2). There were 357 persons who sustained at least 1 injury of any type, 174 who sustained at least 1 exercise-related injury, and 294 who sustained at least 1 sprain or strain injury. The median lengths of follow-up were 2.5, 3.2, and 2.8 years, respectively. A previous descriptive analysis of this population (for the years 2004–2009) demonstrated that 67% of all injuries were sprains and strains, and that number increased to 89% among exercise injuries. Thirty percent of all injuries were reported to have resulted in lost time on the job (10).

Kaplan-Meier analyses (data not shown) indicated that the incidence rate for injury decreased and the median time to injury increased with increasing age (stratified into 10-year categories) ( $P < 0.001$ ). There were no significant differences identified between sexes; however, women accounted for only 5% of the study population (as is common for the fire service (15)). Increases in body fat percentage were related

**Table 2.** Annual Frequency of Injury Outcomes, Tucson, Arizona, 2005–2009

Year	No. of Employees	No. of Recorded Injuries	No. of Sprains and Strains	No. of Exercise-related Injuries <sup>a</sup>
2005	577	128	84	30
2006	625	148	100	50
2007	659	174	120	62
2008	694	199	128	81
2009	667	124	89	45

<sup>a</sup> Of all exercise-related injuries, 85.2% were sprains and strains.

to increased incidence rate, driven most notably by those in the highest tier (>36% body fat).

Table 3 displays the general summary characteristics of the incidence of injury outcomes for VO<sub>2max</sub> levels and repeated measures modeling. Log-rank tests indicated that there were statistically significant increases in incidence rate with a decline in VO<sub>2max</sub> for each of the 3 injury outcomes. In addition, persons with lower VO<sub>2max</sub> levels were likely to sustain any injury sooner than were those who were more fit, as indicated by a median time to injury of 2.24 years in level III (least fit category) compared with 4.07 years for level I (most fit category);  $P < 0.001$ ).

### Cox proportional hazard modeling

Results from Cox proportional hazards models are presented in Table 4. The dependent variables in these models utilized time to first injury as a function of fitness. The hazard ratios for fitness are shown with respect to 2 modeling strategies: 1) VO<sub>2max</sub> adjusted for age and sex and 2) VO<sub>2max</sub> adjusted for other measures of fitness (i.e., resting heart rate, grip strength, flexibility, body fat percentage, number of continuous sit-ups and push-ups, age, and sex). With a hazard ratio of 0.959 for all injuries, a 1-mL/kg/minute increase in VO<sub>2max</sub> decreased the risk of injury 0.041 times ( $P < 0.001$ ). The amount of work needed to complete a given task in relation to the amount of energy expended during 1 minute of seated rest is referred to as the metabolic equivalent of task. For VO<sub>2max</sub>, a single metabolic equivalent of task is approximately 3.5 mL/kg/minute. Thus, these results suggest that improving one's aerobic capacity by 1 metabolic equivalent of task would reduce the risk for any injury by approximately 14%.

Table 5 shows the relationship between the categorical levels of aerobic fitness (VO<sub>2max</sub>) for the repeated measures analyses. For each injury outcome, persons with a lower fitness status (e.g., level III) had a higher hazard ratio for injury than did those in the most-fit category. For example, persons with a VO<sub>2max</sub> between 43 and 48 mL/kg/minute (level II) were 1.38 times more likely to sustain any injury than were those in the top category of VO<sub>2max</sub> (>48 mL/kg/minute). The risk of injury increased with decreasing fitness level, as those with a VO<sub>2max</sub> less than 43 mL/kg/minute (level III) were 2.2 times more likely to have any injury than were those in the top VO<sub>2max</sub> fitness category. The hazard ratios were also found to

**Table 3.** Time-to-Event Summary Statistics Between Fitness Levels and Injury Outcomes, Tucson, Arizona, 2005–2009

Fitness Level <sup>a</sup>	Injury Type								
	All Injuries			Physical Exercise			Sprains and Strains		
	IR <sup>b</sup>	No. at Risk	Years at Risk <sup>c</sup>	IR	No. at Risk	Years at Risk	IR	No. at Risk	Years at Risk
I	17.5	460	921	7.3	532	1116	12.2	482	996
II	21.1	287	442	7.2	332	541	17.2	312	483
III	29.9 <sup>d</sup>	235	338	13.3 <sup>d</sup>	263	407	25.1 <sup>d</sup>	242	355

Abbreviation: IR, incidence rate.

<sup>a</sup> The relative aerobic capacity for each level was as follows: I, >48 mL/kg/minute; II, 43–48 mL/kg/minute; and III, <43 mL/kg/minute.

<sup>b</sup> Incidence rate per 100 person-years.

<sup>c</sup> Contributed time at risk (person-years).

<sup>d</sup> Statistical significance ( $P < 0.05$ ) between levels using log-rank test for equality of survival functions.

be greater when the event outcome was restricted to time to first reported sprain or strain.

### Effect modification

To assess the potential of effect modification of the relationship by age, a simple age-stratified analysis was completed for all injury outcomes, as well as for sprains and strains. Age proved to be a significant modifier of  $VO_{2max}$  ( $P < 0.001$ ). Table 6 presents the crude hazard ratios for the all-injury model and the sprain and strain model in relation to age (<30 and  $\geq 30$  years of age) and overall, stratified by aerobic fitness level. For both outcome types, the risk of injury among those with decreased  $VO_{2max}$  was higher in persons younger than 30 years of age than in those 30 years of age or older. Thirty years of age was chosen as our demarcation value primarily based on incidence rates resulting from the Kaplan-Meier analysis described above. In addition, persons 30 years of age or younger had a consistently increased incidence rate, regardless of the injury type. Our previous descriptive study of injury distributions demonstrated that firefighters (median age, 31 years) sustained the most injuries (30.7%), with lower injury rates for engineers, paramedics, captains, etc. (10). Given the strong relationship between age and rank and the results from Kaplan-Meier estimates, it seemed suitable to use 30 years of age as our cutoff value for assessing potential effect modification.

### DISCUSSION

In the present study, we sought to better understand the association between levels of aerobic fitness and the incidence of injury using a retrospective occupational cohort. The findings were consistent with our original hypothesis that lower fitness levels, as defined by  $VO_{2max}$ , would be associated with increased risk of injury. Furthermore, these increased risks were modified by age, with a larger association between fitness level and subsequent injury in those 30 years of age or younger. The reduction in injury risk was significant for all injuries, sprains and strains, and physical exercise injuries. These findings are especially noteworthy considering that one third of work-related injuries in this population resulted from exercise activities (10), further indicating the need for fitness programs with improved structure and management relevant to the high physical demands of the job.

A number of studies have assessed the relationship between various measures of fitness and the performance of a given task, with varying results. However, in contrast to our present study, few studies have focused on assessing the association among fitness, performance, and injury risk.

Two published studies have demonstrated an increase in injuries associated with fitness or the implementation of fitness programs (9, 16). After a baseline treadmill test to assess  $VO_{2max}$ , participants of the Aerobic Center Longitudinal Study had their physical activity levels assessed over a

**Table 4.** Cox Proportional Hazard Models for Assessing Aerobic Fitness and Risk of Injury, by Injury Type, Tucson, Arizona, 2005–2009

Injury Outcome	Model						
	$VO_{2max}$ <sup>a</sup>			$VO_{2max}$ Full Model <sup>b</sup>			
	No. of Observations	HR	95% CI	No. of Observations	HR	95% CI	
All <sup>c</sup>	716	0.959	0.946, 0.972	710	0.953	0.939, 0.968	
Exercise-related	718	0.960	0.941, 0.979	714	0.953	0.933, 0.973	
Sprains and strains	718	0.952	0.937, 0.967	712	0.947	0.932, 0.963	

Abbreviations: CI, confidence interval; HR, hazard ratio;  $VO_{2max}$ , relative aerobic capacity.

<sup>a</sup> Adjusted for sex and age.

<sup>b</sup> Includes independent variables: resting heart rate, grip strength, flexibility, % body fat, number of sit-ups performed, number of push-ups performed, age, and sex.

<sup>c</sup> There were fewer subjects in this category because of lacerations that occurred during the first clinic visit, which precluded follow-up for those subjects.

**Table 5.** Hazard Ratios<sup>a</sup> for Injuries by Levels Aerobic Fitness in Repeated Measures Modeling, Tucson, Arizona, 2005–2009

VO <sub>2max</sub> Level <sup>b</sup>	All Injuries (n = 716)		Exercise Injuries (n = 718)		Sprains and Strains (n = 718)	
	HR	95% CI	HR	95% CI	HR	95% CI
I		Referent		Referent		Referent
II	1.38	1.06, 1.78	1.20	0.81, 1.77	1.61	1.21, 2.13
III	2.22	1.72, 2.88	2.53	1.76, 3.64	2.63	1.98, 3.50

Abbreviations: CI, confidence interval; HR, hazard ratio, VO<sub>2max</sub>, relative aerobic capacity.

<sup>a</sup> All models were adjusted for sex and age.

<sup>b</sup> The relative aerobic capacity for each level was as follows: I, >48 mL/kg/minute; II, 43–48 mL/kg/minute; and III, <43 mL/kg/minute.

12-month period (16). Increased risk of musculoskeletal injury was associated with increases in cardiorespiratory fitness (as measured by a treadmill test), as well as increases in the amount of reported weekly physical activity. Stratified analyses by physical activity type suggested that the association between cardiorespiratory fitness and musculoskeletal injury was potentially driven by unmeasured intensity levels of exercise. After instituting a new fitness program among United States Air Force service members to increase fitness and participation in fitness-related activities, the mean relative VO<sub>2max</sub> increased significantly (6.04 and 3.24 mL/kg/minute among men and women, respectively) over 3 years of the program (9). The number of injuries also increased during that time, which was likely a result of increased participation in exercise activities with no embedded injury prevention program.

Two studies failed to find an association between fitness and injuries. During an 8-week basic military training regimen, musculoskeletal injuries were assessed in relation to baseline body composition (or body mass index), aerobic fitness (determined by the time participants took to run 3,000 meters), health assessment measures, and age (17). Significant associations were observed at a univariate level between

injury and a variety of variables, including age greater than 23 years, increased body mass index, slow run times, and dysfunction of back or lower limbs. Multivariate logistic regressions showed no relationship between injury and aerobic fitness level; however, increased body mass index, minor back and lower limb dysfunctions, and mental dysfunctions were predictive of injury. In a study of manual material handlers, McSweeney et al. (18) found no difference between exercisers and nonexercisers in terms of the likelihood of reporting an injury. However, the authors noted that increased or regular exercise was likely to reduce absenteeism occurrence and duration. In another study among male material handler employees at 3 separate facilities, no association was observed between injury occurrence and absolute aerobic capacity; however, a significant increase in injury risk was related to a decreased VO<sub>2max</sub>, in addition to increased body fat percentage (19). It is important to note that none of the studies described above used repeated measures of fitness, unlike the present study. The added strength of being able to capture time-series data for the population increased statistical power of our study and our ability to control for confounding effects both within and across cohort members.

**Table 6.** Age-Stratified Hazard Ratios<sup>a</sup> for All Injuries and Sprains and Strains by Fitness Level, Tucson, Arizona, 2005–2009

Fitness Level by Injury Type <sup>b</sup>	Total		Age <30 Years		Age ≥30 Years	
	HR	95% CI	HR	95% CI	HR	95% CI
All injuries						
I		Referent		Referent		Referent
II	1.38	1.06, 1.78	2.28	1.41, 3.71	1.15	0.85, 1.57
III	2.22	1.72, 2.88	3.43	2.10, 5.58	1.86	1.36, 2.53
Sprains and strains						
I		Referent		Referent		Referent
II	1.61	1.21, 2.13	2.27	1.32, 3.90	1.40	1.00, 1.95
III	2.63	1.98, 3.50	4.48	2.63, 7.64	2.10	1.49, 2.96

Abbreviations: CI, confidence interval; HR, hazard ratio.

<sup>a</sup> All models were adjusted for sex and age within the strata.

<sup>b</sup> The relative aerobic capacity for each level was as follows: I, >48 mL/kg/minute; II, 43–48 mL/kg/minute; and III, <43 mL/kg/minute.

Results from our study indicated that there was a modification of injury risk based on age of the person. In particular, younger employees (30 years of age or younger) with a  $VO_{2max}$  below that of the high fit group (i.e.,  $VO_{2max} < 48$  mL/kg/minute) had a higher risk of injury than did their older, less fit counterparts. This effect modification may be due to changes in job rank (and presumably job duties and exposure to external conditions) with increasing age in firefighters. Typically, younger personnel hold the rank of firefighter, whereas promotion or career progression tends to lead into ranks of paramedic, engineer, and captain. For most emergency responses, firefighters are the first to enter an emergency scene and are thus subject to greater hazards, known and unknown emergent threats, and time-limiting stresses. One exception includes the risks to which paramedics are exposed during calls involving advanced life support. Nevertheless, the hazard profile and exposure risk for those with the rank of firefighter can be considered greater than those of their team counterparts (e.g., engineer, captain, chief).

### Limitations

Although injury events that occurred before the first observed clinic visit were removed to avoid left-censoring bias (a product of data merging), there was no knowledge of previous injury history. In addition, analyses were restricted to the first specified injury event; therefore, recurrent injuries were not assessed. Future studies on recurrent injuries should enhance the understanding of injuries in this population by differentiating between the risks of repeated injuries (i.e., the same injury type suffered multiple times by a person) and those of the repeatedly injured (i.e., persons who suffer from multiple injury types). The data assessed for this study also did not permit evaluation of intrinsic factors, such as central motor control (i.e., balance), skeletal abnormalities, alignment of joints, and ligamentous laxity (3–5, 20–29). Ideally, inclusion of these factors would improve future studies (30–32), as intrinsic risk factors each influence local anatomy and biomechanical limitations.

Although  $VO_{2max}$  is linearly related to heart rate and energy expenditure, it is an indirect measurement of a person's maximal capacity to do work aerobically (33). In the present study population,  $VO_{2max}$  was estimated using a submaximal test protocol that was previously validated and has been used widely in the fire service (13). Two recent studies, however, have indicated the potential for submaximal tests to overestimate true aerobic capacity (34, 35). If true, any overestimation of  $VO_{2max}$  should not influence the regression modeling because the potential bias would be nondifferential. Of note, the distribution of  $VO_{2max}$  values in our study is considered higher than that in the general population. Standard fitness assessments classify midrange ("good") aerobic fitness at 40 years of age to be 35–38 mL/kg/minute for women and 42–45 mL/kg/minute for men (2). The notion that firefighters are more fit than the general population is supported by the characteristics of this study's firefighting population, who had an average age of 39 years and a mean  $VO_{2max}$  of 49.6 mL/kg/. These differences are likely due to the use of an employed population and the active nature of the job. As previously mentioned, the cutoff values established for the aerobic

fitness levels in these analyses were based on the range of distributions within this active population in addition to methods used in other research.

When compared with the results from a previous study that described exercise-related injuries, which accounted for one third of all reported injuries, as the most common (10), the present findings may appear somewhat counterintuitive. It was not clear if the injuries sustained during exercise periods were the result of overexposure (i.e., fit people exercising too intensely or for too long while on duty) or if the types of exercises being completed were not appropriately structured and evaluated in an effort to minimize the chances for overexertion. The present study's results regarding increased risks of injury among those deemed less fit suggests that the structure and management of exercise within the fire service needs to be considered more intently and that employees without a physical training background should not necessarily be left to exercise without some level of appropriate programming, training, and oversight. Most professional fire departments promote or require some level of exercise among their employees in an effort to assure their ability to complete job tasks with high physical demands (e.g., rescues). Persons in the fire service, much like the majority of the general population, can benefit from exercise instruction and from resources aimed at maintaining or improving their functional fitness levels, thus reducing the potential injury loss. Given the limited financial and personnel resources, a challenge for all fire departments (and similar occupational settings) will be determining the best measures for assessing each component of functional fitness that are 1) consistent and reliable and 2) feasible for implementation.

### Conclusions

Findings from the present study provide empirical evidence that lower fitness levels are associated with increased risks of injury among career fire service employees. Furthermore, these increased risks were modified by age, which is likely due to the fact that rank, job task, and risk profile are often associated with age in this population. As injuries continue to be of relevant health concern in the fire service, the contribution of fitness to the likelihood of injury is significant. Given that injuries are often the result of a multitude of factors and the efficiency of every response activity in the fire service is dependent on the health and fitness of those responders, comprehensive and multifaceted solutions need to be devised, applied, and distributed in order to prevent further injury loss.

### ACKNOWLEDGMENTS

Author affiliations: Division of Epidemiology and Biostatistics, Mel and Enid Zuckerman College of Public Health, University of Arizona, Tucson, Arizona (Gerald S. Poplin, Denise J. Roe, Robin B. Harris); Center for Applied Biomechanics, School of Engineering and Applied Sciences, University of Virginia, Charlottesville, Virginia (Gerald S. Poplin); and Division of Community, Environment and Policy, Mel and

Enid Zuckerman College of Public Health, Tucson, Arizona (Wayne Peate, Jefferey L. Burgess).

This work was supported by grant 5R01OH009469 from the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

We thank Emily Scobie, Becky Arnold, and all employees of WellAmerica, who deserve our utmost gratitude for their enduring efforts throughout this project.

The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

Conflict of interest: none declared.

## REFERENCES

- Sothmann MS, Saupé K, Jasenof D, et al. Heart rate response of firefighters to actual emergencies: implications for cardiorespiratory fitness. *J Occup Med*. 1992;34(8):797–800.
- Heywood VH. *Advanced Fitness Assessment and Exercise Prescription*. 6th ed. Champaign, IL: Burgess Publishing Company and Human Kinetics; 2010.
- Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: surveillance, research, and prevention. *Am J Prev Med*. 2000;18(3S):54–63.
- Croisier JL. Factors associated with recurrent hamstring injuries. *Sports Med*. 2004;34(10):681–695.
- Crill MT, Hostler D. Back strength and flexibility of EMS providers in practicing prehospital providers. *J Occup Rehabil*. 2005;15(2):105–111.
- Anderson CK. Relationship between aerobic capacity, injury risk and tenure for new-hire delivery drivers. *Ergonomics*. 2010;53(11):1395–1401.
- Hennig PC, Khamoui AV, Brown LE. Preparatory strength and endurance training for U.S. Army basic combat training. *Strength Cond J*. 2011;33(5):48–57.
- Hollander I, Bell NS. Physically demanding jobs and occupational injury and disability in the U.S. Army. *Mil Med*. 2010;175(10):705–712.
- Giovannetti JM, Bembén M, Bembén D, et al. Relationship between estimated aerobic fitness and injury rates among active duty at an Air Force base based upon two separate measures of estimated cardiovascular fitness. *Mil Med*. 2012;177(1):36–40.
- Poplin GS, Harris RB, Pollack KL, et al. Beyond the fireground: injuries in the fire service. *Inj Prev*. 2012;18(4):228–233.
- Bassett DR Jr, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Med Sci Sports Exerc*. 2000;32(1):70–84.
- Lee CD, Blair SN, Jackson AS. Cardiorespiratory fitness, body composition, and all-cause and cardiovascular disease mortality in men. *Am J Clin Nutr*. 1999;69(3):373–380.
- Gerkin R, Kelley P, Perry R. Correlation of VO<sub>2</sub>-max During Maximal Treadmill Stress Testing With VO<sub>2</sub> at 85% Predicted Maximal Heart Rate: a Retrospective Review of the Phoenix Fire Department Treadmill Protocol. Technical Report to the Medical Director of the Phoenix Fire Department Medical Center. Phoenix, AZ: City of Phoenix; 1997:1–4.
- International Association of Fire Fighters. *The Fire Service Joint Labor Management Wellness Fitness Initiative*. 3rd ed. Washington, DC: International Association of Fire Fighters; 2008.
- United States Department of Labor, Bureau of Labor Statistics. *Current Population Survey: Labor Force Statistics*. Washington, DC: Government Printing Office; 2013.
- Hootman JM, Macera CA, Ainsworth BE, et al. Association among physical activity level, cardiorespiratory fitness, and risk of musculoskeletal injury. *Am J Epidemiol*. 2001;154(3):251–258.
- Heir T, Eide G. Age, body composition, aerobic fitness and health condition as risk factors for musculoskeletal injuries in conscripts. *Scand J Med Sci Sports*. 1996;6(4):222–227.
- McSweeney KP, Congleton JJ, Kerk CJ, et al. Correlation of recorded injury and illness data with smoking, exercise and absolute aerobic capacity. *Int J Ind Ergon*. 1999;24(2):193–200.
- Craig BN, Congleton JJ, Kerk CJ, et al. Correlation of injury occurrence date with estimated maximal aerobic capacity and body composition in a high-frequency manual materials handling task. *Am Ind Hyg Assoc J*. 1998;59(1):25–33.
- Lavender SA, Conrad KM, Reichelt PA, et al. Designing ergonomic interventions for EMS workers—part II: lateral transfers. *Appl Ergon*. 2007;38(2):227–236.
- Lavender SA, Conrad KM, Reichelt PA, et al. Designing ergonomic interventions for emergency medical services workers—part III: bed to stairchair transfers. *Appl Ergon*. 2007;38(5):581–589.
- Conrad KM, Reichelt PA, Lavender SA, et al. Designing ergonomic interventions for EMS workers: concept generation of patient-handling devices. *Appl Ergon*. 2008;39(6):792–802.
- Chaffin DB. The evolving role of biomechanics in prevention of overexertion injuries. *Ergonomics*. 2009;52(1):3–14.
- Clemes SA, Haslam CO, Haslam RA. What constitutes effective manual handling training? A systematic review. *Occup Med*. 2010;60(2):101–107.
- Mehta RK, Agnew MJ. Analysis of individual and occupational risk factors on task performance and biomechanical demands for a simulated drilling task. *Int J Ind Ergon*. 2010;40(5):584–591.
- Hamonko MT, McIntosh SE, Schimelpfenig T, et al. Injuries related to hiking with a pack during National Outdoor Leadership School courses: a risk factor analysis. *Wilderness Environ Med*. 2011;22(1):2–6.
- Hewett T, Myer GD. The mechanistic connection between the trunk, hip, knee, and anterior cruciate ligament injury. *Exerc Sport Sci Rev*. 2011;39(4):161–166.
- Fields KB, Sykes JC, Walker KM, et al. Prevention of running injuries. *Curr Sports Med Rep*. 2010;9(3):176–182.
- O'Neill BC, Graham K, Moresi M, et al. Custom formed orthoses in cycling. *J Sci Med Sport*. 2011;14(6):529–534.
- Beynon BD, Murphy DF, Alosa DM. Predictive factors for lateral ankle sprains: a literature review. *J Athl Train*. 2002;37(4):376–380.
- Willems TM, Witvrouw E, Delbaere K, et al. Intrinsic risk factors for inversion ankle sprains in females—a prospective study. *Scand J Med Sci Sports*. 2005;15(5):336–345.
- Willems TM, Witvrouw E, Delbaere K, et al. Intrinsic risk factors for inversion ankle sprains in male subjects. *Am J Sports Med*. 2005;33(3):415–423.
- American College of Sports Medicine. *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription*. 8th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2010.
- Mier CM, Gibson AL. Evaluation of a treadmill test for predicting the aerobic capacity of firefighters. *Occup Med*. 2004;54(6):373–378.
- Tierney MT, Lenar D, Stanforth PR, et al. Prediction of aerobic capacity in firefighters using submaximal treadmill and stairmill protocols. *J Strength Cond Res*. 2010;24(3):757–764.