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ORIGINAL ARTICLE

Fire fit: assessing comprehensive fitness and injury risk in the fire service

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Abstract
Purpose This study sought to develop a comprehensive measure of fitness that is predictive of injury risk and can be used in the fire service to assess individual-level health and fit-for-duty status.
Methods A retrospective occupational cohort of 799 career fire service employees was observed over the years 2005–2009. An equally weighted score for comprehensive fitness was calculated based on cardiovascular fitness, muscular strength, endurance, flexibility, and body composition. Repeated measures survival analyses were used to estimate the risk of any injury, sprain or strain, and exercise-related injuries in relation to comprehensive fitness.
Results A well-distributed comprehensive fitness score was developed to distinguish three tiers of overall fitness status. Intraclass correlations identified flexibility, total grip strength, percent body fat, and resting heart rate as the most reliable fitness metrics, while push-ups, sit-ups, and aerobic capacity demonstrated poor reliability. In general, individuals with a lower comprehensive fitness status had an increased injury risk of injury as compared to the most fit individuals. The risk of any injury was 1.82 (95 % CI 1.06–3.11) times as likely for the least fit individuals, as compared to individuals in the top fire fitness category, increasing to 2.90 (95 % CI 1.48–5.66) when restricted to sprains and strains.
Conclusions This 5-year analysis of clinical occupational health assessments enabled the development of a relevant metric for relating comprehensive fitness with the risk of injury. Results were consistent with previous studies focused on cardiorespiratory fitness, but also less susceptible to inter-individual variability of discrete measurements.

Keywords Firefighter · Occupational health and fitness · Injury risk

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Introduction

Barnard and Duncan (1975) were among the first to document how strenuous fire suppression activities led to near-maximal heart rates, which can remain elevated for extended periods. A more recent assessment of the physiologic stresses associated with structural firefighting was conducted by Brown and Stickford (2009). After evaluating the four most physically demanding job tasks on the fireground (i.e., fire attack, search and rescue, exterior ventilation, and overhaul operations), the need for regularly simulating (training) job tasks within a range of 60–95 % of one's maximal capacity was identified to ensure optimal readiness.

The majority of simulated experiments testing the aerobic capacity needed to perform the activities regularly encountered on the fireground suggest that a minimum aerobic capacity between 33.6 and 49 mL/kg/min is needed to safely perform tasks (Gledhill and Jamnik 1992; Lemon and Hermiston 1977; Malley et al. 1999; Sothmann et al. 1990). Adopted by the majority of US fire departments, the National Fire Protection Association's (NFPA) *Standard* *on Comprehensive Occupational Medical Program for Fire Departments* recommends that individual fire service employees maintain a minimum aerobic capacity of 42 mL/kg/min (NFPA 2007).

In a recent time-series analysis, the authors presented and discussed the association of aerobic fitness (as defined by relative aerobic capacity, VO_2max) with injuries among an occupational cohort of commissioned fire service employees (Poplin et al. 2014). Various metrics can be used to measure and define one's fitness status, which often can differ between disciplines. Defining "fitness" in an occupational, or any other setting, is important for making appropriate evaluations of the population's health status and general risk of adverse outcomes.

Fitness versus "fire fitness"

The American College of Sports Medicine (2010) describes fitness as comprising five components: (1) cardiovascular fitness, (2) muscular strength, (3) muscular endurance, (4) flexibility, and (5) body composition. As mentioned, relative aerobic capacity (VO_2max) is often used in the fire service as a proxy measurement for overall fitness. However, a single-component measure for fitness may not necessarily represent an individual fire service employee's fit-for-duty status or their ability to perform all job-related tasks in a safe and efficient manner. As presented by Smith (2011), firefighting requires high level of aerobic fitness, anaerobic capacity, muscular strength, and muscular endurance.

This study aims to present a more comprehensive measure of fitness for the fire service by integrating a range of fitness measures into a summary score that reflects the five ACSM's components. These five components of fitness should better represent one's performance potential as related to the multitude of job tasks and hazards faced by a firefighter. This metric will be described and compared to the previously reported injury risk established for VO_2max in the same occupational cohort.

Methods

Previously described (Poplin et al. 2012), this study includes commissioned employees of a medium-sized metropolitan fire department in the southwest United States (US) that operates 21 fire stations and responds to approximately 520,000 permanent residents. Like most municipal fire departments, this department requires all commissioned employees to have periodic (i.e., annual) individual fitness testing and medical clearance by means of a medical and physical examination. Data for this study were obtained from annual physical assessments for the years 2005–2009. All of the assessed physical measures are made by one contracted medical group that utilized standardized protocols for conducting the assessment. All employees are required to come to this facility for the assessment every 12 months (±3 months). Inclusion criteria for the present study consisted of all commissioned (non-civilian) employees of the fire department during the study period. Injury outcomes were collected from standard department-level surveillance reporting, further described in previous research (Poplin et al. 2012, 2014).

Measuring components of fitness

The physical assessment included (but was not limited to) the following seven measures of fitness: cardiovascular fitness (aerobic capacity, resting heart rate), muscular strength (handgrip strength), muscular endurance (push-up and sit-up repetitions), flexibility (sit-and-reach distance), and body composition (percent body fat).

The primary measure for cardiovascular fitness was estimated using the Gerkin submaximal treadmill protocol, resulting in a predicted relative maximal aerobic capacity or VO_2max (mL/kg/min) (Gerkin et al. 1997). This method is widely used by the fire service and is recommended by the NFPA with the adoption of a 42-mL/kg/min minimum standard to maintain fit-for-duty status (IAFF 2008).

Resting heart rate (HR) was assessed prior to the treadmill test. It is generally not recommended as a measure of cardiovascular fitness (Heyward 2010), due to the potential for wide individual variability. Regardless, it was included to broaden the cardiovascular assessment given that cardiovascular disease is the leading cause of line-of-duty deaths within the fire service (Moore-Merrell et al. 2008).

A handheld dynamometer was used to assess static muscular strength. The largest of three measurements for each hand was recorded and summed for total grip strength (lbs). The maximum number of push-ups tests the endurance of upper-body musculature, while maximum sit-ups assess abdominal endurance and may also aid in identifying individuals at risk of low back pain or injury (Heyward 2010). Push-ups and sit-ups were assessed with the use of a standard metronomic pace for 2 and 3 min, respectively, recording the maximum number of continuous repetitions completed. The assessment was stopped if the individual reaches the maximal time, performs three consecutive incorrect push-ups, or did not maintain continuous motion with the metronome cadence.

Low back and hamstring flexibility were assessed using the standard sit-and-reach box test. The ideal minimum target value is to reach a stretch point equivalent to touching your toes (a value of 0 in.) from the seated position with the legs straight and flat on the floor.

Body mass index (BMI) and waist circumference were measured during the annual physical examination; however, percent body fat was the principal metric for assessing individual body composition and was measured by the use of an electrical bio-impedance device.

Fitness levels

For each component of fitness measure, three levels were established (Table 1) in order to score a more comprehensive measure for representing one's fit-for-duty status (i.e., "fire fitness"). A combination of factors was considered when establishing these cutoff values, as few normative standards exist for this occupational population. In particular, referenced materials included fitness norms (Heyward 2010), NFPA recommendations (IAFF 2000), currently adopted department standards, medical personnel expertise, distribution of the population data, and the assessment methods used during annual physicals. Level I represented high level of performance, and Level II represented a mid-level of performance of the assessment. Values falling within the Level III fitness category were indicative of a physical state where the ability to safely perform all emergency job tasks could be questioned by an occupational physician. The premise for using three levels was based on a current approach used for annual physical examinations in this population (as per contractually agreed between the fire department and clinic).

Similar to the concept used by Lee et al. (1997), the 25th and 50th percentiles were used to determine the threshold values between "less fit" and "high fit" aerobic capacity, respectively. A resting heart rate (HR) above 100 beats per minute (bpm) resulted in a Level III designation and is regarded as tachycardia (rapid HR). A resting HR below 80 bmp was considered "high fit" in this assessment.

Table 1 Cutoff values for levels for various fitness measures of fire fitness

Fitness measure	Level I (high)	Level II (medium)	Level III (low)
VO_2max (mL/kg/min)	≥48	>43 to <48	≤43
Resting HR (bpm)	≤80	81 to 100	>100
Total grip strength (lbs)			
Male	>258	200 to 258	<200
Female	>157	103 to 157	<103
Flexibility (inches)			
Male	≥4.5	1.0 to 4.5	<1.0
Female	≥5.5	2.0 to 5.5	<2.0
Percent body fat (%)			
Male	≤21	>21 to 29	>29
Female	≤25	>25 to 36	>36
Sit-up (*N*)	≥30	20 to 29	<20
Push-up (*N*)	≥30	16 to 29	<16

As in Heyward (2010), the "good" and "below average" scores for left and right static grip strength norms were combined to determine fitness level cut points for total grip strength. In addition, the 30- to 39-year age bracket of Heyward's norms for the standard sit-and-reach test was used to establish flexibility levels, as the median age for the population was 39 years. Values were adjusted by +2 in. to match the clinic's practice of equating touching the box to 2 in. past toes, given that shoes are worn. The levels used for percent body fat were based on current values used by the contracted medical group facilitating the annual physicals.

While push-up and sit-up levels were also established for this population based on current annual physical procedures, there is an overwhelming tendency for individuals to stop once 30 repetitions are completed as (1) it does not classify them into any higher of a fitness classification and (2) to deter away from any potential competitive-based injury. These measures were therefore treated as pass/fail in reaching the 30 repetition mark, as maximal effort cannot be assumed and very few cases failed to reach that mark.

Scoring comprehensive fitness ("fire fitness")

An equally weighted comprehensive fitness score was calculated for each person-year observation by tallying the respective fitness levels for each of the seven measures given in Table 1. For example, if six measures were assessed within the Level I range and the final measure was Level III, the individual's total fitness score equaled 9. Three categories—"high fit," "fit," and "less fit"—were established for comprehensive fitness and related to scores of 7–8, 9–10, and ≥11, respectively.

This scoring permitted some performance variation. The top fire fitness tier ("high fit") aimed to allow for only one mid-level fitness measure capture, in addition to capturing at least the top 20 % of the population. The middle fire fitness category ("fit") permits for less than half the seven fitness measures to be in the medium range (Tier II) or, at most, one measure in the lowest range (Tier III). If two or more measures were in the lowest range (Tier III), or more than half were in the medium range (Tier II), the individual would be classified as "less fit." Note that any measure in the lowest tier would prompt further medical evaluation, regardless of this fire fitness categorization.

Statistical analyses

Statistical analyses were focused on the descriptive and distributional characteristics of individual and comprehensive fitness measures and their relationship to each other, as well as over time. Repeated measures enabled an assessment of the reliability of the measures, through person-level mean summary statistics, as well as intraclass correlations.

Identical to the time-to-event (i.e., first injury) analyses described in Poplin et al. (2014), Cox proportional hazard models, utilizing repeated measures, were developed to better understand the associated risk of injury with the newly developed fire fitness score and further compared and contrasted against the associations originally reported with VO_2max. In this repeated measures approach, each time point (observation) began with an individual's annual medical examination (which occurs approximately every 12 months) until the outcome (reported injury) or censoring (no reported injury). This method accounts for variable observation periods per employee and enables a single individual to contribute time at risk to each of the fitness levels based on their most recent physical assessment. Models were constructed for any injury sustained, physical exercise injuries, and sprains/strains.

Human subjects' approval and monitoring were provided by the University of Arizona Institutional Review Board. All analyses were conducted using Stata software, version 11.2 (StataCorp, College Station, TX, USA).

Results

For years 2005–2009, 799 fire service employees were seen for at least one physical examination visit, with an average of 3.5 visits per firefighter or employee (at variable time intervals). On an annual average, these 799 subjects represented approximately 87.9 % of the workforce population, making it well representative of the total workforce. As expected, the population was overwhelmingly male, with females encompassing only 4.9 % of the total. Overall, the average age was 39.2, ranging annually between 38.4 and 40.2 years.

Figure 1 displays the total distribution of fire fitness scores for 2005–2009. Approximately one-third (32.8 %) of annual physicals resulted in the top ("most fit") tier (fit score 7–8) classification. The mid-tier fitness scores (9–10) encompassed 46.0 % of evaluations, while the remaining fitness assessments (21.2 %) were classified in the third tier of fire fitness.

With repeated annual measures, components of variance and intraclass correlations (ICC) were calculated to assess the variability within and between individuals (Table 2). In general terms, it is desirable for the between variance to account for a greater proportion of the total variance, thus an ICC greater than 0.50. The population's mean VO_2max was shown to be an inconsistent measure with an ICC of 0.2695, and almost triple the variation within an individual versus between individuals. This is supported by previous findings that demonstrated a wide range of variation between individuals' average first, last, minimum, and maximum fitness component values (Poplin et al. 2014). Sit-ups and push-ups had low ICC values; however, this is thought to be related to the nature of the testing that did not require completion to maximal effort.

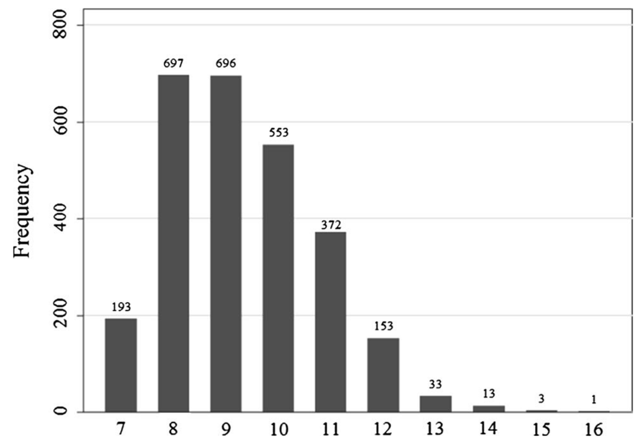

Fig. 1 Distribution of comprehensive fitness scores, 2005–2009

Table 2 Components of variance and intraclass correlation for repeated measures of fitness

Variable	Between variance	Within variance	Intraclass correlation
Flexibility	5.37	2.33	0.6974
Total grip	879.93	519.03	0.6290
Percent body fat	19.02	12.56	0.6023
Resting HR	68.34	56.96	0.5454
Push-up	8.72	20.22	0.3013
VO_2max	18.87	51.16	0.2695
Sit-up	46.93	159.83	0.2270

Table 3 displays a matrix of correlations between the principal measures of fitness. While some correlations were statistically significant, the magnitudes of these correlations were generally not strong. Increases in age were correlated with decreased VO_2max, resting heart rate, flexibility, and increased percent body fat. Greater VO_2max levels were correlated with lower resting heart rate and body fat percentage, in addition to increased push-up repetitions. Increased percent body fat was also shown to be correlated with reduced repetitions in sit-ups and push-ups.

Table 4 demonstrates the frequency and percent distribution of individual fitness levels during the study period. Meeting the top-level mark of 30 repetitions for push-ups and sit-ups was achieved by at least 99 and 94 % of the

Table 3 Correlation matrix for variables of interest using first observations

	Age	VO_2max	Resting HR	Grip strength	Flexibility	% Body fat	Sit-up
Age	1						
VO_2max	−0.368*	1					
Resting HR	−0.122*	−0.309*	1				
Grip strength	−0.010	−0.030	0.054	1			
Flexibility	−0.160*	0.153*	−0.075*	−0.031	1		
Body fat %	0.266*	−0.448*	0.191*	−0.079*	−0.135*	1	
Sit-up	0.025	0.028	0.002	0.003	0.097*	−0.147*	1
Push-up	−0.053	0.120*	−0.071*	0.024	0.088*	−0.289*	0.546*

* Statistically significant at $\alpha = 0.05$

Table 4 Frequency distribution of firefighters fitness level by year, *N* (%)

Fitness measure	Fitness level	2005 ($n = 494$)	2006 ($n = 649$)	2007 ($n = 568$)	2008 ($n = 630$)	2009 ($n = 480$)
VO_2max	I	214 (44.5)	234 (37.1)	286 (50.6)	367 (58.3)	303 (63.1)
	II	147 (30.6)	173 (27.4)	156 (27.6)	168 (26.7)	98 (20.4)
	III	120 (24.9)	224 (35.5)	123 (21.8)	95 (15.1)	79 (16.5)
Resting HR	I	456 (94.6)	605 (94.4)	524 (92.7)	580 (92.1)	445 (92.7)
	II	26 (5.4)	34 (5.3)	38 (6.7)	46 (7.3)	34 (7.1)
	III	0 (0.0)	2 (0.3)	3 (0.5)	4 (0.6)	1 (0.2)
Total grip strength (lbs)	I	191 (38.7)	157 (24.3)	144 (25.4)	167 (26.5)	93 (19.4)
	II	274 (55.5)	415 (64.3)	345 (60.7)	396 (62.9)	307 (64.0)
	III	29 (5.9)	73 (11.3)	79 (13.9)	67 (10.6)	80 (16.7)
Flexibility (inches)	I	285 (58.8)	450 (71.2)	368 (65.0)	415 (66.0)	340 (70.8)
	II	171 (35.3)	154 (24.4)	190 (33.6)	202 (32.1)	133 (27.7)
	III	29 (6.0)	28 (4.4)	8 (1.4)	12 (1.9)	7 (1.5)
Percent body fat	I	387 (81.5)	449 (70.6)	405 (71.6)	466 (74.0)	349 (72.7)
	II	84 (17.7)	170 (26.7)	134 (23.7)	133 (21.1)	106 (22.1)
	III	4 (0.8)	17 (2.7)	27 (4.8)	31 (4.8)	25 (5.2)
Sit-up	Pass	483 (99.8)	632 (99.7)	566 (1.00)	628 (99.8)	479 (99.8)
	Fail	1 (0.2)	2 (0.3)	0 (0.0)	1 (0.2)	1 (0.2)
Push-up	Pass	453 (94.0)	606 (95.6)	548 (97.0)	623 (99.0)	480 (100.0)
	Fail	29 (6.0)	28 (4.4)	17 (3.0)	6 (1.0)	0 (0.0)

population for each year of this assessment, respectfully. In general, the top fitness level for percent body fat declined, while the third fitness level increased and the middle level remained steady. Flexibility was generally improved during this time, with a low proportion of individuals in the third level and increases in the top level. Total grip strength saw some inverse trends over time in the first and third levels, with general decline in the first level and increases in the proportion of individuals in the third level of fitness. The distribution of resting heart rate was consistent with over 92 % of the population meeting the top fitness level (<80 bpm) and few cases of potential tachycardia. With the exception of 2006, aerobic capacity had a steady increase in the number of individuals achieving Level I fitness classification ($VO_2max \geq 48$) and a steady decline with those in the lowest fitness category ($VO_2max \leq 43$).

Cox proportional hazard modeling

Using the repeated measures modeling methods described earlier, Table 5 presents the relationship between the categorical tiers of comprehensive fire fitness and sprains/strains ($n = 294$ injuries), exercise-related injuries ($n = 174$), and all injuries ($n = 357$). Since larger fire fitness categories signify a decrease in comprehensive fitness, the relationship between fitness and injury risk remains consistent. For each injury outcome, individuals with a lower fitness status had an increased injury hazard than those in the referent most fit category. For example, those with comprehensive fire fitness scores placed in Tier III were 1.82 times as likely to have sustained any injury, as compared to individuals in the top (Tier I) fire fitness category.

Table 5 Hazard ratios[a] for injuries by fire fitness tier

Fire fit tier[b]	All injuries ($n = 718$)	Exercise injuries ($n = 719$)	Sprains and strains ($n = 719$)
I	Ref	Ref	Ref
II	1.26 (0.82–1.95)	1.28 (0.68–2.44)	1.97 (1.10–3.54)[†]
III	1.82 (1.06–3.11)[†]	1.60 (0.72–3.53)	2.90 (1.48–5.66)[†]

[†] Statistically significant at $p < 0.05$

[a] All models adjusted for gender and age

[b] Fire fitness tier score ranges: I: 7–8, II: 9–10, III: 11+

The largest association observed was the increased risk of sprain and strain injuries in relation to decline in comprehensive fire fitness. Individuals with the largest comprehensive fitness scores, and thus least fit, were 2.9 times as likely to succumb to a sprain or strain, as compared to those in the most fit tier (Table 5).

To complement findings with aerobic capacity (Poplin et al. 2014), we evaluated the potential of effect modification of the relationship by age. Like relative aerobic capacity, age was shown to be a significant modifier of the risk associated with comprehensive fire fitness. Two findings are apparent: The risk of injury was greatest for those in the worst tier of comprehensive fitness regardless of age; younger individuals (i.e., those less than 30 years) maintain a greater injury risk (especially sprains and strains) than older individuals. For all injuries, as compared to the top tier, individuals less than 30 years in fire fitness Tiers II and III demonstrated non-statistically significant increased injury risks of 1.67 (0.61–4.59) and 2.99 (0.97–9.20), respectively, while those 30 years and older had diminished increased risks: Tier II HR = 1.13 (0.70–1.85), Tier III HR = 1.42 (0.76–2.70). Similarly, the risk of sprains and strains for individuals less than 30 years was 2.65 (0.65–10.9) and 5.04 (1.11–22.9) for Tiers II and III, while those 30+ years and above were at an increased risk of 1.74 (0.91–3.32) and 2.23 (1.03–4.83), respectively.

Discussion

This study aimed to develop a comprehensive measure of fitness to be assessed in relation to injury risk as opposed to the relative aerobic capacity previously reported (Poplin et al. 2014). The objective is not to show which measure predicts or fits a particular statistical model best. Rather, the intent is to show utility in the comprehensive fitness measure and identify areas for continued improvement. While aerobic capacity is a metric most commonly used in the fire service to gauge fitness, a more comprehensive fitness measure may help describe a person's overall functionality, as most fire response activities can require dynamic movements and physiologic demands.

Consistent with previous findings between relative aerobic capacity and injury risk, this study found that individuals with decreased comprehensive fitness levels also exhibited an increased risk of injury as compared to their most fit peers. Given that score values are unitless, a direct interpretation of the relationship between fire fitness scores and injury risk is not as obvious as it was previously described for aerobic capacity alone. That is, it is not sensible to state that a decrease in one unit of "fire fitness" is associated with an *x* percentage change in injury risk; however, the association and magnitude of injury risks were similar between studies. Considering that values are composite scores and categorized into fire fitness tiers, confidence intervals were generally larger in this analysis, reducing the certainty of the point estimates. The association between fitness and injury risk was clearest when restricted to sprains and strains, with age-stratified risk estimates notably larger for individuals in the third tier of comprehensive fitness. As previously reported, this modification with age is thought to be related to the job task and hazard profile associated with early career (i.e., younger) firefighters and less directly attributed to physiologic age effects.

The methodologies used highlight an important distinction as it pertains to the measurement of occupational fitness. A unique advantage to this study was the ability to review and assess five consecutive years of fitness measures for a near-complete occupational cohort of fire service employees. Most notably, while some level of correlation exists, the components of fitness assessed (i.e., cardiovascular, muscular strength, muscular endurance, flexibility, and body composition) are distinct from each other. That is, the measures do not assess the same physiologic component, as indicated by the averaged descriptive statistics, correlations, intraclass correlation (ICC), and factor analyses.

The reliability of these measures can be assessed using Rosner's scale for ICC, in which poor, fair to good, and excellent reliability are indicated by ICC values of <0.4, ≥ 0.4 to <0.75, and ≥ 0.75, respectively (Rosner 2000). Using this scale, the most reliable measures of fitness were shown to be flexibility, total grip strength, percent body fat, and resting heart rate. The poor reliability associated with push-ups and sit-ups was not surprising, considering the common practice of stopping after the 30 repetition mark was reached. What was surprising is the poor reliability associated with relative aerobic capacity (VO_2max), with greater variability across the annual measurements within an individual versus the variability between individuals. Over long enough time, a general decline in aerobic capacity is expected, as an inverse relationship is associated with adult age (Astrand et al. 1997; Hollenberg et al. 2006; McGuire et al. 2001a, b); however, we found individual-level values to fluctuate with no discernible trend.

The cardiorespiratory demands associated with firefighting have been well documented (Barnard and Duncan 1975; Bos et al. 2004; Brown and Stickford 2009; Davis et al. 1982; Gledhill and Jamnik 1992; Holmer and Gavhed 2007; Kilbom 1980; Lemon and Hermiston 1977; Sharkey and Gaskill 2009; Smith et al. 2001; von Heimburg et al. 2006). Aerobic capacity is one of the best measures for determining the ability to meet the physical demands associated with the extreme scenarios and environments related to fire suppression, search and rescue, ventilation, technical rescues, etc. However, given the amount of variation shown within the individual, (estimated) VO_2max may not suitably represent the day-to-day job responses and tasks of the fire service (e.g., patient transport and motor vehicle crashes), as not all tasks require physical responses upward of 90 % maximal effort. The additional components of fitness presented (e.g., total grip strength, flexibility, percent body fat, and resting heart rate) may improve the assessment of an individual's functional readiness for meeting all the physical demands, loads, and hazards associated with the myriad job tasks that exist both on and off of the fireground.

The use of a fitness score that combines various physiologic components supports recent fitness research conducted to predict one's ability to complete firefighting tasks. Prior to fire academy training, candidates must often pass a standard physical test. The Candidate Physical Ability Test (CPAT) was developed by select fire departments to test the candidates' ability to perform basic firefighting tasks and involves a continuous circuit of 8 fire simulation tasks, while wearing a weighted (50 lbs) vest, safety gloves, and helmet (IAFF 2000). Williams-Bell et al. (2009) found that 65 % of the variability in time to complete the CPAT was predicted by VO_2max, body mass index (BMI), and handgrip. Similarly, Michaelides et al. (2011) identified abdominal strength, relative power (via step test), upper-body strength, and upper-body endurance to be associated with time to completion of a fire simulation ability test, while high resting heart rate, BMI, and percent body fat were associated with poor performance in the ability test.

Using the Akaike information criterion (AIC) as a relative comparison of model quality, the previously reported model based on aerobic capacity has slightly lower AIC values than the fire fitness model (AIC = 4250 vs. 4306 for all injuries). However, given the poor reliability of this measure of VO_2max, as described by Rosner's ICC, assessing comprehensive fitness appears to discriminate fitness as well as aerobic capacity without suffering from as much inter-individual variability. The statistical models presented are aimed at demonstrating the potential for using comprehensive fire fitness scores as a more reliable indicator measure for fitness that can be used to prompt further evaluation of the individual's fitness status and to direct where improvements can be made or individualized exercise regimens prescribed.

Limitations and future directions

Questions will undoubtedly arise pertaining to the validity and reliability of measures used to determine fitness. Clinically, VO_2max is intuitively a valid measure. Because oxygen consumption is linearly related to heart rate and energy expenditure, when oxygen consumption is measured, there is an indirect measuring of an individual's maximal capacity to do work aerobically (ACSM 2010). However, this study observed considerable inter-individual differences in VO_2max. Aerobic capacity is primarily limited by the rate of oxygen delivery (via heart, lungs, and blood), not the ability of the muscles to take up oxygen from the blood. It is estimated that 70–85 % of the limitation in VO_2max is linked to maximal cardiac output (Cerretelli and Di Prampero 1987). It is uncertain how these differences, and the fluctuations thereof, are effected when estimated from a submaximal test, as utilized in this study; however, two factors are thought to contribute to the poor reliable of VO_2max: the submaximal nature of the testing procedure and uncertainty in how consistent testing protocols were administered and monitored within the occupational setting.

A primary limitation of this study is the lack of validation of the measurement values used to establish comprehensive fitness scores, as well as the retrospective nature of data. There can be multiple opportunities for measurement error, classification, and information bias. At the person level, there may also be day-to-day limitations in performance, and individuals that naturally border the categorized thresholds will fluctuate between fitness levels and status.

The choice of having three levels in this study was predicated on it being most relevant to methods already in use for the fire service population during their annual physical examinations. The cutoff values established and previously reported on for VO_2max were similar to those shown in other studies assessing the relationship between cardiorespiratory fitness and cardiovascular disease in firefighting populations (Baur et al. 2012a, b). Given that no validated normative standards exist for establishing comprehensive fitness levels applicable to this population, the resources and methods used are believed to be apt and relevant to the fire service. The "fire fitness" scores were developed to allow a wider evaluation of fitness than one focused exclusively on cardiorespiratory fitness.

While the outcomes presented here are one of the first attempts to describe a comprehensive assessment of fitness for a population of fire service employees, there continues to be a need for consensus-driven definitions and validation for comprehensive fitness measures that are of utility to fire departments, especially those with limited resources. The components of fitness assessed (i.e., cardiovascular, muscular strength, muscular endurance, flexibility, and body composition) are considered to be appropriate to the work conducted; however, the metrics used to represent each component may be improved, either by different assessment instruments or by protocols enabling additional accuracy and precision. For example, a modified sit-and-reach test can be used to account for differences in limb length. Muscular strength can be more accurately gauged by a one-repetition maximal bench press, while muscular endurance would be better represented by completing sit-ups and push-ups to failure. Nevertheless, when considered with the pragmatic limitations and financial constraints of most fire departments, the measures for best practice may not match the gold standards of exercise physiology.

This study was not able to assess or account for the semi-regular introductions of health and safety protocols or intervention efforts to improve wellness. Finally, analyses did not account for individuals who may have been recovering from previous injury or illness at the time of their annual physical. Other potential confounding variables such as ergonomic factors, psychosocial factors, stress, and other personal factors were not captured in either the injury surveillance or annual physical forms for the study period, but encourage their assessment when available. It is also recommended that future prospective studies account for the time exposed to the tasks related to injury potential, as fitness directly relates to one's ability to perform tasks. Evaluated over a longer time, more apparent trends and distinct changes in effect size may be discernible.

The occupational demands of fire service employees support the need for integrated methods to assure that reliable measures of comprehensive fitness are available for the regular assessment of "fire fitness." The ability to prospectively monitor individual health and wellness throughout a career is of necessity, as the increasing number and types of hazards exposed to on a daily basis should regularly be of concern. Information from improved measures of fitness should be used to assess changes in health status over time and to determine risks associated with injury, illness, or other morbidities.

Conclusions

What is the purpose of measuring fitness? For this population of fire service employees, the purpose should not be to only assess the ability of meeting the demands of a one-time, maximal effort emergency scenario. While such information is relevant, there is more involved in assessing ability. The individual firefighter, paramedic, engineer, etc. cannot anticipate how many emergency calls he or she will need to respond to during a given shift. The assessment of one's fitness needs to account for not only their maximal potential to meet extreme scenarios, but also their ability to recover and continue to meet the demands of other unanticipated emergency responses. Thus, a summary measure for comprehensive fitness could potentially serve as a broader measure of "fire fitness."

The issue of fitness in the fire service is undoubtedly complex, and discussions surrounding fitness can often be lost due to concerns over establishing any type of physical standard that might put into questions one's ability to safely perform the physical work demands of the job. This can inherently be obstructive, if the intent is actually to protect the individual employee, their colleagues, and the community they unselfishly protect. The ultimate goal should be to establish and promote standard mechanisms by which fitness (and overall health and wellness) can be maintained, if not improved.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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