

Effect of Firefighting Personal Protective Equipment on Estimated Aerobic Capacity from the Forestry Step Test in Firefighter Cadets: A Pilot Study

Original Research

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Abstract

Introduction: Firefighting is a physically demanding occupation, which involves tasks such as rescuing victims, pulling a hose, and carrying a ladder. Thus, firefighters must have excellent cardiovascular fitness (CF). However, the cumbersome movement and added mass of firefighting personal protective equipment (PPE) can place additional stress on the cardiovascular system, not accounted for through traditional CF testing.

Purpose: Determine the effect of wearing PPE on predicted CF compared to athletic attire (AT) in firefighter (FF) cadets completing the Forestry Step Test (FST).

Methods: Male and female ($N = 17$) FFs performed two trials of the FST, one trial completed in PPE and one in AT. Recovery heart rate was measured at the end of each trial and predicted VO_{2max} was calculated. Paired samples t -tests compared heart rate and predicted VO_{2max} values between the PPE and AT conditions.

Results: Predicted VO_{2max} ($p < 0.001$) was lower in the PPE (37.53 ± 3.20 ml.kg.min⁻¹) compared to the AT condition (46.35 ± 7.63 ml.kg.min⁻¹).

Conclusion: Predicted aerobic capacity is lower when wearing PPE compared to AT using the FST as the aerobic capacity assessment method. The effect of PPE on CF effort of firefighting should be considered when developing assessments.

Key Words: athletic attire, predicted VO_{2max} , recovery heart rate

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Introduction

Firefighters (FF) are responsible for reacting to emergency situations in dangerous environments [1-3], such as extinguishing fires and locating and rescuing people trapped inside burning buildings [4-5]. The significant health risks associated with this profession dictate that firefighters wear specific clothing and equipment to protect them from potentially lethal environments. Firefighters wear a variety of different firefighting personal protective equipment (PPE) when responding to emergency calls, but a common PPE kit includes a turnout coat, pants, hood, helmet, and gloves [6].

Yet, despite the potential for burn-related death and injury, the primary cause of death in FF is sudden cardiac death [7]. This is partially due to the mixture of strenuous physical activity, heavy safety gear, and extreme heat that the field

conditions place on the body's cardiovascular and other physiological systems [7-8]. Due to the intense physiological demands of the job, firefighters are encouraged to maintain a high degree of physical fitness [9] to complete tasks such as sprinting upstairs, scaling ladders, carrying equipment, crawling and searching, forcing entry, working hoses, and performing victim drags [5,10-15]. Firefighters must perform these activities while wearing up to >25 kg of PPE [16-17]. Research findings [18,19] suggest that for safety and optimal performance, FF should have aerobic capacity values of 41.5 ml.kg.min⁻¹. Due to the finding of the studies by Storers et al. [18] and Adams et al. [19] the US National Fire Protection Agency recommends firefighters to have a minimum VO_{2max} of 42 ml.kg.min⁻¹ [20].

In an effort to combat the risks involved in the physical demands placed on FF, municipal fire departments are advised to test and evaluate the physical and mental readiness of FF annually with either measured or predicted cardiovascular fitness (CF) tests [1,21-23]. Previous research has largely examined the fitness of experienced FF and has utilized both measured and predicted CF tests [10-15]. However, there are limited studies on FF cadets and most research has examined factors such as fitness standards [24], postural stability [25], and psychological stress [26]. Therefore, it is important to investigate the responses of FF cadets to the physical demands of firefighting duties.

When a person becomes a FF cadet, their physical fitness is routinely monitored, and their performance is regularly evaluated in order to ensure physical preparedness for the demands of their work [27]. Additionally, due to the FF increased risk for cardiac death, regular CF fitness assessments may be helpful in screening for individuals at risk for cardiac-related health conditions. One of the tests used to evaluate the CF of the cadet and experienced FF is the Forestry Step Test (FST) [28] because it does not require expensive equipment and is readily accessible.

The FST imitates climbing stairs (see Figure 1), which is a commonly encountered activity of the active-duty FF [28]. The FST is traditionally performed in a controlled environment [28] with normal academy issued athletic attire (AT; shorts, t-shirt, tennis shoes), which is far from the extreme environment often encountered by a FF while also wearing PPE. The equipment that FF carry with them or on their person while on duty is heavy and may affect the ability of the individual to maintain the level of effort required of the emergency situation [16-17]. However, it is also important to determine the effect of equipment on aerobic performance.



Figure 1. Firefighter cadets performing the Forestry Step Test in the AT and PPE conditions.

Previous studies have investigated differences in measured VO_{2max} between firefighting gear and athletic attire AT conditions [29-30]. However, a measured VO_{2max} test requires expensive equipment and expert knowledge that is not always practical nor easily accessible when evaluating FF cadets. Fire academies also need assessments that are valid but can be performed efficiently with a large number of cadets. Unfortunately, there is limited research comparing the predicted VO_{2max} of submaximal tests for FF cadets in PPE versus that of AT. Therefore, the purpose of this study

was to determine if VO_{2max} estimation is affected by wearing PPE compared to AT during the FST. It was hypothesized that predicted VO_{2max} would be lower when wearing PPE than AT in FF cadets performing the FST.

Scientific Methods

Participants

A convenience sample of FF cadets from a fire academy in the southeast United States volunteered to participate in the study. Healthy adult FF cadets above 18 years of age were eligible for this study. Participants were excluded if they (1) were taking prescribed medications that would alter heart rate; (2) experienced an injury or surgery within the previous six months; (3) had a diagnosed heart condition or experienced recent or regular chest pain or dizziness during exercise; (4) were pregnant; and/or (5) were instructed to refrain from physical activity by a physician [7]. A total of 17 adult FF cadets (5 Females, 12 Males; mean age = 28.1 ± 7.9 years) volunteered to participate in this within subjects' design study. See Table 1 for participant characteristics. Participants did not consume caffeine, alcohol, chew or smoke tobacco, or perform physical activity on the days of testing [31-32] in order to limit external influences on heart rate. All data collection sessions took place in a temperature-controlled environment (68-72°F) at the firefighting academy. The data collection sessions took place in the morning, two hours after consuming a standardized breakfast. The testing sessions were completed on an off day and no exercise was completed at least 24 hours prior to the day of testing. The same test time and standardized breakfast were consumed for both testing sessions. All subjects were under direct supervision of a certified athletic trainer throughout the testing protocol.

Table 1. Participant Characteristics (N = 17, 5 Females & 12 Males)

Variable	Male Firefighters (<i>M</i> ± <i>SD</i>)	Female Firefighters (<i>M</i> ± <i>SD</i>)	Total (<i>M</i> ± <i>SD</i>)
Height (cm)	186.1 ± 7.2	170.8 ± 5.8	180.1 ± 9.2
Body Mass (kg)	94.7 ± 6.4	83.1 ± 5.9	91.7 ± 13.4
Age (years)	29.3 ± 3.9	26.5 ± 3.7	28.1 ± 7.9

Note: Data are Means ± *SD*.

Protocol

Upon approval by the university institutional review board and completion of an informed consent document, participants reported to the fire academy on the first day of testing and the purpose and procedures of the study were explained, as well as the risks and benefits of participation in the study. Each participant filled out a Physical Activity Readiness Questionnaire (PAR-Q+) to screen for medical clearance to perform physical activity. Age and gender were recorded along with anthropometric measurements. Height and body mass were measured barefoot and in AT using a SECA stadiometer (SECA North America, Chino, CA) and SECA scale (Withings, Inc., Cambridge, MA) to the nearest 0.5 cm and 0.1 kg, respectively. Following height and body mass measurements, participants were seated in a dark room for five minutes, after which resting heart rate (RHR) was measured through manual palpation of the radial pulse for 15 seconds with the counted beats multiplied by four [28] to obtain the beats per minute (bpm).

Upon completion of baseline measurements, the firefighters were randomly assigned via coin flip to their first testing condition (PPE vs. AT). Exactly 48 hours of recovery time was assigned before completion of the 2nd submaximal VO_{2max} trial. For the PPE trial, participants wore their turnout coat, pants, hood, helmet, and gloves [6], which weighed approximately 45 lbs. A small difference in FF PPE mass was noted between participants due to the increased mass of the larger size equipment (Large, XL, etc.). A self-contained breathing apparatus (SCBA) was not utilized by the firefighter cadets as part of the PPE for the study. In the AT trial, participants wore standard issue Fire Academy shorts and t-shirt, and their own tennis shoes.

The FST is a submaximal 5-minute rhythm-based assessment whereby the participant must maintain a 90-bpm cadence (22.5 steps per minute) orchestrated by a metronome. Step height is based on the participant's height whereby a 15 ³/₄ in. (40.4 cm) tall step is used for participants measuring over 5 feet two inches in height and a 12-in. (31 cm) tall step is used for participants measuring under 5 feet 2-in. in height [28]. All of the participants in the current study were above 5 feet two inches, as a result only the 40.4 cm step was utilized. The metronome was played for 30 seconds prior to the test and the firefighters marched in place to the beat [28] before the test to acclimate to the step height and testing cadence. Participants were required to maintain the required cadence throughout the test. Any participant falling out of rhythm was given a formal warning to get back on rhythm or the test would be terminated. Prior to conducting the study, the test-retest reliability of measuring predicted aerobic capacity of the FST was assessed in a sample (N =

12) of healthy college-aged students, the intraclass correlation coefficients for both measurements were between 0.910 to 0.993.

A total of three FF were tested at a time, except for the last group which consisted of just two FF cadets. Upon completion of the assessment, participants were required to immediately sit down on the step for 15-seconds, after which a 15-second HR was measured through palpation (radial artery) and calculated for bpm [32,33]. The same procedure was followed for both submaximal aerobic assessment conditions. The prediction equation was similar to the one utilized in studies by Peate et al. [31] and Sharkey et al. [33], wherein weight was rounded to the closest 10 lbs., and weight adjusted $\text{VO}_{2\text{max}}$ was found by noting the intersection of the rounded weight and the 15 second recovery heart rate (RCHR). Age was then rounded to the nearest 5 years and the intersection of this age and weight adjusted $\text{VO}_{2\text{max}}$ yielded the predicted $\text{VO}_{2\text{max}}$ [31,33].

Statistical Analysis

Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) version 28.0. A Shapiro Wilk test of normality was completed, and all data was normally distributed ($p < 0.05$). Separate paired sample t -tests were used to compare heart rate and predicted $\text{VO}_{2\text{max}}$ values with PPE and AT, respectively. Cohen's d was used to determine effect sizes from the paired samples t -tests. The effect sizes were calculated to describe the magnitude of difference between the two conditions [34]. Interpretations of effect size magnitudes were based on the scale described by Hopkins [35]: < 0.2 = trivial, $0.2 - 0.6$ = small, $0.6 - 1.2$ = moderate, $1.2 - 2.0$ = large. Statistical significance was established at $p < 0.05$.

Results

Resting heart rate, recovery heart rate, and predicted $\text{VO}_{2\text{max}}$ values for each condition are listed in Table 2. No significant difference was found in RHR between the testing conditions, $t(16) = .00, p = 1.00, d = 0.00$. Recovery heart rate, $t = 5.9, p = < .001, d = 1.56$, was found to be significantly higher and predicted $\text{VO}_{2\text{max}}$, $t(16) = -5.17, p = < .001, d = 1.43$, significantly lower in the PPE condition compared to the AT condition.

Table 2. Participant Heart Rate and Predicted $\text{VO}_{2\text{max}}$ Values Based on Testing Condition

	Firefighting PPE	Athletic Attire AT	p	Cohen's d
RHR (bpm)	82.41 $\pm$ 12.88	82.41 $\pm$ 12.07	1.00	0.00
RCHR (bpm)	152.94 $\pm$ 13.23	127.76 $\pm$ 18.52	<.001	1.56
$\text{VO}_{2\text{max}}$ (ml.kg.min ⁻¹)	37.53 $\pm$ 3.20	46.35 $\pm$ 7.63	<.001	1.43

Note: Data are Means $\pm$ SD; PPE = personal protective equipment; AT = athletic attire; RHR = resting heart rate; RCHR = Recovery Heart Rate; $\text{VO}_{2\text{max}}$ = predicted $\text{VO}_{2\text{max}}$; $d < 0.2$ = trivial, $0.2 - 0.6$ = small, $0.6 - 1.2$ = moderate, $1.2 - 2.0$ = large.

Discussion

The purpose of this study was to determine if predicted $\text{VO}_{2\text{max}}$ was affected by wearing PPE compared to AT on the FST in FF cadets. It was hypothesized that predicted $\text{VO}_{2\text{max}}$ would be higher (i.e., better) when performing the FST while wearing AT; based on the results, our hypothesis was supported. The predicted $\text{VO}_{2\text{max}}$ was 19% higher in the AT condition compared to the PPE condition (average difference of 8.82 ml.kg.min⁻¹), with a large effect seen in both RCHR ($d = 1.56$) and predicted $\text{VO}_{2\text{max}}$ ($d = 1.43$), respectively. These results clearly indicate the aerobic capacity values predicted via use of the FST submaximal assessment may be altered due to wearing firefighting PPE compared to AT.

Previously conducted research has indicated the addition of PPE can substantially affect aerobic capacity in FF [27-30]. However, there are limited studies that utilize the FST in FF cadets. The FST was utilized by Hale et al. [28] and the results of the study indicated that performing the FST while wearing PPE exhibited a higher predicted $\text{VO}_{2\text{max}}$ (5.61 ml.kg.min⁻¹ml) when compared to firefighters performing the Wellness Fitness Initiative (WFI) stepmill assessment while wearing normal AT. The results of our study also indicated an underestimated predicted aerobic capacity while wearing PPE. The difference in predicted $\text{VO}_{2\text{max}}$ values between the two conditions is also significant because the underestimated predicted $\text{VO}_{2\text{max}}$ values in the current study were lower than the recommended 42 ml.kg.min⁻¹ threshold suggested by the US National Fire Protection Agency [20]. The predicted aerobic capacity values while wearing firefighter PPE, would indicate that the firefighter cadets were at a CF that is not optimal for performance and would place them at a level of safety concern [18-19].

Similarly, Fearheller et al. [30] compared the results of a measured maximal treadmill tests in PPE (boots, pants, jacket, gloves, self-contained breathing apparatus [SCBA], and face mask system) and AT conditions, and also found a reduction in aerobic capacity in the PPE condition. However, these were volunteer FF, where the training and physical fitness requirements are often lower than those from full-time FF. Furthermore, these FF wore an SCBA device during their assessment, whereas the participants in the current study did not.

Lastly, in a group of experienced wildland FF, Carballo-Leyenda et al. [36], found that compared to wearing AT, wearing PPE resulted in a predicted VO_{2max} that utilized a significantly higher percentage of their VO_{2max} ($M = 33.1 \pm SD = 5.6$, $M = 35.8 \pm SD = 4.9$, respectively) during the Pack Test (PT), which is a 4.8 km time to completion event. Similar to the current study, each of these previous findings reflect the impact of PPE on aerobic capacity. However, compared to previous research [28,36], this study is unique due to the direct comparison of PPE to AT on a specific test and the participant population utilized.

Beyond the increased mass of PPE, impaired economy of movement caused by the layers of equipment may have also impacted predicted VO_{2max} values. According to the results of studies by McLellan and Havenith [37] and Phillips et al. [38], additional layers of clothing can restrict firefighter movement and increase the aerobic demand of exercise. In addition to impairing economy of movement, the layers of equipment may have also impacted body temperature. Although this study did not monitor body temperature, the additional layers of PPE, might have decreased the amount of exposed skin and limited heat exchange [36-39], thereby likely increasing body temperature in the cadets and increasing physiological demand.

The findings of this study are important because cadets are promoted to FF based on preliminary testing [18]. Yet, most FF assessments occur in AT rather than PPE [18]. Some cadets may have a higher level of cardiovascular fitness in AT yet have a reduced level of musculoskeletal strength compared to other candidates or experienced FFs, thereby making it more difficult to support the added mass of the PPE [15]. Consequently, a cadet with a higher level of musculoskeletal strength (e.g., 1-repetition max back squat) could potentially adapt to the extra mass of the PPE easier than cadets with a comparatively higher level of aerobic fitness (as measured in AT) but lower level of musculoskeletal strength, respectively. Therefore, it is important to identify inexpensive and easily accessible assessment methods that will produce results that can be reliably transferred to the firefighting environment.

A limitation of this study is the sample size, which is a result of the convenience sampling utilized to recruit this participant pool. Therein, researchers should use a degree of caution when attempting to extrapolate these findings to larger or more diverse groups. Additionally, heart rate values were not continuously monitored during the FST, which would have allowed for the comparison of the mean intensity of the test between conditions. Another limitation is that this study only utilized the attire required for basic/regular firefighting. Therefore, an SCBA device was not included in testing. The addition of an SCBA could alter posture, restrict breathing, and add additional weight, all of which could influence the FF aerobic effort. However, the severity of the firefighting situation, environment (e.g., home fire vs. forest fire) and variables could alter the type of PPE and/or gear utilized by the FF. The degree of postural or mass related stress added by an SCBA compared to minimal PPE is unknown but should be considered as a top priority for future researchers. Core temperature was not measured in this study. Yet, research by Carballo-Leyenda et al. [36] indicated a significantly higher heat stress score (a combined measure based on various thermoregulatory metrics) when wearing PPE compared to AT in Wildland FFs completing a graded exercise test. Thus, the addition of the mass of PPE, along with a reduced capacity for sweat evaporation, could have resulted in an increase in core temperature in the current study, thereby contributing to the difference in aerobic capacity between the two conditions.

Additional future research should examine if the FST predicted VO_{2max} is equally affected by PPE in experienced FF as compared to the cadets utilized in the current study. It could be that experienced FF have grown more adept at wearing PPE and/or physically adapted to the additional thermal stress created by the PPE. Lastly, a submaximal VO_{2max} protocol was utilized in this study because it is more commonly utilized by fire academies than more expensive, specialized, and time intensive VO_{2max} protocols. Though submaximal protocols are commonly used to estimate/predict VO_{2max} , this study's results should not be used as a method to directly supplant the increased validity offered by performance of a measured VO_{2max} assessment utilizing appropriate cardiorespiratory measurement equipment and personnel.

This study found predicted $\text{VO}_{2\text{max}}$ to be underestimated in FF wearing PPE during the FST, when compared to wearing AT. Though not measured individually, it is probable that a combination of factors (e.g., extra mass, reduced mobility, thermal stress) related to the wear of PPE contributed in some way the reduced cardiovascular capacity seen by FF when wearing PPE during the FST. These results highlight the risk of generalizing the use of a specific assessment to a testing situation substantially different than that of its original parameters. The current findings also indicate the need for more profession-specific health/fitness assessments, particularly in firefighting, where the working environment is often substantially different than a controlled laboratory environment or everyday life. It is highly important for fire academies to accurately determine a cadet's firefighting fitness and physical preparedness for service in the most stressful firefighting situations. Therein, it is suggested fire academies seriously consider the unique needs of the profession (e.g., wearing PPE) when developing and utilizing assessments, training tools, and training regimens with their cadet candidates.

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