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Original Research

A Submaximal Field Test of Aerobic Capacity does not Accurately Reflect VO_{2max} in Career Firefighters

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ABSTRACT

International Journal of Exercise Science 15(4): 221-230, 2022. Adequate aerobic capacity is crucial to maintaining firefighter safety. The purpose of this study was to compare predicted VO_{2max} scores from a submaximal and maximal step test. Eighteen career male firefighters from a medium sized urban municipality completed both a submaximal Forestry step test and a maximal laboratory WFI step test. A lack of association (p = .017) and low level of agreement (p = .015) was determined between step test protocols producing a mean bias of ± 5.61 mL.kg-1/min-1 with most scores being overestimated. Use of the Forestry step test to predict true VO_{2max} in firefighters should be used with caution when classifying firefighter fitness.

KEY WORDS: Cardiorespiratory capacity, step test, VO_2

INTRODUCTION

The physical demand of firefighting evokes a significant activation of cardiorespiratory, metabolic, and musculoskeletal systems increasing the physiological and mechanical strain on the body, thus, increasing the risk for injuries at the fireground (19). The National Fire Protection Association (NFPA)(15) established its *Standard on Comprehensive Occupational Medical Program for Fire Departments* that recommended fire service employees maintain a VO_{2max} of ≥ 42 mL·kg^{-1}/min^{-1} to safely perform their job duties. The estimated cardiorespiratory capacity demonstrated in fire suppression tasks has ranged from 33.6 mL·kg^{-1}/min^{-1} to 49 mL·kg^{-1}/min^{-1} in career firefighters (23). In 2008, a joint effort between the International Association of Firefighters and the International Association of Fire Chiefs (10) revised the fitness standards contained in the Wellness Fitness Initiative (WFI) to include more comprehensive measures of cardiorespiratory capacity by recommending more stringent testing via a staged submaximal treadmill and stepmill protocols. These revisions focused on previous studies that determined

the submaximal treadmill protocol overestimated cardiorespiratory capacity due to the prediction equation based only on steady state values (15). The use of a graded exercise testing versus a constant workload testing provides a more valid method for determining cardiorespiratory capacity (4, 22). Assessing cardiorespiratory capacity via graded exercise testing protocols in a laboratory setting is the preferred method. However, feasibility of laboratory testing for large municipal fire departments can be difficult (7). Submaximal field tests of cardiorespiratory capacity (such as the Forestry Step Test) can provide fire departments an alternative for testing cardiorespiratory capacity versus a laboratory setting due to their limited need for equipment. In the current study, the fire municipality administers the Forestry Step test as part of its annual firefighter fitness assessment.

Due to the average duration of fire suppression activities, 20-45 minutes repeated 2-4 times per event, and short rest interval (5-10 minutes), there is a reliance on both aerobic and anaerobic (glycolytic) sources of energy. Previous studies have reported that firefighters experience heart rates close to maximum value (21) and a rapid onset of blood lactate accumulation (18). The cardiorespiratory strain at such intensities creates a significant risk for an acute cardiac event in those firefighters with low levels of fitness. Poplin et al. (19) determined firefighters with a $VO_{2max} \leq 43$ mL·kg^{-1}/min^{-1} were two times more likely to suffer an injury than firefighters whose VO_{2max} was ≈ 48 mL·kg^{-1}/min^{-1}. Thus, utilizing testing protocols which are most representative of fire fitness are vital to firefighter safety (18). The purpose of this study was to assess potential differences in cardiorespiratory capacity values obtained with a maximal laboratory test (WFI stepmill test) and a submaximal field test (Forestry Step Test) in career firefighters. The researchers hypothesized that there would be a significant mean difference in VO_{2max} values obtained between methods.

METHODS

Participants

The study setting was a local medium-sized urban fire department in the Midwest. The fire department covers 201 square miles and serves approximately 400,000 citizens with its 670 members. This research was carried out fully in accordance to the ethical standards of the *International Journal of Exercise Science (*16*)*. Following IRB approval and signing of informed consent, 18 career male firefighters (age 34.21 ± 7.53 yrs.) completed the WFI stepmill test (maximal) on a StairMaster 8 Series Gauntlet step ergometer and the Forestry step test (submaximal) on a 40cm stepping platform. For study inclusion, the firefighters were cleared by departmental physician, met the criteria on their annual physical abilities test, and reported no know physical limitations. Mean number of years on the force for the 18 subjects was 7.95 ± 6.48. The testing sessions were conducted by credentialed and experienced personnel in accordance with ACSM's standards for exercise testing with approval of the fire department and local union. The University of Tulsa institutional review board (Protocol 18-52) approved for the review and use of the data. Each test was administered on separate days when firefighters had not previously exercised or reported taking medications which may alter metabolic responses. Firefighters completed the Forestry Test protocol first, as part of their annual fitness assessment, followed by the WFI testing session within a 5-15 day window.

Firefighter weight (88.83 ± 3.75 kg) and body composition (19.27 ± 8.27 %) was determined with a Tanita TBF-300A scale (Tanita Corporation of America, Inc., Arlington Heights, Illinois) and height (173.84 ± 7.14 cm) was measured using a portable stadiometer (Invicta Plastics ltd., Leicester, England).

Protocol

Previous studies have confirmed that wearing firefighter equipment while assessing aspects of fitness may provide detailed insight into the metabolic demands of firefighting (5, 13). The WFI stepmill condition was altered to replicate exertion in the field by requiring subjects to don their firefighting equipment. The WFI stepmill test was completed under normal laboratory conditions on a StairMaster 8 Series Gauntlet step ergometer while wearing their full complement of firefighting equipment: self-contained breathing apparatus (SCBA), turnout coat, pants, boots, hood, gloves and helmet. The combined mass of the equipment was 24.5 kg. The SCBA mask was replaced with a traditional face piece used to assess expired gases via open circuit spirometry. Firefighters completed the Forestry step test under normal laboratory conditions wearing athletic attire and running shoes utilizing a stepping platform, heart rate monitor, stopwatch, and metronome.

The WFI stepmill test is a modified ramp stepping protocol that consists of 12 one-minute stages of increased stepping rate beginning at 46 steps·min^{-1}. The test began with a warm-up period of two minutes at 46 steps·min^{-1} and 1 minute at 53 steps·min^{-1}. The next stage was increased to 65 steps·min^{-1} and continued to increase ≈ 7.2 steps·min^{-1} every 60 seconds until VO_{2max} was achieved. Firefighter VO_{2max} was measured during the WFI stepmill protocol using the Cardio Coach CO_2™ Fitness Assessment System, Model 9001 (Korr Medical Technologies, Salt Lake City, Utah) by determining the highest 15-second average during a plateau in VO_2 despite increasing work rate. The Cardio Coach CO_2 ™ is a reliable and valid (6, 8, 11) dual gas analyzer that measures heart rate, expired gases, and respiratory exchange ratio every 15 seconds. After achieving VO_{2max} firefighters completed a two-minute cool-down stage at 46 steps·min^{-1}.

The Forestry step test is a submaximal stepping test that is five minutes in duration with a stepping rate of 22.5 steps·min^{-1} on a stepping platform of 40cm in height. The test was first introduced in 1968 as a practical field measure of VO_{2max} for the U.S. Forest Service by comparing post exercise heart rate to age and body weight norms (20). In the current study, firefighters were instructed to maintain the stepping rate for the full five-minute duration then to immediately sit down for heart rate measures. Heart rate recovery was counted for a 15 second period during the timeframe of 15-30 seconds post exercise. This value was then compared to age adjusted norms to determine a predicted VO_{2max} value for each subject.

Statistical Analysis

Using the VO_{2max} values obtained from the WFI stepmill test and Forestry step test, difference scores (WFI - Forestry), mean VO_{2max} (WFI + Forestry/2), and percent difference (WFI + Forestry/mean) were calculated for each participant (Table 1). A Shapiro-Wilk test of normality determined all data to have normal distribution ($p < 0.05$). Two one-samples *t*-test were used to

determine if the mean difference of the difference scores and percent difference significantly differed from zero for the two methods. Two Bland-Altman plots were constructed to depict the mean difference (i.e., bias) and 95% limits of agreement (i.e., mean difference ± (1.96 x standard deviation) between the WFI stepmill test and Forestry step test. The proportional bias about the mean difference and averages were assessed using a simple linear regression, where the mean difference was the dependent variable and mean VO_{2max} was independent variable. For secondary comparisons, a Pearson's correlation coefficient was calculated to examine the relationship between the WFI and Forestry step tests results. For all analyses, the alpha level was set a prior at 0.05. All data was analyzed using SPSS Statistics 24 (IBM, Somers, NY).

RESULTS

All 18 participants completed both the submaximal and maximal exercise conditions with all participants achieving the criteria for achieving VO_{2max} during the WFI protocol. Mean VO_{2max} values for the WFI and Forestry step tests were 38.08 ± 6.2 and 43.83 ± 6.8 $mL \cdot kg^{-1}/min^{-1}$ respectively (Table 1). A one-sample *t*-test was used to determine if the mean difference significantly differed from 0. Results indicated a significant difference from 0 (p = .017; t = -2.65) with a mean difference of -5.61 ± 8.98. A second one-sample *t*-test was used to determine if the mean percent difference significantly differed from 0. Results indicated a significant difference from 0 (p = .015; t = -2.713) with a mean percent difference of -13.70 ± 21.43. A secondary analysis was conducted using a Pearson correlation to provide a point of comparison to prior research. Results from the Pearson correlation coefficients demonstrated a non-significant association between the two measures (r = .053, p = .834). A scatterplot is presented in Figure 1.

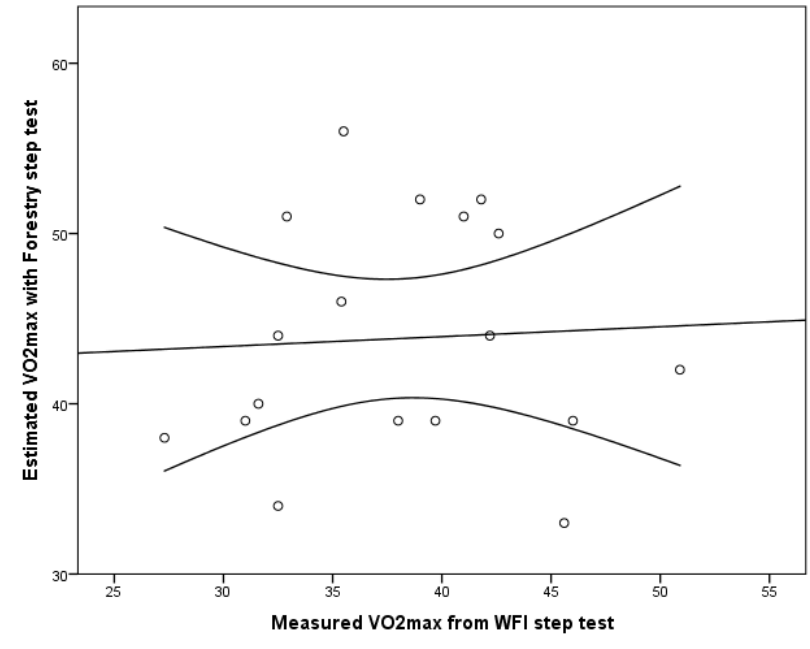

Figure 1. Scatterplot with line of best fit and 95% confidence limits for the association between measured and predicted VO_{2max}

Table 1. Agreement between WFI and Forestry Step Tests

	WFI	Forestry	Mean of WFI+Forestry	WFI-Forestry	WFI-Forestry/Mean (%)
	39	52	45.5	-13	-28.57%
	35	46	40.5	-11	-27.16%
	51	42	46.5	9	19.35%
	32	40	36	-8	-22.22%
	27	38	32.5	-11	-33.85%
	43	50	46.5	-7	-15.05%
	41	51	46	-10	-21.74%
	36	56	46	-20	-43.48%
	46	33	39.5	13	32.91%
	33	51	42	-18	-42.86%
	31	39	35	-8	-22.86%
	42	52	47	-10	-21.28%
	46	39	42.5	7	16.47%
	33	44	38.5	-11	-28.57%
	33	34	33.5	-1	-2.99%
	40	39	39.5	1	2.53%
	38	39	38.5	-1	-2.60%
	42	44	43	-2	-4.65%
Mean	38.08	43.83	41.03	-5.61	-13.70%
SD	6.2	6.8	4.73	8.98	21.43%

Mean differences and standard deviations are shown

Two Bland–Altman plots were created with the difference scores between the two methods (Figures 2 and 3). Figure 2 depicts a mean difference of -5.61 $mL \cdot kg^{-1}/min^{-1}$ (95% CI = -1.14 to -10.08). The upper limit of agreement was 11.99 (95% CI = 4.25 to 19.73), while the lower limit of agreement of -23.22 (95% CI -15.48 to -30.96). In the current sample, the line of equality (i.e., 0) falls out of the 95% CI (-1.14 to -10.08) of the mean difference (-5.61) indicating a significant bias between the two measures.

A second Bland-Altman plot with the difference scores expressed as percentages was conducted (Figure 3) and produced a -13.7% (95% CI = -24.4 to –3.0) mean difference between the two measures. The upper limit of agreement was 28.3% (95% CI = 9.8% to 46.8%), while the lower limit of agreement of -55.7% (95% CI –37.24% to –74.2%). In the current sample, the line of equality (i.e., 0) falls out of the 95% CI (-24.4% to 3.0%) of the mean percent difference (-13.7%) indicating a significant bias between the two measurements.

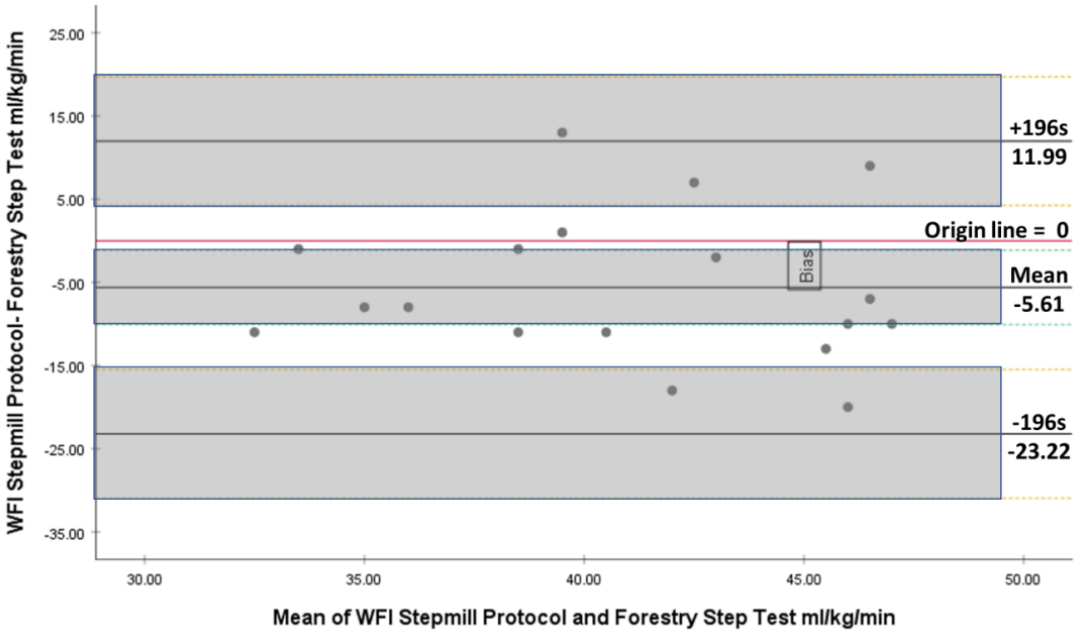

Figure 2. A Bland–Altman plot displaying the level of agreement in mean difference scores between VO_{2max} estimated using the Forestry Step test and VO_{2max} measured using a metabolic cart (WFI). Shaded areas represent the 95% confidence intervals for the mean and agreement limits.

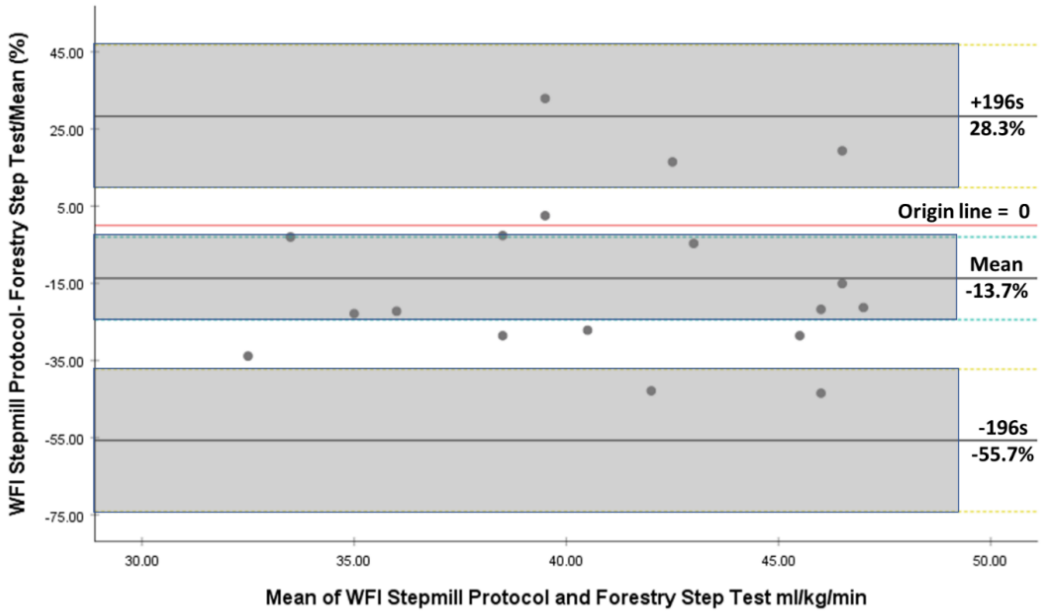

Figure 3. Plot of differences between WFI and Forestry step tests, expressed as percentages of the values on the axis. Shaded areas represent the 95% confidence intervals for the mean and agreement limits.

For each Bland Altman Analysis, a simple linear regression was performed to determine if there was evidence of proportional bias about the mean difference and mean percent difference. Results from the two separate simple linear regression analyses and subsequent inspection of the β_1 coefficient revealed there was no proportional bias about the mean difference (t = 0.348, p = .732) or mean percent difference (t = .040, p = .968).

The results presented in Table 2 reflect the number of firefighters whose VO_{2max} was over- and under- estimated by the Forestry submaximal step test. The Forestry submaximal step test overestimated the true VO_{2max} in 77.7% of firefighters and underestimated the true VO_{2max} in 22.2% of the firefighters tested. The firefighters whose scores were overestimated had an average "over-predicted" VO_{2max} of 45.4 $mL \cdot kg^{-1}/min^{-1}$, resulting in a 19.8% average overestimation of aerobic capacity. The firefighters whose scores were underestimated had an average "under-predicted" VO_{2max} of 38.2 $mL \cdot kg^{-1}/min^{-1}$, resulting in a 15.9% average underestimation of aerobic capacity.

Table 2. Prediction error between Forestry submaximal step test compared with WFI VO_{2max} step test

Direction	N	Mean	SD	Max	Min
Overestimated	14	45.4	6.69	56	34
Underestimated	4	38.2	5.43	46	33

DISCUSSION

The purpose of this study was to compare average VO_{2max} values obtained with a maximal laboratory step test and a submaximal step test in career firefighters. The main findings of the study were that the Forestry step test overestimates VO_{2max} by as much as 5.61 $mL \cdot kg^{-1}/min^{-1}$ or 13.7%. We hypothesized that there would be a significant mean difference in VO_{2max} values obtained between methods; thus, our hypothesis was supported. To the authors' knowledge, this is the first study to compare results from these two firefighter specific step tests using a Bland-Altman method. The usage of a Bland-Altman plot to compare agreement from the two clinical measures was selected versus using a product-moment correlation coefficient. The researcher justified using the Bland-Altman method due to its ability to discern differences from calculating the limits of agreement based on the instruments' difference scores rather than associations (1, 9). Results from the Pearson's test of association and regression analysis indicated a lack of association between the two measures with no proportional bias.

The reported lack of association was similar to findings from Klaren et al., who found a non-significant, weak relationship in scores compared from a maximal WFI treadmill test to a submaximal WFI prediction equation (12). The researchers comment on the lack of agreement between the two measures which may lead to systematic error while discerning firefighter aerobic capacity. In addition, researchers Perroni et al. tested the correlation from a maximum treadmill protocol and submaximal 3-minute step test in career firefighters and determined a non-significant correlation with an average difference of ± 3.6 $mL \cdot kg^{-1}/min^{-1}$ between conditions (17). On the contrary, Delisle and colleagues reported a significant, moderate correlation between a maximal treadmill and submaximal treadmill protocol in career firefighters (4). Even with the significant correlation, the researchers reported the submaximal treadmill protocol underestimated true VO_{2max} in 72.4% of the firefighters by as much as 21% and overestimated the true VO_{2max} by as much as 30.6%.

The Bland-Altman analysis determined a large variation among the difference scores between both tests (Figures 2 and 3) due to the line of equality falling out of the 95% CI of the mean bias

on both plots suggesting the level of agreement between the Forestry and WFI step tests is significantly low. The Forestry submaximal step test overestimated the true VO_{2max} in 77.7% of firefighters and underestimated the true VO_{2max} in 22.2% of the firefighters tested. The inaccuracy of assessing cardiorespiratory capacity via a submaximal protocol in the current study aligns with previous findings from Drew-Nord and colleagues [12] who determined laboratory VO_{2max} scores from a WFI maximal and WFI submaximal treadmill protocol in career firefighters varied ≈ 11% (4.06 $mL \cdot kg^{-1}/min^{-1}$). The researchers emphasize caution when relying on field-based submaximal tests to predict peak VO_2 due as most are based on steady state values or age-predicted norms. In the current study, the mean bias between predicted and laboratory VO_{2max} scores was 5.61 $mL \cdot kg^{-1}/min^{-1}$. As the magnitude of measurement increased, scores tended to move further outside of the 95% CI of the mean difference.

Such findings are concerning as the Forestry Step test is used to classify firefighters who have a substandard aerobic capacity. The misclassification of firefighter fitness has clinical implications given the high rate of firefighter mortality due to an acute cardiac event. Given the resource and time constraints in municipal fire operations, fitness testing may not be feasible with an ergometer and/or in a laboratory setting. Thus, selection of a robust multi-stage step test (versus a single-stage) with limited equipment may be of value. One such test is the Chester Multi-Stage Step Test (3). This particular test does not use a stepping ergometer but a fixed stepping platform with an increased stepping rate every 2 minutes. More research is needed to determine the accuracy of a submaximal (w/increasing rate) multi-stage step test with fixed platform in career firefighters.

The estimated cardiorespiratory capacity demonstrated in fire suppression tasks has ranged from 33.6 $mL \cdot kg^{-1}/min^{-1}$ to 49 $mL \cdot kg^{-1}/min^{-1}$ in career firefighters (7) with most municipalities requiring a minimum of 42 $mL \cdot kg^{-1}/min^{-1}$. In the current study, 14 firefighters would have been incorrectly classified as meeting the standard for aerobic fitness due to the Forestry step test's tendency to over-predict true VO_{2max}. Accurate fitness classification of firefighter aerobic capacity is pertinent to mitigate an acute cardiac event and/or risk for injury (19). The range of mean VO_{2max} values and standard deviations (SDs) produced from the WFI and Forestry protocols had a wide range of variation (27-51 $mL \cdot kg^{-1}/min^{-1}$ and 33-56 $mL \cdot kg^{-1}/min^{-1}$; and SDs ± 6.2-6.8 respectively). These SDs demonstrate high individual variability in the accuracy of the Forestry Step test to predict true aerobic capacity. In the current study, a SD value of ± 8.98 $mL \cdot kg^{-1}/min^{-1}$ was calculated from the WFI and Forestry mean difference scores (Table 1) which corresponds to a similar SD of ± 9 determined by Klaren and colleagues who compared VO_2 values from a maximal WFI treadmill test to a submaximal WFI prediction equation.

In the current study, the Forestry step test contained a large variation in its ability to accurately predict VO_{2max}. The Forestry Step test is a field measure of VO_{2max} developed for the U.S. Forest Service for wildland firefighters that compares post exercise heart rate to age and body weight norms (20). The test uses heart rate recovery as an indication of aerobic fitness based on age-related predicted max heart rates (4). A constant workload of 22.5 steps/min for five minutes is maintained throughout the test producing a steady state effect. The WFI step test

protocol is staged exercise test with increasing workload. Determination of VO_{2max} using a staged exercise protocol occurs when the VO_2 fails to increase with an increase in workload. Thus, predicting aerobic capacity with a constant workload test may increase the potential for error (2, 14) and should be used with caution when making physical readiness decisions.

The limitations of this study include a smaller sample size and the limited gender and ethnic demographics of the Tulsa Fire Department. The current study tested only male career firefighters with a mean number of years on the force of 7.95 ± 6.48. A follow-up investigation is needed to determine the level of agreement between a single-stage step test and a multi-stage maximum step test in female firefighters. Strengths of the study include career firefighters, usage of the mask to measure VO_{2max} and the usage of firefighter gear during the WFI stepmill protocol.

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