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Physical and physiological performance determinants of a firefighting simulation test

Running title: Determinants of firefighting performance

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Conflicts of interest

The authors express no conflict of interest

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ABSTRACT

Objective: To examine determinants of firefighting simulation task performance. Methods: Sixty-eight (63 male; 5 female) firefighters completed a firefighting simulation (e.g. equipment carry, casualty evacuation) previously validated to test occupational fitness among UK firefighters. Multiple linear regression methods were used to determine physiological and physical attributes that best predicted completion time. Results: Mean (±SD) time taken to complete the simulation was 610 (±79) seconds. The prediction model combining absolute cardiorespiratory capacity ($L.min^{-1}$) and fat mass explained the greatest variance in performance and elicited the least random error ($R=0.765$, $R^2=0.585$, SEE: ±52 seconds). Higher fitness and lower fat mass were associated with faster performance. Conclusions: Firefighter simulation test performance is associated with absolute cardiorespiratory fitness and fat mass. Fitter and leaner individuals perform the task more quickly. Work-based interventions should enhance these attributes to promote safe and effective operational performance.

Key words: Firefighting;body composition; physical fitness; occupational performance; performance prediction

INTRODUCTION

Firefighting is a physically demanding occupation, requiring regular fitness assessments to ensure that incumbents possess the physical competencies to perform their duties safely and effectively. Physical demands analyses of firefighting focusing on cardiorespiratory stress and/or cardiovascular strainare well-documented[1–3]. Consequently, laboratory-measuredmaximal oxygen uptake (VO_2 max)expressed relative to body mass ($ml\cdot kg^{-1}\cdot min^{-1}$) is aprevalent form of minimum physical employment standard assessment in firefighting and other physically arduous occupations[4,5]. However, occupational tasks are complex, invariably involving the wearing of heavy, restrictive clothing and the carrying of external loads, meaning cardiorespiratory fitness is just one of several factors impacting on firefighters' work performance[6]. This is particularly noteworthy giventhat both health-related predictive fitness tests and utilising relative aerobic capacitycan advantage smaller individuals, especially if body mass is unsupported during fitness testing (i.e. treadmill running), and disadvantageheavier individuals[7,8]whomay carry load more effectively and/or while experiencing less physiological strain than their smaller counterparts[9]. However, recent research suggests that these notions are greatly influenced by the exact nature of load carriage; the dimensions and relative mass of load, whether the individual is working against gravity or horizontally, as well as how the load isdistributed on the body[8,10].As such, researchinto the interaction between performance on these complex job-related tasks and easily-measuredindices of body mass or compositioncould be valuable. When combined with routinely conducted fitness assessments, these measures may be effectivedeterminants of firefighting performancebuthave not been investigated in UK firefighters.

Multivariate regression methods have been previously adopted in occupational and sporting contexts to identify predictors of physical performance or physical fitness[11–14].Determinants of performance on job-based tasks,suchas body composition (e.g. lean body mass (LBM) and fat mass (FM)), upper-body fitness and various strength measureshave been identified in non-UK firefighters[6,12,15,16]and other physically demanding occupations[17]. Several investigations suggest that LBM to FM ratiocan be a surrogate indicator of functional muscular strength and/or power-to-mass ratio[13,17]. For individuals with higher body mass, a given load will represent a smaller percentage of body mass than for lighter counterparts, whichusually results in a lower relative metabolic demand to perform the same task.This relationship can become less clear in thetranslationto exercise tolerancebetween unloaded and heavily-loaded conditions, where the negative correlation between body mass and reduction in exercise time is only small-to-moderate[18].As such, examining body composition rather than solely body mass may be prudent in physically demanding occupations. Although it is customary in health research to use VO_2 max normalised to body size, for occupations that involve external load carriage absolute units may be more suitable[8,19].

The combined aims of attempting to simulate the varied nature of physically arduous occupations,allow reproducibility and reduce costs have led to increased use of criterion (job simulation) fitness tests and standards[20].Specifically, the UK Fire & Rescue Service have an established model in place where specific surrogate tests (i.e. for cardiorespiratory fitness) are completed as part of an annual health screening for duty where borderline personnel may be referred for criterion (job-related) performance testing.Research into UK firefighters has demonstrated the validity and reliability of a firefighting simulation test (FFST) (a timed circuit comprising essential, physically demanding firefighting tasks) as anoperational readiness test[21]. However, the determinants of performance on this test, and therefore the physical attributes that are most relevant to firefighting in the UK, have not been examined.The aim of this study was to identify the combination of physical and/or anthropometric variables coupled with cardiorespiratory fitnessthat most effectively predictFFST performance. We hypothesised thataerobic capacityin absolute units would be a stronger predictor of simulated firefighting performance than when expressed relative to body mass, and that the inclusion of a measure of body composition would further increase the explained variance.

METHODS

Participants

Sixty-eight operational firefighters gave written informed consent to take part in the study following a full written and verbal briefing. Participants were recruited through contacting fire services, health and fitness advisors and occupational health employees, and represented a total of seven UK Fire &Rescue Services.The study was approved by the University of Bath's Research Ethics Approval Committee for Health (REACH Reference number: EP 12/13 6).

Study protocol

Researchers attended each participant's resident fire station to completetwo trial days, separated by at least 7 days.During the first trial day anthropometric data (body mass, height, estimated body fat percentage (BF%; Bodystat 1500, Bodystat Ltd, UK)) were obtained prior to completion of a maximal cardiorespiratory fitness test and a full description and demonstration of the FFST. Beforetrial day two, participantscompleted a familiarisation session by attempting the FFSTunder the supervision of a health and fitness advisor or project researcher.On trial day two participants completed a best-effort performance of the FFST.

Cardiorespiratory fitness test

Oxygen uptake (VO_2) was measured breath-by-breath with a portable gas analyser Cosmed K4 B2 (Cosmed, Rome, Italy) during a graded uphill running protocol on a motorised treadmill (Life Fitness, USA). An incremental warm up of five minutes precededthe test in order to determine a suitable running speed which was chosen by participant comfort, and a heart rate of over 120 beats.min^{-1}. The test was conducted at the selected running speed, and consisted of three minute stages, with a3% increase in gradient at the end of each stage.The test was terminated at volitional fatigue and/or when participants were not able to continue running. Cardiovascular strain was measured at 5–s intervals by chest-mounted heart rate monitor (Polar, Finland) and rating of perceived exertion was taken at the end of exercise using the Borg scale[22]. Maximal oxygen uptake was determined as an average of the final minute of steady state oxygen uptake. Participant VO_2 max was computed both in absolute (VO_{2ABS}; L.min^{-1}) and relative to body mass (VO_{2REL}; mL·kg^{-1}·min^{-1}).

Firefighting simulation test (FFST)

The FFST was previously validated for assessing occupational performance in UK firefighters and conforms to best practice guidance and safety regulations of the UK Fire and Rescue Service[21]. The FFST in this study was a continuous circuit of three tasks completed on a 25 m shuttle course as described previously[21,23]. Before beginning the circuit, a full verbal brief of the test was given and throughout the test a project researcher followed the participant and gave verbal instructions. Participants were asked to complete the FFST with maximal effort, as quickly as possible while adhering tonormal safety regulations. Briefly, the tasks and order were as follows:

1. The ‘equipment carry’: 25 kg barbell carried over 200 m.
2. The ‘casualty evacuation’: Charged hose reel dragged 75 m (with one unladen 25 m traversal) followed by a 55 kg dummy dragged 50 m.
3. The ‘hose run’: Simulation of setting up a 100 m water relay using four lengths of 25 m hose (each ~13 kg). Consists of (not in this order): Eight 25 m unladen traversals (200 m) at both the start and end, four 25 m traversals (100 m) carrying two hoses, two 25 m traversals (50 m) carrying one hose, two 25 m unladen traversals (50 m) and four 25 m traversals (100 m) rolling out hose, totalling 700 m.

The total distance of the FFST was 1025 m. Completion time and rating of perceived exertion were taken at the end of exercise using the Borg scale[22]. Firefighters wore full personal protective clothing consisting of helmet, shirt, tunic, leggings, boots and gloves (mass of ensemble: ~8.2 kg). A self-contained breathing apparatus (SCBA; mass: 12.1 kg) was donned for the casualty evacuation section of the simulation and removed prior to the hose run. The transitions between sections were not recorded and are included in the total completion time.

Inclusion and exclusion criteria

Since some of the procedures in the study protocol (e.g. the hose run) would not be performed safely or reliably without sufficient training and experience with the handling of this equipment, only incumbent operational firefighters could be used in this study. In order to observe a relationship between cardiorespiratory fitness and time on the FFST, we required participants to treat the test as a performance test with close to maximal effort and without performing any part of the test incorrectly or outside standard safety regulations. Therefore, inclusion criteria werethat participants were trained and currently operational and medically fit for service as a firefighter in the UK Fire & Rescue Service, completed all tasks successfully/correctly and with "very hard" to "maximal" perceived exertion/effort (a rating of perceived exertion of ≥ 17 on the 6-20 Borg scale).

Statistical analysis

All numerical and statistical analyses were completed on IBM SPSS (IBM, New York, USA). Measures of central tendency and sample variance were calculated for physical characteristics and performance on the cardiorespiratory fitness test and FFST.The estimation of percentage body fat allowed the determination of fat mass (FM) from body mass, and subsequently lean (fat-free) body mass (LBM). Since the external load was the same for each participant, LBM to FM (LBM/FM) ratio (rather than 'dead mass') was used. As well as absolute FFST completion time, z-scores for individual performance times were calculated in order to classify the performance of participants into five categories based on standard deviation[14]: A z-score of '0' is the sample average, '*Outstanding*' (< - 2 SD), '*Above average*' (-1 SD to -1.99 SD),'*Average*' (-0.99 SD to +0.99 SD) '*Below average*' (+1 SD to +1.99 SD), and '*Poor*' (> +2 SD). Pearson correlations coefficients were used to assess the prediction of FFST performance time from VO_{2ABS} andVO_{2REL}. Stepwise multiple regression analysis was conducted to determine whichcombination(s) of selected variables (age, sex, body mass, height, BF%, FM, LBM/FM) alongside VO_2 max best predicted FFST completion time. Variables highly correlated with (or inherently involved in the computation of) one another were not included in the same model to avoid multi-collinearity. A model was deemed to have violated this when the Durbin-Watson statistic ranged outside 1.5-2.5 and model tolerance was < 0.2. The prediction model(s) with the highest proportion of explained variance (R^2) and lowest standard error of the estimate (SEE) was then selected.An alpha value of $p<0.05$ was considered statistically significant. Nonstandardised beta correlation coefficients from the most successful prediction model were used to construct a prediction equation for FSTT completion time.

RESULTS

Participant characteristics

Participant physical characteristics, physical fitness and performance data are organised in Table 1. Mean (±SD)time taken to complete the FFST was 610(±79) seconds.By computed z-scores of FFST completion time, 11 firefighters were 'above average' performers (-1 to -1.99 SD), 46 firefighters were 'average' performers (-0.99 SD to +0.99 SD), eight were 'below average' (+1 to +1.99 SD), and three firefighters were 'poor' performers (> +2 SD), while none were 'outstanding' (< -2 SD).It should be noted that z-scores are relative to the observed sample group, illustrating the variance of performance in this study, and are not a reflection of performance thresholds in firefighting populations. Supplementary Table A, http://links.lww.com/JOM/A423 shows selected variables of performanceand physiological monitoring from treadmill tests and the FFST.

Prediction models for simulated firefighting performance

In isolation,VO_{2REL}had a stronger inverse correlation with FFST performance time (R=-0.711; R^2=0.506, SEE= ±56 s)than VO_{2ABS}(R=-0.577; R^2=0.332; SEE= ±65 s), explaining ~18% more of thevariance in FFST performance.This is such that higher cardiorespiratory fitness predicted faster FFST completion time.

Themultiple-regression prediction models derived are summarised in Table 2 organised in ascending variance explained alongside adjustment for the number of terms in the model. Note that prediction models such as those in Table 2 are presented with correlations (R values) in the positive direction. This is because the multiple-regression models compute R values by correlating actual FFST completion time against predicted FFST completion time.Standard error of the estimate between models were markedly similar, ranging between 52 and 55 seconds. Age, sex, height or lean mass did not significantly contribute to the prediction of FFST performance time and did not appear in any prediction model. The combination of variables that produced the strongest prediction of FFST time was the$VO_{2ABS}$and fat mass (Model 5; Table 2), which explained26% and 8% more variance than either VO_{2ABS} and VO_{2REL} alone.The direction of these individual variables into the correlation were such that higher VO_{2ABS} and lower fat mass predicted faster FFST completion.

While error parameters were similar between models, the two models with strongest predictive ability comprised measures of fat content with absolute VO_2max. The following equation was produced from Model 5 for prediction of FFST completion time (where VO_{2ABS} is in L·min^{-1} and FM is in kg):

$$Equation\ for\ predicted\ completion\ time.\ Model\ 5.$$

$$FFST\ completion\ time\ (s) = 765.219 - (63.034\ \times\ VO_{2ABS}) + (5.731\ \times FM)$$

Predicted FFST completion time from Model 5 is plotted against actual FFST completion time in Figure 1.

In contrast to Model 5, fat mass was not a significant determinant of FFST time whencombined with VO_{2REL}. Estimated BF% resulted in similar prediction models when combined with VO_2 maxexpressed in either unit of measurement (Models 3 & 4). Body mass only contributed significantly to the prediction of FFST time when combined with VO_{2ABS} (Model 1), and LBM/FM only when combined with VO_{2REL} (Model 2).

Fat mass and FFST completion time

Since fat mass was identified as the strongestanthropometric determinant of FFST completion time when combined with absolute cardiorespiratory capacity, further analysis into this characteristic was conducted. Participant quintiles of fat mass (kg) were computed as ≤11.84 (Q1), 11.85-13.79 (Q2), 13.80-17.88 (Q3), 17.89-23.16 (Q4) and >23.16 (Q5). FFST completion time was significantly lower (i.e. faster) for firefighters in both Q1 (557 ± 59) and Q2 (559 ± 50) than those in Q3-Q5 ($p<0.05$; Figure 2a). When comparing individual z-scores for FFST completion time, all but one participants in Q1 were 'average' or 'above average' performers, while all participants in Q5 were close to, or below sample mean performance (Figure 2b).

DISCUSSION

Absolute VO_2max combined with fat mass produced the strongest model for predicting performance on a firefighting simulation test (FFST) circuit,in a sample of UK firefighters, such that higher fitness and low fat mass predicted faster completion time. The model explained 59% of variance in FFST duration. This circuit hasbeen previously validated as a test for occupational readiness in the UK Fire & Rescue Service and can form part of the organisational assessmentsforsafe and effective work.In support of the above finding,firefighters in the lowest quintiles for fat mass performed the circuit quicker than both the overall average andthose in thehighest quintiles for fat mass. While in isolation, expressing cardiorespiratory capacity in units relative to body mass predicted completion time better than when expressed in absolute units. Taken together however, the findings of the study suggest that fat mass, rather than total body mass, is a stronger mediator of firefighting task performance. Since cardiorespiratory fitness is already routinely examined in incumbent firefighters, fat mass could be a practical and pragmatic additiontoan occupationalfitness screeningprogramme, to improveunderstandingof occupational readiness and individualperformance.

Key findings

Firefighting is a physically arduous occupation and requires specific levels ofphysical fitness and competency for safe and effective job performance[5,24,25]. In addition to cardiorespiratory fitness, many physical and physiological characteristics of an individual could impact on occupational performance. Multiple determinants of occupational task performance have been examined in non-UK firefighters using multiple-linear regression techniques previously[11,14,15].Of the variables measured, we foundthat higher absolute VO_2 max and lower fat mass represented the best combination of predictors for successful simulated firefighting performance. This was also supported by the next most successful model in the present study also being a product of fat content and absolute aerobic capacity. This is consistent with previous studies demonstratingexcess body fat is related to poorer task performance[11,26]. This finding isexpected giventhat a)fat mass is not functionallyor metabolically involved in the completion of physical tasks and thereforerepresents an additional mass to be carried/moved and b) as suchloadsare increased human movement becomesprogressively less efficient[17]. During heavy load carriage tasks, when ambulation is less efficient, a higher absolute aerobic capacitythen becomes progressively more central to maintaining work performance[17]. Our findings support this notion, suggesting the cumulative effect of possessing lower absolute cardiorespiratory fitness and excess body fat can be detrimental to firefighting task performance.

Aerobic capacity and body mass

Normalisation of aerobic capacity to body mass, in part for ease of comparison between personnel of different body sizes, is prevalent in professions that involve load carriage[19,27,28]. This is despite larger, heavier individuals being at a potential advantage when performing heavy load carriage tasks when compared to smaller counterparts, but at a disadvantage during body-size normalisation[7,26]. Where load carriageis prevalent, the measurement and/or utilisation of VO_2 max in absolute units has been recommended as more relevant to occupational performance[8]. However, the interaction of body mass and loaded task performance extends further than purely the size of mass carried relative to body mass. This is supported by our data exhibitinga trend for a body mass bias, such that heavier individuals tended to perform the FFST slower ($R=0.276$; $R^2=0.08$, $p=0.02$; data not shown), despite the test containing some load carriage.Performance in load carriage tasks can vary based on the dimensions of the mass carried, its distribution on/around the body and the mechanical nature and direction of movement[8]. Recent evidence examining firefighting tasks has suggested that lighter individuals may be advantaged in movements where the body must be supported and heavier individuals advantaged when exerting force against high absolute external loads[10].Since this study was not designed to specifically examine load carriage, and the loads carried varied at different stages of the FFST, the precise impacts of individual masses carried cannot be easily discerned and is unfortunately beyond the scope of this paper.However, aside from external load carriage,our data suggestpart of the variance in task performance is likely a product of the contribution of fat mass to total body mass, rather than body mass *per se*, where high fat mass is commensurate with poorer firefighting task performance.This would explain why, in isolation, relative VO_2 max(i.e.

normalised to body mass) appears to predict performance more effectively thanVO_2 maxwith no body mass correction.

Body composition and job-related task performance

Our observation that absolute lean mass was not a significant mediator oftask performance is not consistent with studies that observed positive correlations between fat-free mass and load carriage tasks[17], occupational strength tests[29] and measured critical power[13]. It is particularly surprising given that both excess mass in the form of lean mass and LBM/FM ratio are well-established surrogate measures of physical fitness and muscular strength. This relationship typically becomes equivocal in activities where body mass serves as the (only) external resistance, but this was not the case in the current task protocol.However, the absence of a significant contribution from lean mass in our predictive models is likely either due to a) its relationship with total time being markedly similar to absolute $VO_2$and therefore explaining no further variance or b) the relationship not being strictly linear.The former is supported by lean body mass typically being linearly correlated with absolute aerobic capacity. The latter would occur if, hypothetically, groups of personnel with small and excessive amounts of lean mass were equally proficient at completing the circuit, by representing two body compositions that are relevant to firefighting. In tandem, those with excessively low or moderate lean mass would be less successful. This would result in a non-linear relationship between lean mass and performance, such that the current statistical analysis is not suitable.It should be noted that the models in this study represented ~52 to 59% of explained variance in completion time, leaving areas for future research.

Modelling firefighter performance

While consistent with the majority ofcomparable previous investigations, producing53%, 60% and 59-84% in previous models[6,11,12], there is clearly improvement to be made in modelling the multiple determinants of occupational performance. Lindberg et al (2015) was able to produce a model, which explained a high proportion of variance, by examining discrete tasks and by including a wide range of physical tests and attributes as potentialpredictor variables. Evidence has identified strength or strength tests as being useful determinants of firefighting performance[6], but is typically dependent on the nature and composition of the tasks investigated[15].The types of load carriage and the specific tasks involved in the current investigation suggest that measures of muscular endurance may have further differentiated between more or less effective performers and been useful additional parameters here.It is likely that the addition of otherphysical and physiological variables, as well as technical aspects not included or measurable in the present study, would likely have improved predictive power.

The present study concentrated oncompletion time of the FFST since this is a performance measure used to monitor occupational readiness in the UK Fire & Rescue Service. While it is evident that firefighting tasks are time-critical, recent research has investigated combinations of parameters that may be more closely related to an aggregate of firefighting performance measures. Windisch et al.(2017) produced a composite score from completion time of a work simulation, cardiovascularstrain (by percent of maximum heart rate) and air depletion from breathing apparatus. The best combination of predictors in this sample of German firefighters were absolute VO_2 max, low average breathing rate and time spent below ventilatory threshold. This, in combination with work combining environmental factors[30],highlight further potential limiters to firefighting performance as a product of work tolerance and work efficiency.In both this setting and that of the current study, z-scores alone contain a sample bias where performance scores are relative to the sample mean and distribution, and should not be extrapolated to the larger population without caution. While we applied similar statistical analyses to the above, reproduction of this type of aggregateperformance score from individual z-scoresmay reduce this bias and be a more occupationally relevant way of understanding the necessary attributes for safe and effective firefighting in larger populations, including the UK.

Practical relevance

The current study was primarily designed to focus on the protocols and tests currently used by the UK Fire & Rescue Service. This was in order to maximise the practical relevance of the findingsfor the service, and be easily-applicable.The fitness management system for UK firefighters involves a health screen andcardiorespiratory fitness test prior to any criterion testing. As such, with the addition of body fat estimation in screenings,theregression model provided in this study could be used to help inform potential criterion performance.This would also help occupational health staff and individual employees understand the relationship between their own health, fitness, body composition, performance on surrogate tests alongside occupational performance.

Current research in occupational performance has shown the advantage of using occupationally-relevant load and clothing when performing cardiorespiratory fitness testing. While this could not be included in the current study focus, it could be a sensible recommendation for use in the service and in modelling occupational performance in this population in future.

Limitations

This study aimed to recruit a large sample of firefighters with a range of physical abilities and attributes to potentiate the efficacy of a prediction model for FFST performance. A main limitation was the inability to use a larger variety of variables in the analysis. Performance on various tests of muscular strength and endurance[31]and other classifications of 'firefighting ability' could have substantially improvedidentification of factors relevant to firefighting.In addition, due to the nature of the primary study aims, a proportion of FFST completion time istransition times (such as donning the breathing apparatus) between sections. While this does retain ecological validity since the transition time would be present in the 'real' test, these times were not recorded and likely account for some of the unexplained variance. The inability to measure metabolic demand or cardiovascular strain during the circuit meant we were unable to ascertain the relative work rate of each participant, except by rating of perceived exertion, which may have been a useful outcome variable for further predictive modelling.

It was also unfortunate that more female firefighters did not volunteer for thecurrent investigation. While occupational employment standards for identical jobs should remain independent of biological sex, it is conceivable that the physical and physiological determinants of FFST performance may be different between male and female personnel. The small current sample may have contributed to sex not being a significant determinant of FFST completion time and meant there it was not possible to analyse data separately from male firefighters with sufficient statistical confidence. Given the above, and well-documented sex differences in body composition[32,33], it should be noted that a model driven by body composition from a predominantly male sample may discriminate against female firefighters. Using absolute body fat rather than percentage body fat may lessen this bias, but it would be prudent to investigate a different prediction model for female firefighters for achievement of the same criterion standard on the FFST.

Conclusions

The findings of this study demonstrate that during simulated firefighting the combination oflower fat mass and higher absolute cardiorespiratory capacity are relevant attributes to predict effective FFST performance. Thestrengthof these predictors is likely a product of the occupational tasks involving load carriage where having a larger body mass can be advantageous but where the contribution of excess body fat to total body mass can be detrimental. As such, the customary normalisation of VO_2 peak to body mass does not account for the complexity of body composition as a surrogate indicator for effective load carriage and manipulation.While further work is warranted to include other possible determinants of performance and investigate predictive models for female firefighters, it appears that the estimation of fat mass, as part of a routine fitness assessment, could be useful for understandingpotential occupational performance.

REFERENCES

1. Eglin CM, Coles S, Tipton MJ. Physiological responses of fire-fighter instructors during training exercises. *Ergonomics* 2004;47:483-494.

2. Sothmann MS, Saupe KW, Jasenof D, et al. Advancing Age and the Cardiorespiratory Stress of Fire Suppression: Determining a Minimum Standard for Aerobic Fitness. *Human Performance* 1990;3:217.

3. von Heimburg ED, Rasmussen AKR, Medbø JI. Physiological responses of firefighters and performance predictors during a simulated rescue of hospital patients. *Ergonomics* 2006;49:111-126.

4. Bilzon JLJ, Scarpello EG, Bilzon E, et al. Generic task-related occupational requirements for Royal Naval personnel. *Occup Med (Lond)* 2002;52:503-510.

5. Siddall AG, Stevenson RDM, Turner PFJ, et al. Development of role-related minimum cardiorespiratory fitness standards for firefighters and commanders. *Ergonomics* 2016:1-9.

6. Lindberg A-S, Oksa J, Antti H, et al. Multivariate Statistical Assessment of Predictors of Firefighters' Muscular and Aerobic Work Capacity. *PLOS ONE* 2015;10:e0118945.

7. Bilzon JL, Allsopp AJ, Tipton MJ. Assessment of physical fitness for occupations encompassing load-carriage tasks. *Occup Med (Lond)* 2001;51:357-361.

8. Taylor NAS, Peoples GE, Petersen SR. Load carriage, human performance, and employment standards. *Appl Physiol Nutr Metab* 2016;41:S131-147.

9. Vanderburgh PM. Occupational relevance and body mass bias in military physical fitness tests. *Med Sci Sports Exerc* 2008;40:1538-1545.

10. Phillips DB, Scarlett MP, Petersen SR. The Influence of Body Mass on Physical Fitness Test Performance in Male Firefighter Applicants. *J Occup Environ Med* 2017;59:1101-1108.

11. Michaelides MA, Parpa KM, Henry LJ, et al. Assessment of physical fitness aspects and their relationship to firefighters' job abilities. *J Strength Cond Res* 2011;25:956-965.

12. Williford HN, Duey WJ, Olson MS, et al. Relationship between fire fighting suppression tasks and physical fitness. *Ergonomics* 1999;42:1179-1186.

13. Byrd MT, Switalla JR, Eastman JE, et al. Contributions of Body Composition Characteristics to Critical Power and Anaerobic Work Capacity. *Int J Sports Physiol Perform* 2017:1-20.

14. Windisch S, Seiberl W, Schwirtz A, et al. Relationships between strength and endurance parameters and air depletion rates in professional firefighters. *Sci Rep* 2017;7:44590.

15. Harvey DG, Kraemer JL, Sharratt MT, et al. Respiratory gas exchange and physiological demands during a fire fighter evaluation circuit in men and women. *Eur J Appl Physiol* 2008;103:89-98.

16. Williams-Bell FM, Villar R, Sharratt MT, et al. Physiological demands of the firefighter Candidate Physical Ability Test. *Med Sci Sports Exerc* 2009;41:653-662.

17. Lyons J, Allsopp A, Bilzon J. Influences of body composition upon the relative metabolic and cardiovascular demands of load-carriage. *Occup Med (Lond)* 2005;55:380-384.

18. Phillips DB, Stickland MK, Petersen SR. Physiological and performance consequences of heavy thoracic load carriage in females. *Appl Physiol Nutr Metab* 2016;41:741-748.

19. Perroni F, Guidetti L, Cignitti L, et al. Absolute vs. weight-related maximum oxygen uptake in firefighters: fitness evaluation with and without protective clothing and self-contained breathing apparatus among age group. *PLoS ONE* 2015;10:e0119757.

20. Lindberg A-S, Oksa J, Gavhed D, et al. Field tests for evaluating the aerobic work capacity of firefighters. *PLoS ONE* 2013;8:e68047.

21. Stevenson RDM, Siddall AG, Turner PFJ, et al. Validity and Reliability of a Firefighter Fitness Simulation Test. *[Under review]* 2017.

22. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982;14:377-381.

23. Stevenson RDM, Siddall AG, Turner PFJ, et al. A Task Analysis Methodology for the Development of Minimum Physical Employment Standards. *J Occup Environ Med* 2016;58:846-851.

24. Jamnik V, Gumienak R, Gledhill N. Developing legally defensible physiological employment standards for prominent physically demanding public safety occupations: a Canadian perspective. *Eur J Appl Physiol* 2013;113:2447-2457.

25. Tipton MJ, Milligan GS, Reilly TJ. Physiological employment standards I. Occupational fitness standards: objectively subjective? *Eur J Appl Physiol* 2012.

26. Crawford K, Fleishman K, Abt JP, et al. Less body fat improves physical and physiological performance in army soldiers. *Mil Med* 2011;176:35-43.

27. Vanderburgh PM, Crowder TA. Body mass penalties in the physical fitness tests of the Army, Air Force, and Navy. *Mil Med* 2006;171:753-756.

28. Vanderburgh PM. Occupational relevance and body mass bias in military physical fitness tests. *Med Sci Sports Exerc* 2008;40:1538-1545.

29. Sharp MA, Patton JF, Knapik JJ, et al. Comparison of the physical fitness of men and women entering the U.S. Army: 1978-1998. *Med Sci Sports Exerc* 2002;34:356-363.

30. Windisch S, Seiberl W, Hahn D, et al. Physiological Responses to Firefighting in Extreme Temperatures Do Not Compare to Firefighting in Temperate Conditions. *Front Physiol* 2017;8. Available at: http://journal.frontiersin.org/article/10.3389/fphys.2017.00619/full. Accessed August 25, 2017.

31. Stevenson RDM, Siddall AG, Turner PFJ, et al. Physical Employment Standards for UK Firefighters: Minimum Muscular Strength and Endurance Requirements. *J Occup Environ Med* 2017;59:74-79.

32. Sharp MA. Physical fitness and occupational performance of women in the u.s. Army. *Work* 1994;4:80-92.

33. Nindl BC, Jones BH, Van Arsdale SJ, et al. Operational Physical Performance and Fitness in Military Women: Physiological, Musculoskeletal Injury, and Optimized Physical Training Considerations for Successfully Integrating Women Into Combat-Centric Military Occupations. *Mil Med* 2016;181:50-62.

Figure Legends

FIGURE 1. Measured FFST completion time (seconds) for each individual performer (n=68), againstFFST completion time predicted from Model 5 (Predictor variables: VO_{2ABS}, fat mass; R=0.765, R^2: 0.585, SEE: 52 s).

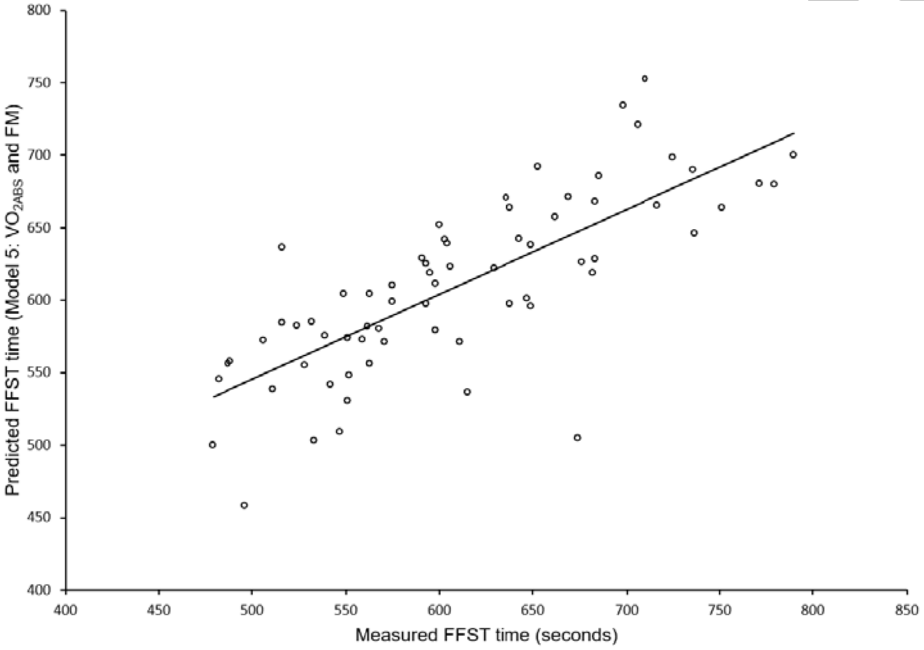

FIGURE 2. (A) Comparison of FFST completion time (seconds) between firefighters (n=68) in quintiles of estimated fat mass (kg). Quintiles are: ≤11.84 kg (Q1), 11.85-13.79 kg (Q2), 13.80-17.88 kg (Q3), 17.89-23.16 kg (Q4) and >23.16 kg (Q5). Data are mean ± 95% confidence intervals. *denotes significantly different from Q3, Q4 and Q5. **(B)** Individual FFST completion times (in standard deviations from the population mean '0') as z-scores, classified into *Outstanding*, *Above average*, *Average*, *Below average* and *Poor* performers. White bars denote those in Q1 (lowest) of fat mass and black bars denote those in Q5 (highest) of fat mass.

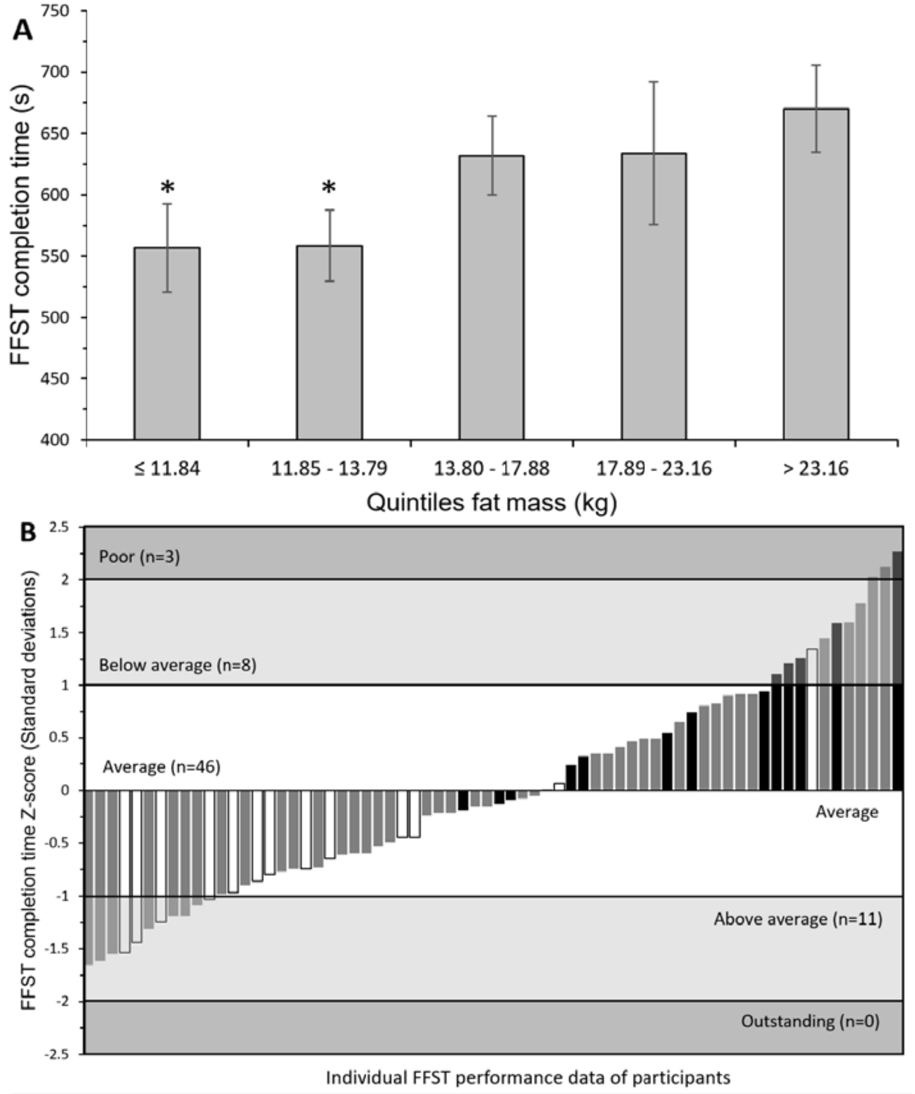

Table Legends

TABLE 1. Participant characteristics. Data are mean (±SD).

Characteristic	All (*n*=68)
Age (y)	41 (±8)
Mass (kg)	85.7 (±12.9)
Height (m)	1.78 (±0.06)
Estimated body fat (%)	19.7 (±5.6)
Fat mass (kg)	17.3 (±7.0)
Lean mass to fat mass ratio	4.6 (±1.9)
VO_2 max ($L \cdot min^{-1}$)	4.0 (±0.7)
VO_2 max ($mL \cdot kg^{-1} \cdot min^{-1}$)	47.7 (±9.0)
FFST completion time (s)	610 (±79)

TABLE 2. Prediction models for firefighting simulation completion time and correlation statistics, arranged in ascending order of variance explained (R^2).

Model number	Prediction variables included	R	R^2	Adjusted R^2	SEE (s)
1	$VO_{2ABS,}$ body mass	0.727	0.528	0.513	55
2	VO_{2REL}, LBM/FM	0.745	0.555	0.541	54
3	VO_{2REL}, BF%	0.752	0.565	0.552	53
4	VO_{2ABS}, BF%	0.762	0.580	0.567	52
5	VO_{2ABS}, FM	0.765	0.585	0.572	52