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Development of role-related minimum cardiorespiratory fitness standards for firefighters and commanders

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Abstract

A minimum cardiorespiratory fitness standard was derived for firefighters following a metabolic demands analysis. Design and minimal acceptable performance of generic firefighting task simulations (i.e., hose running, casualty evacuation, stair climb, equipment carry, wild-land fire) were endorsed by a panel of operationally experienced experts. Sixty-two UK firefighters completed these tasks wearing a standard protective firefighting ensemble while being monitored for peak steady state metabolic demand and cardiovascular strain. Four tasks, endorsed as valid operational simulations by ≥90% of participants (excluding wild-land fire; 84%), were deemed to be a sufficiently valid and reliable basis for a fitness standard. These tasks elicited an average peak steady state metabolic cost of 38.1 ± 7.8 $ml \cdot kg^{-1} \cdot min^{-1}$. It is estimated that healthy adults can sustain the total duration of these tasks (~16 min) at ≤90% maximum oxygen uptake and a cardiorespiratory fitness standard of ≥42.3 $ml \cdot kg^{-1} \cdot min^{-1}$ would be required to sustain work.

Practitioner Summary: A cardiorespiratory fitness standard for firefighters of ≥42.3 $ml \cdot kg^{-1} \cdot min^{-1}$ was derived from monitoring minimum acceptable performance of essential tasks. This study supports the implementation of a routine assessment of this fitness standard for all UK operational firefighters, to ensure safe physical preparedness for occupational performance.

Key words: Physical Demands Analysis; Metabolic cost; Oxygen uptake; Firefighting; Role-related fitness; Physical Employment Standards.

Introduction

The role of a firefighter requires a relatively high level of cardiorespiratory fitness to perform operational tasks safely and effectively (Gledhill and Jamnik 1992; von Heimburg, Rasmussen, and Medbø 2006). Cardiac events during emergency incidents account for the largest number of on-duty firefighter fatalities in the United States (Kales et al. 2007; Fahy, LeBlanc, and Molis 2013), and so firefighters with poor physical fitness and cardiovascular health may be at increased personal risk when performing occupational duties. However, physical fitness standards are not consistently based on metabolic demand of essential occupational tasks.

Direct measurement of oxygen uptake in firefighter populations indicate the metabolic demand is rarely below 35 $mL·kg^{-1}·min^{-1}$ (Sothmann et al. 1990), and consistently in excess of 40 $mL·kg^{-1}·min^{-1}$ (Gledhill and Jamnik 1992; Bilzon et al. 2001; von Heimburg, Rasmussen, and Medbø 2006). Physical demands analyses in firefighters, however, are typically limited to estimating (but not directly measuring) metabolic demand, indicating cardiovascular strain of between 60-95% of maximum (Eglin, Coles, and Tipton 2004; Richmond et al. 2008). In addition, the majority of work has utilised tasks paced by the participant, where measured physical demand is altered by individual effort and absolute work capacity (Lemon and Hermiston 1977). Notably, in one study using Naval firefighters metabolic demand was measured using tasks with constant predetermined "acceptable" paces and protocols designed to elicit a representative peak demand (Bilzon et al. 2001). Reproduction of this study design, in combination with further considerations from the gold-standard process for developing role-related physiological employment standards (Tipton, Milligan, and Reilly 2012; Jamnik, Gumienak, and Gledhill 2013), should therefore be replicated in civilian (non-military) firefighters. In addition, the physical roles expected of different ranks within those working at emergency incidents may have disparate physical responsibilities and therefore different physical demand. This would suggest different fitness standards would be employed for generic 'operational' firefighters tackling the incident and for those in an 'incident command' role at the scene. However, the predominance of physical demand research has not attempted to assess these differences, electing to solely examine the demands upon the firefighter.

The primary aim of this study was to quantify the peak oxygen cost (and therefore metabolic demand) of several simulated firefighting tasks, performed to a minimum acceptable and representative standard for firefighters and, separately, for those in incident command. The secondary aim was to derive minimum cardiorespiratory fitness standards for safe and efficient work in these two roles using these data, in conjunction with well-established methods for the development of physiological employment standards.

Methods

Task analysis

Best practice for the development of fair and justifiable occupational capability tests and minimum physical fitness requirements was recently reviewed by Tipton, Milligan & Reilly (2012) and the recommendations implemented for this study. A technical panel of 13 highly experienced fire service personnel (comprising one firefighter, two crew managers, five watch managers and five station managers from 10 UK fire and rescue services with an average of 17 years of experience) was established to provide information on the composition and best practice of firefighting tasks. This panel was assembled by requesting nominations for highly experienced incident managers from the UK fire and rescue services. Though a gender- and sex- diverse panel would have been preferable, unfortunately no female personnel came forward to sit on the panel. Through a series of focus groups, the panel was consulted to identify the most physically arduous generic tasks that all firefighters must be able to perform. In the case of UK firefighters, this includes both the duties of structural and wild-land fire suppression. Subsequently, with further consultation, single-person simulations of five tasks were designed using the criteria that each simulation should: (a) replicate and employ best practice for the criterion tasks; (b) reflect one individual's responsibility within the task; (c) be reproducible and standardised in nature; (d) be long enough to elicit a steady state of metabolism during exercise and; (e) be completed at a "minimum acceptable pace" agreed by the technical panel in order to assess minimum occupational demand and standardise task intensity. These focus groups included open discussion and agreement of the typical distances covered during these specific tasks during an operational incident, whilst adhering to health and safety regulations. The agreed distances subsequently became those employed in the single-person simulations designed. To select the minimum acceptable pace, a voting system was used in which panel members were shown a set of videos of each task at a variety of calculated speeds, and were asked to vote anonymously for the minimum expectation for safe and efficient task completion. The speeds were determined using the bookmark method (Todd Rogers, Docherty, and Petersen 2014), specifically by examining the typical speed of a training instructor performing the tasks, then having the task completed one integer of speed faster and slower than this pace (giving a "slow", "moderate" and "fast" pace). Voters were also given an option of choosing a speed half way between these, giving five choices in total. Before each video, a contextual scenario was given to control for the perception of the intensity and/or urgency of each task. The panel also identified which tasks would also be completed by 'incident commanders' and if/how these would differ from the physical responsibilities of generic firefighters. If differences were identified, separate addition single-person simulations of tasks were then designed to be appropriate for the 'incident commander' role.

Participants

Sixty two (50 male, 12 female) operational firefighters (Table 1) attended the Fire Service College (Moreton-in-Marsh, Gloucestershire, UK) and gave written informed consent to take part in the study following a full written and verbal brief. Inclusion criteria were that participants were trained, currently operational and deemed medically fit for service. Estimated maximum oxygen uptake data from ramped submaximal treadmill test (Buckley et al. 2004) were extracted from personnel records but were only available for 60 of the 62 participants (mean ± SD: 50.0 ± 6.6 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$). The study was approved by the University of Bath's Department for Health Research Ethics Committee (Reference number: EP 12/13 6).

[INSERT TABLE 1 ABOUT HERE]

Study protocol

Anthropometric data (body mass, height, estimated body fat (BodyStat 1500, Bodystat Ltd., UK)) were obtained in the morning prior to the physical demands analysis. Participants were then randomly assigned to complete five simulated firefighting tasks with at least 60 min of recovery separating each task. Before each task a full verbal brief of the simulation was given. During each task a project researcher moved with the participant and gave instruction. Throughout the trial day participants were allowed access to food and drink *ad libitum*.

Four out of the five tasks were paced by audible beeps that corresponded with cones placed at five metre intervals. The stair climb was paced by a metronome where each sound corresponded to one step, played to the participant via headphones. All tasks were completed in full personal protective clothing consisting of helmet, shirt, tunic, leggings, boots, gloves (Mass of ensemble: 8.2 kg), with the exception of the wild-land fire task where tunic and helmet were not worn. In two tasks, the stair climb and casualty evacuation, a rucksack was also worn equivalent to the mass of a self-contained breathing apparatus unit (12 kg). The various equipment worn for each simulation was in keeping with what would realistically be worn during an emergency incident according to the subject-matter expert technical panel.

Task descriptions

For the purpose of the task descriptions a "length" is a traversal of the 25 m course. All tasks were conducted in accordance with UK manual handling regulations, which stipulates maximum manual lifting of 25 kg. Note that both the stair climb and wild-land fire tasks each contain two sections that simulate, separately, the roles of a generic firefighter and an 'incident commander'. From the minimum acceptable pace and distance, a minimum expected time for task completion is also stated below.

The <u>hose run</u> task was designed to simulate an operational scenario of establishing a water supply between a fire engine and a fire hydrant 100 m apart by carrying and 'running out' four 25 m standard issue 70 mm hoses (13 kg each). 'Running out' hose consists of the firefighter jogging while holding the hose in front of them at chest height on an attached spindle – letting the hose unravel as they traverse the course. The task was completed on a straight 25 m course at 8 $km \cdot h^{-1}$ over a total distance of 700 m. This adhered to the realistic scenario of advancing to, and returning from, the hydrant (200 m) at both the start and end of the task, in combination with the most efficient procedure for 'running out' four hoses by the conclusion of the task. The task consisted of (in this order): 8 x unladen lengths, 3 x lengths carrying two hoses, 1 x length carrying one hose, 2 x lengths running out two hoses, 2 x unladen lengths, 1 x length carrying two hoses, 1 x length carrying one hose, 2 x lengths running out two hoses, 8 x unladen lengths. Minimum expected task duration: 5:05 min.

The <u>equipment carry</u> task was designed to simulate the single-person contribution to a team manually transporting a portable pump (or similar) over 200 m and was completed on a straight 25 m course at 5.5 $km \cdot h^{-1}$. The participant carried a 25 kg barbell 8 x lengths, and was allowed to place the weight down to shift grip if necessary as long as pace was then recommenced in a timely manner. Minimum expected task duration: 2:11 min.

The stair climb task was designed to simulate a single-person contribution to a breathing apparatus team (ie: wearing a breathing apparatus unit; 12 kg) carrying a high-rise pack (50 kg between two people) to an incident six floors above ground level. This task was completed at 95 steps·min^{-1} in a high-rise stairwell which consisted of six floors, with two flights of stairs between each floor and 10 steps per flight where they fully ascended and descended the stairwell unladen then fully ascended the stairwell while carrying a dumbbell (25 kg), and descended again, unladen. Total minimum expected task duration: 6:04 min. The first half of the task was used to simulate the 'incident commander' role.

The casualty evacuation task was designed to simulate entry (with breathing apparatus unit; 12 kg) to a commercial property fire (Phase 1) and casualty evacuation (Phase 2) at speeds of 6 km·h^{-1} and 3 km·h^{-1}, respectively. The task was completed around a 25 m square course, with a fire engine with charged hose reel (37 kg) and sledgehammer (4 kg) at one corner, and a dummy at the opposite corner (55 kg, which represents half of the 95th percentile of body mass of UK residents). Total minimum expected task duration: 2:30 min. The participant started at the fire engine.

1) The participant (in this order) completed: 1 x length with sledgehammer, 1 x unladen length, 1 x length dragging charged hose, 1 x unladen length, 2 x lengths dragging charged hose (to approach the dummy). In this phase, the two sides of the square utilised were marked with cones every 5 m.
2) The participant (using standard procedure grip under armpits) dragged the dummy 2 x lengths (the final two sides of the square). In this phase, the lengths utilised were marked by cones at every 2.5 m (to elicit half the speed as the first phase, for the same bleeps).

The wild-land fire task was designed to simulate an individual's contribution to a team fighting a wild-land fire. In the UK, this would consist of a fire on dry grassy terrain (not woodland) that is beaten using a standard issue fire beater (consisting of a long pole with an attached foam/rubber pad; total mass 5 kg) as part of a slowly advancing team of firefighters. This task covered a 400 m distance and was completed on a 50 m stretch of uphill undulating grassy terrain at 3.5 $km{\cdot}h^{-1}$. The participant completed 2 x ascent and 2 x descent (200 m) of the course without a fire beater then completed 2 x ascent and 2 x descent again (200 m) while equipped with a fire beater. The fire beater was used to strike the ground on every alternate walking step during the final two ascents. Total minimum expected task duration: 6:52 min. The first half of the task (without the fire beater) was used to simulate the 'incident commander' role.

Task validity and authenticity

A series of questions were posed to participants at the end of each exercise to assess validity and authenticity of the tasks. Participants were asked a) whether they received adequate instruction, b) whether the task was an adequate reflection of what one might be expected to perform in a training or operational setting *(validity)* and c) whether, in their experience, the task pace was "too slow", "too fast" or "about right" *(authenticity).*

Measurement of physical demand

During each task, oxygen uptake (VO_2) was measured continuously using portable breath-by-breath gas analyser (K4 B2, Cosmed, Rome, Italy) and cardiovascular strain was measured at 5–s intervals by chest-mounted heart rate monitor (Polar, Finland). Rating of perceived exertion was taken at the end of exercise using the Borg scale (Borg 1982).

To determine aerobic demand of the tasks, a minute of peak steady state VO_2 was selected for each participant within each task. Peak steady state was defined as the minute of oxygen uptake within the final two minutes of exercise which exhibited the fewest perturbations and which also did not appear to contain any substantial fluctuation in oxygen uptake. Each minute of steady state was cleaned for anomalous breaths by removing values above or below three standard deviations of the mean from that minute, and averaged for each task. For each steady state minute, average heart rate was also calculated. Resting heart rate was taken as the lowest heart rate observed during the entire day of data collection. Heart rate reserve (HRR) was then calculated by subtracting resting heart rate from age-predicted heart rate max (220-age). For each task, the steady state heart rate was also expressed as a percentage of heart rate reserve (%HRR).

Deriving a minimum cardiorespiratory fitness standard

Two different empirically-informed methods of deriving physiological employment standards were applied to the metabolic demand data. This was both to allow a means of comparison between methods, and in order to make an informed empirically valid decision on the appropriateness of the resultant standard. The first method subtracts one standard deviation of group metabolic demand from the demand of the most arduous measured task, with the rationale that 83.3% of the work force is then incorporated in the calculation of an employment standard (V. K. Jamnik et al. 2010). The second method uses the mean of the metabolic demands of the representative tasks, with the rationale that a) this would be closest to the cardiorespiratory level expected of an average participant without prior experience (assuming normally distributed data) and b) this mimics a generic emergency response by incorporating multiple occupationally-representative tasks (Bilzon et al. 2002). To calculate the fitness requirement for each of these methods, a generic work-time relationship was used to estimate the work intensity that could be sustained for the duration of the given task(s) (Louhevaara et al. 1986; Blondel et al. 2001). For instance, if an individual should be capable of completing a 15-min task at approximately 90% of maximal oxygen uptake, the physical demand of that task represents 90% of the resultant minimum fitness requirement required for that task.

Data analysis

All statistical analyses were completed using IBM SPSS version 20 (IBM, New York, USA). Group averages were calculated for all variables. A one-way paired analysis of variance (ANOVA) with post-hoc bonferroni adjustment was used to analyse differences, and locate variance, between physical demand characteristics of tasks. Sex was included as a between-subjects factor to assess any difference in physiological responses to tasks between males and females. When deriving the fitness standard, participants who did not complete a task, or did not keep to the designated pace for that tasks were removed (only) from the data for that specific task. When comparing between tasks, ANOVA solely analysed those that completed every task successfully (n=47). Statistical significance was set at $p \leq 0.05$. All data are presented as mean ± SD unless otherwise stated.

Results

Task validity and authenticity

All participants (100%) stated they received adequate instruction for each of the tasks. Almost all respondents (94%) stated that tasks were a valid reflection of what they might be expected to perform in training or operationally (Table 2). With the exception of the wild-land fire task, an average of 91% of respondents confirmed authenticity by agreeing the task paces were "about right". The wild-land fire task was the only task not to be perceived as valid by more than 90% of respondents (84%), and to have work rate deemed too slow to be authentic by the majority of participants (52%).

[INSERT TABLE 2 ABOUT HERE]

Firefighter task performance

In the hose run 52 of 62 participants completed the task correctly (83.9%), with nine individuals completing the task but at an incorrect pace (six too slow and three too fast), and one unable to complete (ankle soreness). Three individuals in the equipment carry, and four individuals in each of the stair climb and casualty evacuation tasks did not complete the tasks correctly and/or erratically changed work rate. The wild-land fire task was completed successfully by all participants. In total, 47 individuals completed every task at the correct pace successfully and could be included in the statistical comparison between tasks.

Incident commander task performance

While all participants completed the 'incident commander' portions of the stair climb and wild-land fire tasks, one individual did not have sufficient data to analyse physical demand during the stair climb and was removed from the "incident commander" physical demands analysis.

Firefighter physical demand

Examining each task separately (by including all successful completers for each individual task), physical demand was measured by mean ± SD peak steady state oxygen uptake ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$) and percentage of estimated VO_2 max for hose run (47 ± 7; 94 ± 15%; n=52), equipment carry (29 ± 4; 58 ± 11%; n=59), stair climb (41 ± 7; 83 ± 15%; n=58), casualty evacuation (36 ± 7; 72 ± 13%; n=58) and wild-land fire (29 ± 5; 59 ± 13%; n=62). Statistical comparison between tasks (n=47) revealed that the hose run task elicited significantly higher mean peak metabolic demand than all other tasks ($p<0.01$), whilst wild-land fire and equipment carry tasks both elicited the lowest relative to the other three tasks ($p<0.01$; Table 3). Mean ± SD heart rate responses were different between tasks ($p<0.01$), with the hose run eliciting the highest cardiovascular strain (171 ± 11 $beats{\cdot}min^{-1}$) and wild-land fire the lowest (137 ± 14 $beats{\cdot}min^{-}$

^{1}). Similarly, the hose run and stair climb elicited the highest percentage of heart rate reserve, with 92 ± 7 % and 88 ± 10 %, respectively, and wild-land fire lowest (64 ± 10 %). Perception of exertion differed between each task ($p<0.05$), increasing in corresponding order to measured physical demand (Table 3). Metabolic demand did not significantly differ between male and female firefighters within any task ($p>0.05$; Table 4).

[INSERT TABLE 3 ABOUT HERE]

[INSERT TABLE 4 ABOUT HERE]

Incident commander physical demand

When including participants that successfully completed the tasks, mean ± SD oxygen uptake values for tasks that simulated an incident commander role were 35 ± 5 $ml \cdot kg^{-1} \cdot min^{-1}$ for the stair climb and 23 ± 3 $ml \cdot kg^{-1} \cdot min^{-1}$ for wild-land fire task. The physical demand characteristics used in statistical analyses for the ‘incident commander’ tasks are presented in Table 5. The physical demand of the stair climb and wild-land fire tasks simulating ‘incident commander’ duties were significantly lower than the two same corresponding tasks simulating the roles of operational firefighters ($p<0.05$). The ‘incident commander’ simulation of wild-fire elicited significantly lower physical demand than all other simulations ($p<0.05$). While the stair climb for ‘incident commanders’ elicited lower physical demand than the operational firefighter stair climb, the physical demand was statistically similar to the casualty evacuation task ($p>0.05$).

[INSERT TABLE 5 ABOUT HERE]

Deriving cardiorespiratory fitness standards

One standard deviation below the metabolic demand of the most arduous task (hose run; 46.92 $ml \cdot kg^{-1} \cdot min^{-1}$) was 39.80 $ml \cdot kg^{-1} \cdot min^{-1}$. An exercise intensity of 95% VO_2 max was deemed sustainable for the duration of the task (Louhevaara et al. 1986), meaning that following the Jamnik et al., (2010) approach, the minimum cardiorespiratory fitness standard was calculated as 41.9 $ml \cdot kg^{-1} \cdot min^{-1}$. Since authenticity and physical demand data suggested the wild-land fire task was not sufficiently representative of the occupational task, and thereby not externally valid, it was not included in the production of a fitness standard in the method described by Bilzon et al. (2002). Therefore, the mean of the four valid tasks (hose run, equipment carry, stair climb, casualty evacuation) was taken (38.03 $ml \cdot kg^{-1} \cdot min^{-1}$). The summation of the minimum expected durations of these tasks (Table 3) was 15:50 min. This was deemed sustainable at 90% VO_2 max (Louhevaara et al. 1986), and produced a resultant cardiorespiratory fitness standard of 42.3 $ml \cdot kg^{-1} \cdot min^{-1}$.

For individuals in ‘incident command’ roles, from utilisation of the stair climb alone (sustainable at 95% VO_2 max), minimum cardiorespiratory standards from the two methods were 31.6 and 36.8 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively.

Discussion

Firefighters must possess adequate levels of cardiorespiratory fitness to meet the physical demands of arduous occupational tasks. Yet minimum occupational fitness standards are rarely directly derived from these demands to ensure empirical validity. The primary purpose of this study was to quantify the metabolic demand during minimum acceptable performance of representative occupational tasks of operational firefighters and, separately, “incident commanders”, to inform the implementation of minimum cardiorespiratory fitness standards. Group mean metabolic demand for firefighters ranged from 27 $ml \cdot kg^{-1} \cdot min^{-1}$ (wild-land fire task) to 47 ml·kg^{-1}·min^{-1} (hose run), eliciting an average of 57% and 93%, of estimated VO_2 max and 64% and 92% of heart rate reserve. All tasks were agreed to be accurate representations of occupational duties by over 90% of study participants, with the exception of the wild-land fire task (84%). Using published methods for the development of physiological employment standards, a minimum cardiorespiratory fitness standard of 42.3 ml·kg^{-1}·min^{-1} was calculated for safe and efficient work in operational firefighters, and 36.8 ml·kg^{-1}·min^{-1} for 'incident commanders'. This investigation is the first to publish both occupation-specific metabolic demands for UK (non-military) firefighters and, by implementing pre-determined minimum acceptable paces during tasks, role-specific minimum cardiorespiratory fitness standards for this occupational group.

The few previous physical demands analyses completed in UK firefighters published in peer-reviewed journals (Eglin, Coles, and Tipton 2004; Richmond et al. 2008), have been limited to measuring cardiovascular strain, finding exertion of between 60-95% of maximum heart rate. By direct measurement of metabolic demand, Sothmann et al. (1990) observed an average metabolic demand of 30.5 ml·kg^{-1}·min^{-1} during seven successive firefighting tasks in United States firefighters, representing 76% of the sample average VO_2 max (39.9 ml·kg^{-1}·min^{-1}). During stair climb and casualty evacuation tasks Gledhill & Jamnik (1992) and von Heimburg, Rasmussen & Medbø (2006) in Canadian and Norwegian firefighters, respectively, measured substantially higher metabolic demand values (44 ml·kg^{-1}·min^{-1}), similar to those in the present study. The above studies involved entirely self-paced tasks. Where minimum acceptable paces were employed, the average physical demand of a sample of UK shipboard Naval firefighters over five tasks was 36.2 (range 23-43) ml·kg^{-1}·min^{-1} representing between 44 and 82% of the average participant VO_2 max (Bilzon et al. 2001). Although these tasks were paced and designed to elicit a valid steady state of physical demand, it is evident that wide variation exists in the different occupational roles of firefighters, as well as the occupational requirements of different national and civilian/military services. As such, the specificity and experimental control implemented within the present study produce the first accurate articulation of the aerobic capacity required to safely and effectively complete the role of an operational UK domestic firefighter.

The tasks implemented in the current study compare favourably to those used in other firefighting physical demands analyses. Gledhill & Jamnik (1992) and Bilzon et al. (2001) investigated highest occupational applications of cardiorespiratory endurance and strength in Canadian and shipboard UK naval firefighters, respectively, incorporating combinations of hose manipulation; dragging a casualty; ladder and/or stair ascension and carrying heavy equipment over distance. In government research to develop point-of-entry standards for UK operational firefighters, a task analysis by Rayson et al. (2009) produced tasks including a shuttle-run based equipment carry and casualty evacuation scenario. These tasks, while specific to UK firefighters, were designed for entry-standard fitness testing, and not with the same specific aims of the current research (Blacker et al. 2015). Therefore, a task analysis specific to this study was required. In addition to task selection itself, other design elements, such as the bookmark method (Todd Rogers, Docherty, and Petersen 2014), were used to optimise relatedness to the job and accommodate the specific physical measurements needed to inform the development of a minimum cardiorespiratory standard (Tipton, Milligan, and Reilly 2012; Jamnik, Gumienak, and Gledhill 2013). Our study is the first to apply a voting system with subject matter experts, where voters were blinded to others' responses and to the actual speeds they were observing, to establish minimum acceptable paces for each physical task. The visual observation of a task at a variety of speeds without having the actual speed values available (ie: 6 vs. 8 $km{\cdot}h^{-1}$) facilitated the decision making process. This process (a) removes subjectivity of successful task performance, and (b) improves experimental control by establishing a steady state of oxygen cost, since large alterations in pace or exertion during physical activity would likely introduce error in oxygen uptake.

Two empirically-informed methods for producing occupational fitness standards from physical demands analyses were applied to the data from the present study (Bilzon et al. 2002; Jamnik et al. 2010) with additional consideration of the relationship (of human limitations) between work-load and time. The two methods applied here produced remarkably similar results, lending confidence to the minimum bounds of cardiorespiratory fitness required for firefighting. The authors recommend that 42.3 $ml \cdot kg^{-1} \cdot min^{-1}$, derived from the mean of sustained metabolic demand of the representative tasks (hose run, equipment carry, stair climb, casualty evacuation), be the minimum cardiorespiratory capacity for operational UK firefighters. This is with the rationale that the occupational fitness standard is derived from a range of tasks, which incorporate different physical requirements of the occupation while also possessing high relatedness to the job and more closely mimicking a generic emergency response than the hose run task alone. During emergency duties, it is typical for firefighters to move from one physical task to another with little to no break, akin to a circuit exercise scenario (Jamnik, Gumienak, and Gledhill 2013). In addition, the summed duration of the tasks 15:50 mins) is similar to mean duration observed for in-dwelling fire incidents during emergencies (14:20 minutes; Sothmann et al. 1990) and the practical limit of a standard breathing apparatus. As it is unreasonable for an individual to complete any task at maximal oxygen uptake for more than a few minutes (Louhevaara et al. 1986; Blondel et al. 2001), the resultant minimum fitness requirement of 42.3 $ml \cdot kg^{-1} \cdot min^{-1}$ surpasses the physical demand of the tasks and/or a generic emergency response scenario to the extent that the occupational duties can be completed safely for their expected duration (Gleser and Vogel 1973; Billat and Koralsztein 1996; Blondel et al. 2001). It is also expected, since humans can work supra-maximally (in relation to cardiorespiratory capacity) for short durations, that the period of peak steady state of 47 $ml \cdot kg^{-}$

$^{1}\cdot min^{-1}$ observed for approximately two minutes of the hose run would still be achievable for firefighters who possess fitness at, or marginally above, the proposed fitness standard.

A novel aspect of this study was the examination of role-specific job requirements. The lower fitness standard of 36.8 ml·kg^{-1}·min^{-1} we recommend for incident commanders reflects the identified differences in physical responsibility from those of generic firefighters. Physiological employment standards should be role-specific, based on successful performance of the minimum expected requirements of that occupation, irrespective of sex or any other individual characteristic. This is particularly relevant for an occupation where the physical requirements for men and women are the same, as is the case for UK firefighters. However, the comparison between males and females can be useful to highlight if female personnel complete tasks safely and efficiently at a significantly lower metabolic cost than male personnel (who would typically be larger, possess greater muscle mass and higher cardiorespiratory fitness). This could ultimately suggest that the minimum standard should be derived from the metabolic demand of single-sex groups. However, in the present study there were no significant intra-sex differences in metabolic demand in any tasks. It was necessary to exclude any participant from the derivation of the fitness standards if prescribed task pace was not maintained, either by completing the task(s) too quickly (n=5), too slowly (n=8, 6 with available fitness data) or too erratically (n=2). With these small sample groups and only estimated aerobic capacity data it would be misleading to base assumptions on whether the fitness of these individuals was the cause for unsuccessful adherence to prescribed task speed. However, in light of our proposed fitness standard for firefighters, it is interesting to note that the average estimated fitness levels of participants who performed tasks too quickly and too slowly were 54 ml·kg^{-1}·min^{-1} and 40 ml·kg^{-1}·min^{-1}, respectively.

It is worth noting that the cardiorespiratory fitness data in this study were estimated, rather than directly measured, and data were not available for two participants, which may limit the interpretation of the relative physical demands data, as well as comparisons with data from other firefighter populations. The comparatively low validity and authenticity scores for the wild-land fire task indicate the task was not of a suitable level of ecological validity, where the shortened task simulation was not able to replicate the fatigue experienced in the real-world example, which would likely endure for several hours over much longer distances. Such a task was therefore not considered suitable, nor practical, for a controlled testing environment. Similarly, a challenge for any such trial is that it is not possible to safely replicate other stressors in the operational environment (i.e. fire, heat, smoke, darkness). However, it is evident that in healthy, euhydrated adults environmental heat stress and subsequent hyperthermia, has greater deleterious effect on altering perception of exertion (i.e. RPE) driven, in part, by protective cerebral mechanisms (Nielsen and Nybo 2003; Nybo 2007), than on actual metabolic rate. While absolute metabolic rate remains similar during exercise in the heat, the ability to attain VO_2 max may be attenuated (Arngrímsson et al. 2003). Performing a task at a work-load relative to VO_2 max in the heat can, therefore, cause metabolic demand to appear higher than when the same work is performed in a thermoneutral environment. In reality, only approximately half of one task in the present study (i.e. casualty evacuation) would be completed under thermal stress in a real world setting. This task would not be expected to be performed near participant VO_2 max (group mean metabolic demand: 36 $ml \cdot kg^{-1} \cdot min^{-1}$), nor expected to result in significant hyperthermia. As such, including a task in excessive heat would likely not have affected the overall metabolic demands observed, and instead have reduced the safety and reliability of the experimental conditions. It is also acknowledged that the varied role of a firefighter requires components of fitness that extend beyond cardiorespiratory fitness, and while the tasks included require a wide variety of applications of fitness, further work should take a similar approach to investigate the muscular strength and endurance requirements for specific operational firefighting tasks. Validation of such a battery of fitness tests would provide a more holistic understanding of the physical requirements for operational firefighting.

This study supports the rationale for conducting physical demands analyses to derive evidence-based occupational fitness standards for arduous occupations. The metabolic demands exhibited were similar to those observed in other firefighting populations. We used well-established methods to determine that a cardiorespiratory fitness standard below 42.3 $ml \cdot kg^{-1} \cdot min^{-1}$ would not be commensurate with safe and efficient operational performance and that a lower standard of ≥36.8 $ml \cdot kg^{-1} \cdot min^{-1}$ would appropriate for 'incident commanders'. This study supports the implementation of routine assessments of minimum cardiorespiratory fitness standards for operational firefighters and their incident commanders.

Conflict of interest

The authors express no conflict of interest.

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