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Development of Occupational Fitness Standards for the UK Fire and Rescue Services (FRS)

By

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Executive Summary

It is widely recognised that the role of a firefighter involves a variety of tasks that can be both physically and mentally arduous, and often unpredictable in nature and duration. As such, an integral part of being able to perform the role of a firefighter safely and effectively is the maintenance of physical health and fitness. The importance of fitness is recognised at the point of selection, where personnel are required to pass a battery of Firefighter Selection Tests (FST). It is now important for the UK Fire & Rescue Services (FRS) to establish empirically-informed minimum occupational fitness requirements, based on the demands of the job, to form the basis of an annual firefighter health and fitness assessment. However, it is also important to understand the health behaviours of current personnel and identify associated lifestyle and occupational risks to health and wellbeing.

This programme of work, led by the University of Bath, was commissioned by the Chief Fire Officer's Association (CFOA), with financial support from the Fire Service Research and Training Trust (FSRTT) and the FireFit Steering Group (FFSG). The project has been guided by a 'Stakeholder Panel', with invitees from the Chief Fire Officer's Association (CFOA), the Fire Brigade's Union (FBU), the Retained Firefighters' Union (RFU), as well as the FRS health and fitness community. Any representatives of these groups who did not attend meetings were kept updated separately. The initial phase of research, reported here, had three clear aims:

- Conduct a task analysis to identify the most arduous physical tasks, which are reasonably required to be performed by all UK FRS operational personnel.
- Assess the physical demands of these tasks, performed to a minimum acceptable standard, and make proposals for a fitness standard and associated annual fitness test.
- Determine gym-based surrogate tests appropriate for predicting performance in criterion tasks involving strength and muscular endurance.
- Conduct a health and lifestyle survey of UK FRS personnel and identify behaviours associated with adverse health outcomes.

This report will focus entirely on the first three aims, with the overarching objective of deriving empirically informed cardiorespiratory fitness standards and strength requirements for operational firefighters in the UK FRS.

A 'Technical Panel' was established, comprising 13 highly experienced operational firefighters and training instructors currently employed in the UK FRS. The panel were invited to consider a number of 'single-person' fire-fighting tasks and identify a minimum acceptable pace for each. We subsequently recruited 62 (50 male, 12 female) FRS volunteer personnel to participate in a Physical Demands Analysis at the Fire Service College, Moreton-in-Marsh. The cardiovascular and metabolic strain associated with each task was quantified.

From these data, we have drawn the following conclusions and recommendations:

- The task analysis revealed five essential tasks (i.e. hose run, equipment carry, stair climb, casualty evacuation and wild-land fire) for all operational firefighters, two of which were applicable to an incident command role (i.e. stair climb and wild-land fire).
- A Physical Demands Analysis (PDA) was completed and the occupational tasks were endorsed by participants as reasonable minimum expectations.
- Results of the PDA suggest that a $VO_2\text{max}$ of $42.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ is necessary to perform these tasks safely and effectively. This recommended cardiorespiratory fitness standard was endorsed by both technical and stakeholder panels.
- In order for such a national guidance to be successful in improving the health and fitness of UK firefighters, consideration must be given to the resources required to ensure employees are able to meet capability criteria.
- Further consultation was conducted to derive a fitness management protocol. A guidance document should now be produced, recommending a process for the conduct and reporting of annual fitness assessments for all UK FRS personnel.
- Data collection was also completed to determine the strength tests and standards for completing essential fire-fighting tasks that require either static

strength (e.g. ladder lift) or muscular endurance (e.g. ladder extension). Three predictive surrogate tests were chosen to simulate performance in ladder manipulation tasks; a seated barbell shoulder press (35 kg); a single rope pull down (60 kg) and a repeated rope pull of 28 kg (23 repetitions). These requirements require validation and impact assessment with a larger sample, post implementation.

Further work is required to ensure that the UK FRS benefit fully from this initial investment:

- User guidance needs to be published and distributed to promote common practice in term of annual firefighter fitness assessment across the services.
- Following implementation, data should be collated to assess the relationship between drill ground test performance (criterion tasks) and cardiorespiratory fitness (surrogate tests). There is a strong desire to use the drill ground tests as part of a comprehensive package of annual fitness testing, but we must clearly understand the relationship between these testing protocols before doing so.
- Alongside the PDA work, an online health and lifestyle survey has been administered nationally to 3139 UK FRS personnel. As part of this health and lifestyle work, blood samples have been collected and analysed from 54 participants with an aim to assess the relationship between lifestyle risk factors and cardiovascular disease. However, in order to attain a large enough population sample to complete these analyses, blood samples are now required from ~250 further participants who have already completed the health and lifestyle survey.
- In order to understand the complex inter-relationships between lifestyle behaviours and risk factors for adverse health in this population, further statistical analyses are required. Multivariate statistical analyses of health and lifestyle survey responses will inform the design and development of health promotion initiatives for FRS personnel.

Contents

| | | |
|------------|---|-----------|
| 1.0 | Context | 6 |
| 2.0 | Introduction | 6 |
| 3.0 | Task Analysis | 12 |
| 4.0 | Physical Demands Analysis | 26 |
| 5.0 | Strength & Muscular Endurance Requirements | 38 |
| 6.0 | Conclusions & Recommendations | 53 |
| 7.0 | Future Directions | 56 |
| 8.0 | References | 58 |

1.0 Context

The research contained in this report was commissioned by the Chief Fire Officer's Association (CFOA), with significant financial support from the Fire Service Research and Training Trust (FSRTT) and the FireFit Steering Group (FFSG). CFOA are currently reviewing the management of policies for health and fitness within the UK Fire & Rescue Service (FRS). This report comprises two studies that have the overall aim of ensuring and improving the health and safety of UK FRS employees. The first aimed to objectively quantify the physical demands of firefighting to inform on minimum fitness requirements for safe and effective work. Preceding this, it was necessary to perform a thorough analysis of firefighter tasks. The second was an examination of the strength requirements for criterion firefighting tasks, evaluating the extent to which gym-based surrogate tests could be used to best predict occupational task performance. Separate to this report, other work was completed investigating the lifestyle, well-being and health profile of FRS employees, with a view to identifying groups at risk of adverse health conditions and examining potential links to lifestyle behaviour. It is the aim of the research group to release the findings of this work in a separate future document, providing health and fitness advice for all fire service employees.

2.0 Introduction

It is widely recognised that the role of a firefighter involves a broad range of tasks that can be both physically and mentally arduous, and often unpredictable in nature and duration. To be prepared for such tasks, firefighters require appropriate training and development throughout their careers. Such training is designed to deliver continued operational capability as well as ensuring the health and safety of employees and members of the public involved in emergency incidents.

An integral part of being able to complete the role of a firefighter safely and effectively is maintaining physical health and fitness. It is widely-recognised that a firefighter should aim for a high level of physical fitness to be capable of coping effectively, both mentally and physically, with the stresses and physical demands of

the occupation. This is of particular concern when cardiac events, predominantly associated with coronary heart disease, account for the largest number of on-duty firefighter fatalities in the United States (Fahy, LeBlanc & Molis 2013). The majority of fatal cardiac events in firefighters (63%) are associated with responding to, or returning from, emergency incidents (Kales et al. 2007), further indicating the risk that the physical stress of the occupation imparts on the firefighter. Due to a lack of information on the health profile of the UK FRS population, it is not known whether UK firefighters are under the same risk as equivalent international occupational groups. However, in 2008 the proportion of UK firefighters that were either overweight or obese was 65%, compared with 42% of the general population (Munir et al. 2012). This is particularly noteworthy given the strong association between obesity and cardiovascular disease risk, amongst other health issues such as hypertension and type II diabetes.

Firefighters with poor physical fitness and health performing occupational duties may be being placed under high personal risk. Despite this, after initial capability testing at entry, there is no national policy nor official accepted guidance regarding the implementation of minimum physical fitness standards nor the maintenance of physical health and fitness thereafter. This appears to be, in part, due to there being a wide variation of skills and resources (i.e. Health & Fitness Advisors) across the services, which influences the provision of health and fitness testing and advice. However, it is a concern that firefighters may be unable to receive the resources necessary to best achieve appropriate levels of health and fitness, which directly affects occupational ability and safety.

In light of the background information above, it has become increasingly important for occupational capability testing and minimum physical fitness requirements to be based on evidence from well-controlled scientific research. This protects employees by helping to ensure their safety while also aiding organisations by lending confidence that capability testing is entirely integral to the occupation. The comprehensive and challenging process of establishing robust and legally defensible fitness standards has been reviewed by Tipton, Milligan & Reilly (2012). It was identified that a thorough task analysis should first be performed to determine the most physically arduous and critical tasks, which all personnel are required to

perform and to develop descriptions of standard practice for those tasks. This process, for instance, was followed in order to develop the physical tests for UK firefighter entry selection (Rayson et al. 2009). Following this, the metabolic demand (oxygen uptake) of the selected task(s) should be measured in a controlled trial, from which a fitness standard can be derived. Currently, within the UK FRS there exist two fitness standards for trained firefighters based on maximal oxygen uptake ($\text{VO}_2 \text{ max}$), a measure of cardiorespiratory fitness, typically presented as a rate of oxygen uptake relative to body mass ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). However, these standards are not based on the direct measurement of the physical demands of firefighting tasks which are specific to the UK population and, as such, are not sufficiently supported by empirical evidence.

The general fitness standards within the UK FRS are a predicted $\text{VO}_2 \text{ max}$ of $42 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, below which an individual may continue work but is advised to improve fitness; and $35 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, below which an individual is deemed unacceptable for work until they attain a suitable standard from remedial training. These values were derived from a review of previous physical demands studies from other national fire services, with an expectation that further work would be completed to produce population-specific empirical evidence at a later date.

Typically, the critical tasks perceived to be most arduous in firefighting populations include hose running, casualty evacuation and stair climbing with equipment (Misner, Plowman & Boileau 1987; Bugajska et al. 2007; Rayson et al. 2009). Several job and task analyses specific to UK firefighters have been conducted previously with similar findings, identifying operations using breathing apparatus or hose running as those eliciting highest cardiovascular demand, and casualty and equipment handling requiring the most physical strength (Scott 1988; David et al. 1997; Brewer 1999). An internal government report identified running and climbing ladders, strength tasks such as lifting and carrying, and coping with different extreme environments to be critical to UK operational duty (Rayson 2004). Optimal Performance Limited (OPL) performed a task analysis to design the physical tests now currently used for point-of-entry firefighter selection (Rayson et al. 2009). To fulfil the aim of encompassing the overall role of a firefighter, in consultation with subject matter experts, scenarios were identified that contained a mixture of

cardiorespiratory, strength, psychological and/or skill-based demands. Subsequently, simulations for rural fire, domestic fire search and rescue, enclosed space and ladder lift/extensions were devised (Rayson et al. 2009). While performance of trained and non-trained firefighters in task completion was assessed to validate tasks and derive entry standard thresholds, metabolic demands of scenarios were not monitored.

Previous studies have estimated the physical demands of firefighting but some limitations exist in the measures of physical exertion, level of experimental control within trials and the process of identifying the tasks used. Several studies first indicated from heart rate data that firefighting can elicit near maximal cardiovascular strain, and that this physical exertion could continue for the duration of the emergency event (Barnard & Duncan 1975; Manning & Griggs 1983). Physical demands analyses completed in UK firefighters have so far been limited to monitoring cardiovascular strain during firefighting activities and estimating, but not directly measuring, metabolic demand (Scott 1988; David et al. 1997; Brewer 1999). Heart rate responses to an in-built firefighting scenario suggested physical strain of between 60-95% of maximum based on heart rate reserve in trained firefighters and instructors (Eglin, Coles & Tipton 2004; Richmond et al. 2008). From studies in other firefighting populations whose protocols directly measured oxygen uptake, few have identified the metabolic demand of firefighting to be under $35 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Sothmann et al. 1990), while others have consistently reported values of critical firefighting tasks in excess of $40 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Gledhill & Jamnik 1992; Bilzon et al. 2001; von Heimburg, Rasmussen & Medbø 2006). Further to this, however, many studies have been limited by having tasks paced by the participant. In a self-paced environment, participants who possess more appropriate fitness for a job have the capacity to work at a greater work rate relative to those of lower fitness and will perform the task faster (Lemon & Hermiston 1977), subsequently increasing the physical demand measured. Bilzon et al. (2001), while investigating the physical demands of shipboard UK Naval firefighting tasks, set a constant predetermined pace for each activity, meaning the physical demand of the task itself was measured without any bias towards the fitness of the participating individual. In addition, each task was designed to allow a steady-state of oxygen uptake, resulting in the ability to direct measure metabolic demands, which ranging from 23 to $43 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. The

reproduction of this study and task design would, therefore, be useful in UK civilian firefighting.

Possessing a VO_2 max equal to that of the occupational physical demand is not necessarily sufficient to work safely for the duration of an emergency response. The current literature appears to suggest that with the current UK FRS fitness standards, there are individuals with an aerobic capacity of 35-42 mL·kg⁻¹·min⁻¹ completing occupational duties which may place them at supra-maximal exertion, and subsequently at high risk of injury or cardiovascular event. While some comparisons can be drawn between the occupational work of firefighters within different nations, it would appear vital for the minimum fitness requirements of an occupation to be derived directly from task and physical demands analyses specific to that population.

It is also evident that the physical strain placed on a firefighter is not solely encompassed by cardiorespiratory elements of fitness. The ability to carry heavy equipment, and manipulate ladders and extricate casualties while maintaining technical skill have been identified as critical to the role (Rayson et al. 2009) and require a certain level of muscular strength. In several firefighting populations, strength capabilities have been tested via hose and casualty dragging, equipment carrying, and ladder manipulation at a range of masses (Davis, Dotson & Santa Maria 1982; Rhea, Alvar & Gray 2004; Dennison et al. 2012). The aforementioned preparatory work for UK firefighter entry selection utilised previously commissioned simulators for ladder lift and extension tasks to development strength tests. However, much like cardiorespiratory fitness, no further routine strength testing occurs in serving firefighters. While these simulators accurately mimic strength tasks, low availability and some safety concerns mean that gym-based surrogate tests that are more readily available to fire services for use in serving employees may be useful in improving strength monitoring in the UK FRS.

It is evident that completing an accurate physical demands and strength analysis of the role of a UK firefighter would better inform the overall fitness required to ensure occupational health and safety in this population. The inclusion of appropriate scientific evidence could more clearly define the implementation of a fitness standard and a collectively accepted national framework for achieving or

maintaining it, which currently does not exist for trained firefighters within the UK FRS. These findings may go some way to improving the guidance and provision of resources for ensuring firefighter health and fitness.

3.0 Task analysis

3.1 Aim

To use a consultation process to produce single-person simulations of the most physically arduous, predictable and essential tasks a firefighter might undertake and determine the minimum acceptable pace for these tasks, with a view for their use in quantifying the physical demands of firefighting.

3.2 Methods

It is generally accepted that an empirically valid occupational fitness standard should be produced from the measurement of the physical demand of tasks directly representative of necessary occupational tasks. These should be the most arduous tasks that are critical for any member of that occupation. In order to determine the physical fitness required to undertake the role of a firefighter then, it is prudent to complete a task analysis. A recent review by Tipton, Milligan & Reilly (2012) of best practice for developing fitness standards based on job capability listed the following three points for effective task analysis:

1. Establish the critical tasks: identify the critical, physically demanding tasks through task analysis and determine the number and nature of tasks to be included.
2. Determine the “Method of Best Practice” for undertaking the critical tasks.
3. Agree on an acceptable minimum level of performance on the critical tasks.

This process was followed with a view to measuring the physical demand of these tasks in a sample of firefighters to determine an appropriate fitness level. The requirements of an occupation, as well as what constitutes the successful completion of an occupational task, inherently contain a balance of objective and subjective considerations. As such, it is recommended by authors (Constable & Palmer 2000; Tipton et al. 2012) that a task analysis is completed by individuals who are highly

experienced in the tasks and the occupation itself, but also by researchers or members of an organisation external from the occupation. This ensures that decisions made are free from unnecessary bias and that several practical and scientific considerations are also made. For instance, whether the task facilitates the use of the equipment that will measure metabolic demand, or whether the task will be easily paced or controlled. While similar task analyses have been conducted before in the UK FRS (Rayson et al. 2009), the design and implementation of the resultant tasks would require fulfilment of specific criteria for our aims, and using specific subject matter experts. Addressing these considerations ensures that the tasks that are chosen for physical demands analysis are (a) suitable (from both an occupational and practical stand point), (b) applicable to the chosen population, (c) representative of actual job performance and (d) able to accommodate the accurate measurement of physical demands of the occupation.

Technical and Stakeholder Panels

Two panels of individuals were assembled that were consulted at different stages of the task analysis process. The first was termed a “technical panel” and was composed of 13 highly experienced operational firefighters and training instructors currently employed in the UK FRS. The technical panel would fulfil the need for job-specific experience, supplying detailed technical knowledge of job requirements. The research team ensured that the technical panel included specialists in different areas of firefighting and represented a wide range of geographical locations within the UK.

A second panel, of “stakeholders” was assembled with invitees from the chief fire officer’s association (CFOA), fire brigade and retained firefighters’ unions, as well as senior health, safety and fitness staff. This panel was formed to critically evaluate the work and discuss practical and potential implications at each juncture. Any representatives of these groups that did not attend scheduled meetings were kept informed by organising separate meetings and by written research updates.

The university research team worked closely with both panels and gained consultation and endorsement on key decisions during the programme of work (Figure 1).

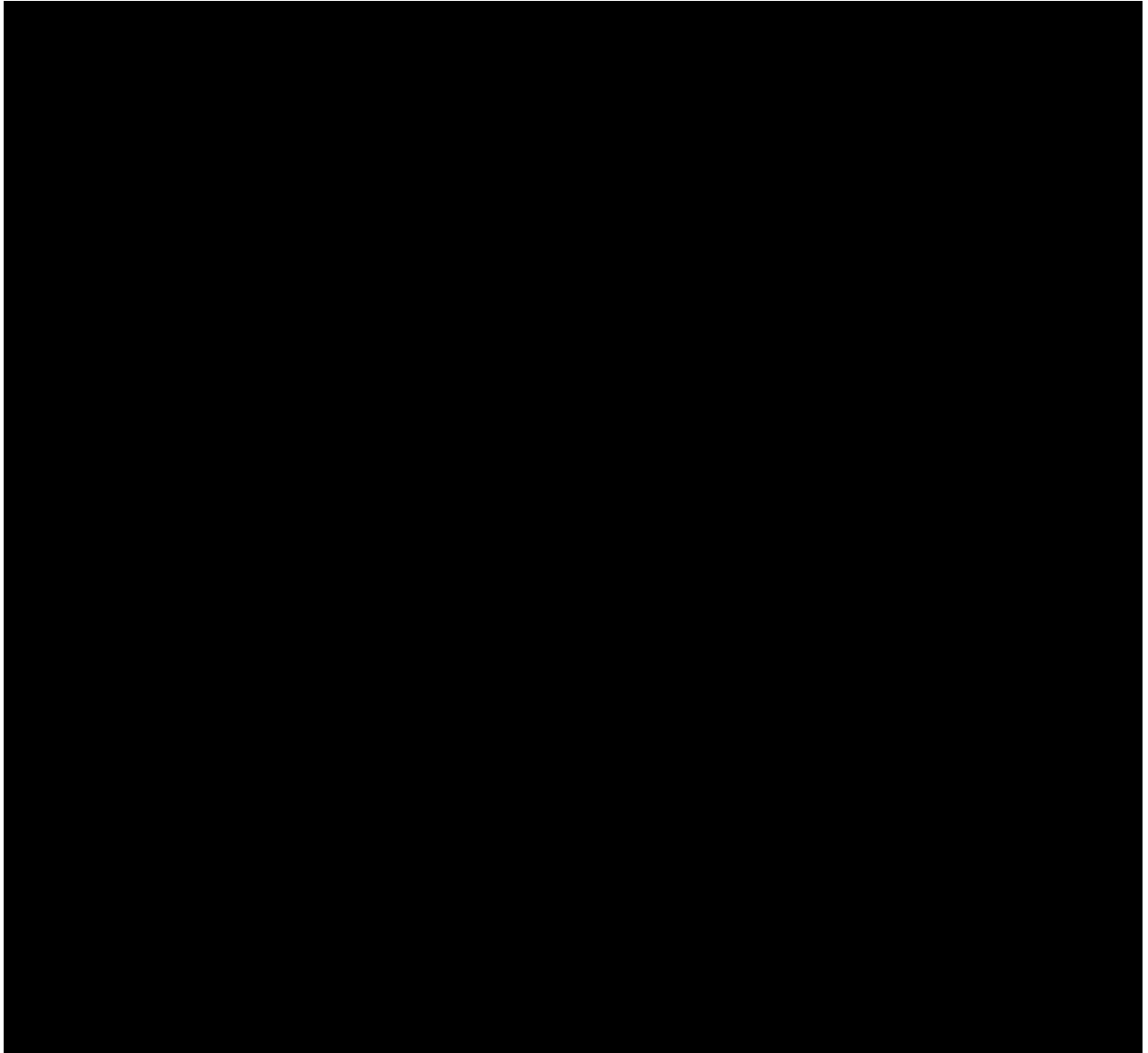


Figure 1. Task analysis consultation process, organised by meetings with technical and stakeholder panels. Boxes with rounded edges denote work completed by the research team.

Identifying the Most Arduous Firefighting Tasks

In an open discussion session, the technical panel members were asked to identify the most physically arduous tasks a firefighter might face. These were then filtered by tasks that may not be undertaken by all firefighters (i.e. specialist roles such as swift water rescue). It was evident that if a fitness standard was derived from these tasks, the tasks must be representative of the expected occupation for all firefighters.

As the tasks being considered were solely to identify the degree of physical exertion required for completion, considerations were also made towards whether the real-world occupational tasks are predictable in nature and would therefore be reproducible as a simulation. In order to assess the physical demands, these simulations needed to be replicable on a fire-ground and contain a high level of control. Reducing the number of uncontrolled variables during the task increases the likelihood that all participants would complete precisely the same task, thereby eliciting a similar physical demand. As such, it was important to also gain feedback from the panel to describe best practice of the tasks. These discussions centred on the variability of techniques, equipment and protective clothing used, and the typical duration and distances involved in completing the tasks. For designing simulations of the occupational tasks in the next stage of the task analysis, these factors would become vital for achieving high external validity but also reducing inter-individual variability when completing the physical demands analysis.

Producing Single-person Task Simulations

From the previous meeting with technical panel members, a fire-ground based single-person simulation and an appropriate contextual scenario were designed for each occupational task. To fulfil the research aims, criteria for the simulations were that they should (a) replicate the occupation tasks, (b) determine individual performance, (c) be reproducible and standardised in nature, and (d) be long enough to elicit a steady state of energy metabolism during exercise. If an identified task was typically completed as part of a team, the simulation was designed such that the simulation covered one individual's input to that task. The exact specifications of these tasks were then sent to the technical panel for feedback and amended as

necessary. Upon unanimous agreement on all tasks from the technical and stakeholder panels, the intensity (pace) of the tasks then needed to be established.

Establishing the Minimum Acceptable Pace of Task Simulations

As the simulations were agreed to be representative of good practice of critical firefighting tasks and the aim is to achieve a minimum fitness standard, the pace of the simulations were required to be the “minimum acceptable pace” for safe and effective completion of the occupational tasks. A process was followed to reduce the potential subjectivity of this decision. Experienced training instructors from the Cardiff Gate Training and Development Centre completed the tasks as designed at their own pace. The average speed was calculated and was used as a central reference for then deciding a “slow” and “fast” speed for each task. Audio files were produced that made an audible bleep at time intervals to correspond with 5 metre intervals for each of the speeds required. Completion of the tasks was filmed with cones at 5 metre intervals in order to set each required speed.

The videos of each task were shown to the technical panel. Before each video, the contextual scenario for each of these tasks was given. This allowed the perception of the intensity and/or urgency of the task to be controlled. Technical panel members voted anonymously for which speed was, in their opinion, the minimum acceptable pace for the simulated operational task under question and that the decision should be irrespective of current employee ability. Members were also given the chance to choose the task pace that lay half way between those displayed in each of the three videos, giving a choice of 5 speeds in all. These were then numbered 1-5 (With “1” scored for the slowest video) for voting purposes and discussions from video analysis. Members were invited to report back if they thought the minimum acceptable pace was outside of the 1-5 range offered. Summary results were then shown to the panel and the modal response was considered. Any remaining concerns were discussed, particularly where scores varied widely. A group consensus was achieved for each task.

Incident Command Role Requirements

It was a secondary aim of the group to attempt to understand the physical demand of those in a position of incident command. The technical panel were also asked to comment on which tasks would be completed by senior officers, and how these roles would be different, physically, from those of the operational firefighter. For the tasks where this was applicable, a section was designed and included with the endorsement of the technical panel that simulated the demand of an incident command role.

3.3 Results

Task Descriptions

Five tasks were chosen and designed from discussions with the technical panel. These consisted of hose run, equipment carry, stair climb, casualty evacuation and wild-land fire tasks. All tasks were endorsed by technical and stakeholder panels as single-person simulations of jobs necessary to the role of a UK FRS firefighter. Below are the procedures and contextual scenarios for these tasks.

Hose Run Task: This task was designed as an assessment of the physical requirement of carrying and running out four lengths of standard issue 70 mm hose. The contextual scenario was as follows:

- 1st pump attendance at fire in rural village.
- Four in the team, three are involved in other tasks.
- Driver unable to position appliance any closer than 4 lengths (100 m) from hydrant.
- Single-person task to access hydrant with single line of hose.

A shuttle run (25 m) is set up on a drill ground, with markers at every 5 m. The participant first runs eight shuttles (200 m) simulating the transport to and from the

hydrant of a standpipe, key and bar. The participant then carries two rolled lengths of 70 mm hose over four shuttles (100 m), but dropping one at 75 m and the second at 100 m. The participant immediately carries and rolls out each of these hoses over 25 m shuttles. Two further shuttles are run to simulate returning to the appliance. Two more hoses are collected and carried for two shuttles (50 m), dropping one at 25 m and the second at 50 m. As before, these are then carried and rolled out across the two 25 m shuttles. The task is completed with eight further shuttles (200 m) to simulate returning to activate the hydrant and a return to the appliance. The task has a total distance of 700 m and is completed in full personal protective clothing (Tunic, leggings, boots, helmet, gloves). The 70 mm hose used was standard issue and was 25 m in length and a mass of 13 kg.

Equipment Carry Task: This task was designed as an assessment of single-person requirement to transport a light-portable pump (or similar) over 200 m. Portable pumps range from a two person carry 60 kg pump (~30 kg per person), to a 4 person carry 110 kg pump (~27.5 kg per person). Manual handling regulations stipulate a 25 kg limit, which is adhered to in this task. The contextual scenario is as follows:

- Barn fire in remote rural village.
- Open water access required from stream at rear of property.
- Light portable pump and associated equipment to be transported to stream 200 m away.

A shuttle run (25 m) is set up on a drill ground, with markers at every 5 m. Participants carry a 25 kg barbell over eight shuttles (200 m). The participant is allowed to place the weight down to shift grip if necessary. This task is completed in full personal protective clothing (Tunic, leggings, boots, helmet, gloves).

Stair Climb Task: This task was designed as an assessment of an individual member of a Breathing Apparatus (BA) team carrying a high-rise pack to “bridge head” in a high rise incident. A high rise pack ranges from a 50-60 kg and is typically carried by

two people. As above, the single person carry in this task adheres to manual handling regulations (25 kg). The contextual scenario is as follows:

- Fire on 6th floor of high-rise building (2 flights per floor).
- A high-rise pack is required at the bridge head.

This task is completed in a high-rise stairwell. The stairwell consists of six floors, with two flights of stairs on each floor and 10 steps per flight. The participant first fully ascends and descends the stairwell to simulate the occupational demands of an incident command role in this scenario. The participant then ascends while carrying a dumbbell (25 kg) to simulate the carriage of a high rise pack. The dumbbell is left at the top before descent. This task is completed in simulated breathing apparatus by wearing a backpack equivalent to the mass of a UK FRS breathing apparatus unit (12.1 kg; at time of investigation) and full personal protective clothing (Tunic, leggings, boots, helmet, gloves).

Casualty Evacuation Task: This task was designed to assess the physical demand of the role of team leader in a commercial property fire with entry and casualty evacuation. The contextual scenario is as follows:

- Fire in a medium-sized commercial property. Persons reported inside.
- Two pump attendance. Second pumping appliance arriving 10 min after first.
- Four riders on initial pump in attendance.
- BA team of two.
- Forcible entry to property required.
- Team leader to take sledge hammer and charged hose to point of entry.
- Second team member to carry TIC and entry control board to point of entry.
- Both team members to make progress and locate casualty
- Team leader to drag casualty back to point of entry.

A 25 m square of drill ground is required, with an appliance with charged hose reel and sledgehammer (3.8 kg) at one corner, and a dummy (55 kg), simulating a casualty, at the opposite corner. This task has two phases:

- 1) The participant carries the sledgehammer directly away from the appliance, dropping it at 25 m, and returns. The participant then pulls the hose reel away from the appliance, dropping the branch of the hose at 25 m and returning to pick up the mid-section of hose and drag that to the branch. The branch is collected and pulled around the corner of the square and 25 m to the dummy. This section (two sides of the square) is marked with cones every 5 m.
- 2) The participant places down the branch of the hose and using standard operating procedure (grip under armpits) drags the dummy 50 m along the final two sides of the square. This section is marked by cones at every 2.5 m.

The alteration in cone marking allows for the same audible bleeps to be used to elicit a pace in the second phase that is half that of the first. This task is completed in simulated breathing apparatus by wearing a backpack equivalent to the mass of a UK FRS breathing apparatus unit (12.1 kg; at time of investigation) and full personal protective clothing (Tunic, leggings, boots, helmet, gloves). The charged hose in this task weighs approximately 37 kg.

Wild-land Fire Task: This task was designed to assess the demand of an individual firefighter's contribution to a team fighting a wild-land fire. The contextual scenario is as follows:

- Firefighting is taking place at a wild-land fire.
- All-terrain vehicle to transport equipment near to scene of operations.
- Working as a team, each team member equipped with fire beater.
- Firefighters required to extinguish fires behind flame front over 50 m² area.

A shuttle run (50 m) is set up on a stretch of undulating grassy terrain on an ascent, with markers at every 5 m. The participant ascends (and descends) twice (200 m) to simulate an incident command role in this scenario. Then participant then ascends

(and descends) twice more (200 m) equipped with a fire beater. The fire beater is used to strike the ground on every other walking step during the two ascents. The task is completed while wearing only the leggings, boots and gloves of the personal protective clothing, on top of any personal clothes. The fire beater was standard issue and consisted of a long pole with an attached foam/rubber pad (mass 5 kg).

Minimum Acceptable Pace

For each task described above the three speeds that were shown to voting panel members are detailed in Table 1. From anonymous blinded voting, the minimum acceptable paces were established for the hose run ($8 \text{ km}\cdot\text{h}^{-1}$), equipment carry ($5.5 \text{ km}\cdot\text{h}^{-1}$), stair climb ($95 \text{ steps}\cdot\text{min}^{-1}$), casualty evacuation (Hose section: $6 \text{ km}\cdot\text{h}^{-1}$; Dummy drag section: $3 \text{ km}\cdot\text{h}^{-1}$) and wild-land fire ($3.5 \text{ km}\cdot\text{h}^{-1}$) tasks (Table 2).

Table 1. The speeds of tasks (blinded) shown by video to the voting panel to establish minimum acceptable pace.

| Task | Video A | Video B | Video C |
|---------------------------|--|--|---|
| Hose Run | $6 \text{ km}\cdot\text{h}^{-1}$ | $8 \text{ km}\cdot\text{h}^{-1}$ | $10 \text{ km}\cdot\text{h}^{-1}$ |
| Equipment Carry | $4 \text{ km}\cdot\text{h}^{-1}$ | $6 \text{ km}\cdot\text{h}^{-1}$ | $8 \text{ km}\cdot\text{h}^{-1}$ |
| Stair Climb | $75 \text{ steps}\cdot\text{min}^{-1}$ | $95 \text{ steps}\cdot\text{min}^{-1}$ | $115 \text{ steps}\cdot\text{min}^{-1}$ |
| Casualty Evacuation: | | | |
| <i>Hose Section</i> | $4 \text{ km}\cdot\text{h}^{-1}$ | $6 \text{ km}\cdot\text{h}^{-1}$ | $8 \text{ km}\cdot\text{h}^{-1}$ |
| <i>Dummy Drag Section</i> | $2 \text{ km}\cdot\text{h}^{-1}$ | $3 \text{ km}\cdot\text{h}^{-1}$ | $4 \text{ km}\cdot\text{h}^{-1}$ |
| Wild-land Fire | $2 \text{ km}\cdot\text{h}^{-1}$ | $3 \text{ km}\cdot\text{h}^{-1}$ | $4 \text{ km}\cdot\text{h}^{-1}$ |

Note: A vote for the speed in Video A (slowest) was scored a "1" and Video C (fastest) was scored a "5" with corresponding numbers for paces between each video.

Table 2. Minimum acceptable paces established from panel voting, organised by task.

| Task | Average voting score (1-5) | | General Consensus | |
|---------------------------|----------------------------|---------------------------------|-------------------|----------------------------|
| | Mean (SD) | Mode (Number of occurrences) | Score | Corresponding speed |
| Hose Run | 2.8 (0.4) | 3 (10) | 3 | 8 km·h ⁻¹ |
| Equipment Carry | 2.3 (0.9) | 2 (6) | 2.5 | 5.5 km·h ⁻¹ |
| Stair Climb | 3.1 (0.7) | 3 (7) | 3 | 95 steps·min ⁻¹ |
| Casualty Evacuation: | | | | |
| <i>Hose Section</i> | 3.5 (0.8) | 3, 4 (5) | 3 | 6 km·h ⁻¹ |
| <i>Dummy Drag Section</i> | 3.0 (0.9) | 3 (7) | 3 | 3 km·h ⁻¹ |
| Wild-land Fire | 3.9 (1.2) | 4 (5) | 4 | 3.5 km·h ⁻¹ |

Note: Voting was scored on a 5-point scale with 1 being the slowest and 5 for the fastest pace observed.

3.4 Discussion

A task analysis of operational firefighters in the UK Fire & Rescue Service was conducted with a view to identifying the most physically arduous tasks that are critical to any firefighter's occupational role. Specific criteria were set to allow tasks to be replicated in a controlled manner for future work on determining firefighter physical demand. Five tasks were identified by a highly experienced panel of firefighters, comprising a hose run task (running, carrying and manipulating hose); carrying equipment, both over flat ground and to high-rise incidents; tackling a wild-land fire using fire beaters; and entry to, and extraction of a casualty from, a large industrial fire. Fire-ground simulations of these tasks were designed that would be easily controlled and replicated, that followed standard methods of practice, and that had minimum acceptable paces that were chosen and verified by the same panel.

Previous studies investigating the physical demands of firefighters from outside of the UK have used a wide variety of tasks and tests. Gledhill and Jamnik (1992) completed a physical demands analysis using five tasks that were deemed the highest occupational applications of endurance and strength in Canadian firefighters, which comprised the advancement of charged hose; dragging a dummy (casualty) over distance; climbing stairs with equipment and two repetitive pulling activities. Previous task, job and physical demands analyses conducted for local government in firefighters in the UK have similarly identified rural and domestic fire, search and rescue, and hose running as operational duties with high cardiovascular strain (David et al. 1997; Brewer 1999; Rayson et al. 2009). Similarly, when studying shipboard UK naval firefighters, Bilzon (2001) included a hose manipulation task as well as ladder ascension and carrying heavy equipment over distance. Since the specific aims of the present study meant a novel task analysis was required, it is reassuring that several independent UK studies have found similar tasks to be appropriate for physical demands measurement. In addition, Bilzon (2001) also found that 97% of the firefighters that participated agreed the tasks were an accurate reflection of an occupational task, similar to the current investigation, and supporting the authenticity and validity of such tasks. The present task analysis has resulted in similar tasks to those in the above studies, exhibiting a mixture of strength based carrying tasks and those potentially eliciting a high aerobic demand, in a setting specifically appropriate to the occupation of a UK firefighter.

Within the scientific domain, attention has shifted towards ensuring that employment capability is supported by valid and robust research, indicating a need for a thorough task analysis and comprehensive physical demands analysis in UK firefighters. The consultation process implemented in this study and the composition of the panels of members to endorse decisions follows criteria drawn out in recently published guidelines for establishing scientifically supported employment standards (Tipton et al. 2012). The process followed also appears to improve on previous work by including video analysis, blinded voting and separate panels to each solely deal with technical and potential political implications of the work.

In the present study, it was important that the tasks and subsequent simulations were chosen and designed, respectively, such that the final products

would be easily controlled, reproducible on a fire-ground with standard equipment, and contain sufficient physical activity to elicit a steady state of metabolism during performance. However, it was also important to not have these criteria affect the external validity of the tasks to their real-world counterparts. Typical concerns raised by the panel, and acted upon, included the correct and safe weight of appropriate equipment for the scenario, the prohibition of running while wearing breathing apparatus and credible transition of group tasks to single person simulations. As such, gaining feedback and consensus from a panel of experienced operational firefighters at each step of simulation design ensured a high level of rigour. These criteria encompass the need for a task analysis specifically for the present investigation, and not the replication of others previously described.

Furthermore, the aspect of minimum pace within this task analysis has improved on previous research. If a physical demands analysis is to be used to inform on a minimum fitness standard, it follows that the tasks involved should be completed at the “minimum acceptable” pace. Unfortunately, determining this pace always contains some subjectivity (Tipton et al. 2012). However, the blinded voting system using video evidence in the present task analysis was designed to be the foremost process for reducing subjectivity in this subject area. Additionally, it was decided that having a repeated sound to pace tasks instead of a self-paced task or a task paced by a resident experienced instructor would reduce inconsistency and introduction of error from subjectivity. Many studies from Bilzon et al. (2001) onwards have attempted to establish a constant pace as it improves experimental control and establishes a steady state of oxygen cost, as large alterations in pace or exertion during physical activity would likely introduce error in oxygen uptake.

It should be noted that a typical, but inaccurate, perception is that high temperatures, and thereby compartment fire conditions, greatly increase metabolic demand of physical tasks. However, it has been established that the effect of environmental temperature on actual metabolic rate is negligible and is outweighed by altered perception of fatigue driven by protective mechanisms in the brain (Nybo 2007). This, combined with the practical implications of both producing a reproducible, controlled environment and using instruments not designed to withstand excessive heat meant that setting all tasks in temperate environments

would maintain experimental control and improve validity and reliability. The latter of these reasons probably also explains why so few studies have been completed that directly measure metabolic demands of firefighting.

Finally, it is acknowledged that the varied role of a firefighter requires components of fitness that extend that of solely an aerobic fitness standard. However, it is generally accepted that oxygen uptake is the most robust measure of overall physical fitness, having been previously correlated with performance in a range of athletic events and populations. The tasks derived in the present study do include a variety of applications of physical exertion. However, later in this report, the strength requirements of operational UK firefighters are also examined based on individual occupational tasks that solely require application of strength, and not cardiorespiratory demand.

4.0 Physical Demands Analysis

4.1 Aims

To measure the oxygen cost, and therefore metabolic demand, of several simulated fire-fighting tasks completed at pre-determined “minimum acceptable” pace in a sample of UK firefighters.

4.2 Methods

Sample Stratification

In the context of this research question, evidence would suggest that gender, fitness and bodily characteristics are largely irrelevant to the physical demands of a set task. However, efforts were made to attempt to use a sample representative of the UK FRS nationally, by completing a sample stratification prior to recruitment. Anthropometric data (body mass, height, body mass index) and age from four UK Fire & Rescue Services (n=2866) were used to establish terciles of age and BMI for males and females. Fire services were then approached to attempt to recruit firefighters for the study such that a third of their sample fulfilled each of these criteria.

Participants

Sixty two (50 male, 12 female) operational firefighters (Mean (\pm SD): age 40 (\pm 10) y, mass 80.8 (\pm 11.8) kg, height 1.76 (\pm 0.07) m, BMI 26 (\pm 3) kg·m², estimated body fat 21.8 (\pm 5.6)%) gave written informed consent to take part in the study following a full written and verbal brief. Participants represented a total of 15 UK Fire & Rescue services and contained 50 whole-time and 12 retained staff. Inclusion criteria were that participants were trained and currently operational and medically fit for service as a firefighter in the UK Fire & Rescue Service. Participants were recruited using

chief fire officer channels and correspondence with health and fitness advisors and occupational health employees.

Study Location

All physical demands data collection was completed at the Fire Service College, Moreton-in-Marsh, Gloucestershire, UK.

Study Protocol

Following a morning collection of anthropometric data (body mass, height, estimated body fat (Bodystat 1500, Bodystat Ltd, UK)) and grip strength (Hand-grip dynamometer, Takei, Japan), participants completed the five tasks described in the previous section; the hose run, equipment carry, stair climb, casualty evacuation and wildland fire simulation, in a randomised order. Each task was separated by an hour of recovery. Throughout the day, participants were allowed access to food and drink *ad libitum*. Before each task, a full verbal brief of the task was given, and throughout tasks a project researcher moved with the participant and gave instruction.

Four out of the five tasks were paced by audible beeps that corresponded with cones on the fire-ground at every 5 metres. 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 worn equivalent to the mass of a UK FRS breathing apparatus unit at time of investigation (12.1 kg).

Task Validity and Authenticity

To assess validity of the tasks and their paces, participants were asked a series of questions at the end of each exercise. Participants were asked whether they received adequate instruction and whether the task was an adequate reflection of

what one might be expected to perform in a training or operational setting. Additionally, participants were asked whether, in their experience, the task pace appeared to them to be “too slow”, “too fast” or “about right”.

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.

To determine aerobic demand of the tasks, a minute of steady state VO_2 was selected for each participant within each task. 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 either a substantial incline or decline in oxygen uptake. Steady state minutes were cleaned from anomalous breathes 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 was then calculated by subtracting resting heart rate from age-predicted heart rate max ($220 - \text{age}$). For each task, the steady state heart rate was also expressed as a percentage of heart rate reserve (roughly equivalent to percentage VO_2 max).

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 tasks. Job status and sex were included as between-subjects factors to assess any differences in physiological responses to

tasks between whole-time and retained firefighters, and males and females, respectively. Participants who did not complete the tasks, or did not keep to the issued pace were removed from physical demands analysis. When comparing between tasks, ANOVA solely analysed those that completed all tasks successfully (n=47). Statistical significance was set at $p \leq 0.05$. All data are presented as mean \pm SD unless otherwise stated.

Derivation of a Fitness Standard

Only the physical demands data for tasks that were deemed to be an adequate reflection of training or operational duties were used to derive a cardiorespiratory fitness standard. As the tasks were designed to separate the roles for operational firefighters and senior officers in incident command roles, separate fitness standards were produced for both roles. Standards were derived by first taking an average of the physical demands of all suitable and replicable tasks and second, correcting for the exercise intensity required to elicit an appropriate work-time.

4.3 Results

Task Validity and Authenticity

All participants (100%) stated they received adequate instruction for each of the tasks. Almost all respondents (93.5%) stated that tasks were an adequate reflection of what they might be expected to perform in training or operationally. The wild-land fire task was the only task not to be perceived as adequate by more than 90% of respondents (83.9%). Similarly, the wild-land fire task was perceived to be “too slow” by a proportion (58.3%) of participants, whereas the work rates of all other tasks were deemed “about right” by the majority of respondents (91.1%). Further feedback collected on the wild-land fire task indicated that some individuals felt the pace was appropriate while walking when using the beater, but not appropriate without.

Task Performance

The equipment carry and wild-land fire tasks were completed successfully by all participants. 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, and one unable to complete. Three individuals in the equipment carry, and four individuals in each of the stair climb and casualty evacuation tasks did not maintain the allotted work rate. In total, 47 individuals completed every task at the correct pace successfully and could be included in statistical analyses. One individual did not complete the incident command portion of the stair climb.

Physical Demand

Examining each task separately by including all successful completers, mean (\pm SD) peak steady state oxygen uptake for hose run ($n=52$), equipment carry ($n=59$), stair climb ($n=58$), casualty evacuation ($n=58$) and wild-land fire ($n=62$) were $47.0 (\pm 7)$, $28.8 (\pm 4)$, $41.0 (\pm 7)$, $35.5 (\pm 7)$ and $28.7 (\pm 5)$ $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively. Analysis with mixed-model ANOVA ($n=47$) demonstrated the hose run task elicited significantly higher mean (\pm SD) peak steady state metabolic demand than all other tasks ($p<0.01$), whilst wild-land fire and equipment carry tasks both elicited the lowest ($p<0.01$; Table 3). Metabolic demand did not significantly differ between whole-time and retained firefighters or male and female firefighters in any task ($p>0.05$).

Table 3. Metabolic demand, cardiovascular strain and perceived exertion for peak steady state during firefighting tasks for all participants who completed all tasks successfully (n=47).

| Task | Physical demand | | | RPE Mean (±SD) |
|------------------------|--|--|-----------|----------------------|
| | VO ₂ (mL·kg ⁻¹ ·min ⁻¹) Mean (±SD) | HR (beats·min ⁻¹) Mean (±SD) | %HRR | |
| Hose Run | 47 (±8)* | 171 (±11)* | 92 (±7)* | 15 (±2) |
| Equipment Carry | 29 (±5) | 141 (±16)* | 68 (±13)* | 11 (±2) |
| Stair Climb | 42 (±7)* | 166 (±13)* | 88 (±10)* | 14 (±2) |
| Casualty Evacuation | 36 (±6)* | 159 (±13)* | 82 (±9)* | 13 (±2) |
| Wild-land Fire | 29 (±5) | 137 (±14)* | 64 (±10)* | 9 (±2) |

Table shows oxygen uptake (VO₂), heart rate (HR), percentage of heart rate reserve (%HRR) and rating of perceived exertion (RPE). Symbols denote that mean values were significantly different from *all other tasks (p<0.05) by two-way mixed model ANOVA (n=47).

Mean (±SD) heart rate during peak steady state VO₂ was significantly different in each task (p<0.01), with the hose run eliciting the highest cardiovascular strain (171 (±11) beats·min⁻¹) and wild-land fire the lowest (137 (±14) beats·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)%). Perceived exertion exhibited similar results, with all tasks significantly different (p<0.05) and in corresponding order to measured physical demand.

Incident Command Role Physical Demand

When including all successful completers, mean (±SD) oxygen uptake values for the stair climb and wild-land tasks that simulated senior officer work were 34.7 (±5) and 23.1 (±3) mL·kg⁻¹·min⁻¹, respectively. The physical demands characteristics used in statistical analyses for the incident command tasks are presented in Table 4. The physical demands of the two simulated incident command duties were significantly

lower than the two corresponding tasks for operational firefighters ($p < 0.05$). The senior officer simulation of wild-fire elicited significantly lower physical demand than all other simulations ($p < 0.05$). While the stair climb for senior officers elicited lower physical demand than the operational firefighter stair climb, the physical demand was statistically similar to the casualty evacuation task ($p > 0.05$).

Table 4. Metabolic demand, cardiovascular strain for peak steady state during simulated incident command duty within firefighting tasks.

| Task | Physical demand | | |
|----------------|--|--|------------------------|
| | VO ₂ (mL·kg ⁻¹ ·min ⁻¹) Mean (±SD) | HR (beats·min ⁻¹) Mean (±SD) | %HRR |
| Stair Climb | 35 (±5) ^b | 149 (±13) ^b | 74 (±11) ^b |
| Wild-land Fire | 23 (±3) ^{ab} | 124 (±15) ^{ab} | 53 (±11) ^{ab} |

Table shows oxygen uptake (VO₂), heart rate (HR), percentage of heart rate reserve (%HRR). ^an=47, significantly different from all other tasks ($p < 0.05$). ^bn=61, significantly different from the corresponding operational firefighter task ($p < 0.05$).

Cardiorespiratory Fitness Standards

For operational firefighters, an average was taken using the physical demands for all tasks except the wild-land fire simulation, which received less than 90% agreement on the adequacy of the simulation as a reflection of real working conditions. The average physical demand of the four remaining tasks was 38.1 mL·kg⁻¹·min⁻¹. Utilising a combined average has been used previously to produce an aerobic capacity applicable for a, “typical emergency response,” as part of a firefighter’s occupational role. As such, the cardiorespiratory standard was calculated by establishing the maximum oxygen uptake required to allow an individual to work at 38.1 mL·kg⁻¹·min⁻¹ for a typical emergency response duration. From the combined duration of the four simulations (17:38 minutes) and the mean duration for in-dwelling fire incidents observed previously (14:20 minutes), the long-established work-time relationship

would suggest an intensity of 90% VO_2 max would allow sufficient work duration. As such, VO_2 max required was calculated to be $42.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

In similar fashion, for senior officers in an incident command role wild-land fire physical demand was excluded, meaning stair climb physical demand ($34.7 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) alone was used to derive a fitness standard. As the stair climb task for senior officers lasted an average of 3:25 minutes, an intensity of 95% VO_2 max was deemed appropriate to allow work duration, and the VO_2 max required was calculated as $36.8 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

4.4 Discussion

A physical demands analysis was performed on UK Fire & Rescue Service operational firefighters using tasks representing accepted practice of necessary occupational tasks at a pre-defined minimum acceptable pace. Average oxygen uptake for the five tasks ranged between $29\text{-}47 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and between 64-92% of heart rate reserve. The hose run task elicited the highest steady state metabolic demand, and the wild-land fire task the lowest. All tasks were agreed to be authentic and accurate representations of occupational duties by over 90% of study participants, with the exception of the wild-land fire task (84%). Using average physical demand of replicable tasks and work-time calculations, minimum acceptable cardiorespiratory fitness standards were derived for operational firefighters ($42.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and for those in incident command ($36.8 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$).

During representative firefighting tasks lasting a total of five minutes, cardiovascular strain tends to rise between 85-100% of maximum (Manning & Griggs 1983). In both ambient and live-fire conditions, UK-based firefighters and instructors have exhibited between 60-90% of heart rate reserve (Eglin et al. 2004; Richmond et al. 2008), and, from estimations from heart rate, metabolic demands of between 30.5 and $40.0 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Brewer 1999). Direct measurement of oxygen uptake during simulated firefighting activity, which has only been reported in international or non-civilian fire services, negates some of the error based on prediction of metabolic demands from heart rate, which is especially prudent during occupational stress. In 20 United States firefighters, Sothmann et al. (1990), observed seven successive

firefighting tasks which elicited an average metabolic demand of $30.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, which represented 76% of the average $\text{VO}_2 \text{ max}$ ($39.9 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). However, 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 values ($44 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), similar to those in the present study. The above studies involved entirely self-paced tasks. Sothmann et al. (1990) observed that fitter individuals would tend to perform tasks faster than less fit individuals, suggesting that in emergency situations, less fit individuals would compensate by completing the tasks slower. This further highlights the importance of a minimum acceptable pace as a means of measuring physical demand. In a study where minimum acceptable pace has been employed, the average physical demand of a sample of UK shipboard Naval firefighters over five tasks was 36.2 (range 23-43) $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ representing between 44 and 82% of the average participant $\text{VO}_2 \text{ max}$ (Bilzon et al. 2001). Although these tasks are paced and designed to elicit a valid steady state of physical demand, it is evident that wide variation exists in the occupational roles and subsequent tasks performed in different national services. As such, the specificity and experimental control implemented within the present study produce the most accurate description of the physical fitness required to safely and effectively complete the role of an operational UK firefighter.

Physical demands analyses can be used to produce a physical fitness standard for safe and effective work within an occupation (Tipton et al. 2012). Recent concerns have arisen surrounding the requirement for fitness standards to be based on occupational ability which can be scientifically justified should the need arise. As such, the process taken to produce a physical fitness standard requires comprehensive and thorough objective and subjective analysis and documentation throughout. Previously, authors have endorsed attaining a required fitness using the average metabolic demand of the examined physical tasks (Bilzon et al. 2002; Reilly et al. 2006). The reasons for this approach appear to be two fold. First, that assuming normal distribution of a population, this is the physical demand that would be expected in an average, untrained individual; and second that a mixture of critical tasks may be completed during emergency response in a relatively unpredictable order and duration, best represented by an average. As such, utilising a combined

average produces an aerobic capacity applicable for a, “typical emergency response,” as part of a firefighter’s occupational role. Conversely, some authors have proposed that if all tasks are equally necessary, then a minimum fitness standard should be based solely on the most arduous critical task. Jamnik et al. (2010) followed this approach using Canadian firefighters. However, in order to recognise inherent inter-individual variability in both oxygen uptake and in exercise efficiency, the fitness requirement was produced by subtracting one standard deviation of measured oxygen uptake from the peak physical demand, thereby being inclusive of a larger proportion of the sample population. While it is understandable to predict the influence of a fitness standard on a current work force, a fitness standard should not be based on the fitness of those currently employed, but simply on the demands of the tasks themselves. Unfortunately, in the context of correcting for error and establishing an actual fitness standard, the use of a standard deviation, or any other range of variance below a measured physical demand could seem somewhat arbitrary. However, In the case of an average physical demand, the standard deviation could theoretically be used to suggest a boundary for people who do not achieve the fitness standard, but may well be efficient enough to complete occupational duties below the given standard. Similarly, a standard deviation of the average of tasks could be used to allow for variation between tasks. In the context of a “typical emergency response” this variation could reflect the possible relative proportions of each task duration/intensity within a single emergency incident.

Furthermore, deriving a fitness standard extends further than the concept of physical demand alone. The relationship of work-time and work intensity must also be considered. While a physical demand measurement alone is valuable, it is unreasonable for an individual to complete any task at maximal oxygen uptake for more than a few minutes (Gleser & Vogel 1973; Billat & Koralsztein 1996; Blondel et al. 2001). As such, the minimum fitness required needed to surpass the physical demand of a task to the extent that the task can be completed safely for its entire duration. As the average of oxygen uptake measurements were used, representing an assortment of tasks, a work-time representing the average duration of an emergency response was suitable. By monitoring firefighters during emergencies Sothmann et al. (1990) measured a mean duration for in-dwelling fire incidents of

14:20 minutes. This suggested that an individual could complete a task of this duration at approximately 85-90% of maximal oxygen uptake (Louhevaara et al. 1986; Blondel et al. 2001). Subsequently, the average oxygen uptake from the physical demands analysis would then represent 85-90% of the resultant minimum fitness requirement.

It is of the authors' view that the metabolic demand of the wild-land fire task, by receiving a lower score in both validity and authenticity in comparison to other tasks, should not contribute toward the production of a fitness standard in this population. The task may not have reflected the physical demand of the real-world task, meaning the data has less external validity with regards to operational capability than other examined simulations, and was excluded. This is likely explained by a wild-land fire incident ordinarily taking place over several hours over highly variable terrain, and over a distance that was not practical for a controlled testing environment. As such, the minimum acceptable pace used in the present study also represents a pace that could be continued for far longer than the simulation lasted. The fatigue experienced in the real-world example is likely to be a product of duration of exercise at a low intensity and extended focus, rather than peak metabolic demand as examined here.

From these data, using the long established work-time relationship, minimum acceptable cardiorespiratory fitness standards were derived for this population. It is recommended that these fitness standards, along with a fitness management framework be presented to the stakeholder and technical panels and discussed as part of a continued consultation process. This study indicates that the aerobic capacity derived from physical demands data would help to ensure safe and effective work within the population during a generic emergency response. However, to adequately determine the suitability of the fitness standard, and the possibility of using the criterion tasks themselves to test capability, further work is warranted. A cross-validation study would be vital, whereby a sample of firefighters with aerobic capacities that extend both above and below the proposed fitness standard complete the criterion tests, and the ability to complete the tasks is compared.

This study quantified the metabolic demand of generic firefighting tasks within the roles of an operational firefighter and senior officers in incident command within the UK Fire & Rescue Service and derived appropriate fitness standards for occupational duty. The present investigation represents the first physical demands analysis of UK fire service roles, and improves on previous research in other nations by implementing a thorough task analysis and setting a minimum acceptable pace for tasks during experimentation. As such, it is recommended that future occupational fitness management in the UK Fire and Rescue Service be based on the fitness standards and occupational demands of the job identified in the findings of the present study. Given that several study participants currently employed as operational firefighters did not complete some tasks satisfactorily or maintain necessary pace, an alteration to the guidelines surrounding the national fitness standard may be warranted, as well as cross validation work between the proposed standard and the criterion tasks. The present study indicates that firefighters with an aerobic capacity below an occupational fitness standard of $42.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ would not be guaranteed to be safe and effective in their ability to complete necessary roles within their occupation. Although this does not greatly differ from the current fitness standard of $42 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, it does indicate that the lower VO_2 max standard of $35 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for continuation of work with remedial training amongst operational firefighters is potentially unsafe for the majority of firefighters. It is also recognised that aerobic capacity is not the sole contributor to the physical capability of a firefighter, and the next section of the report covers how this programme of work aimed to quantify the strength requirements of firefighting specific to UK personnel, and identify how surrogate gym-based tasks could be used as a means of testing physical readiness for these strength-based tasks.

5.0 Analysis of Strength and Muscular Endurance Requirements

5.1 Aims

This study had two aims, a) to implement a task analysis to determine the necessary operational tasks that require the largest applications of physical strength and b) to examine the relationship between specific gym-based strength tasks and performance in the criterion tasks, to assess their value as predictors of performance.

5.2 Methods

Task Analysis

Using the process described in section 3, a task analysis was performed for strength requirements of firefighters. Specifically, the consultation process for strength tasks is summarised in Figure 2. Technical panel members were asked to identify essential tasks within a firefighter's occupational role that required the largest applications of strength. The strength tasks identified involved the manipulation and carrying of ladders and movement of casualties, the latter fulfilled in the casualty evacuation task within the previous physical demands analysis. Therefore, within ladder manipulation tasks, it was important to ascertain, under best practice, which tasks would be completed alone or as part of a team so that strength demands analysis would be applicable to the physical requirement of an individual firefighter. An online survey was administered to technical panel members that explored whether there would be any situations where a firefighter would be required to complete any ladder-based tasks alone, and if not, how many people would be required to complete the portions of that task requiring muscular strength.

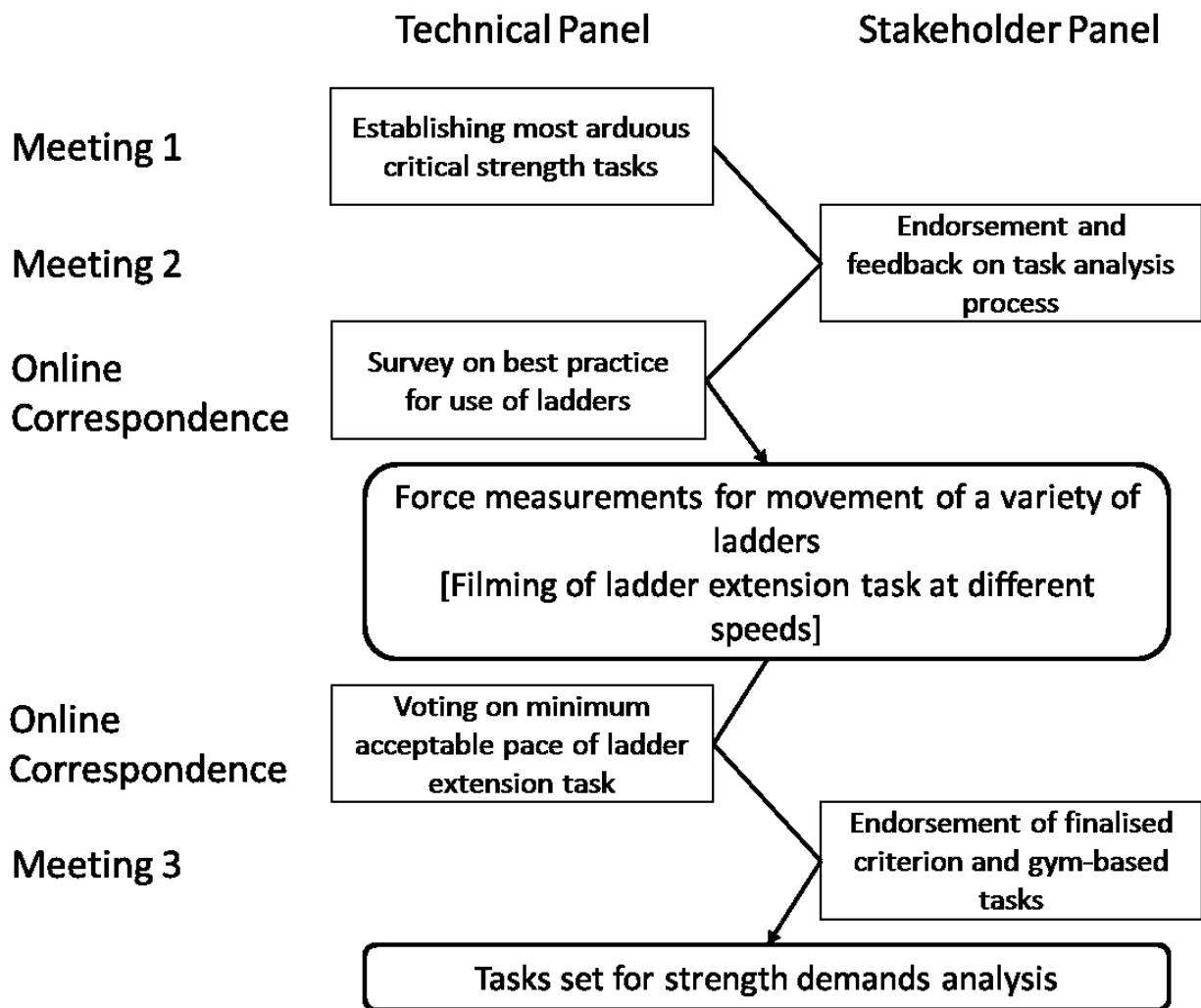


Figure 2. Task analysis consultation process for strength requirements of firefighters, organised by meetings and online correspondence with technical and stakeholder panels. Boxes with rounded edges denote work completed by the research team.

Occupational Tasks

The first task chosen by the technical panel was the action of lifting a triple extension 13.5 m ladder (~104 kg) to the top of a fire appliance, typically completed as a group of four firefighters. The second task identified was the unlatching of a 13.5 m ladder from an extended locked position. This is typically performed by a lone firefighter and requires one single downward pull on a rope to lift the ladder into motion and unhook the locking mechanism. The third and final task was fully

extending a 10.5 m double extension ladder. It was the view of the technical panel that, while it might be possible for a specific firefighter to extend a 13.5 m ladder alone, in best practice and when adhering to recommended guidance this task should be completed in tandem by two individuals. As such, the 10.5 m double extension ladder is the heaviest ladder that a firefighter would be expected to extend, as an individual operator.

Pilot Testing

Pilot testing was completed at South Wales FRS Training and Development Centre to take measurements required to simulate the occupational tasks. Work previously completed by Rayson et al. (2009) to develop the national firefighter selection tests, outlined in a Communities and Local Government (CLG) report, validated physical tests using a ladder lift simulator (Fire Experimental Unit Ltd, Moreton-in-Marsh, UK) and a ladder extension simulator (PowerSport Fitness Ltd, Bridgend, UK). The ladder lift simulator is based on one individual's requirement when lifting a 13.5 m ladder from waist height to overhead, using a weighted bar and pivot system to attain the appropriate mass and range of motion. The ladder extension simulator is based on the design of a pitched ladder with a rope to extend it, using a wall-mounted ladder and rope assembly positioned vertically with an adjustable weight stack to allow simulation of different ladder types. This requires a participant to repeatedly pull down on a rope to extend the weighted cradle.

A force dynamometer (Takei, Japan) was used to measure peak static and dynamic force required to extend standard issue 10.5 and 13.5 m ladders. Static and dynamic values for extending the 10.5 m ladder were 27 kg and 42 kg, respectively, and 41 kg and 58 kg for the 13.5 m ladder, respectively. Force measurements were also taken for every weight increment on the ladder extension simulator such that a mass could be chosen that most closely resembled the forces required to move the actual ladders in question. For the two tasks, these increments were the 4th (Static: 28 kg; Dynamic: 40 kg) and 7th (Static: 42 kg; Dynamic: 60 kg) pin holes on the simulator, respectively.

In addition, the ladder extension task was filmed at five speeds (30, 50, 70, 90 and 110 pulls/min) where an individual was paced by an audible metronome. In an identical voting process to that described in section 3, the technical panel were shown these videos and determined the minimum acceptable pace of a ladder extension via a second online survey to be 70 pulls.min⁻¹.

Criterion Strength Tasks and Surrogate Gym-based Tasks

The criterion tasks below use the ladder lift and ladder extension simulators combined with information from the pilot work above to accurately simulate the single-person demand within the occupational tasks. Each criterion task is accompanied by a description of each respective surrogate gym-based task chosen to mimic the criterion task. It was an aim of the research to determine what gym-based tasks could measure the most appropriate applications of strength and best predict performance in the most arduous essential strength tasks of a firefighter. The criterion and gym-tasks are also summarised in Table 5.

Criterion Task: Ladder lift

This is to simulate an individual's role in lifting a triple extension 13.5 m ladder from waist- to overhead- height (onto a fire appliance). An individual must lift the bar from waist- to shoulder-height with an underhand grip, before changing to an overhand grip to press the bar overhead. The bar must surpass the height of a marked vertical bar equal to the height required to position the ladder on the fire appliance.

Surrogate Task: Seated barbell overhead press

In the interest of safety, and for an instructor to help if the need arises, this exercise is performed seated on an adjustable gym bench in the upright position, as opposed to standing. A barbell is pressed upwards from shoulder height to overhead while seated, using an overhand grip.

Criterion Task: Ladder “extend-to-lower” (Ladder extension simulator, 7th weight increment)

This is to simulate unlatching an extended 13.5 m ladder from its locked position. A single downward pull on the rope is performed from overhead to chest height. The ladder extension simulator is set to the 7th pin hole (42 kg) for this task.

Surrogate Task: Single rope pull down (seated)

A single downward pull on a rope is performed using two hands on a vertical pulley machine (LifeFitness, Illinois, USA) from overhead to chest height. The cushioned bar designed to hold participant legs in place is engaged.

Criterion Task: Ladder extension (Ladder extension simulator, 4th weight increment):

This is to simulate the one-storey extension of a 10.5 m double extension ladder. Repeated hand-over-hand downward pulls are performed on the ladder extension simulator. Each pull is completed in time with an audible metronome set to 70 beats per minute. The pulls are repeated until the ladder reaches the top of the simulator. The simulator is set to the 4th pin hole (28 kg).

Surrogate Task: Repeated rope pull down (seated, 28 kg)

Using two hands downward pulls on a rope from overhead to chest height are completed on a vertical pulley machine (LifeFitness, Illinois, USA). Between every pull, the rope is returned to its overhead starting position. Each downward pull and each return to start position is in time with an audible metronome set to 70 beats per minute, thereby resulting in 35 pulls·min⁻¹. The task is continued until volitional fatigue and/or an inability to keep to the designated pace. The cushioned bar designed to hold participant legs in place is engaged.

Table 5. Details on strength-based firefighting tasks and gym-based predictive tasks.

| Occupational Task | Criterion Task | | | Predictive Task | | | |
|--|----------------------------|-----------|--|------------------------------|-------|---|---|
| | Equipment | Mass (kg) | Action | Task | Mass | Action | Measure |
| Lifting 13.5 ladder onto appliance in team of four | Ladder lift simulator | ~29 | Waist-to-overhead lift | Seated shoulder press | 1RM | Single press | 1RM |
| Extend-to-lower 13.5 m triple extension | Ladder extension simulator | 42 | Single downward pull from overhead to chest | Seated single rope pull down | 1RM | Single pull | 1RM |
| Extension of 10.5 m ladder | Ladder extension simulator | 28 | Full extension via repeated hand-over-hand downward pulls at 70 pulls per minute | Seated single rope pull down | 28 kg | Two-hand repeated pull at 35 pulls per minute | Number of repetitions to volitional fatigue |

Participants

Fifty one (26 male and 25 female) individuals (Mean (\pm SD): age 24 (\pm 6) y, mass 74 (\pm 15) kg, height 1.72 (\pm 0.1) m, BMI 25 (\pm 4) kg.m⁻¹, estimated body fat 21 (\pm 8)%) gave written informed consent to take part in the study. Participants were recruited in January-March 2014 from two UK universities and from control staff in South Wales FRS. Participants were deemed physically able to complete high intensity exercise based on successful completion of a PAR-Q,

The predictive strength and accuracy of a surrogate test is improved by using a varied sample population in order to give a range of results. If the criterion tasks also contain no occupational-specific skill, it is also preferable to have individuals who are unfamiliar with these tasks. As such, operational firefighters were not approached to participate. In addition, there was no requirement for participants to be experienced in resistance training or habitually partake in physical activity. The physical capabilities and successful/unsuccessful performance on the contained tasks are expected to be varied in order to improve the predictive analysis of the test, and are not a reflection of how operational firefighters would be expected to perform.

Study Protocol

All strength demands data collection was completed at Cardiff Gate Training & Development Centre, South Wales, UK. Participant anthropometric data (body mass, height, estimated body fat (Bodystat, Bodystat Ltd, UK), grip strength and static lift strength dynamometers (Takei, Japan) were collected in the morning upon arrival at the study location. For these preliminary strength measures, each exercise was completed twice, and the maximum value was recorded. Participants then completed all occupational and predictive tasks with adequate rest between each activity. Occupational tasks were completed in full fire kit (i.e. leggings, tunic, gloves, helmet). Success or failure to complete the occupational tasks was noted.

For the shoulder press and single pull-down, a progressive warm up protocol was implemented where the exercises were performed with masses estimated to allow 10, five and three repetitions with recovery between each set. A one repetition

maximum (1RM) was then obtained for each participant. For the repeated pull-down exercise, number of repetitions before volitional failure (or before the inability to keep to the designated pace) were noted. Gym-based predictive tasks were completed in recreational sports clothing.

Statistical Analysis

For each occupational task the binary result (pass/fail) was plotted against participant maximum load lifted/performance in the respective predictive gym task. For each predictive test, sensitivity (true positive rate) and specificity (false positive rate) was calculated at several hypothetical performance standards set at regular increments. Sensitivity, the ability of the predictive test to correctly identify those who passed the operational test, was calculated using the following formula:

$$Sensitivity = \frac{TP}{TP + FN}$$

* where *TP* denotes true positives, and *FN* denotes false negatives.

Specificity, the ability of the predictive test to correctly identify those who failed the operational test, was calculated using the following formula:

$$Specificity = \frac{TN}{FP + TN}$$

* where *TN* denotes true negatives and *FP* denotes false positives. Accuracy is then determined by summing the number of true positives and true negatives and dividing by the total number in the population sample.

Receiver-operating characteristic (ROC) curves were plotted using the range of performance standards, with sensitivity on the y-axis and 1-specificity on the x-axis. The performance standard that was mathematically closest to maximising both specificity and sensitivity (perfect classification would be where both have a value of

1) was then calculated and, if applicable, rounded to the nearest whole increment suitable for that performance measure.

5.3 Results

Task Performance

The ladder lift task was successfully completed by 31 individuals (61%; 26 male, 5 female). The single extend-to-lower task was completed successfully by thirty nine individuals (77%, 26 male, 13 females). All participants who failed these two tasks were female. The one-story ladder extension task was completed by thirty six individuals (71%, 25 male, 11 female). Of those who failed this task, one participant was male and 15 female.

Prediction of Ladder Lift Task Performance

Mean (\pm SD, range) shoulder press performance of those who passed and failed the ladder lift test were 53 (\pm 13, 35-75) kg and 25 (\pm 5, 20-32.5) kg, respectively (Figure 3, Panel A). A hypothetical performance standard of 35 kg on the seated shoulder press represents ideal specificity and sensitivity (Figure 3, Panel B). At this performance level, both sensitivity and specificity are 1, and accuracy is 100%.

Prediction of Ladder Extend-to-lower Task Performance

Mean (\pm SD, range) single rope pull-down performance of those who passed and failed the ladder extend-to-lower test were 76 (\pm 19, 46-109) kg and 48 (\pm 9, 30-60) kg, respectively (Figure 4, Panel A). A hypothetical performance standard of 60 kg on the single rope pull-down represents the closest value to predictive test ideal specificity and sensitivity (Figure 4, Panel B). At this point the sensitivity is 0.76 and specificity is 0.92 (1-specificity = 0.08), and accuracy is 80%.

Prediction of Ladder Extension Task Performance

Mean (\pm SD, range) repeated rope pull-down performance of those who passed and failed the ladder extend-to-lower test were 37 (\pm 16, 10-68) repetitions and 13 (\pm 9, 1-34) kg, respectively (Figure 5, Panel A). A hypothetical performance standard of 23 repetitions at 28 kg on the repeated rope pull-down elicited the closest value to predictive test ideal specificity and sensitivity (Figure 5, Panel B). At this point the sensitivity is 0.81 and specificity is 0.93 (1-specificity = 0.07), and accuracy 80%.

5.4 Discussion

This investigation was performed to identify whether selected surrogate tasks could predict performance on strength and muscular endurance tasks critical to firefighting, and subsequently attempt to ascertain suitable performance standards on those predictive tasks. Sensitivity and specificity analysis of performance of civilians (non-firefighters) on ladder lift, ladder extend-to-lower, and ladder extension tasks indicated that a shoulder press of \geq 35 kg, a rope pull-down of \geq 60 kg, and \geq 23 repetitions of a rope pull down of 28 kg represent optimum performance standards for the three respective tasks.

It is well-established that the physical role of a firefighter often contains a combination of strength and cardiorespiratory demand (Barr, Gregson & Reilly 2010), where it can be challenging to understand optimal fitness for firefighter. In UK firefighters, it has been generally viewed that while cardiovascular demand is highest during the completion of operations involving hose running or using breathing produce, casualty and equipment handling require the most physical strength (Scott 1988; David et al. 1997; Brewer 1999). Currently, however, strength monitoring in trained firefighters during service is non-existent. Previous firefighter physical demands analyses that have attempted to isolate strength-based tasks have typically utilised ladder extensions, equipment hoists, hose pulling and/or a casualty drag (Davis et al. 1982; Rhea et al. 2004; Rayson et al. 2009). Since the aim of the present study was to ascertain the highest applications of strength, some less arduous strength tasks are not included, and it is acknowledged that some

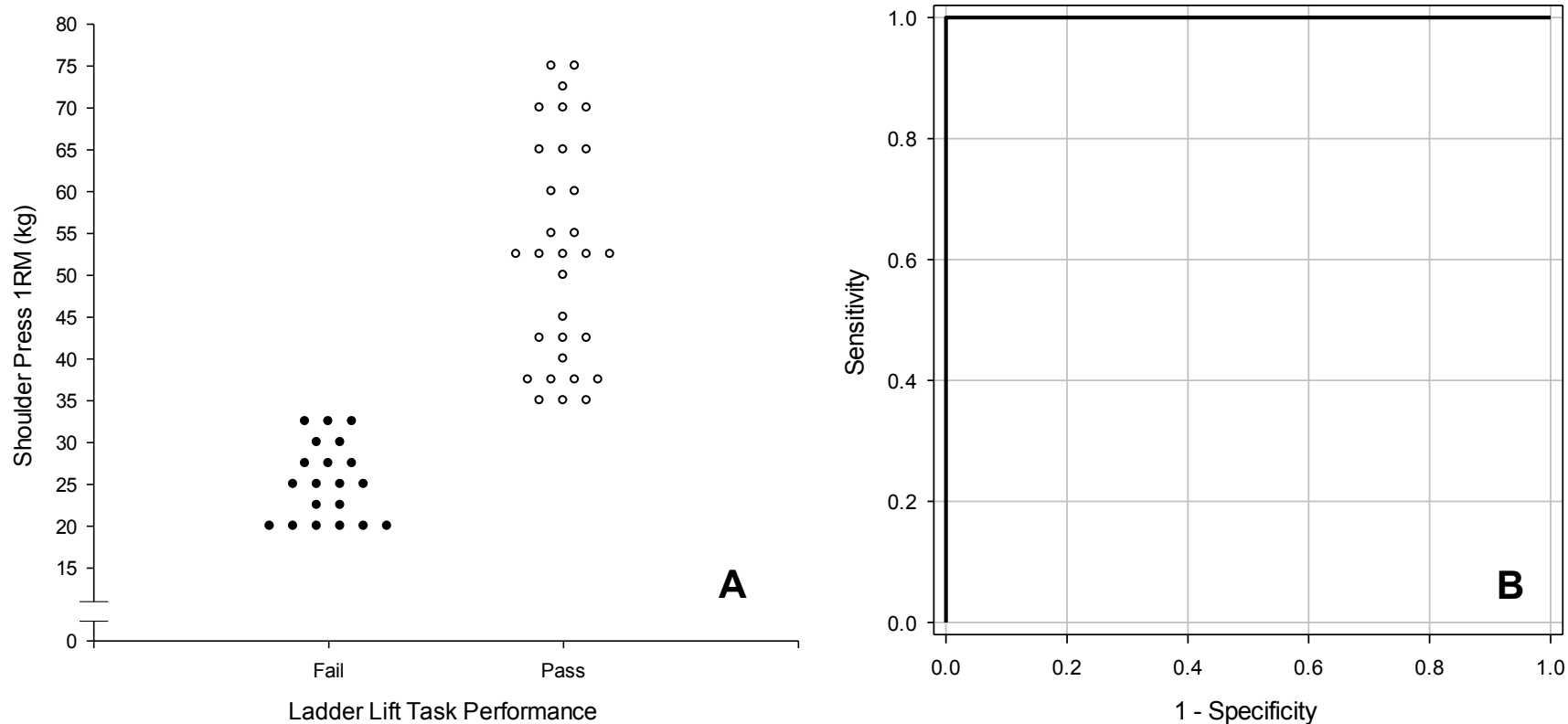


Figure 3. Individual performances (Pass/Fail) in ladder lift occupational task against 1RM in predictive seated shoulder press (A, n=51), and corresponding ROC curve (B) derived from these data. The point corresponding to ideal sensitivity and specificity (0,1) represents a standard of 35 kg for the shoulder press exercise.

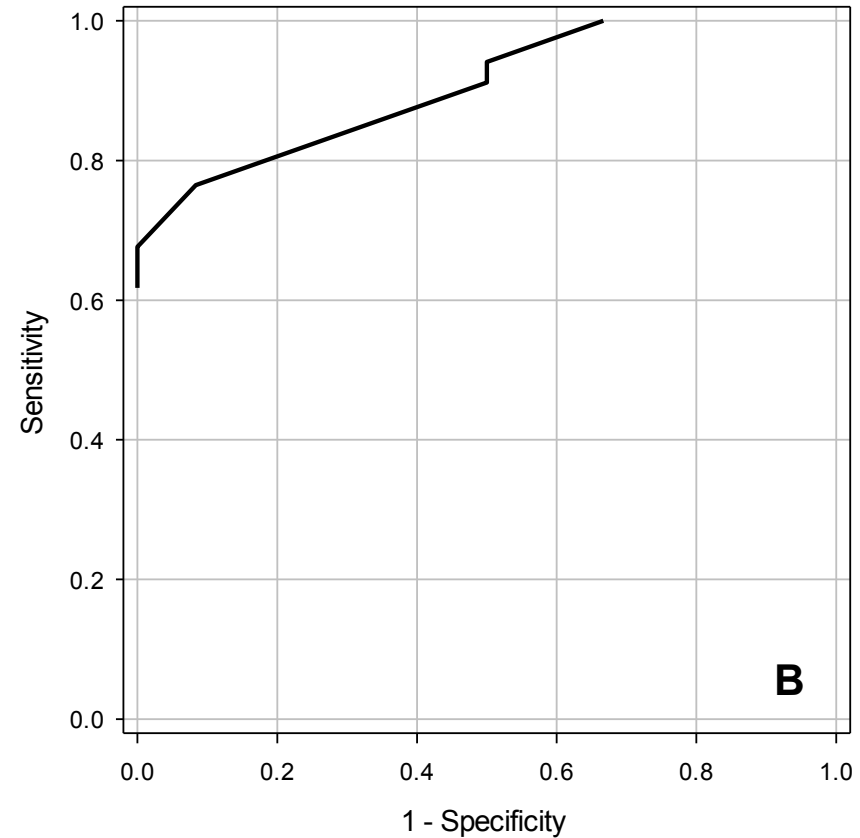
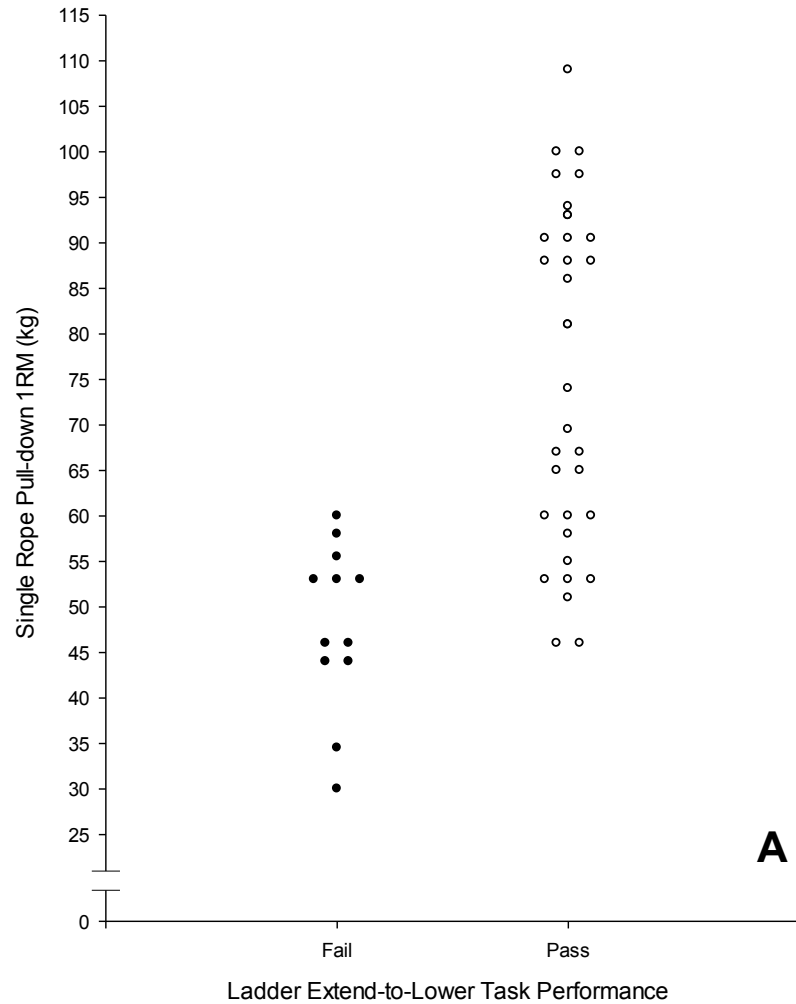


Figure 4. Individual performances (Pass/Fail) in 13.5 m ladder extend-to-lower occupational task against 1RM in predictive single rope pull-down task (A, n=46), and corresponding ROC curve (B) derived from these data. The optimal achievable balance of 1-specificity (0.08) and sensitivity (0.76) represents a standard of 60 kg for the single rope pull down exercise.

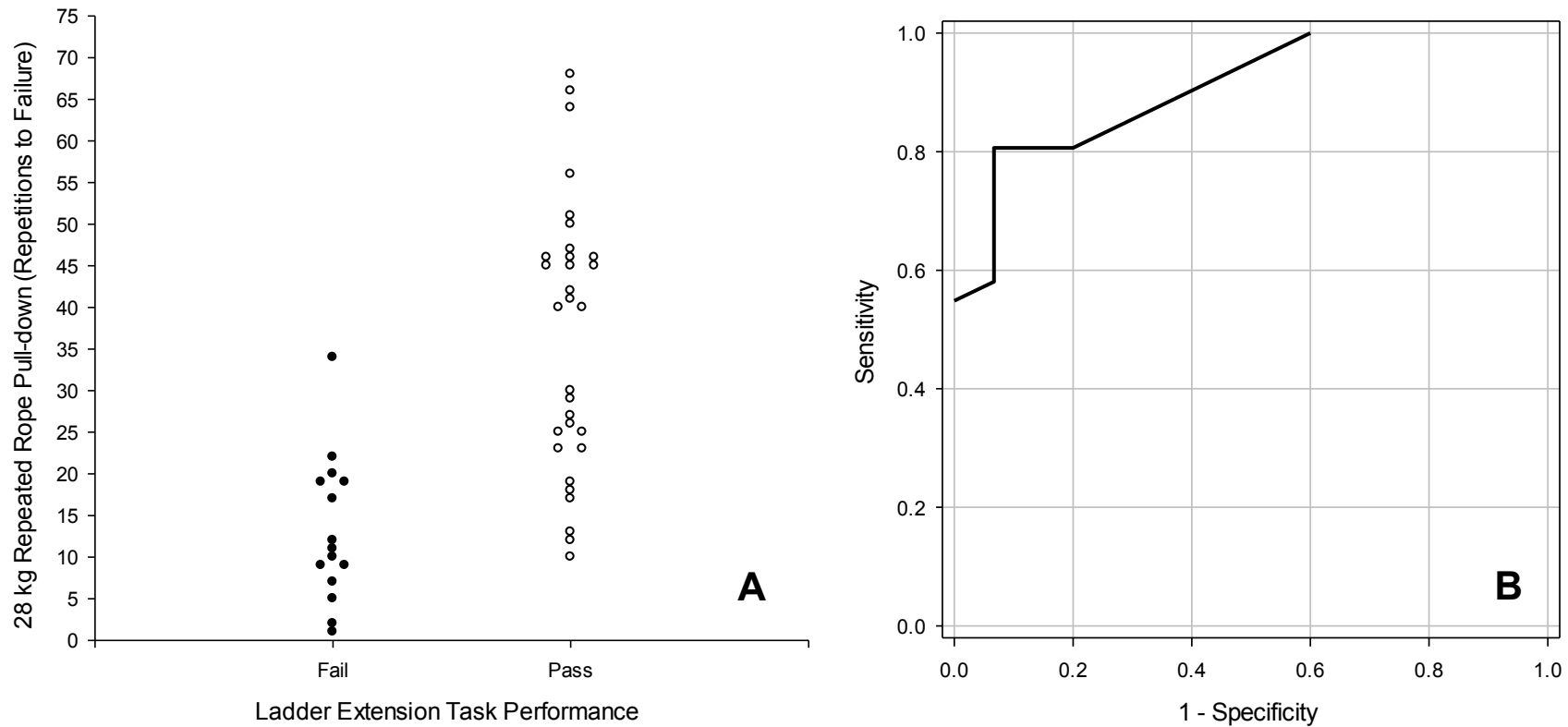


Figure 5. Individual performances (Pass/Fail) in 10.5 m ladder extension occupational task against repetitions to failure in the repeated pull-down task at 35 pulls·min⁻¹ (A, n=46), and corresponding ROC curve (B) derived from these data. The optimal achievable balance of 1-specificity (0.07) and sensitivity (0.81) represents a standard of 23 repetitions for the repeated rope pull-down exercise at 28 kg.

(e.g. casualty drag) were encompassed within the physical demands analyses detailed in the previous section of this report. Within the included tasks, similarities exist with previously published ladder lifts ranging from 22 to 28 kg and equipment hoists and ladder extensions ranging from 16 to 42 kg in previous studies (Misner et al. 1987; Rhea et al. 2004; Rayson et al. 2009).

The particular similarities with the CLG report (Rayson et al. 2009) for national firefighter selection tests are both understandable and encouraging. The study used the same simulators as the present investigation, since they were developed for the selection tests, and used similar methods to both produce task design and obtain force measurements. Maintaining consistency with the physical tests at point-of-entry is particularly important for successful future application in trained firefighters of these tests. Two differences from the work of Rayson et al. (2009) are that our technical panel concluded that a 13.5 m ladder extension is not a single-person task and consequently a 10.5 m ladder extension is the heaviest ladder an individual firefighter would be expected to complete. This option, potentially owing to availability of this ladder or the subject matter experts present, was not explored by Rayson et al. (2009) and explains differences in the difficulty setting of the extension simulator. In addition, some static and dynamic force measurements obtained from the ladders and extension simulators were different from the pilot work conducted for the CLG report. However, certain variation can be expected depending on the age, working condition and design of ladders and the specific simulators. For the specific outcomes of this investigation, it was of paramount importance for the static force required to move the ladder simulator to be as closely matched as possible to the static force required to move the weight stack in the simulation task.

High levels of sensitivity and specificity were achieved for the chosen tasks in this investigation, indicating good predictive strength of the surrogate tests with their criterion counterparts, and optimal performance standards achieving a range of 80-100% accuracy. The standards found at these optimum levels of test validity would be suitable to indicate a firefighter's readiness to complete necessary occupational tasks requiring greatest physical strength. The gym-based tasks were designed to have a high level of simplicity and safety to allow for their potential use in health and

fitness testing. The specific resources, equipment and instructional work required will need to be supported by the service to implement these standards. However, it is acknowledged that with variable resources and staff in services across the UK, it may be that some tests are not as easily implemented. This will need to be considered by individual services.

With any predictive test, there will inherently be some error by nature of it extrapolating data. The statistical optimum of sensitivity and specificity is objectively the most robust method to attain balance of objectives from a test. However, in some real-world cases the need to specifically limit false positives or alternatively reduce false negatives may outweigh the other. As such, the balance of sensitivity and specificity can be shifted, within certain bounds, for the needs of a population of interest but requires careful consideration by occupational governance. Similarly, based on the 80% accuracy achieved in the two pull down tests, a pragmatic approach to managing those individuals within a boundary below the strength standards should be outlined to lessen adverse impact of potential inaccuracy. This could take the form of different strength zones (e.g. green, amber, red), in which a person in the amber zone is given remedial strength training while remaining in occupational duty, or where an individual is re-tested within a certain time frame. For example, these secondary thresholds of performance could utilise sensitivity values of 85-90% to identify individuals who may or may not be safe to perform specific duties, but would likely benefit considerably from structured resistance training. It is encouraging that carefully-designed resistance training-based occupational interventions have a high level of effectiveness (Williams, Rayson & Jones 2002) and would be simple to implement given the basic nature of the exercises and movements applied in these tests.

This work facilitates the use of normal gym-based practices to give a sufficiently robust prediction of a firefighter's optimal strength for operational duty. The practical simplicity of these tasks allows services without the access to the specific simulators to test physical strength appropriately, and allows testing to be completed as part of laboratory-based health checks. This may go some way to maintain consistency of the strength and ability of trained firefighters, and maintaining strength achieved at the point-of-entry to the UK FRS.

6.0 Conclusions & Recommendations

- A thorough task analysis was completed in consultation and partnership with experienced operational staff to ensure that tasks used to quantify the physical demands of firefighting were **suitable and reasonable minimum expectations for all firefighters**. It was recommended that the metabolic demands of these tasks be assessed and data used to establish minimum acceptable cardiorespiratory fitness standards, as part of an annual assessment. This would establish an empirically-informed direct link between individual fitness and occupational capability.
- The most arduous critical tasks that were authenticated by study participants in this programme of work were designed to attain a reasonable and empirically supported cardiorespiratory fitness standard. By implementing, and improving upon, protocols used in previous studies, we developed recommendations for cardiorespiratory fitness testing. The standards were derived using different approaches from previously published scientific methods, combining the human work-time relationship with the combined duration of the tasks that might comprise a 'typical' firefighting scenario (e.g. hose run, equipment carry, stair climb and casualty evacuation).
- In order for the implementation of empirically-informed fitness standard to be successful in improving and maintaining the health and fitness of UK firefighters there must be some national agreement on the implementation and governance of fitness testing and standards. Furthermore, consideration should be given to the necessary resources to ensure employees are able to meet recommended criteria.
- It is recommended that single cardiorespiratory fitness standards for each occupational role (operational firefighters and officers in an incident command role) be recommended to the entire UK Fire and Rescue Service. The programme of work suggests that an inability to reach a minimum acceptable

standard could compromise the safety of individual firefighters and those in their team. Individuals below the minimum standard would need to be given remedial training and support in attaining the standard to ensure safe and effective work performance.

- The protocols of each task used for the physical demands analysis are directly linked to the role of an individual during arduous necessary occupational tasks and are assigned a minimum acceptable pace. As such, it is also recommended that these tasks, provided a high-intensity health screen is passed by the participant, could be used for training and monitoring purposes. For individuals who wish to maintain fitness directly related to occupational ability, these tests are replicable on drill-grounds using standard fire-fighting equipment. Similarly, for those who have not attained the fitness standard, the minimum acceptable pace could be used to monitor progression of fitness and determine the areas of fitness an individual may need to improve.
- Taking into account the tasks that require applications of strength already included in the physical demands analysis, a task analysis was completed to determine the tasks that elicit the highest strength demands in operational firefighting. The technical panel identified ladder lift and extensions tasks, with specific tasks using the 13.5 m and 10.5 m standard issue ladders. Previously described ladder lift/extension simulators used in national firefighter selection, which are not readily available to all services, were used to simulate these tasks in a validation study.
- Gym-based tests were shown to effectively predict performance in the simulated operational strength tasks. Strength standards for each of these predictive tasks were derived by statistically locating optimal sensitivity and specificity of each test.
- The predictive tasks used were identified in order for services with limited resources to maintain monitoring and testing of strength in trained firefighters using tasks that are safe and easy to use. It is recommended that the strength

standards and specific associated standards be recommended to the UK FRS for trained firefighters as an integral component of physical fitness and operational readiness.

- With an overall framework tailored to the attainment of the national fitness standard and strength requirements, the management of consistent fitness testing and monitoring across staff and services in the UK could become less challenging and more rewarding.

7.0 Future Directions

Cross-validation of arduous physical tasks and aerobic fitness

Currently, the tasks designed, in their individual forms, could be used to derive an average physical demand akin to completing a generic emergency response. Efforts were made to design the tasks specifically to have minimum paces, and to be easily replicable on any fire station for the possibility of their use in future understanding of the ability of trained firefighters. At present, the tasks would be useful for firefighters as training resources and testing different components of operational ability. In order to fully understand whether the tasks implemented during the physical demands analysis can be used for occupational readiness and fitness testing, however, a cross-validation study would be required. This would involve a group of individuals with varied fitness, both above and below the assigned fitness standard, completing the tasks. The tasks could also be completed in varying orders, with varying recovery times between each, or as a whole scenario. From here, information could be gathered that allows the tasks themselves to be used to predict performance in an aerobic capacity test. These procedures would then allow any error associated with the predictive ability of the tasks to be quantified, and the sensitivity of the tests themselves, as we have conducted within strength demands of firefighting. Although all precautions can be taken to minimise error, every predictive test will produce false positives and false negatives. If these can be quantified on a large sample, then the operational scenario can be amended accordingly, to reduce error and even more accurately reflect occupational ability.

Multi-level modelling of Health and Lifestyle Survey responses

Currently, an online health and lifestyle survey has been implemented nationally to UK FRS employees. However, the results of this survey have only been analysed using a univariate method, which allows for identifying associations between two lifestyle behaviours, but does not allow the quantification of risk based on lifestyle behaviours independent of one another. By completing further analysis, it would be

possible to determine the independent risk factors of cardiovascular disease when taking into account other variables. This would provide information on which lifestyle factors are markedly associated with which health outcomes, and how best to advise and treat those at high risk from each different risk category. In a population sample of the size collected from the Health and Lifestyle Survey so far, this would represent a powerful tool to help occupational health workers give confident consistent advice to individual employees.

Biomarkers of Cardiovascular disease risk

While not discussed in this report, analysis of biomarkers of cardiovascular disease risk were completed in a relatively small sample of the respondents to the above health and lifestyle survey. Completing this analysis in a larger sample (i.e. $n=300$) would allow for stronger correlations to be drawn between actual objective markers of health and wellbeing with lifestyle behaviours. This would involve a further sample of survey respondents to be contacted and a blood sample obtained that is subsequently linked to their questionnaire responses. With a larger sample size, sufficient statistical power will be reached to allow biochemical markers to be included in the aforementioned multi-level analysis of survey responses and become part of a much larger health monitoring tool.

Specific Health and Fitness Guidelines for the UK FRS

With the culmination of this work, it would be prudent to complete a guidance document that can be readily available for health & fitness advisors as well as employees (operational and non-operational) to receive targeted advice for specific groups. This could take the form of separate documents for fitness (cardiorespiratory and strength) and health (health, lifestyle and behaviour) that help individuals understand the implementation of fitness standards, intervention to promote a healthy lifestyle and the management and maintenance of personal safety and readiness for a long operational career.

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