Human Performance Laboratories (Australia)

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PHYSIOLOGICAL EMPLOYMENT STANDARDS FOR FIREFIGHTERS: *REPORT 2:* THE PHYSIOLOGICAL DEMANDS OF PERFORMING PHYSICALLY DEMANDING FIRE-FIGHTING DUTIES.

Nigel A.S. Taylor, Hugh H.K. Fullagar, John A. Sampson, Sean R. Notley, Simon D. Burley, Daniel S. Lee, and Herbert Groeller

Centre for Human and Applied Physiology
Faculty of Health and Behavioural Sciences
University of Wollongong

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Physiological employment standards for firefighters: *Report 2:* The physiological demands of performing physically demanding fire-fighting duties.

EXECUTIVE SUMMARY

Background:

The demands of fire fighting are such that most fire-fighting organisations use pre-employment screening tests to identify individuals who are well suited to coping with the physiological strain typically encountered within this occupation. These procedures are broadly aimed at increasing the capability of the workforce, whilst simultaneously minimising the risk of injury to both firefighters and members of the community.

The current investigators have been tasked with identifying screening tools and physiological standards to facilitate the identification of capable and robust recruits for Fire & Rescue New South Wales (NSW). The overall project involves five discrete Research Phases, leading to the provision of a series of sensitive and specific screening tools, and employment standards (thresholds) that will maximise the identification of true positive (suitable) and true negative (unsuitable) outcomes during recruit screening. However, these tools are also aimed at minimising the number of false positive (recruiting the unsuitable) and negative results (rejecting the suitable) within this process. The critical legal and scientific steps leading to the development of *bona fide* physiological employment standards have been established (Table E-1), and these steps formed the framework for this research.

Table E-1: Procedural summary and framework for developing *bona fide* pre-employment screening tests and physiological employment standards. Steps performed within this research Phase have been coloured.

Project phase	Step	Description
0	1	Justify need for establishing employment standards
	2	Establish a Project Management Team
1	3	Familiarise research team with the trade
	4	Trade review and preliminary analysis of all tasks
	5	Identify the essential, physically demanding tasks
	6	Validate and approve the fire-fighting task list
	7	Employee survey: importance, difficulty, frequency of tasks
2	8	Characterise critical tasks: observe, measure, quantify
	9	Determine criterion fire-fighting tasks
	10	Validate and approve criterion fire-fighting tasks
3	11	Develop defensible physiological screening tests

Project phase	Step	Description
	12	Standardise screening tests and administration
	13	Validate and approve screening tests
4	14	Evaluate validity and reliability of screening tests
	15	Acknowledge and approve performance standard development
5	16	Develop physical performance standards
	17	Validate and approve performance standards
	18	Implement pre-employment screening
		Review the screening process and its outcomes: ongoing

Aims:
The aim of this research Phase was to observe, quantify and evaluate the physical and physiological demands placed upon firefighters performing a broad range of physically demanding fire-fighting tasks as controlled simulations. In this report, the methods and outcomes of the second Phase of this project are described, leading to the identification of valid criterion tasks that may be used to screen potential fire-fighting recruits.

The occupational tasks used within these simulations were initially identified from interviews conducted with 106 firefighters at eleven Fire Stations, three of which were retained-only Fire Stations. To verify and validate these occupational tasks, firefighters employed by Fire & Rescue NSW, from across all ranks and employment classifications, were invited to participate in an electronic or paper survey concerning these tasks. More than 1,000 firefighters participated in this survey. Based upon the task performance importance, difficulty and frequency responses of permanent and retained firefighters within both metropolitan and regional areas, a list of fifteen fire-fighting activities was identified for more detailed investigation during structured simulations (Table E-2). These tasks were validated and approved (Taylor *et al.*, 2012a).

Table E-2: Fire-fighting tasks and observation durations (minutes) for this project Phase. Data were derived from a survey (N=1011) administered across four firefighter classifications (Taylor *et al.*, 2012a).

Task	P-Metro	R-Metro	P-Region	R-Region
Simulation 1: Hazmat incident	30	18	32	20
Simulation 2: Motor-vehicle rescue	20	14	24	19
Simulation 3: Rolling out hose (70 mm)	3	1	6	2
Simulation 4: Coupling hoses	2	4	6	2
Simulation 5: Locating and connecting to hydrant	6	5	10	4
Simulation 6: Drag charged 70-mm hose (lateral)	7	4	10	5

Task	P-Metro	R-Metro	P-Region	R-Region
Simulation 7: Fire attack	18	18	24	16
Simulation 8: Firefighter down - rescue	8	10	12	12
Simulation 9: Bushfire incident	58	21	50	24
Simulation 10: Stair climb dragging charged hose	10	7	13	8
Simulation 11: Prolonged use of hose (38 mm)	32	24	32	24
Simulation 12: Prolonged use of hose (70 mm)	38	19	30	17
Simulation 13: Ladder use (10.5 m)	8	5	10	7
Simulation 14: Stair climb with ventilation fan	7	6	10	7
Simulation 15: Using sledge axe to gain entry	3	4	7	5

Notes: P-Metro = permanent metropolitan; R-Metro = retained metropolitan; P-Region = permanent regional; R-Region = retained regional.

Methods:

Participating firefighters

A total sample of 51 operational firefighters (mean age: 37.3 years [range: 23-57]; mean operational experience: 9.2 years [range 1-29]) participated in this research Phase. Participation was voluntary, with most individuals participating in more than one task simulation. To ensure that data collection did not suffer from bias due to the selection of an unrepresentative (skewed) sample, all testing was performed using experienced, operational firefighters. Moreover, male and female firefighters participated in all simulations, being drawn from a range of Fire Stations in an attempt to provide a representative mixture of task performance skills, ages, body sizes and fitness levels, such that these would reflect current operational firefighters within Fire & Rescue NSW. Females were recruited in proportion to their representation within this organisation. Each firefighter provided written, informed consent and completed a screening questionnaire prior to participation.

In most circumstances, firefighters participated as whole platoons, under the direction of their Station Officer. This process ensured that each simulation was performed at a realistic operational efficiency that was not affected by individual variability and unfamiliarity. Some occupational tasks will elicit a relatively fixed oxygen cost on the worker, and, regardless of the size of an individual, this demand must be met to successfully complete the task. In these situations, it becomes absolutely necessary to characterise occupational tasks using individuals of widely varying body masses. This criterion was comprehensively satisfied within the current research, since, across all simulations, firefighter mass ranged from 55.3 kg to 113.6 kg.

Fire-fighting simulations

The fifteen occupational tasks were studied under controlled and simulated conditions, plus a hot-fire cell search and rescue (with and without heat and smoke). Each simulation was initially designed by a subject-matter expert to represent a realistically difficult operational scenario, and data were collected using experienced, operational firefighters. Eight subject-matter experts (Senior Training Officers) were identified by Fire & Rescue NSW for this

purpose. Each was assigned the responsibility of liaising with the Research Team to develop these simulations. In the first instance, this involved discussions (teleconference meetings) to define the parameters for each simulation. Then, at each local site, the simulations were set out by the respective Training Officers. Some tasks were fine tuned to facilitate data collection, but no tasks were changed beyond the normal operational realm.

Each simulation was performed under controlled conditions, but at work rates consistent with those encountered during fire-fighting operations, such that each activity faithfully represented a realistically difficult operational scenario. These intensities were set by the firefighters themselves, but regulated, where appropriate, by Station Officers, subject-matter experts and training officers. All simulations were performed using contemporary tools and equipment, as well as the appropriate clothing, personal protective equipment and breathing apparatus designated by Fire & Rescue NSW. Every simulation was directed and supervised by a Senior Training Officer (subject-matter expert), who were explicitly instructed not to set either excessive or rarely encountered work rates or workloads. This level of supervision was also designed to ensure both firefighter safety and the integrity of the simulations. These procedures not only permitted a quantification of the physical and physiological attributes commensurate with successful operational performance, but also the physiological demands accompanying such performance.

Precise details and specifications for each of these simulations, along with the physical characteristics of each participating firefighter, are contained within Sections 2.4 to 2.19 of this report.

Standardisation
To ensure testing was conducted using well-hydrated individuals, firefighters were asked to refrain from strenuous exercise and the heavy consumption of alcohol during the 12 h prior to testing. They were instructed to drink 15 $mL.kg^{-1}$ of additional water in the evening before testing (1.125 L for 75-kg person), and to eat an evening meal and breakfast high in carbohydrate and low in fat. On the morning of testing, subjects were asked to drink 500 mL of fluid (in any form) with breakfast. Water was provided *ad libitum* throughout testing.

Physiological and psychophysical measurements
Throughout each simulation, the following physiological variables were monitored continuously: heart rate, oxygen consumption, minute ventilation, tidal volume and breathing frequency. During the heated, hot-fire cell simulations, core temperatures and heart rates were measured. Intermittently, and at the conclusion of each simulation, ratings of perceived exertion were obtained.

Results:
The experimental observations for each of the sixteen fire-fighting simulations are contained within Sections 3.1-3.16 of this report. Each section was written to stand alone, and to be read almost independently of the other simulations, but with detailed explanations being provided only within Section 3.1. Therefore, for each simulation, the results are presented in three discrete sections. Firstly, representative time-series (raw) data are presented so that readers may visualise changes in physiological strain (Section 3.x.1: *Example experimental*

data). These are followed by summary Tables, each of which contains descriptive data across the physiological variables measured during each occupational simulation (Section 3.x.2: *Physiological and psychophysical strain*). Box plots are also provided to illustrate the time that firefighters spent within zones of progressively increasing physiological strain. Thirdly, detailed assessments of each task are tabulated (Section 3.x.3 *Observational summary*). These evaluations involved identifying the primary, secondary and tertiary physical fitness attributes, the movement patterns performed, the postural characteristics of firefighters, the muscle groups activated and the loads carried during each simulation.

However, this complex analysis has resulted in a very detailed presentation of these observations. This level of detail was provided for several reasons. Firstly, since this research was aimed at eventually providing valid and defensible recruit screening tools and standards, then it was absolutely necessary to establish sound and thorough physiological criteria upon which these may be based. Secondly, since it is reasonable to expect that legal challenges may be mounted to contest these tools and standards, then this level of detail may be necessary to defend their implementation. Thirdly, the Research Team felt that it was necessary that Fire & Rescue NSW possessed the most comprehensive treatment of these observations possible, since the organisation may find these data to serve purposes beyond the brief of this research. Indeed, this level of treatment is not currently available within the existing scientific literature.

Two simulations provided an opportunity for a cross-validation of the physiological strain encountered by firefighters during this investigation. These were activities seven and sixteen, both of which included the fire-attack simulation, but performed with different firefighters, supervised by different Training Officers and conducted under very different operational conditions. For both of these activities, the mean heart rate had a 95% probability of falling within the following overlapping ranges: 135-163 (simulation seven) and 135-151 beats.min^{-1} (simulation sixteen). Similarly, there was a 95% chance that the absolute oxygen consumption would fall within the zones: 1.41-1.81 (simulation seven) and 1.34-1.72 L.min^{-1} (simulation sixteen). This overlap verifies that, between these two simulations, a valid characterisation of fire-attack activity was obtained.

The final analysis for this Phase of the project had two aims. Firstly, from the fifteen occupational activities investigated, the Research Team endeavoured to derive a sub-set of tasks that would impose meaningful, yet broadly representative levels of physiological strain when performed by operational firefighters from across a wide range of experience and skill levels. Since the next Phase of this project is centred upon the development of physiological screening tests for possible use within recruiting, and since it would be inefficient to consider using all fifteen activities within such screening, the Research Team set about excluding tasks if efficiencies could be gained without compromising the integrity of the process. Therefore, the second aim was to establish a filtration process through which some activities could be culled to minimise the duplication of movement patterns and loads within this sub-set of criterion tasks.

To achieve these aims, a decision-analysis approach was used to generate an algorithm for evaluating each occupational task (Figure E-1). The resulting decision tree permitted the

separation of strength- and endurance-related activities. Subsequent steps within strength-related activities resulted in the classification of tasks according to the body region involved, the primary movements performed and the loads carried. Endurance activities were also sub-divided on the basis of load carriage. However, before a task was eliminated from further consideration, its criticality was first assessed. The overall results of this algorithm are presented in Table E-3.

Conclusion:

The observations arising from these sixteen investigations have been built upon three solid foundations:

- Focus-group sessions (106 firefighters) that identified the fifty most physically demanding tasks performed by contemporary firefighters.
- Consultation with Executive Staff and high-level, subject-matter experts to consolidate and reduced these.
- A firefighters survey concerning these tasks, with >1,000 firefighters participating.

These steps resulted in a final list of fifteen fire-fighting activities (Taylor *et al.*, 2012a) that were studied within the current research Phase. The ultimate goal of this was to identify valid criterion tasks that may be used to develop screening tests to identify capable and robust potential fire-fighting recruits.

Task durations ranged from 1.14 min through to 52.33 min, with eight of the simulations being less than 5 min, two were within the 5-10 min range, one simulation fell within the 10-15 min time frame, whilst five tasks lasted 15 min or longer. Since these occupational tasks are valid representations of the most physically demanding duties performed by contemporary firefighters (Taylor *et al.*, 2012a), then one may, at least from a superficial perspective, conclude that at least 50% of these tasks relied on physiological attributes other than whole-body endurance (cardiorespiratory) fitness. A further 30% were dependent upon whole-body fitness, either in the form of cardiorespiratory or muscular endurance.

The occupational task evaluation algorithm (Figure E-1) was designed to first cull the least demanding of these activities, and then to group tasks that shared common movement characteristics and physiological attributes. However, only one task was culled using the algorithm: simulation four (coupling hoses). Whilst this is a critical task, it was eliminated for three reasons: loads handled were <10 kg, tools existed to help those with small hands or low grip strength, and other activities were identified that could provide an assessment of this capacity, but under more stressful conditions. This last consideration was important, and has been applied elsewhere, since screening efficiencies can be gained through the elimination of activities that evaluate common physiological or physical attributes. When such instances were found, the more difficult occupational task has been selected for retention.

> **Recommendation one:** It is recommended that occupational task four (the coupling of hoses) not be included within the list of criterion tasks for fire fighting.

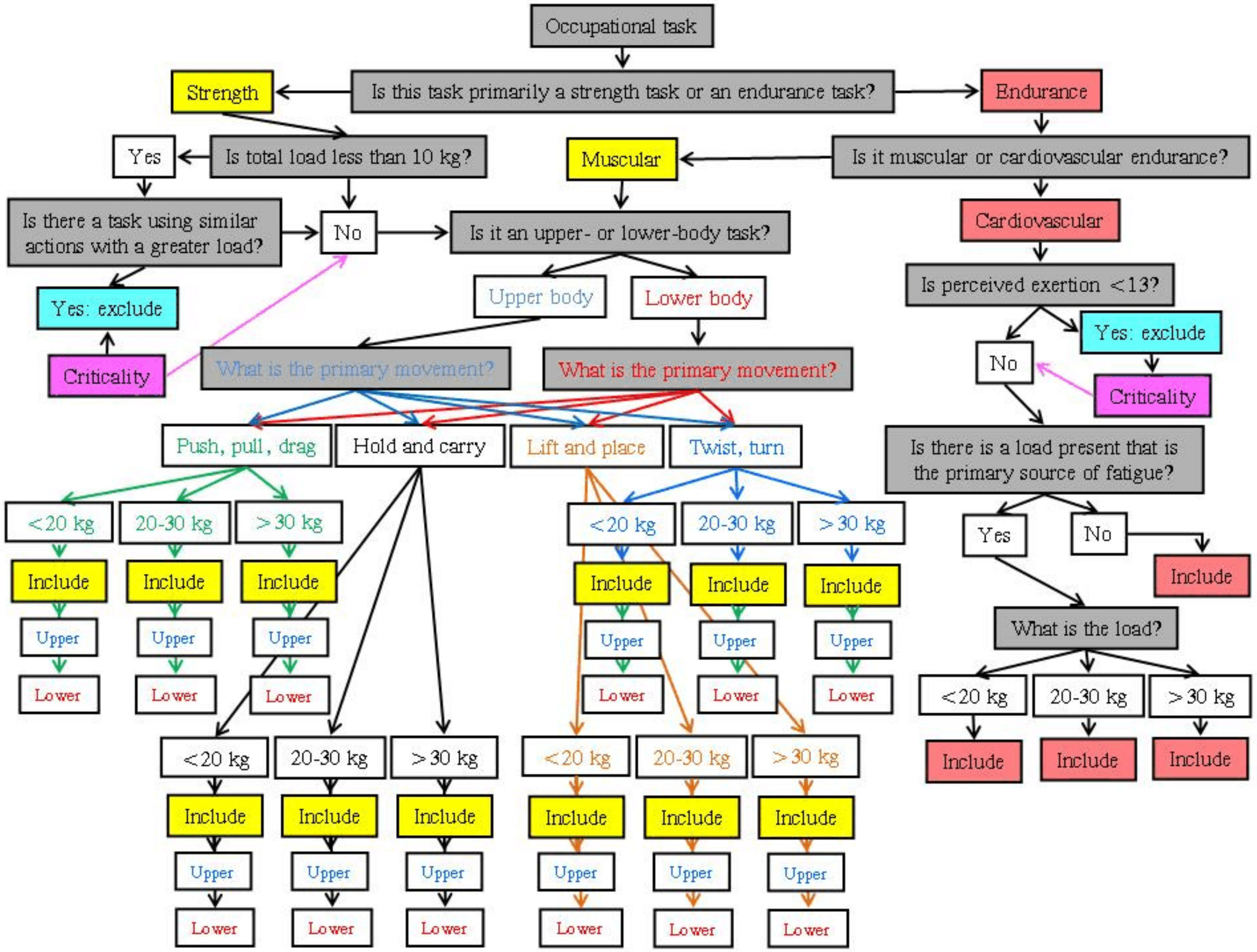

Figure E-1: A flow chart for the distillation of occupational tasks into activities that reflect the breadth of physically demanding tasks that would impose meaningful levels of physiological strain upon firefighters.

Table E-3: Occupational task (simulation numbers 1-15) classifications based upon the analysis algorithm presented in Figure E-1. Where a task appears within more that one cell, it has been deemed to be a whole-body activity (*i.e.* tasks 8, 10 and 14).

Strength and muscular-endurance activities						Cardiorespiratory-endurance activities		
Upper-body activities			Lower-body activities			Loaded		Unloaded
Push, pull, drag	< 20 kg		Push, pull, drag	< 20 kg		< 20 kg	15	
	20-30 kg			20-30 kg	7			
	> 30 kg	8, 10		> 30 kg	8, 10			
Hold and carry	< 20 kg	2, 3, 5, 11	Hold and carry	< 20 kg				
	20-30 kg	1, 6, 12, 13, 14		20-30 kg	14	20-30 kg		
	> 30 kg			> 30 kg				
Lift and place	< 20 kg		Lift and place	< 20 kg				
	20-30 kg			20-30 kg				
	> 30 kg			> 30 kg		> 30 kg	9	
Twist, turn	< 20 kg		Twist, turn	< 20 kg				
	20-30 kg			20-30 kg				
	> 30 kg			> 30 kg				

Examination of the shaded cells within Table E-3 reveals that, of the fifteen occupational tasks evaluated, none involved unloaded cardiorespiratory endurance. Moreover, no strength or muscular-endurance activities performed with either the upper- or lower-body involved the movement classes of lifting and placing, or twisting and turning. The immediate implication of this first main outcome is that recruit screening should not involve assessment items that focus upon these movements or physiological attributes. For instance, it is well known that unloaded evaluations of cardiorespiratory endurance make unreliable predictors of performance when load carriage is involved. Since, at least to the knowledge of the Research Team, a thorough scientific analysis of this occupation has not been recently performed, then this is the first time that Fire & Rescue NSW has been made aware of this fact. It is therefore recommended that the current endurance test used by Fire & Rescue NSW to screen recruits be discontinued (*i.e.* shuttle-run test), and, if appropriate, that it be replaced by a test that better reflects the demands of contemporary fire fighting.

> **Recommendation two:** It is recommended that the current endurance test (shuttle-run) be discontinued and replaced, once appropriate screening tests have been identified (research Phase three) and validated (research Phase four).

Within Table E-3, four cells contain more than one occupational task. Similarly, within the separate upper- and lower-body movement classes, several different tasks are listed, but with different loads. These horizontal and vertical relationships provided immediate opportunities to fine tune this task list by culling activities that evaluate common physiological or physical attributes, if a more difficult occupational task exists.

> **Recommendation three:** It is recommended that occupational task six (lateral dragging of 70-mm charged hose) not be included within the list of criterion tasks for fire fighting, since a more demanding task exists that would evaluate equivalent physiological attributes.

> **Recommendation four:** It is recommended that task eleven (prolonged use of 38-mm hose) not be included within the criterion task list, since a more demanding task exists that would evaluate equivalent physiological attributes.

> **Recommendation five:** It is recommended that task twelve (prolonged use of 70-mm hose) not be included within the list of criterion tasks, since a more demanding task exists that would evaluate equivalent physiological attributes.

From Table E-3, it also becomes clear that these occupational tasks are dominated by activities in which the holding and carrying of objects dominates the movement patterns. Furthermore, there exists a clear bias across these activities towards a reliance upon upper-body strength or muscular endurance.

> **Recommendation six:** It is therefore recommended that occupational tasks one (hazmat), two (motor-vehicle rescue), three (rolling out 70-mm hose), five (hydrant location and connection), thirteen (ladder use) and fourteen (ventilation fan carry) be treated as a pool of similar, upper-body criterion tasks upon which may be

developed either generic or occupation-specific screening tests. This development will occur within the next Phase of this project.

When cardiorespiratory fitness is important within contemporary fire fighting, it was found to be associated with load carriage, with greater demand being found within occupational task nine: the dragging of a charged 38-mm hose over uneven terrain in the simulation of fighting a bushfire.

Recommendation seven: It is recommended that occupational task nine (dragging charged 38-mm hose [uneven terrain]) should become one of the criterion tasks upon which a generic or occupation-specific screening test may be developed.

A second task relied upon cardiorespiratory fitness, but also upon upper-body muscular endurance. This was task fifteen: using a sledge axe to gain entry into a building.

Recommendation eight: It is recommended that occupational task fifteen (using a sledge axe to gain entry) also be included as a criterion task, leading to the development of either a generic or an occupation-specific screening test.

Finally, three occupational tasks involved movement patterns dominated by the pushing, pulling or dragging of objects >20 kg in mass. Whilst two of these activities could be classed as being whole-body in their demands, each had a heavy reliance upon lower-body strength or muscular endurance.

Recommendation nine: It is recommended that occupational tasks seven (fire attack), eight (firefighter rescue) and ten (stair climb dragging a charged hose) be treated as a pool of similar, predominantly lower-body criterion tasks upon which may be developed either generic or occupation-specific screening tests. This development will also occur within the next Phase of this project.

On the basis of these analyses, the following criterion fire-fighting tasks have been grouped into four activity classes that are recommended to be carried into the next research Phase:

- **Class one:** tasks one (hazmat), two (motor-vehicle rescue), three (rolling out 70-mm hose), five (hydrant location and connection), thirteen (ladder use) and fourteen (ventilation fan carry)
- **Class two:** task nine (dragging charged 38-mm hose [uneven terrain])
- **Class three:** task fifteen (using a sledge axe to gain entry)
- **Class four:** tasks seven (fire attack), eight (firefighter rescue) and ten (stair climb dragging a charged hose).

Verification and approval of the criterion task list

The above criterion list of fire-fighting tasks was submitted to the Project Management Team for consideration, endorsement and validation. Approval to progress to the next research Phase (screening test development) was also sought at this meeting. These outcomes were each achieved at the Project Management Team meeting held on May 21st (2012: Appendix Three of this report).

Human Performance Laboratories (Australia)

AUTHORS

Assoc. Prof. Nigel A.S. Taylor, *Ph.D.*
University of Wollongong.
*Nigel is a human stress physiologist with over 25 years of research experience, and with particular research emphases within exercise physiology, temperature regulation and occupational physiology. Nigel's research training was based in Europe and North America, and included extensive involvement with Defence organisations from both continents. He participates in a five-way research collaboration (Environmental Physiology and Ergonomics Research Exchange) involving laboratories in France, Japan, Slovenia and the United Kingdom (www.uow.edu.au/health/epere/index.html). Nigel's research often focuses upon the interface between the worker and the environment, and how human performance may be optimised under physical and environmental extremes (occupational physiology). He has an extensive research background, with more than 300 publications. Nigel is the Vice Chair of the **IUPS Advisory Committee for Thermal Physiology and Pharmacology**. He is the Reviews Editor for the **European Journal of Applied Physiology** and an International Editorial Board member of seven other refereed journals (including Medicine & Science in Sports & Exercise).*

Hugh H.K. Fullagar, *B.Sc.*
University of Wollongong.
Hugh is a Master of Science student within the School of Health Sciences (University of Wollongong). His undergraduate training was in the discipline of exercise science, majoring in exercise physiology. His current research is centred around the development of valid and reliable physiological employment standards for Fire & Rescue NSW.

Dr. John A. Sampson, *Ph.D.*
University of Wollongong.
John has recently completed his Doctoral dissertation within the School of Health Sciences (University of Wollongong), examining musculoskeletal adaptation to resistance exercise. His primary research interest is encompassed within the physiological adaptations that are associated with exercise. The focus of his current and future work is in manipulating exercise training programmes to reduce total work, but without compromising the associated physiological adaptations observed during exercise training.

Sean R. Notley, *B.Sc.*
University of Wollongong.
Sean is a Master of Science student within the School of Health Sciences. His undergraduate training was in the discipline of exercise science, majoring in exercise physiology. His research focusses upon the cardiac and metabolic responses to work-related exercise, with specific interests in the separate influences of load carriage, posture, exercise mode, muscle mass recruitment and thermal strain upon the validity of heart rate and ventilatory predictions of metabolic demand.

Simon D. Burley, *M.Sc.*
University of Wollongong.
Simon is a doctoral candidate within the School of Health Sciences (University of Wollongong). His masters and undergraduate training were in the discipline of exercise science, majoring in exercise physiology. His current research is broadly focussed on supporting the development of physiological employment standards for Australian Defence Force. More specifically, his research deals with evaluating the development of physical endurance (aerobic power) and the capacity of skeletal muscle through basic military training tasks ranging from manual handling to load carriage activities.

Daniel S. Lee, *B.Ex.Sc. (rehab)*
University of Wollongong.
Daniel is a Master of Science student within the School of Health Sciences. His undergraduate training was in the discipline of exercise science, majoring in exercise physiology and rehabilitation. His current research deals with changes in the maximal acceptable working rate during load carriage tasks. In this work, he has investigated the impact of load carriage upon cardiac, pulmonary and metabolic rate across a broad range of exercise intensities.

Dr. Herbert Groeller, *Ph.D.*
University of Wollongong.
Herb has over 20 years of experience working as an exercise physiologist with occupational, healthy active, sports-injured, aged and cardiac patient groups. He has also worked with various groups as a consultant, advising on the physiological demands and requirements of specific work tasks, the implementation of functional testing regimens, and medical screening procedures and health initiatives. Herb's past research centred upon the impact of exercise habits on cardiovascular risk factors in middle-aged and older males. His current research focus is upon skeletal muscle strength adaptation within healthy and clinically relevant population samples.

CONTACT DETAILS

Centre for Human and Applied Physiology

Nigel A.S. Taylor, *Ph.D.*
Associate Professor
Centre for Human and Applied Physiology
www.uow.edu.au/health/chp/
School of Health Sciences
University of Wollongong
Northfields Avenue
Wollongong, NSW 2522
Australia.
Telephone: 61-2-4221-3463
Facsimile: 61-2-4221-5945
Electronic mail: nigel_taylor@uow.edu.au

Fire & Rescue New South Wales:

Brendan Mott
Team Leader Health and Fitness
Health and Safety Branch
Fire & Rescue New South Wales
227 Elizabeth Street
Sydney, NSW 2000
Australia
Telephone: 61-2-9265-2800
Facsimile: 61-2-9265-2986
Electronic mail: Brendan.Mott@fire.nsw.gov.au

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1. INTRODUCTION

For centuries, firefighters have served critical public-service roles in times of emergency. In addition to roles of fire suppression and containment, contemporary fire-fighting organisations now respond to transport accidents (road, rail, aircraft), rescues, hazardous materials incidents, natural disasters (earthquakes, floods, landslides, storms, tsunamis), structural damage to buildings, possible threats of terrorism and other emergency situations. Many of these roles place firefighters under significant physiological and physical strain[1]. Indeed, the scientific literature contains many reports quantifying this strain (Barnard and Duncan, 1975; Lemon and Hermiston, 1977; Duncan *et al.*, 1979; Budd *et al.*, 1986; Romet and Frim, 1987; Faff and Tutak, 1989; Sothmann *et al.*, 1992; Smith and Petruzzello, 1998; Bos *et al.*, 2004; Holmér and Gavhed, 2007).

Given these heavy occupational demands, fire-fighting organisations often use pre-employment screening tests to identify individuals who are well suited to coping with such extremes of physiological strain. These procedures are aimed at increasing the capability of the workforce, whilst simultaneously minimising the risk of injury to both firefighters and members of the community.

The current investigators have been tasked with identifying screening tools and physiological standards to facilitate the identification and recruitment of capable and robust individuals for Fire & Rescue New South Wales (NSW). This project involves five discrete Research Phases, with the research reported herein representing the second Phase of testing, in which operational firefighters were studied whilst performing a broad range of physically demanding fire-fighting (occupational) tasks. The Research Team observed, quantified and evaluated the physiological and physical demands placed upon firefighters during the performance of these tasks, and this report summarises those observations.

1.1 Establishing legally defensible physiological employment (occupational) standards

The provision of genuine, certifiable (*bona fide*) and legally defensible physiological employment standards will answer two fundamental questions:

- How certain can one be that those who are accepted into this job will be capable of successfully performing the necessary work-related tasks without exposing themselves to an undue risk of injury?
- How certain can one be that those who are deemed to be unacceptable, will actually be incapable of successfully performing the necessary work-related tasks, or that during the performance of these tasks, such individuals would expose themselves or others to an undue risk of injury?

The legal and scientific issues related to providing defensible answers to these critical questions have previously been identified and described (Gledhill and Jamnik, 1992a, 1992b; Gledhill *et al.*, 2001; Constable and Palmer, 2000; Taylor and Groeller, 2003; Payne and Harvey, 2010). These are summarised as steps within Table 1, which forms the

[1] Strain refers to the impact of stress, which is generally of an external origin (*e.g.* heat, load carriage), upon physiological function (*e.g.* heart rate, sweating, oxygen consumption).

framework for the overall project. The current research is focussed upon steps eight-ten of Phase Two.

Table 1: Procedural summary and framework for the development of *bona fide* pre-employment screening tests and physiological employment standards for physically demanding trades. The current Research Phase is highlighted.

Project phase	Step	Description
0	1	Justify need for establishing employment standards
	2	Establish a Project Management Team
1	3	Familiarise Research Team with the trade
	4	Trade review and preliminary analysis of all tasks
	5	Identify the essential, physically demanding tasks
	6	Validate and approve the fire-fighting task list
	7	Employee survey: importance, difficulty, frequency of tasks
2	8	Characterise critical tasks: observe, measure, quantify
	9	Determine criterion fire-fighting tasks
	10	Validate and approve criterion fire-fighting tasks
3	11	Develop defensible physiological screening tests
	12	Standardise screening tests and administration
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	17	Validate and approve performance standards
	18	Implement pre-employment screening
		Review the screening process and its outcomes: ongoing

1.2 Understanding the demands of job performance

The stress most commonly placed upon firefighters is frequently believed to be that which is associated with heat exposure. Certainly, firefighters face life-threatening heat sources, and many investigators have reported high levels of physiological strain accompanying these exposures (Duncan *et al.*, 1979; Budd *et al.*, 1986; Sköldström, 1987; Faff and Tutak, 1989; Gavhed and Holmér, 1989; Ilmarinen *et al.*, 1996; Smith and Petruzzello, 1998; Eglin and Tipton, 2005). However, over the ten-year period from 1998-2008, only 2% of

injuries to firefighters within Fire & Rescue NSW were ascribed to thermal exposure (137 injuries: Taylor and Kerry, 2010). Various operational practices and safety equipment will account for this low incidence, yet, over the same period, 39% of all reported injuries were related to muscular stress (2,731 injuries: Taylor and Kerry, 2010). This contrast highlights the significance of physiological strain beyond heat exposure, and this is associated with the materials handling aspect of fire fighting, both with respect to the protective equipment worn by firefighters and to the equipment that is used during the performance of daily tasks.

It is well established that load carriage can have adverse affects upon gait, metabolic efficiency, fatigue and the risk of injury (Knapik *et al.*, 2004; Blacker *et al.*, 2010; Qu and Yeo, 2011). In addition to load mass, its positioning on the body will largely dictate its physiological impact (Parkes, 1869; Zuntz and Schumburg, 1901; Goldman and Iampietro, 1962; Datta and Ramanathan, 1971; Myers and Steudel, 1985). Indeed, the most inefficient locations for load carriage are the hands and feet (Munson, 1901; Turrell and Robinson, 1943; Lind and McNicol, 1968; Soule and Goldman, 1969; Legg and Mahanty, 1986), and all equipment beyond that which is worn is carried in the hands (see Section 2.3.3).

Firefighters wear 19-20 kg of personal protective clothing (PPC) and equipment (PPE). This is comprised of layered thermal protective clothing, heavy footwear to protect against penetration and crush injuries, a helmet to protect the head, and breathing apparatus to protect against smoke and noxious gases. The impact of each component of this ensemble has recently been described in detail (Taylor *et al.*, 2012b), and with a particular emphasis upon the metabolic costs. It was found that, under steady-state conditions, the footwear exerted the greatest relative metabolic impact during walking and simulated stair climbing, being 8.7 and 6.4 times greater per unit mass than the breathing apparatus. Indeed, the relative influence of the thermal protective clothing on oxygen cost was at least three times that of the breathing apparatus. Therefore, the most efficient way to reduce the physiological burden of firefighters' protective equipment, and thereby increase safety and capability, would be to reduce the mass of the boots and thermal protective clothing.

What now remains to be investigated is the physiological impact of the other loads handled during fire fighting when also wearing personal protective clothing and equipment. This renders fire fighting a rather unique occupation with respect to load carriage, and this is the focus of the research reported herein.

1.3 Research aims

The aim of this research Phase was to observe, quantify and evaluate the physical and physiological demands placed upon firefighters performing a broad range of physically demanding fire-fighting (occupational) tasks. These tasks were identified and validated within the first research Phase (Taylor *et al.*, 2012a: Table 2), and were studied in this Phase under controlled and simulated conditions. Each simulation was designed by a subject-matter expert to represent a realistically difficult operational scenario, and data were collected using experienced, operational firefighters. These procedures permitted a quantification of the physical and physiological attributes commensurate with successful operational task performance, leading to the identification of criterion tasks that may be used to screen and identify capable and robust potential firefighters.

Table 2: Recommended fire-fighting tasks and observation durations (minutes) for this project Phase. Data were derived from a survey (*N*=1011) administered across four firefighter classifications (Taylor *et al.*, 2012a).

Task	P-Metro	R-Metro	P-Region	R-Region
Simulation 1: Hazmat incident	30	18	32	20
Simulation 2: Motor-vehicle rescue	20	14	24	19
Simulation 3: Rolling out hose (70 mm)	3	1	6	2
Simulation 4: Coupling hoses	2	4	6	2
Simulation 5: Locating and connecting to hydrant	6	5	10	4
Simulation 6: Drag charged 70-mm hose (lateral)	7	4	10	5
Simulation 7: Fire attack	18	18	24	16
Simulation 8: Firefighter down - rescue	8	10	12	12
Simulation 9: Bushfire incident	58	21	50	24
Simulation 10: Stair climb dragging charged hose	10	7	13	8
Simulation 11: Prolonged use of hose (38 mm)	32	24	32	24
Simulation 12: Prolonged use of hose (70 mm)	38	19	30	17
Simulation 13: Ladder use (10.5 m)	8	5	10	7
Simulation 14: Stair climb with ventilation fan	7	6	10	7
Simulation 15: Using sledge axe to gain entry	3	4	7	5

Notes: P-Metro = permanent metropolitan; R-Metro = retained metropolitan; P-Region = permanent regional; R-Region = retained regional.

2. METHODS

2.1 The Project Management Team

Overall project management was undertaken through a Project Management Team. These individuals, their positions and their roles are summarised in Table 3.

Table 3: The Project Management Team.

Name	Position	Role
Alison Donohoe	Assistant Director Health and Safety (FRNSW)	Project Manager and Steering Committee Member
Darren Husdell	Director Human Resources (FRNSW)	Project Sponsor and Steering Committee Member
Jim Hamilton	Director Metropolitan Operations (FRNSW)	Steering Committee Member
Ken Murphy	Acting Director Regional Operations (FRNSW)	Steering Committee Member

Name	Position	Role
Geoffrey Parkes	Assistant Director Training (FRNSW)	Steering Committee Member
Brendan Mott	Team Leader Health and Fitness (FRNSW)	Research liaison and Steering Committee Member
Megan Smith	Manager Health Promotion (FRNSW)	Research liaison and Steering Committee Member
Nigel Taylor	Associate Professor (UOW)	Scientific expertise
Herb Groeller	Senior Lecturer (UOW)	Scientific expertise
John Sampson	Lecturer (UOW)	Scientific expertise
Hugh Fullagar	Postgraduate student (UOW)	Data collection and analysis

2.2 Subject-matter experts

Eight subject-matter experts (Senior Training Officers) were identified by Fire & Rescue NSW (Table 4). Each was assigned the responsibility of liaising with the Research Team to develop these simulations. In the first instance, this involved discussions (teleconference meeting) to define the parameters for each simulation. Then, at each local site, the simulations were set out by the respective Training Officers. Some tasks were fine tuned to facilitate data collection, but no tasks were changed beyond the normal operational realm. Most tasks were studied individually. However, one group consisted of four tasks performed consecutively (Table 4: group 3). This enabled the least demanding tasks to be performed first, without introducing physiological bias from the more challenging activities.

Table 4: Occupational task simulations, simulation groups and subject-matter experts.

Group	Task	Name	Rank
1	Hazmat operation	Duncan White Mark Black	Superintendent Station Officer
2	Motor-vehicle rescue	Tony Waller and Colin Whiteman	Station Officer Senior Firefighter
3	Rolling out uncharged hoses	John Mcdonough	Inspector
	Coupling/uncoupling hoses		
	Hydrant location and connection		
	Drag 70-mm charged hose		
4	Fire attack		
5	Firefighter down: rescue		
6	Bushfire	John Sullivan	Qualified Firefighter
7	Stair climb with hose	Craig Sheehan John Sheehy	Senior Firefighter Qualified Firefighter
	Prolonged use of 38-mm hose		
	Prolonged use of 70-mm hose		

Group	Task	Name	Rank
	Ladder use (10.5 m)		
	Sledge axe entry		
	Ventilation fan carry: stairs		
8	Structural search and rescue	Stephen Jones Mark Holmes	Station Officer Station Officer

2.3 Methodological overview

2.3.1 Experimental subjects

A total sample of 51 operational firefighters (mean age: 37.3 years [range: 23-57]; mean operational experience: 9.2 years [range 1-29]) participated in this research Phase. The physical characteristics of each individual are provided in Tables that appear within the text describing each of the task simulations and the data collection procedures. Participation was voluntary, with most individuals participating in more than one task simulation. To ensure that data collection did not suffer from bias due to the selection of an unrepresentative (skewed) sample, all testing was performed using experienced, operational firefighters. Moreover, male and female firefighters participated in all simulations, being drawn from a range of Fire Stations in an attempt to provide a representative mixture of task performance skills, ages, body sizes and fitness levels, such that these would reflect current operational firefighters within Fire & Rescue NSW. Females were recruited in proportion to their representation within this organisation. In most circumstances, firefighters participated as whole platoons, under the direction of their Station Officer. This process ensured that each simulation was performed at a realistic operational efficiency that was not affected by individual variability and unfamiliarity. Each firefighter provided written, informed consent and completed a screening questionnaire prior to commencing procedures approved by the Human Research Ethics Committee (University of Wollongong). This screening procedure was aimed at identifying and eliminating individuals for whom the performance of these simulations might be considered an unacceptable health risk[2].

2.3.2 Fire-fighting task simulations

The Research Team observed, quantified and evaluated the physical and physiological demands placed upon operational firefighters when performing fifteen physically demanding (occupational) tasks (Table 2; Taylor *et al.*, 2012a), plus a hot-fire cell simulation. Each simulation was performed under controlled conditions, but at work rates consistent with those encountered during real fire-fighting operations. These intensities were set by the firefighters themselves, but regulated, where appropriate, by Station Officers, subject-matter experts and training officers (Section 2.3). All simulations were performed using contemporary tools and equipment, as well as the appropriate clothing, personal protective

[2] It was recognised that operational firefighters, by definition, must be capable of performing strenuous physical exercise on a daily basis. However, research ethics procedures dictate that preventative screening must occur before each experiment. Therefore, this questionnaire addressed the following conditions and health states: high blood pressure, deep vein thrombosis, blood clotting disorders, chest pain, heart problems, heat stroke, heat exhaustion, respiratory disorders, renal problems, diabetes, muscle, bone and joint injuries, neural disorders, and major operations. Participants were also questioned regarding prescribed medication and medical recommendations concerning physical activity restrictions.

equipment and breathing apparatus designated by Fire & Rescue NSW. Every occupational simulation was defined, directed and supervised by a Senior Training Officer of Fire & Rescue NSW (subject-matter expert), such that each activity would faithfully represent a realistically difficult operational scenario. Training Officers were explicitly instructed not to set either excessive or rarely encountered work rates or workloads. This level of supervision was also designed to ensure both firefighter safety and the integrity of the simulations. These procedures not only permitted a quantification of the physical and physiological attributes commensurate with successful operational performance, but also the physiological strain associated with this performance.

2.3.3 Equipment carried and used by firefighters at work

The Fire Station to which an individual is appointed dictates the equipment that is handled during an incident. Table 5 catalogues some of that equipment, but is limited to items used within the current fire-fighting simulations.

Table 5: Items used within the fire-fighting simulations.

Item	Name	Size	Mass	Quantity
1	Bin, hazmat recovery	960 mm * 710 mm * 710 mm	28 kg (200 L)	1
2	Block step (6 piece)	600 mm * 100 mm * 75 mm	7.2 kg	1
3	Breathing apparatus, self-contained, air set	530 mm * 140 mm * 140 mm	11.6 kg	6
4	Crowbar	1800 mm * 25 mm	5.8 kg	1
5	Halligan Tool	750 mm * 175 mm * 170 mm	4.5 kg	1
6	Hose assembly set, hydraulic	5 and 10 m	5 m= 4.9 kg 10 m= 6.9 kg	3
7	Hydrant, fire, bar	600 mm	1.8 kg	1
8	Hydrant, fire, delivery elbow	540 mm * 120 mm * 100 mm	7.1 kg	1
9	Hydrant, fire, standpipe, single head	190 mm * 300 mm * 930 mm	8 kg	2
10	Hydrant, fire, wide breach	70 mm	5 kg	1
11	Ladder, fire, extension	10.7 m (extendable)	49.6 kg	1
12	Ladder, jumbo	4600 mm * 300 mm * 200 mm	16.3 kg	1
13	Pump, hydraulic, gasoline driven	500 mm * 335 mm * 365 mm	24.5 kg	1
14	Ram, hydraulic	1642 mm (maximum)	19.1 kg	1

Item	Name	Size	Mass	Quantity
15	Shear set, hydraulic, double acting	830 mm * 220 mm * 125 mm	13 kg	1
16	Spreaders, double acting	920 mm * 810 mm * 300 mm	19.5 kg	1
17	Sheet, non-metallic, protective, salvage	3600 mm * 3600 mm	8.3 kg	2
18	SIAMESE connection, fire hose, non-valved	38 mm * 200 mm * 220 mm	1.3 kg	2
19	SIAMESE connection, fire hose, valved	65 mm * 300 mm * 320 mm	4.9 kg	2
20	Sledge axe	750-mm long	4.7 kg	1
21	Suit kit, chemical protective	Height: 2.2 m Armspan: 2.0 m	7.7 kg	2
22	Ventilation fan	560 mm * 500 mm * 400 mm	35 kg	1
23	Viewer set, thermal imaging	275 mm * 112 mm * 205 mm	1.35 kg	1
24	38-mm hose, charged	30 m	~35 kg	10
25	70 mm hose, charged	30 m	~115 kg	10
26	70-mm hose, rolled	$520mm^2$ * 100 mm	16.6 kg	10

2.3.4 Physiological and psychophysical measurements

2.3.4.1 Heart rate

Heart rates were monitored continuously from ventricular depolarisation (Polar Electro Sports Tester, Kempele, Finland). In most circumstances, these monitors were integrated into the data acquisition system for measuring oxygen consumption (see below), with both sets of data being simultaneously recorded. These data were sampled on a breath-by-breath basis. However, during the hot-fire cell simulations that involved heat and smoke, heart rates were monitored using a more robust portable system (Polar Team System, Polar Electro Oy, Kempele, Finland). These data were sampled at 5-s intervals.

2.3.4.2 Oxygen consumption and data acquisition system

Oxygen consumption was measured using a portable, open-circuit, expired gas analysis and ventilation system (Figure 1: Metamax 3B, Cortex Biophysik, Leipzig, Germany: mass = 1.82 kg). This involved separate determination of minute ventilation (turbine), and expired oxygen (electro chemical cell) and carbon dioxide concentrations (infra-red). Data were recorded on a breath-by-breath basis and reported at 5-s intervals. Equipment was calibrated prior to going into the field, with calibration verification performed throughout test days.

2.3.4.3 Minute ventilation

A first-principles approximation of minute ventilation was also derived for work completed within the hot-fire cell. Total air use was computed from the change in air cylinder pressure

over the duration of the simulation. Cylinder pressures at identical surface temperatures were determined by Breathing Apparatus Training personnel from Fire & Rescue NSW.

Equation 1: Minute ventilation [$L.min^{-1}$] = ((initial pressure * cylinder volume) - (final pressure * cylinder volume)) / time [min]

where: cylinder volume = 6.8 L.

Figure 1: The open-circuit, expired gas analysis and ventilation system.

2.3.4.4 Body core temperature

During the hot-fire cell simulations that involved heat and smoke, core temperature was approximated from gastrointestinal temperatures, and recorded continuously using a radio capsule (Jonah 500-0100-02, Respironics Deutschland, Herrsching, Germany; mass = 1.6 g; size = 8.7 mm diameter * 23 mm length) ingested prior to each trial. Data were sampled at 1-min intervals (VitalSense, Mini Mitter Co. Inc, OR, U.S.A.; mass = 200 g; size = 120 mm * 90 mm * 45 mm), with sampling activated immediately. However, data for the first 60 min of each trial were discarded. This method of measuring core temperature has been validated during routine daily activities (McKenzie and Osgood, 2004), and also during intermittent exercise of varying intensities (Gant *et al.*, 2006).

2.3.4.5 Perceived exertion

Perceived exertion ratings (RPE) were obtained during exercise using the 15-point Borg Scale, after being asked: “How hard are you exercising” (6-20: 6 = very, very light, and 20 = very, very hard; Borg, 1962a, 1962b).

The 15-point Borg scale

6	
7	**Very, very light**
8	

9	**Very light**
10	
11	**Fairly light**
12	
13	**Somewhat hard**
14	
15	**Hard**
16	
17	**Very hard**
18	
19	**Very, very hard**
20	

2.3.5 Experimental standardisation

To ensure testing was conducted using well-hydrated individuals, firefighters were asked to refrain from strenuous exercise and the heavy consumption of alcohol during the 12 h prior to testing. They were instructed to drink 15 $mL.kg^{-1}$ of additional water in the evening before testing (1.125 L for 75-kg person), and to eat an evening meal and breakfast high in carbohydrate and low in fat. On the morning of testing, subjects were asked to drink 500 mL of fluid (in any form) with breakfast. Water was provided *ad libitum* throughout testing.

2.4 Simulation one: Hazmat incident (in pairs)

2.4.1 Subjects

Sixteen firefighters participated in this simulation (including one woman): Table 6. Eight firefighters were tested in the morning and another eight in the afternoon (Ingleburn Training Centre). Since each firefighter also performed the next simulation, each person rested for a minimum of 30 min between successive simulations.

Table 6: Characteristics of firefighters. Fire Stations: Hazmat Advisory Response Team, Hurstville, Liverpool, City of Sydney.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S1	SFF	46	10	171.20	86.80
S2	SO	57	28	197.00	108.20
S3	QFF	29	4	179.70	89.20
S4	FF	23	1	171.00	65.00
S5	FF	26	1	181.10	113.60
S6	FF	25	2	182.90	82.30
S7	SFF	46	20	168.50	82.30
S8	SO	47	20	171.00	92.75
S9	SFF	42	9	163.00	84.20

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S10	QFF	47	9	173.00	91.05
S11	LFF	34	10	179.00	97.10
S12	SFF	39	13	178.50	95.30
S13	SFF	45	10	179.50	95.40
S14	SFF	37	13	184.50	91.15
S15	SO	42	13	189.00	100.00
S16	SFF	42	21	190.00	108.90
Mean		39.2	11.5	178.70	92.70
SD		9.5	7.8	8.89	11.93

Notes: FF = firefighter, QFF = qualified firefighter, SFF = senior firefighter, LFF = leading firefighter, SO = Station Officer.

Figure 2: Firefighters performing a hazmat incident simulation.

2.4.2 Simulation description

This simulation commenced with a 5-min seated rest, and two individuals were investigated

simultaneously[3]. Firefighters wore station-wear clothing (mean: 1.4 kg), breathing apparatus (mean: 11.44 kg), an encapsulating ensemble (mean: 7.7 kg) and the respiratory gas analysis system (Figure 1: 1.82 kg). This data acquisition equipment prevented full encapsulation. Instead, firefighters wore this suit over station-wear garments, but with the head and partial chest exposed (Figure 2). An exclusion zone was established 64 m from the hazard. Firefighters commenced the simulation by walking into this zone carrying a ladder (16 kg; Figure 2). Walking covered three surfaces (bitumen, gravel and an elevated concrete slab), and the same route was used by all firefighters during entry to, and the removal of items from the hazard. At the incident (simulated truck tray 1.1 m above ground), eight items required removal beyond the exclusion zone: seven gas cylinders (8.45, 9.55, 18.50, 20.65, 21.45, 40.30 and 52.25 kg) and one plastic container (21.85 kg). The larger objects were carried in pairs whilst others were carried by one firefighter. The simulation ended when all equipment had been removed from the exclusion zone. The average duration of these simulations was 15.24 min (SD 2.47).

2.5 Simulation two: Motor-vehicle rescue (spreaders, shears: in pairs)

2.5.1 Subjects

The same firefighters who completed simulation one participated in this activity (Table 6).

Figure 3: Firefighters performing a motor-vehicle rescue simulation.

[3] The simulations were controlled by Senior Training Officers, but the Station Officer that accompanied each firefighter team dictated the pairing of firefighters and, in some cases, the approach taken within each scenario, as would normally occur at an incident.

2.5.2 Simulation description

Firefighters rested >30 min after the first simulation, and commenced with a 5-min seated rest. This task was performed in pairs, and firefighters wore long-sleeved shirts or bushfire jackets, protective boots (mean: 2.61 kg), rescue helmets (mean: 1.48 kg) and the data acquisition system (1.82 kg). The simulation commenced at an equipment dump, with tools positioned on a salvage sheet (Figure 3, Table 5). The objective was to remove two doors from the side of a damaged vehicle[4] using hydraulic tools (spreaders and shears). One pair from every three firefighter pairs also removed the vehicle roof (Figure 3). The simulation ended for each pair when vehicle entry was achieved and equipment was returned to the salvage sheet. The average duration of these simulations was 13.57 min (SD 5.40).

2.6 Simulation three: Rolling out 70-mm hose (individual)

2.6.1 Subjects

Sixteen firefighters participated in this occupational simulation (including two women: Table 7), with eight tested in the morning and the balance in the afternoon.

Table 7: Characteristics of firefighters performing the following simulations: bowling 70-mm hose, coupling hoses, locating and connecting to a hydrant, dragging charged 70-mm hose, fire attack, firefighter down (rescue). Fire Stations: Blacktown, Kellyville, Mount Druitt and Seven Hills.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S17	FF	32	3	185.00	79.75
S18	SO	41	22	176.00	77.30
S19	FF	39	3	183.00	81.05
S20	QFF	33	4	177.00	78.55
S21	SO	49	24	177.00	102.55
S22	QFF	33	4	168.00	68.00
S23	SO	50	29	177.50	86.40
S24	FF	29	2	182.50	77.75
S25	QFF	26	3	189.00	89.00
S26	QFF	29	5	167.50	92.20
S27	SFF	41	6	161.10	55.30
S28	SO	44	15	177.00	70.70
S29	SFF	42	9	177.00	76.90

[4] The Senior Training Officer supervised the placement and damage inflicted upon each vehicle (four sedans and one station wagon). The only means of entry was by removing the doors and roof of each vehicle.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S30	SFF	46	8	179.50	69.50
S31	QFF	36	3	182.30	92.10
S32	FF	26	3	194.50	108.45
Mean		37.3	8.9	178.37	81.59
SD		7.9	8.7	8.21	13.34

2.6.2 Simulation description

This simulation was performed as the first activity of a group of four simulations (see Table 4), with suitable rests separating each activity. For simulations three to six, firefighters wore full thermal protective and station-wear clothing (mean: 4.72 kg), protective boots (mean: 2.58 kg), breathing apparatus (mean: 11.53 kg), helmets (mean: 1.39 kg), radio (1.1 kg) and data acquisition system (1.82 kg: mean total mass 23.14 kg). Each task commenced with a 5-min seated rest. This simulation involved rolling (bowling) out two, 70-mm hoses (16.6 kg each) prior to using these hoses to connect the hydrant to the appliance (pump). It involved the following steps (Figure 4): roll one, 70-mm hose[5] diagonally; carry one end of this hose plus a second 70-mm rolled hose ~15 m to fully extend the first hose; place the first hose on the ground; roll out the second 70-mm hose; pick up one end of this hose and walk to hydrant (~24 m); place the hose end over the hydrant. Each of these distances were fixed, with markers used to clearly show each point (Figure 4). This simulation involved a walking distance of 41 m. The average duration was 1.68 min (SD 0.34).

2.7 Simulation four: Coupling hoses (individual)

2.7.1 Subjects

After completing the hose roll, the same firefighters participated in the hose coupling task.

2.7.2 Simulation description

As this occupational task was completed as the second part of a series of four simulations (using identical clothing protective equipment), participants rested for 2 min (standing) before commencing the activity, which started from the hydrant where the previous simulation finished. Firefighters walked from the hydrant to the appliance (41 m), and coupled the hose to the appliance using either both hands or the coupling spanners to make this connection (Figure 5). Participants then walked 15 m to the point where the two ends of the two 70-mm hoses lay on the ground. These hoses were then coupled (hands or coupling spanners: Table 5). Finally, firefighters walked 15 m to the hydrant and coupled the hose to the hydrant (hands or coupling spanners). Each distance was fixed, with markers used to clearly show these points. The simulation ended with this third coupling task, and lasted an average of 1.14 min (SD 0.34).

[5] Hoses are rolled with both coupling components at one end, so when rolled out, the firefighter still holds both ends of the hose.

Figure 4: Firefighters rolling out (bowling) 70-mm hoses.

Figure 5: Firefighters coupling hoses.

2.8 Simulation five: Locating and connecting hydrant to appliance (individual)

2.8.1 Subjects

After completing the hose coupling, these 16 firefighters continued this grouped simulation, which now involved firefighters locating and connecting a hose to a fire hydrant[6].

2.8.2 Simulation description

This task was the third in a series of four task simulations (identical clothing and protective equipment). Before commencing, participants again rested for 2 min (standing), then started with a 41-m walk to the appliance. Firefighters opened the sliding doors on the side of the appliance to remove one, 70-mm hose, hydrant bar, standpipe and breaching piece (Table 5, Figure 6). All items were carried as quickly as possible to the hydrant marked 70 m away. Some firefighters chose to carry all items at once, thus performing the task in one trip (70 m), while others elected to make two trips (210 m: 70 m to hydrant, 70-m return and the final 70-m trip to the hydrant). Each distance was fixed, with markers used to clearly designate these points. The simulation ended at the hydrant, and lasted an average of 2.78 min (SD 0.83). After completing this task, firefighters rested for 5 min (seated) before commencing the final simulation within this group of activities.

Figure 6: Firefighters locating hydrant and connecting to appliance.

[6] It is, of course, recognised that this activity was performed out of its normal sequence. This task is performed by the driver of the appliance immediately upon arrival at a fire. However, it was considered by the Research Team to be more strenuous than either rolling out and coupling hoses, so to avoid residual fatigue and an artificial elevation in the resting metabolic rate prior to each of those tasks, this simulation was performed third in the sequence of four activities.

2.9 Simulation six: Dragging charged 70-mm hose (lateral: individual)

2.9.1 Subjects

Finally within this group of four simulations, all 16 firefighters participated in dragging a charged, 70-mm fire hose.

2.9.2 Simulation description

This task was the final activity of four consecutive simulations, designed to last 7 min in total. Three markers were placed in a line on the ground, with each being 4 m from the next. Firefighters were instructed to move (drag) a fully charged 70-mm hose laterally, moving between adjacent markers as quickly as possible. At each marker, participants maintained a stationary position for 30 s, before moving to the next position. This simulated both moving of the hose laterally, and redirecting it to a different part of a building. Movement between these cones was repeated until 7 min had elapsed. The mass of water in this hose was estimated to be ~ 115 kg, with 7-8 kg being held above the ground (Figure 7). The simulation lasted an average of 7.09 min (SD 0.03). Once completed, firefighters rested fully before commencing other simulations.

Figure 7: Firefighters dragging charged 70-mm hoses.

2.10 Simulation seven: Fire attack (in pairs)

2.10.1 Subjects

Following a full, seated recovery from the previous four simulations, the same 16 firefighters now participated in a fire-attack simulation (Table 7).

2.10.2 Simulation description

Firefighters performed this occupational simulation in pairs, with one leading and holding the hose branch, while the other assisted by helping to drag two lengths of charged 38-mm hose. Thus, data were collected for eight firefighters is each position. The mass of water in two lengths hose was estimated to be about 70 kg. This simulation commenced with a 5-min seated rest, and firefighters again wore full thermal protective clothing, breathing apparatus and the data acquisition system described above (total mean mass: 23.14 kg). All activities were performed in a crouched position, working below the neutral plane, simulating a residential fire in which very hot air, smoke and flames would prevent an upright posture. The following sequence was replicated by each firefighter holding the branch: move 2.3 m to the door; cool door; make entry; move to a point inside the building (18.2 m from start); walls were placed at 7.9 m and 12.2 m (firefighters negotiated both); turn and move 8 m to fight a second fire (now 15.5 m from start); make way back to the start. These distances were fixed with markers. Throughout this simulation, gas cooling and the knocking down of spot fires were simulated. For the firefighters assisting, the sequence was identical, but this firefighter was ~1-3 m behind the first. The second firefighter ensured the hose was able to be freely dragged and that the first firefighter had sufficient hose to perform the tasks and to continue moving forwards. The simulation lasted an average of 4.16 min (SD 0.63). Once completed, firefighters rested (seated) fully before commencing the next simulations.

2.11 Simulation eight: Firefighter down: one-person rescue (individual)

2.11.1 Subjects

Following a full recovery from the fire-attack simulation, these 16 firefighters (Table 7) completed a one-person, firefighter rescue simulation.

2.11.2 Simulation description

In this occupational task, a fire-attack simulation was used to provide a lead-up activity, with two firefighters performing each simulation (as described above), and wearing full protective clothing, equipment and the data acquisition system (total mean mass: 23.14 kg). However, this task replicated a scenario in which the lead firefighter collapsed, and needed to be rescued by the second firefighter. As such, the firefighter down was wearing the complete thermal protection equipment and self-contained breathing apparatus, and the rescue was performed by a single individual, also wearing complete protective equipment. However, to standardised this rescue across all participants, and to ensure that the rescued firefighter was representative of those employed by Fire & Rescue NSW, one of the Training Officers (85.15 kg plus 19-20 kg of protective equipment and breathing apparatus: total mass = 106.57 kg) was the rescued firefighter for all 16 rescue simulations (Figure 8).

The fire attack proceeded as follows: move 2.3 m to the door; cool door; make entry; upon entry, move to the room on the right and enter (4.8 m from start); search room and leave; move to a second room and enter (6.6 m from start); search room and leave; move to a third room and enter (11.2 m from start); search room; fallen firefighter was always at the same point in this room; drag fallen firefighter from room to a point outside the building. The total drag distance was 10.5 m, and the complete simulation lasted an average of 3.88 min (SD 0.66). To simulate a residential fire, all movements were performed below the neutral plane. No other simulations were performed by these firefighters on that day.

Figure 8: Firefighters performing a one-person simulated firefighter rescue.

2.12 Simulation nine: Bushfire (dragging charged hose forwards: individual)

2.12.1 Subjects

Sixteen firefighters participated in this simulation (including one woman). With the exception of one individual (S33), all had previously completed simulation eight (Table 7). For convenience, the characteristics of all firefighters are provided in Table 8.

Table 8: Characteristics of firefighters performing the bushfire simulation. Fire Stations: Blacktown, Kellyville, Mount Druitt and Seven Hills.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S17	FF	32	3	185.00	79.75
S18	SO	41	22	176.00	77.30
S19	FF	39	3	183.00	81.05
S20	QFF	33	4	177.00	78.55
S21	SO	49	24	177.00	102.55
S22	QFF	33	4	168.00	68.00
S23	SO	50	29	177.50	86.40
S24	FF	29	2	182.50	77.75

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S25	QFF	26	3	189.00	89.00
S27	SFF	41	6	161.10	55.30
S28	SO	44	15	177.00	70.70
S29	SFF	42	9	177.00	76.90
S30	SFF	46	8	179.50	69.50
S31	QFF	36	3	182.30	92.10
S32	FF	26	3	194.50	108.45
S33	QFF	25	4	175.00	72.20
Mean		37.0	8.9	178.84	80.34
SD		8.2	8.7	7.75	13.22

2.12.2 Simulation description

This activity was designed to last approximately 52 min (Table 2), and it was completed as a continuous task performed over two different bushland terrains in succession: hilly and flat. Firefighters wore station-wear clothing, bush helmet, bushfire jacket, radio and data acquisition equipment (mean total mass: 9.42 kg). Since the area had recently been exposed to a controlled burn as part of routine bushfire prevention operations, the Training Officer was familiar with both the area and how firefighters tackled the task. Prior to commencing, each firefighter rested for a minimum of 5 min. Firefighters then walked slowly down a gentle slope to the test site location (~300 m), and were allocated to commence either on hilly, or flatter terrain. Each participant was instructed to move to the designated area and to simulate extinguishing and mopping up a region of bush. To do this, each firefighter was responsible for the movement of one length (30 m) of fully charged, 38-mm hose. The mass of water in this hose was ~35 kg, and the branch remained closed at all times. The movement of hoses attached to this single length were the responsibility of a second firefighter, with no physiological data being collected from this individual. For 13 min, the firefighter walked away from the point of origin, simulating the extinguishing of burning bush. At this point, firefighters were instructed to move quickly and extinguish a spot fire 15-25 m away. This activity also lasted 13 min, and included firefighters returning to the point of origin, during which they continued to knock down, mop-up or extinguish spot fires. At the end of 26 min, the first terrain was deemed to have been completed, and without rest, firefighters switched over to the second terrain to complete the same activities. Half of the firefighters commenced the task on the hilly terrain while the other half started the simulation on the flatter terrain, and the simulation lasted an average of 52.33 min (SD 0.01; Figure 9). Ratings of perceived exertion were recorded every 3 min.

Figure 9: Firefighters simulating the dragging of charged hoses over flat and hilly terrain.

2.13 Simulation ten: Stair climb dragging charged hose (forwards: in pairs)

2.13.1 Subjects

Seventeen[7] firefighters participated in a block of six activities (including two women): simulations ten to fifteen. Participants in this simulation are described in Table 9.

2.13.2 Simulation description

This simulation was performed in pairs, and within the high-rise structure at the Alexandria Training College (Figure 10). Prior to commencing, each firefighter rested for 5 min (sitting). Firefighters wore station-wear clothing, turnout gear, breathing apparatus, radio and data acquisition equipment (mean total mass: 23.8 kg). From a designated starting

[7] Sixteen firefighters performed this simulation in the first instance. However, equipment failure resulted in incomplete data being collected for some individuals on some activities. Therefore, four additional firefighters were recruited to ensure the collection of sufficient data across all tasks and across both genders.

point, both firefighters walked 7.3 m through a ground-level doorway to the stairs, and ascended 64 stairs (4 storeys). Each participant was instructed to ascend at the pace that would be used during a high-rise walk up. The horizontal displacement per storey was 9.7 m, and the vertical displacement was 4.2 m per storey. Each step was 0.26 m in height, and each storey had a landing midway between the upper and lower levels, with eight steps above and below each landing. The simulation ended at the fourth storey. Thus, the total horizontal distance travelled was 38.9 m, whilst the vertical displacement was 16.8 m.

Figure 10: Firefighters dragging a charged 38-mm hose into a building and up stairs.

The leading firefighter was positioned on the branch of a fully charged 38-mm hose. The assisting firefighter moved the hose, but remained approximately one hose length behind (30 m) of the leading firefighter. That is, the leading firefighter had to manipulate this hose, and the mass of the water that it contained (~35 kg). The second firefighter carried door entry tools, including a Halligan tool (4.5 kg) and sledge axe (4.7 kg). The method by which each team went about this occupational task varied among pairs, and according to the experience

of each pair. Physiological data were collected on both firefighters simultaneously, and the simulation lasted an average of 2.75 min (SD 0.80). Ratings of perceived exertion were recorded after the simulation was completed.

Table 9: Characteristics of firefighters dragging charged hose (stairs) and using 38-mm hose in prolonged fire suppression. Fire Stations: Alexandria, Hurstville, Liverpool and City of Sydney.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S2	SO	57	28	197.00	108.20
S4	FF	23	1	171.00	65.00
S5	FF	26	1	181.10	113.60
S6	FF	25	2	182.90	82.30
S10	QFF	47	9	173.00	91.05
S11	LFF	34	10	179.00	97.10
S14	SFF	37	13	184.50	91.15
S34	QFF	31	6	182.30	85.35
S35	QFF	41	4	177.00	87.35
S36	QFF	32	4	185.70	84.70
S37	SFF	25	7	179.00	76.95
S38	SFF	40	11	184.30	94.60
S39	SFF	47	8	169.70	90.20
S40	SFF	47	10	186.30	88.90
S41	QFF	26	6	168.80	62.50
S42	FF	46	3	174.00	69.30
S43	SFF	41	13	178.80	94.45
Mean		36.8	8.0	179.70	87.20
SD		10.1	6.5	7.17	13.57

2.14 Simulation eleven: Prolonged use of 38-mm hose (lateral movement: individual)

2.14.1 Subjects

Fourteen firefighters participated in this activity (including two women). Data from subjects S40, S42 and S43 were lost due to technical failure. Information and data from these individuals has not been included.

2.14.2 Simulation description
This activity was designed to last approximately 15 min, and followed a 5-min seated rest. Firefighters wore all clothing and equipment described above (mean total mass: 23.8 kg). Each firefighter was instructed to hold a 38-mm hose and to direct water onto a wall 16.4 m away (Figure 11). The hose pressure was set at 700 kPa, providing a water flow of 300 $L.min^{-1}$. This activity required firefighters to move between a set of three markers, spaced 5 m apart. At the end of each minute, and on the command of a researcher, firefighters moved between a set of three markers. For these movements, the branch was closed and the hose was dragged to the new position, with the branch being opened again after the new position was reached and the firefighter was stationary. Thus, 15 positional changes were completed by each firefighter. Firefighters could change posture and position as required, but not move away from the marker until instructed. The simulation lasted an average of 15.36 min (SD 0.25), with ratings of perceived exertion recorded every 3 min.

Figure 11: Prolonged use of 38-mm hose.

2.15 Simulation twelve: Prolonged use of 70-mm hose (stationary: in pairs)
2.15.1 Subjects
Fourteen firefighters participated in this activity (including two women: Table 10).

Table 10: Characteristics of firefighters performing simulations involving paired and prolonged use of a 70-mm hose. Fire Stations: Alexandria, Hurstville, Liverpool and City of Sydney.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S2	SO	57	28	197.00	108.20
S4	FF	23	1	171.00	65.00
S5	FF	26	1	181.10	113.60

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S6	FF	25	2	182.90	82.30
S8	SO	47	20	171.00	92.75
S10	QFF	47	9	173.00	91.05
S11	LFF	34	10	179.00	97.10
S14	SFF	37	13	184.50	91.15
S34	QFF	31	6	182.30	85.35
S35	QFF	41	4	177.00	87.35
S36	QFF	32	4	185.70	84.70
S37	SFF	25	7	179.00	76.95
S38	SFF	40	11	184.30	94.60
S39	SFF	47	8	169.70	90.20
Mean		36.6	8.9	179.80	90.00
SD		10.4	7.6	7.35	12.03

2.15.2 Simulation description
As per the 38-mm hose simulation, this activity lasted approximately 15 min, and followed a 5-min seated rest. Firefighters wore all clothing and equipment described above (mean total mass: 23.8 kg). In this case, firefighters worked in pairs, holding a 70-mm hose, and directing water onto a wall target 16.4 m away (Figure 12). The hose pressure was set at 700 kPa, which elicited a water flow of 750 $L.min^{-1}$. The branch of the 70-mm hose was open for the entire simulation, and both firefighters remained relatively stationary at a designated point during the simulation. Firefighters were allowed to change posture and hose position as required, but the firefighter on the branch remained in that position throughout the simulation, and neither firefighter left the hose. The simulation lasted an average of 15.40 min (SD 0.20), with ratings of perceived exertion recorded every 3 min.

2.16 Simulation thirteen: Ladder use (10.5 m: in pairs)
2.16.1 Subjects
Fifteen firefighters participated in this activity (including two women: Table 11).

2.16.2 Simulation description
Firefighters performed this occupational simulation in pairs, wearing all of the clothing and equipment previously described (mean total mass: 23.8 kg). However, only one from each pair performed the more difficult aspects of the simulation, whilst the other assisted. Thus, the working firefighter completed the following tasks: climbing onto the appliance to release and lower the ladder; carrying the ladder 32 m (one firefighter holding each end); under-running to raise the ladder (Figure 13); ascending the ladder (to the fourth rung above the

top of the building (Figure 13): approximately 25 rungs or 8.1 m); descending the ladder; lowering the ladder; carrying the ladder; climbing onto the appliance to return and correctly stow the ladder. This ascent task replicated a scenario where a ladder would be required to ascend into, or onto a two-storey building. The assisting firefighter helped by keeping the ladder balanced during its carriage, supporting the foot of the ladder and helping when it was being raised (under run) and lowered, and stabilising the ladder during the ascent. The simulation lasted an average of 5.39 min (SD 1.10).

Figure 12: Prolonged use of 70-mm hose (two person).

Table 11: Characteristics of firefighters from the 10.5-m ladder simulations. Fire Stations: Alexandria, Hurstville, Liverpool and City of Sydney.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S2	SO	57	28	197.00	108.20
S4	FF	23	1	171.00	65.00
S5	FF	26	1	181.10	113.60
S6	FF	25	2	182.90	82.30
S10	QFF	47	9	173.00	91.05
S11	LFF	34	10	179.00	97.10
S14	SFF	37	13	184.50	91.15
S34	QFF	31	6	182.30	85.35

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S35	QFF	41	4	177.00	87.35
S36	QFF	32	4	185.70	84.70
S37	SFF	25	7	179.00	76.95
S38	SFF	40	11	184.30	94.60
S39	SFF	47	8	169.70	90.20
S40	SFF	47	10	186.30	88.90
S41	QFF	26	6	168.80	62.50
Mean		35.9	8.0	180.1	87.90
SD		10.4	6.6	7.50	13.54

Figure 13: Firefighters using 10-5-m ladder (one person).

2.17 Simulation fourteen: Carrying ventilation fan up stairs (in pairs)

2.17.1 Subjects

Seventeen firefighters participated in this activity (including two women: Table 12).

Table 12: Characteristics of firefighters performing the ventilation fan carry. Fire Stations: Alexandria, Hurstville, Liverpool and City of Sydney.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S2	SO	57	28	197.00	108.20
S4	FF	23	1	171.00	65.00
S5	FF	26	1	181.10	113.60
S6	FF	25	2	182.90	82.30
S8	SO	47	20	171.00	92.75
S10	QFF	47	9	173.00	91.05
S11	LFF	34	10	179.00	97.10
S14	SFF	37	13	184.50	91.15
S34	QFF	31	6	182.30	85.35
S35	QFF	41	4	177.00	87.35
S36	QFF	32	4	185.70	84.70
S37	SFF	25	7	179.00	76.95
S38	SFF	40	11	184.30	94.60
S39	SFF	47	8	169.70	90.20
S40	SFF	47	10	186.30	88.90
S42	FF	46	3	174.00	69.30
S43	SFF	41	13	178.80	94.45
Mean		38.0	8.8	179.80	89.00
SD		9.9	7.1	7.00	12.02

2.17.2 Simulation description

Prior to the simulation, each firefighter rested for a minimum of 5 min (seated). This task was again performed in pairs, wearing all clothing and equipment described above (mean total mass: 23.8 kg). One firefighter was positioned on either side of the ventilation fan (35 kg). From a designated starting point, both firefighters walked 7.3 m through a ground-level doorway to the stairs, and ascended 64 stairs (4 storeys: Figure 14). Each participant was instructed to ascend at the pace similar to that used during actual task performance. The

horizontal displacement per storey was 6.9 m, and the vertical displacement was 2.9 m per storey. Each step was 0.26 m in height, and each storey had a landing midway between the upper and lower levels, with eight steps above and below each landing. The simulation ended at the fourth storey. Thus, the total horizontal distance travelled was 38.9 m, whilst the vertical displacement was 16.6 m. The simulation lasted an average of 1.51 min (SD 0.29), with physiological data collected on both firefighters simultaneously, and ratings of perceived exertion recorded at the completion of the activity.

Figure 14: Firefighters carrying ventilation fan up stairs (two person).

2.18 Simulation fifteen: Using sledge axe to gain entry (individual)

2.18.1 Subjects

Sixteen firefighters participated in this simulation (including one woman: Table 13).

Table 13: Firefighter characteristics for the sledge axe entry simulation. Fire Stations: Alexandria, Hurstville, Liverpool and City of Sydney.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S2	SO	57	28	197.00	108.20
S4	FF	23	1	171.00	65.00
S5	FF	26	1	181.10	113.60
S6	FF	25	2	182.90	82.30
S10	QFF	47	9	173.00	91.05
S11	LFF	34	10	179.00	97.10
S14	SFF	37	13	184.50	91.15
S34	QFF	31	6	182.30	85.35

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S35	QFF	41	4	177.00	87.35
S36	QFF	32	4	185.70	84.70
S37	SFF	25	7	179.00	76.95
S38	SFF	40	11	184.30	94.60
S39	SFF	47	8	169.70	90.20
S40	SFF	47	10	186.30	88.90
S42	FF	46	3	174.00	69.30
S43	SFF	41	13	178.80	94.45
Mean		37.4	8.1	180.40	88.80
SD		10.0	6.7	6.82	12.38

Figure 15: Firefighters using sledge axe to gain entry.

2.18.2 Simulation description

This activity was designed to last about 3 min, and followed a 5-min seated rest. Dressed in the clothing and equipment previously described (mean total mass: 23.8 kg), firefighters gained entry to a room via a locked aluminium door using a sledge axe (4.7 kg). The participants could hit any part of the door (Figure 15), but if it was not opened after five attempts, the door was opened by the instructor. At this point, the firefighter walked approximately 5 m into an open room, across to a pillar that was lined with tyres and a punching bag. The task now required each firefighter to continue to hit these tyres for a further 2 min. This was designed to replicate task times reported by firefighters (Table 2) and a scenario where a firefighter was unable to gain entry, but may be required to repeatedly attempt to break through the door, as may occur occasionally with a steel door. However, this extended simulation also permitted the collection of more representative data,

since the demands of such high-intensity work could not be evaluated if the duration was too brief. These simulations lasted an average of 2.50 min (SD 0.14), with ratings of perceived exertion recorded at the completion of the task.

2.19 Simulation sixteen: Structural search and rescue (hot-fire cell: in pairs)

2.19.1 Subjects

For this occupational activity, eight firefighters who had not participated within any of the previous simulations were involved (including one woman: Table 14).

2.19.2 Simulation description

This simulation occurred within the hot-fire cell at the Alexandria Training College. This is three-storey, concrete structure containing steel stair cases and floors. The tasks performed by each firefighter were wholly controlled by Training Officers, and involved the dragging of a charged hose to the third floor, the rescue of two victims (70-kg and 50-kg dummies) and various movements and equipment carriage within the structure, as dictated by these Officers (Figures 16 and 17).

Table 14: Characteristics of firefighters performing the hot-fire cell simulation. Fire Stations: Darlinghurst and Redfern.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)
S44	SO	36	13	171.00	90.10
S45	QFF	25	5	193.00	70.40
S46	FF	30	1	177.80	102.50
S47	QFF	35	4	181.40	87.25
S48	SO	52	28	173.80	87.10
S49	SFF	36	6	169.30	70.80
S50	SFF	38	7	184.40	80.70
S51	FF	28	1	180.60	71.85
Mean		35.0	8.1	179.00	82.60
SD		8.2	8.9	7.67	11.35

This simulation was included at the request of the Research Team, since it provided, within a single task, an opportunity to join several tasks into a single simulation that would have high ecological validity[8], and for which the Research Team had collected preliminary data Taylor *et al.*, 2010). Each firefighter performed the simulation twice (once under heat and smoke, and once without). Six platoons supported this activity, with two platoons fulfilling

[8] Ecological validity refers to research methods, materials and settings that replicate real-life situations, such that those employed within the job, and external observers, would consider the simulation to approximate an occupational task as it might be performed under realistic conditions.

the roles of experimental subjects (one person at a time) and with one firefighter from the other platoons accompanying each experimental firefighter, and providing assistance as would occur within a structural fire scenario. This rotation of firefighters minimised the strain encountered by any one firefighter, and ensured that each of the experimental firefighters commenced the simulation in a well-rested and normothermic state. Firefighters wore full thermal protective and station-wear clothing, protective boots, breathing apparatus, helmets, radio (1.1 kg) and data acquisition system (mean total mass: 24.10 kg).

During the first simulation, firefighters used self-contained breathing apparatus (Figure 16). The average temperature of the cell was regulated between 68-73°C, but varied throughout the cell. The Research Team did not accompany the firefighters on this simulation. Since the cell has no windows, and since all lights were extinguished and the cell was filled with smoke, visibility was reduced to zero. The durations of this simulation were set by several criteria. Firstly, since it is well known that elevations in core temperature are a function of both work rate and exposure time, then the Research Team was interested in evaluating the impact of a more prolonged thermal stimulation. The Team was also advised that, under some circumstance, firefighters may be required to change breathing apparatus and re-enter a building. Therefore, firefighters were asked to continue the simulation as long as possible, and this may include changing breathing apparatus. Only one firefighter was able to continue the simulation beyond the use of one set of breathing apparatus. Secondly, there were two firefighter withdrawal criteria set by the Research Team: the attainment of a core temperature >39.5°C (checked on each exit from the cell), or a desire of the firefighter to withdraw for any reason. Two firefighters reached this temperature limit. One firefighter asked to be withdrawn due to fatigue, and, on withdrawal, was found to have a core temperature of 39.35°C. Thirdly, if air cylinder pressure fell below 5 MPa for anyone within the cell, a warning signal was triggered, and all firefighters immediately left the cell. This criterion led to the termination of four additional simulations, but since the core temperatures of these individuals were >39°C, they were not asked to continue. Finally, the Training Officers were at liberty to terminate the simulation if they felt that firefighter health and safety was at risk. One firefighter was withdrawn on this basis. These simulations lasted an average of 25.64 min (SD 5.10), with ratings of perceived exertion being recorded at the conclusion of the simulation.

On the following day, these firefighters repeated each scenario, but now also wearing portable expired gas analysis equipment (Figure 17). These simulation replications lasted an average of 19.57 min (SD 4.22). The lights were extinguished as per the first simulation, but heat and smoke were not used. Air temperature was 24.6°C. The Research Team accompanied firefighters, who replicated their own individual scenario, as instructed by the Training Officers. Ratings of perceived exertion were recorded upon the completion of specific sub-tasks, as determined by the Research Team.

Figure 16: The structural search and rescue simulation (hot-fire cell).

Figure 17: Firefighters performing a structural search (left) and rescue simulation (right) in the hot-fire cell, but without heat and smoke, whilst wearing portable open-circuit spirometry apparatus.

Simulation scenarios (day two):

Subject 44:

Initial search with hose from ground to top of third floor
50-kg dummy removed from third floor and dragged to ground floor
Dragged 50-kg dummy back up to the third floor
Walked down from third floor (dragging hose) to ground floor
Secondary search of the ground floor
Removal of hose and exit building.

Subject 45:

Initial search with hose from ground to top of third floor
70-kg dummy removed from third floor and dragged to ground floor
Walk up to the third floor
Drag hose to ground floor and exit due to cylinder change
Drag 70-kg dummy back up to the third floor
Secondary search of all floors with hose *en route* to ground floor
Removal of hose and exit building.

Subject 46:

Initial search with hose from ground to top of third floor
50-kg dummy removed from third floor and dragged to ground floor
Walk back up to the third floor
70-kg dummy removed from third floor and dragged to ground floor
Secondary search of all floors with hose *en route* to ground floor
Removal of hose and exit building.

Subject 47:

Initial search of ground floor
Drag 50-kg dummy up to the third floor
Walk down to ground floor
Drag 70-kg dummy up to the third floor
Drag hose up to the third floor
50-kg dummy removed from third floor and dragged to ground floor
Ground floor secondary search and exit building.

Subject 48:

Initial search with hose from ground to top of third floor
70-kg dummy removed from third floor and dragged to first floor.
Walk down to ground floor, secondary search and exit building.

Subject 49:

Initial search of the ground and first floors
Drag 70-kg dummy from the first to the third floors
Drag hose from third floor to ground floor and remove hose from building
Walk up to the second and third floors and conduct final search
Return to ground floor and exit from building.

Subject 50:

Initial search from the ground to the third floors
70-kg dummy removed from third floor and dragged to ground floor
Drag 50-kg dummy from the ground floor to the second floor
Walk down to the ground floor

Drag hose to the third floor
Walk down to ground floor and remove 70-kg dummy from building
Final search of all floors, return to ground floor and exit from building.

Subject 51:

Initial search of the ground floor
Drag 70-kg dummy to the second floor
Search of the second and third floors
Return to the ground floor and exit from building.

2.20 Data analysis

Oxygen consumption data are reported in both absolute ($L.min^{-1}$) and relative (specific) units. In the latter instance, two normalisation procedures were used. The first involved a linear mass normalisation ($mL.kg^{-1}.min^{-1}$) using body mass at rest and total mass (body, clothing and all protective and experimental equipment) during each simulation. In the second instance, data were normalised to the 0.67 power of either body mass (rest) or total mass (simulation: $mL.kg^{-0.67}.min^{-1}$). A theoretical justification for these procedures is presented within Appendix Two of this report.

Time-series heart rate and oxygen consumption data from each individual, and within each simulation, were analysed with respect to zones of physiological strain. For cardiovascular strain, these zones were defined relative to each individual's heart rate reserve (or heart rate scope), which was defined as follows:

Equation 2: Heart rate reserve = predicted maximal heart rate - resting heart rate [$beats.min^{-1}$]

where:

predicted maximal heart rate = 208 - age * 0.7 [$beats.min^{-1}$]

after: Tanaka *et al.* (2001)

resting heart rate = mean over last 2 min of a 5-min seated rest [$beats.min^{-1}$].

Strain thresholds were set at 25%, 50%, 75% and 90% of the heart rate reserve. For oxygen uptake, zones were set at increments of 0.5 $L.min^{-1}$ over the range 1.0-3.0 $L.min^{-1}$.

To further evaluate central cardiovascular strain, both the cardiovascular impulse and load were derived for each of the simulations. These were defined as:

Equation 3: Cardiovascular impulse = task duration * average heart rate [beats]

Equation 4: Cardiovascular load = average task heart rate / resting heart rate * duration [non-dimensional units].

Data from this experimental Phase were analysed using descriptive statistical procedures, and are reported as means (averages), standard deviations[9] (SD) and response ranges. Some summary data are presented as box plot[10].

[9] The standard deviation is a measure of variability (distribution) of the observed results around the mean.

[10] Box plots are summary graphs that present three descriptive details for each data set in the form of a rectangle (box). The lower boundary of the rectangle indicates the 25th percentile, whilst the upper border shows the 75th percentile. A line is shown within the box, and this marks the median value for these data.

3. RESULTS AND DISCUSSION

This section has been sub-divided into the sixteen discrete fire-fighting simulations, such that the data presented for each simulation can stand alone, and be read independently of the other simulations. This presentation style is consistent with the methods section of this report. However, within the first of these simulations (the hazmat incident), more detailed explanations are provided for these data, the presentation format, the descriptive statistics and the graphical procedures that have been used. Therefore, readers are encouraged to read this section and Appendix Two first.

3.1 Simulation one: Hazmat incident (in pairs)

3.1.1 Example experimental data

Physiological strain during the hazmat simulation is illustrated within the time-series data for the heart rate (Figure 18), absolute oxygen consumption (Figure 19) and ventilatory responses of one representative firefighter (Figure 20). Within each graph, the coloured bands define zones of increasing physiological strain as one moves (over time) from the lower left to the upper right corners of each Figure.

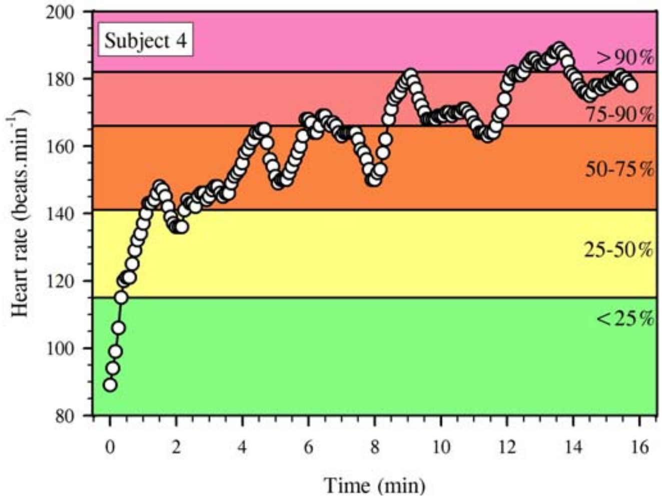

Figure 18: Example heart rate response during the hazmat simulation.

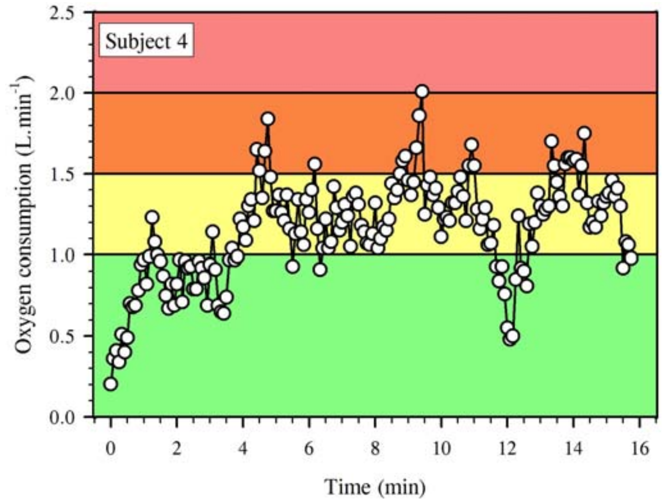

Figure 19: Sample oxygen consumption response during the hazmat simulation.

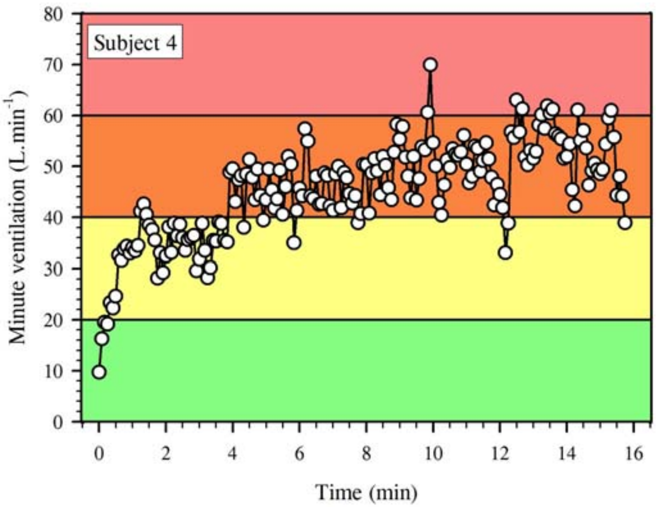

Figure 20: The ventilatory response during the hazmat simulation.

3.1.2 Physiological and psychophysical strain

Using data collected from every subject during this fire-fighting simulation, Table 15 was constructed to summarise physiological strain experienced during the simulation[11]. Data are presented for each of the five physiological variables of primary interest, with oxygen consumption also being normalised to the total mass of each individual (body mass plus the mass of the protective clothing, equipment and data acquisition hardware that was carried). Average data are presented for the resting and simulation states. For the latter state, the range parameters (minimal and maximal) define the lower and upper boundaries of physiological strain observed during the simulation. The 95% confidence interval informs the reader that one can be 95% certain in the assumption that the true average strain for firefighters may be located within the range defined by the mean (*e.g.* heart rate: 133 beats.min^{-1}) minus the confidence interval (7 beats.min^{-1}), and the mean plus that confidence interval. Thus, in this example, the true simulation mean has a 95% probability of falling between the heart rates of 126-140 beats.min^{-1}. Similarly, the mean absolute oxygen consumption will lie within the zone ranging from 1.47 to 1.75 L.min^{-1}.

In Figure 21, further summary data are presented in the form of box plots for heart rate and absolute oxygen consumption. This form of data presentation is designed to graphically display work rate intensities, with each graph showing times spent (ordinate) within zones of different physiological strain (abscissa) during the simulation. Thus, moving from the left (zone 1: lowest intensity) to the right side of the graph (zones 5 or 6: highest intensity) reflects progressive increments in work rate, but with the times contained within each zone (intensity) coming from work performed across the entire hazmat simulation. Therefore, the fractional contributions may actually have been drawn from different parts of, or from different times within this simulation, as is evident from the raw data presented in Figures 18-20. Within each box, five pieces of descriptive information are provided concerning the

[11] Table 15, and other similar Tables that follow, contain five physiological variables. These variables are reported for completeness, and for the benefit of readers with interests beyond the scope of this project. However, for this report, the focus is upon heart rate, absolute oxygen consumption and its mass-normalised derivation: relative (specific) oxygen consumption.

simulation:

- the horizontal line within each box is the median[12] time within each zone
- the upper box border is the 75th percentile: 75% of times were below this line
- the upper error bar defines the 95th percentile
- the lower box border is the 25th percentile: 75% of times were above this line
- the lower error bar defines the 5th percentile.

These work rate intensity data are critical, as they complement and extend the data presented within Table 15. Primary attention should be directed to the median within each box, and how the medians varied across the zones of physiological strain, since the highest median reveals the zone within which firefighters spent most of the simulation.

Table 15: Summary parameters for physiological strain in firefighters (*N*=16) performing the hazmat incident simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	79 (10)	134 (13)	82	189	7
Absolute oxygen consumption (L.min^{-1})	0.32 (0.08)	1.61 (0.29)	0.30	3.36	0.14
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.47 (0.62)	13.96 (2.21)	2.73	28.45	1.08
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	15.45 (2.90)	66.79 (10.66)	12.89	134.92	5.22
Minute ventilation (L.min^{-1})	15.70 (3.60)	57.44 (6.91)	14.47	94.97	3.39
Tidal volume (L)	0.93 (0.31)	1.80 (0.32)	0.48	3.22	0.16
Breathing frequency (breaths.min^{-1})	19 (6)	33 (5)	9	61	2

From Table 15, the reader cannot really appreciate the likely physiological impact of the different work rates. For instance, no temporal information is gained concerning the observed maximal oxygen consumption of 3.36 L.min^{-1}. This is a very high work intensity

[12] The median is a measure of central tendency: the middle result. It corresponds with the actual number that is closest to the middle of a range of data.

(zone 6 on Figure 21), and it could be misinterpreted to indicate that a significant proportion of the simulation, which lasted 15.24 min, was performed working at this intensity. However, whilst this value certainly was observed, the durations in each of work rate zones five (2.5-3.0 $L.min^{-1}$) and six (>3.0 $L.min^{-1}$) were relatively brief: 19.8 s and 1.8 s respectively. In the latter case, zone six data can be ignored for oxygen consumption, as it is too brief to represent a significant workplace demand, and this is the zone in which the maximal observed oxygen consumption was located.

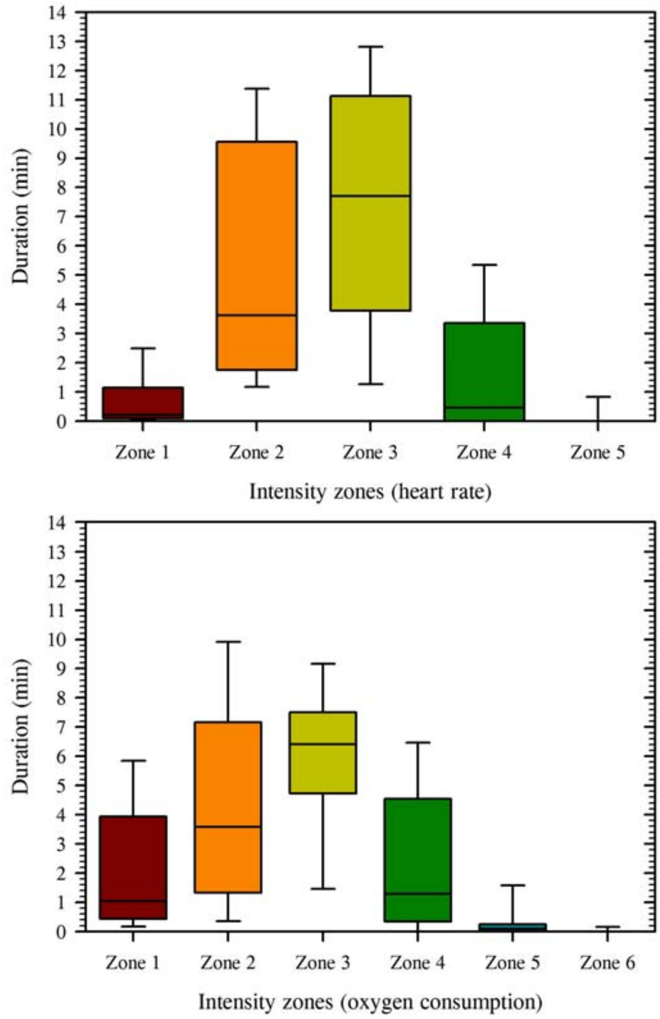

Figure 21: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the hazmat incident simulation. Zone thresholds were set at 25%, 50%, 75% and 90% of the heart rate reserve (scope), and at increments of 0.5 $L.min^{-1}$ over the absolute oxygen consumption range 1.0-3.0 $L.min^{-1}$. The lower border of each box shows the 25th percentile, the line within the box is the median and the upper border is the 75th percentile. The error bars above and below each box define the 95th and the 5th percentiles.

For the heart rate zones, a similar picture emerges. That is, work within the second and third zones dominated this simulation. However, heart rates will also reflect strain in

addition to that which is directly related to the work being performed, and the hazmat simulation provides an ideal illustration of this fact. For instance, the firefighters were wearing encapsulating, chemical and biological protective clothing (Figure 2). Due to using open-circuit respiratory gas analysis methods to collect oxygen consumption data, the head and upper torso were not wholly encapsulated. Nevertheless, this encapsulating clothing imparts two added stresses upon the wearer. Firstly, such ensembles increase the metabolic demand of locomotion due to elevated frictional forces that exist within layered clothing, and the restrictive nature of such garments across limb joints (Teitlebaum and Goldman, 1972; Nunneley, 1989; Dorman and Havenith, 2009). Secondly, multi-layered garments, and in particular encapsulating ensembles, trap heat (Nunneley, 1989; McLellan, 2008). As a consequence, skin blood flow increases to facilitate the dissipation of metabolic heat, thereby driving heart rate upwards, and out of proportion to the increase in metabolic rate. This is still a stress that firefighters must face, and it cannot be ignored. Thus, whole-body physiological strain must be evaluated from both heart rate and oxygen consumption data, and this is why these variables were measured simultaneously within this project.

3.1.3 Theoretical background: absolute versus relative (specific) oxygen consumption

It is important to first comment upon the indices used within this report to quantify the metabolic demands of each simulation: absolute and relative oxygen consumption. These indices are reported in Table 15, and in the corresponding Tables for the simulations that follow. Oxygen consumption is reported in three forms: one absolute and two relative.

The first index reflects the total oxygen cost[13] of each simulation. For instance, cycling an ergometer at a fixed work rate (125 Watts) requires all cyclists to perform the same external work on the ergometer. This will elicit a fairly predictable oxygen consumption (1.54 $L.min^{-1}$ above resting level), and this holds regardless of the gender, age or size of the cyclist[14]. This is because the external work performed on the ergometer is constant, and the body mass is supported on the seat, contributing very little to the external work. In this example, it is the absolute oxygen consumption that is important. Whilst in none of the current simulations was the body mass of firefighters supported, all tasks involved the manipulation of external loads, in the form of standard equipment used by Fire & Rescue NSW (Table 5), that were identical for each firefighter. Thus, one may expect that the external work performed on these objects would remain somewhat similar across firefighters of varying gender, age and size. So the consideration of absolute oxygen consumption is important, and we will return to this in subsequent paragraphs.

However, if the activity involves walking or running at a fixed speed, then one's body mass will also contribute to the oxygen cost of the activity, since it is both raised and moved forwards with each stride. Now, at the same speed and gradient, a heavier individual will

[13] This is the absolute rate at which oxygen must be consumed (oxygen flow: $L.min^{-1}$) to liberate the energy required to successfully complete this work. Some individuals may be unable to satisfy this demand.

[14] This generalisation assumes that the metabolic efficiency of cycling remains constant across individuals.

have a larger absolute oxygen consumption. In this circumstance, normalising[15] these data for variations in mass will help to remove the influence of inter-individual variations in body mass, permitting one to compare the oxygen cost of locomotion across people with different body sizes. These normalised data are presented in two different forms (Table 15).

In the first instance, data are presented in a form that is most familiar to readers; the simple division of oxygen consumption by body mass ($mL.kg^{-1}.min^{-1}$). This linear format is also consistent with the current practise within many organisations that use fitness standards for recruiting purposes (*e.g.* maximal aerobic power of 45 $mL.kg^{-1}.min^{-1}$ [Gledhill and Jamnik, 1992a]). It is also consistent with the popular procedure by which variations in physical endurance or fitness are compared among individuals (maximal aerobic power). That is, normalisation is performed using a linear (arithmetic) assumption, such that across the entire range of body sizes, this simple ratio is assumed to permit a valid comparison of the relative impact of a task on different individuals, with the influence of body mass on oxygen consumption being removed (body mass-independent). Data presented in this manner are described as the relative or specific[16] oxygen cost of a task (Royal Society, 1975).

Notwithstanding its popular use, the difference between the absolute and specific oxygen consumption derived in this manner is often misunderstood. Indeed, this normalisation is frequently inappropriate (Appendix Two). This is so for several reasons: (1) a one-to-one relationship between oxygen consumption and body mass does not exist (Kleiber, 1932; Tanner, 1949; Taylor *et al.*, 1981; Schmidt-Nielsen, 1984; Åstrand and Rodahl, 1986; Nevill *et al.*, 1992); (2) linear normalisation fails to account for all of the inter-individual variability in oxygen consumption (Kleiber, 1947); (3) the coefficient of variation for oxygen consumption often exceeds that for body mass (Tanner, 1949); (4) for maximal aerobic power, there is a positive relationship between the peak absolute oxygen consumption and body mass, but a negative relationship is evident between peak specific oxygen consumption ($mL.kg^{-1}.min^{-1}$) and body mass (Taylor *et al.*, 1981; Schmidt-Nielsen, 1984; Åstrand and Rodahl, 1986; Nevill *et al.*, 1992; Bilzon *et al.*, 2001a); and (5) the affect of these artefacts increase as individuals approach the extremes of body size, so the extrapolation of such regression relationships beyond the range of the primary observations is fallacious (Tanner, 1949; Schmidt-Nielsen, 1984). Therefore, the injudicious division of body mass into oxygen consumption may be invalid in many circumstances.

Accordingly, a second form of data normalisation has been adopted for this report, and this relies upon the well-established power relationship between oxygen consumption and body mass that obtains across metabolic states from rest (Kleiber, 1932; Schmidt-Nielsen, 1984) through to maximal exercise (Taylor *et al.* 1981; Åstrand and Rodahl, 1986; Nevill *et al.*, 1992). Thus, for one to compare the mass-independent oxygen consumption of individuals of different sizes, one must derive specific oxygen consumption as a power, and not as a linear function. Therefore, whilst it is well established that body size is important, it is

[15] Normalising involves dividing the index of interest (*e.g.* oxygen consumption) by some variable that is tightly correlated with that index (*e.g.* surface area or mass). Thus, the absolute oxygen consumption ($L.min^{-1}$) is converted to a relative (specific) oxygen consumption ($mL.m^{-2}.min^{-1}$ or $mL.kg^{-1}.min^{-1}$). In these examples, it is assumed that the relationship between the index of interest and the chosen divisor is always linear.

[16] The word "specific" designates any quantity normalised to (divided by) body mass (Royal Society, 1975).

absolutely critical to apply the correct scaling function (power), rather than the more convenient (linear) function. Accordingly, this convention has been adopted for this project ($mL.kg^{-0.67}.min^{-1}$), and these specific (relative) oxygen consumption data are presented in Table 15, and in the corresponding simulation Tables that follow.

When data are presented in this power-scaled format, one can describe the specific oxygen cost of any simulation (*e.g.* Figure 21 and Table 15) with a knowledge that the inter-individual variations in the body masses of the firefighters studied (*e.g.* Table 6) were not responsible for determining the outcome. This is an absolutely essential attribute for any occupational task assessment, if the corresponding physiological attributes of potential recruits are to be gender neutral and legally defensible. With respect to the current simulation, which was a loaded ambulatory task, firefighter mass varied by almost 50 kg from the heaviest (113.6 kg) to the lightest (65 kg) person tested. Thus, one would predict the absolute oxygen consumption of the larger firefighter to be considerably higher, since that individual was carrying approximately 50 kg more mass, even before donning the personal protective clothing and equipment, and before the loads associated with the activity were considered. This expectation was realised, with the mean absolute oxygen consumption of the heaviest individual being 0.39 $L.min^{-1}$ during seated rest, and 1.93 $L.min^{-1}$ when averaged across the entire simulation. The corresponding data for the lightest firefighter were 0.20 $L.min^{-1}$ and 1.17 $L.min^{-1}$. It was noted above that, for some equipment manipulation tasks, the absolute oxygen consumption is an important consideration. Before returning to this, we will further develop our discussion concerning locomotion.

The metabolic cost (per unit mass) of ambulatory tasks performed on flat surfaces will increase as a linear function of movement speed in both animals (Taylor *et al.*, 1970) and humans (Mayhew, 1977). The applicable units may be expressed as $mL.kg^{-1}.h^{-1}$ for the (dependent) metabolic cost, and as $km.h^{-1}$ for speed. Thus, the oxygen cost derivative[17] will have the units of $mL.kg^{-1}.km^{-1}$ (an analogue of specific fuel economy), and this is independent of speed, but it is dependent upon body mass and the distance covered within the task (Schmidt-Nielsen, 1984). If the distance remains fixed, as it does in these fire-fighting simulations, then the metabolic cost of a level-surface ambulatory activity simplifies to a mass-dependent, power relationship. It has been established that the exponent of this relationship is a negative function of body mass across both quadrupedal mammalian species (mouse to the horse: Taylor *et al.*, 1970) and bipedal species (birds and humans: Fedak *et al.*, 1974). For bipeds, the exponent is -0.33 (Schmidt-Nielsen, 1984). Within the context of the current fire-fighting simulations, this implies that the oxygen cost of load carriage will be greater within smaller individuals. This is a well-known fact (Louhevaara *et al.*, 1986; Bilzon *et al.*, 2001a).

Indeed, Taylor *et al.* (1980) demonstrated that when carried loads were normalised to body mass, the absolute oxygen cost changed in direct proportion with the change in the specific load, such that a 5% increase in relative load was accompanied by a 5% elevation in oxygen consumption. However, if the load carried is constant (*e.g.* a 35-kg ventilation fan; two-person carry: 17.5 kg), and it is carried by individuals having different body masses (*e.g.*

[17] Simplification: $mL.kg^{-1}.h^{-1} / km.h^{-1} = mL.kg^{-1}.km^{-1}$

our heaviest [113.6 kg] and lightest firefighters [65 kg]), then this load will represent a greater metabolic demand for the lighter individual (27% versus 15%), relative to performing the same task in the unloaded state. This is precisely the scenario that firefighters face, and it enables larger individuals to work with less strain and for longer durations without fatigue (Louhevaara *et al.*, 1986; Bilzon *et al.*, 2001a). Thus, when load carriage is of importance within an occupation, one must evaluate physiological function under loaded situations (Vanderburgh and Flanagan, 2000; Bilzon *et al.*, 2001a; Vanderburgh, 2008; Vanderburgh *et al.*, 2011), as has occurred within the current project.

The discussion to this point relates only to activities performed on level ground. During activities that have a significant vertical component, it appears that the possession of a lighter body may be advantageous. The specific oxygen costs of moving 1 kg a vertical distance of 1 m is reasonably constant across species (1.36 $mL.kg^{-1}.m^{-1}$), even in those of widely different body masses (Taylor *et al.*, 1972; Cohen *et al.*, 1978). Since smaller animals have a much larger specific oxygen consumption at rest than bigger animals, then this constant demand represents a much smaller change for these animals[18]. Of course, the comparisons between mice and horses (Taylor *et al.*, 1972) are extreme examples that prove the principle, which does transfer to humans. However, and of much greater importance, is the fact that larger individuals must first move a greater absolute body mass through the same vertical distance (Teh and Aziz, 2002). Therefore, smaller people will have an advantage on the stairs. This advantage may be increased marginally since the smaller individual (*e.g.* 55.3 kg [Table 7] versus 113.6 kg [Table 6]), like smaller animals, will have a greater specific oxygen consumption at rest. Thus, the constant specific oxygen cost of the ascent represents a slightly smaller change, relative to the resting state.

In some situations, it may be the absolute oxygen cost of an occupational task that is important. In cycling, where the body mass is fully supported, this is absolutely so. However, within some occupations, the performance of some tasks will elicit a relatively fixed oxygen cost on the worker, and, regardless of the size of an individual, this demand must be met to successfully complete the task. In these situations, it becomes absolutely necessary to characterise occupational tasks using individuals of widely varying body masses. This criterion was comprehensively satisfied within the current observations, since, across the sixteen simulations investigated, firefighter mass ranged from 55.3 kg (Table 7) to 113.6 kg (Table 6).

Let us now consider an activity that would elicit, on average, an absolute oxygen consumption of 3.0 $L.min^{-1}$ above rest, across a wide range of individuals. For simplicity, let us think only about this oxygen cost as if it were independent of body mass. Now let us evaluate the capacity of a group of 21 different (hypothetical) individuals to perform this activity. We will consider people with body masses ranging from 40-100 kg (seven 10-kg categories), and, within each mass category, we will have three individuals, each of whom will possess one of the following levels of specific peak aerobic power: 40, 50 and 60

[18] This helps to explain why small animals can ascend tress with ease: there is only a small difference between the oxygen cost of horizontal and vertical locomotion in these animals (Schmidt-Nielsen, 1984).

$mL.kg^{-1}.min^{-1}$ (considered as: "average", "good", "excellent")[19]. The hypothetical question of interest is as follows: which of these individuals could complete this occupational task with an oxygen cost less than 90%[20] of their peak aerobic power? Asked another way, who would be capable of consuming an additional 3.0 $L.min^{-1}$ of oxygen above rest, whilst still working at an intensity below 90% of maximal? Through a series of elementary calculations, one could determine that only seven people might be able to complete this task[21]. Indeed, it would appear to be impossible for all but one individual with a body mass below 80 kg. This demonstrates that lighter people, even those with an excellent specific peak aerobic power, may simply be unable to generate the required absolute oxygen consumption to perform some occupational activities. Accordingly, one may question the utility of setting some physiological employment standards on the basis of a specific peak aerobic power, particularly when a linear normalisation procedure has been applied.

3.1.4 Observational summary

The final stage of this analysis involved an overall evaluation of each fire-fighting simulation, with the aim being to identify the fitness classifications essential to each occupational task (from an analysis of the task duration, heart rate and oxygen cost), to analyse the movement patterns (including muscle actions), and to summarise the principal cardiovascular and metabolic strain indices. The outcomes from these observations for the hazmat incident simulation are summarised in Table 16.

Table 16: Overall occupational task assessment: hazmat incident simulation.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 40-50%
Secondary fitness classification (%)	Cardiorespiratory endurance: 25-35%
Tertiary fitness classification (%)	Muscular endurance: 15-25%
Primary movement action	Lift from truck tray, then extended one-hand, team carry
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Lift and place (upper and lower body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Upper body

[19] For this illustration, the validity of this linear normalisation is ignored in favour of simplicity.

[20] The 90% threshold is deliberately liberal, chosen only for this illustration, and it creates a 10% margin for safety. However, in the workplace, this safety margin might need to be closer to 25%.

[21] Physiological strain = (resting + task oxygen demand [$L.min^{-1}$]) / (peak oxygen consumption [$L.min^{-1}$])% Successful task performance is possible when strain (metabolic scope) is <90%.

Attribute	Evaluation
Major muscle groups involved	*Shoulder flexors*: eccentric and isometric actions *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Unilateral
Individual or team	Team
Load	Various: 8.45-52.25 kg
Approximate position of load and percentage of task time in that position	80% ground to waist (0-100 cm) 20% above shoulder (150+ cm)
Average task duration (min)	15.24 (range: 12.75-21.00)
Average task heart rate (beats.min^{-1})	134 (range: 111-163)
Cardiovascular impulse (beats)	2037.41
Cardiovascular load (arbitrary units)	25.68
Perceived exertion (6-20)	12.3 (range: 7-16)
Average absolute oxygen cost (L.min^{-1})	1.61 (range: 1.06-2.11)
Peak absolute oxygen cost (L.min^{-1})	2.51 (range: 1.78-3.36)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	13.96 (range: 9.00-18.00)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	21.84 (range: 15.05-28.45)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	66.79 (range: 43.45-83.59)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	104.36 (range: 72.71-134.92)

3.2 Simulation two: Motor-vehicle rescue (spreaders, shears: in pairs)

3.2.1 Example experimental data

Physiological strain during the motor-vehicle rescue simulation is illustrated, using data extracted for one firefighter, within the time-series responses for heart rate (Figure 22),

absolute oxygen consumption (Figure 23) and ventilation (Figure 24). Within each graph, the coloured bands define zones of increasing strain, moving (over time) from the lower left to the upper right corners of each Figure.

For this simulation, which was always performed with a sense of urgency, but at a well-controlled and disciplined pace, cardiovascular strain was generally contained within the lower half of these zones (Figure 22). This trend was also reflected within the absolute oxygen consumption raw data (Figure 23).

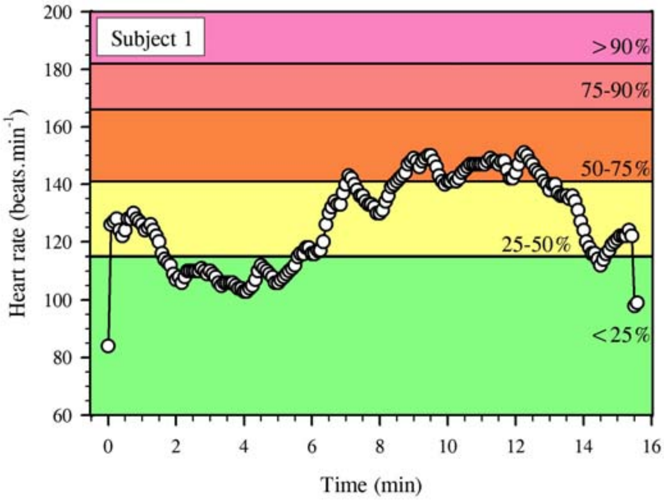

Figure 22: Heart rate response of one firefighter during the motor-vehicle rescue simulation.

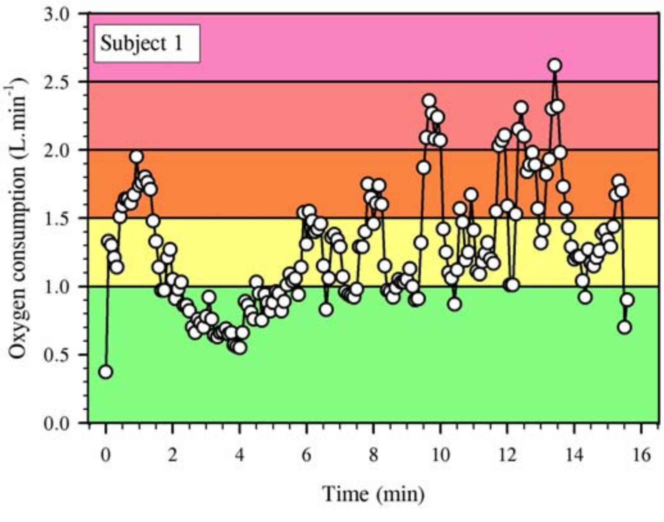

Figure 23: Oxygen consumption response of one firefighter during the motor-vehicle rescue simulation.

3.2.2 Physiological and psychophysical strain

Table 17 summarises the physiological strain experienced by firefighters performing the motor-vehicle rescue simulation. Average data are presented for the resting and simulation states. For the latter, the range parameters (minimal and maximal) define the lower and upper boundaries of physiological strain observed during the simulation. Oxygen

consumption data are presented in absolute values, but also normalised to the total mass of each firefighter (body mass, protective clothing and equipment, and data acquisition hardware worn). During this rescue simulation, the mean heart rate had a 95% probability of falling between 119-135 beats.min^{-1}. Similarly, the mean absolute oxygen consumption will lie within the zone 1.15-1.35 L.min^{-1}.

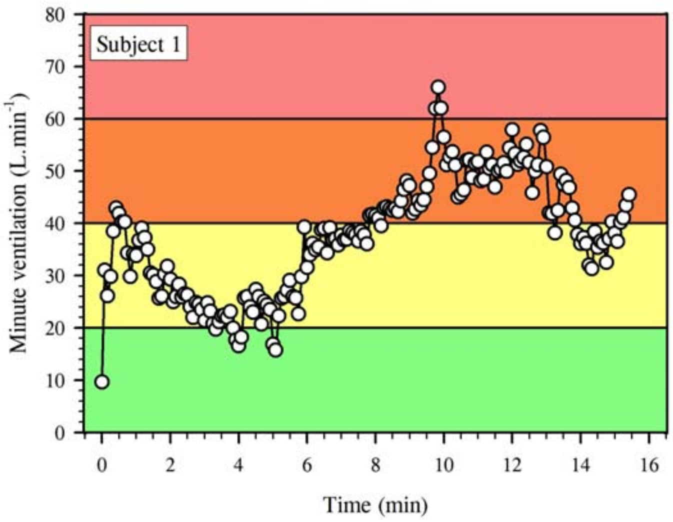

Figure 24: The ventilatory response of one firefighter during the motor-vehicle rescue simulation.

Table 17: Summary parameters for physiological strain in firefighters (N=16) performing a motor-vehicle rescue simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	78 (15)	127 (17)	88	192	8
Absolute oxygen consumption (L.min^{-1})	0.34 (0.11)	1.25 (0.21)	0.26	2.84	0.10
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.72 (1.15)	11.07 (1.68)	2.28	24.85	0.82
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.51 (4.99)	52.50 (7.91)	10.89	118.56	3.88
Minute ventilation (L.min^{-1})	16.14 (3.24)	47.52 (9.67)	15.76	114.23	4.74

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Tidal volume (L)	0.78 (0.12)	1.44 (0.23)	0.43	2.89	0.11
Breathing frequency (breaths.min^{-1})	21 (4)	34 (5)	14	79	2

In Figure 25, these observations for heart rate and absolute oxygen consumption are graphically summarised. Each graph displays work rate intensities, showing times spent (ordinate) within zones of different physiological strain (abscissa) during the simulation. Thus, moving from the left (zone 1: lowest intensity) to the right side of the graph (zones 5 or 6: highest intensity) reflects progressive increments in work rate, but with the times within any one zone (intensity) being taken from work performed across the entire simulation. These data complement and extend those presented within Table 17.

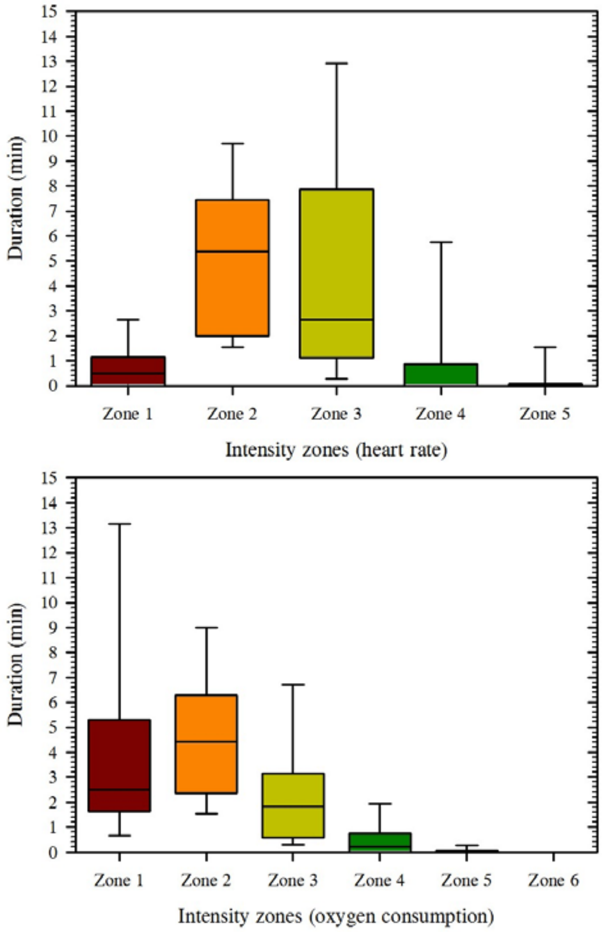

Figure 25: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the motor-vehicle rescue simulation. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

Figure 25[22] provides temporal information for physiological strain across the entire simulation, which averaged 13.57 min. Readers should primarily direct their attention to the median[23] within each box (horizontal lines), and how the position of each line varies across the zones of strain: the highest median reveals the region within which firefighters spent most time during this simulation. In this case, that was zone two for both heart rate and absolute oxygen consumption. Therefore, whilst the handling of the heavy tools during a motor-vehicle rescue was undoubtably demanding, it did not impose a particularly heavy cardiovascular or metabolic burden upon the firefighters. Instead, this task would seem to rely more heavily upon muscular endurance and strength than upon cardiorespiratory endurance.

3.2.3 Observational summary

The final stage of this analysis involved an overall evaluation the motor-vehicle rescue. The purpose of this was to identify the fitness classifications essential to this simulation, to analyse the movement patterns, including muscle actions, and to summarise the principal cardiovascular and metabolic strain measures. The outcomes from these observations are summarised in Table 18.

Table 18: Overall occupational task assessment: motor-vehicle rescue simulation.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 50-60%
Secondary fitness classification (%)	Strength: 20-30%
Tertiary fitness classification (%)	Power: 10-20%
Primary movement action	Prolonged hold in different positions (level ground)
Primary movement classification	Carry and hold (upper body)
Minor movement action	Twist and turn (torso)
Primary postural position	Upright
Minor postural position	Stoop and forward bend
Dominant body region	Upper torso

[22] A detailed description of these box plots is contained within the hazmat simulation.

[23] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

Attribute	Evaluation
Major muscle groups involved	*Shoulder flexors, extensors and abductors:* concentric, eccentric and isometric actions *Elbow flexors*: concentric and isometric actions *Hip flexors and extensors:* isometric actions *Knee Extensors*: isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of movement symmetry	Bilateral
Individual or team	Individual, with team assistance if required
Load	Spreaders: 19.5 kg Shears: 13 kg Crowbar: 5.8 kg
Approximate position of load and percentage of task time in that position	60% waist to chest (100-150 cm) 25% above shoulder (150+ cm) 15% ground (0-80 cm)
Average task duration (min)	14.37 (range: 5.67-22.50)
Average task heart rate (beats.min^{-1})	127 (range: 106-155)
Cardiovascular impulse (beats)	1830.59
Cardiovascular load (arbitrary units)	23.39
Perceived exertion (6-20)	10.7 (range: 7-14)
Average oxygen cost (L.min^{-1})	1.25 (range: 0.96-1.80)
Peak oxygen cost (L.min^{-1})	2.22 (range: 1.72-2.84)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	11.07 (range: 9.14-13.22)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	19.66 (range: 15.68-24.85)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	52.50 (range: 43.39-75.56)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	93.38 (range: 74.88-118.56)

3.3 Simulation three: Rolling out 70-mm hose (individual)

3.3.1 Example experimental data

This simulation was short and skill-related, but, due to its rapid completion, it did not elicit

physiological strain much beyond that which may be expected during a short-duration ambulatory activity with a load carriage. The time-series responses are shown for one firefighter for heart rate (Figure 26), absolute oxygen consumption (Figure 27) and ventilation (Figure 28). The coloured bands define zones of increasing strain, moving from the lower left to the upper right corners of each Figure. Cardiovascular, metabolic and ventilatory strain were generally contained within the lower half of these zones.

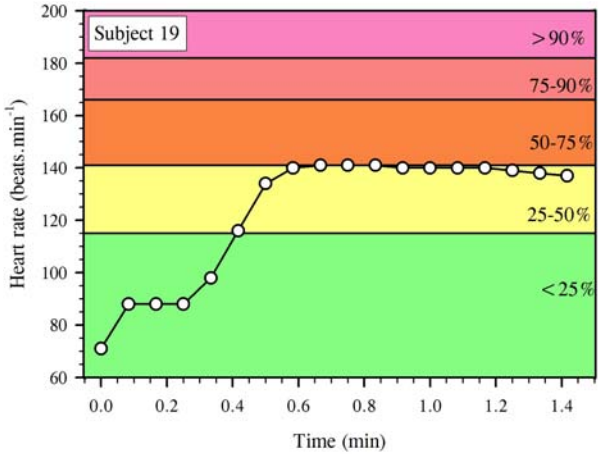

Figure 26: Heart rate response of one firefighter performing a hose roll-out (bowling 70 mm) simulation.

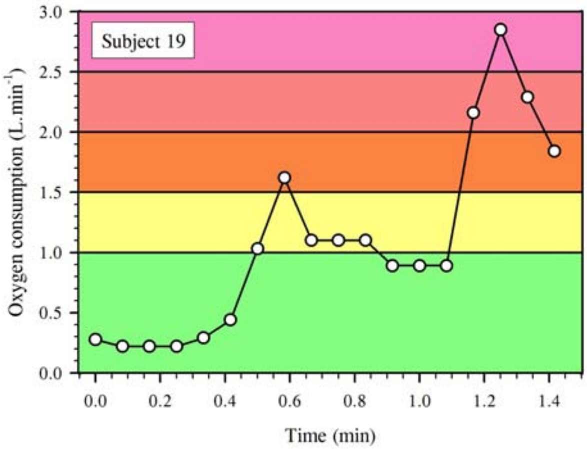

Figure 27: Oxygen consumption response of one firefighter performing a hose roll-out (bowling 70 mm) simulation.

3.3.2 Physiological and psychophysical strain

Physiological strain across five variables, as experienced by all firefighters performing the hose roll-out simulation, is summarised in Table 19. Average data are presented for rest and the simulation. In the latter state, the range parameters (minimal and maximal) define the lower and upper boundaries of physiological strain observed during the simulation. Oxygen consumption data are presented in both absolute and normalised values. The latter reflect the extent to which the influence of the total body and equipment masses (body mass, protective clothing and equipment, and data acquisition hardware worn) have been negated. During this simulation, the mean heart rate had a 95% probability of falling between 138-

150 beats.min^{-1}. Similarly, the mean absolute oxygen consumption will lie within the zone 1.41-1.75 L.min^{-1}.

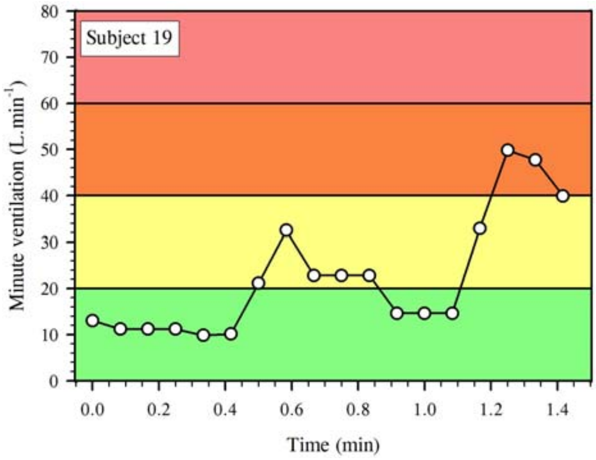

Figure 28: The ventilatory response of one firefighter performing a hose roll-out (bowling 70 mm) simulation.

Table 19: Summary parameters for physiological strain in firefighters (*N*=16) performing a hose roll-out (70 mm) simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (11)	144 (13)	88	175	6
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	1.58 (0.36)	0.22	3.02	0.17
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	15.21 (3.45)	2.12	32.27	1.69
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.94 (5.21)	70.27 (15.43)	9.82	144.31	7.56
Minute ventilation (L.min^{-1})	18.15 (5.21)	47.62 (14.58)	9.84	125.44	7.14
Tidal volume (L)	0.90 (0.22)	1.61 (0.29)	0.41	3.18	0.14
Breathing frequency (breaths.min^{-1})	21 (4)	30 (7)	10	57	3

In Figure 29, these observations for heart rate and absolute oxygen consumption are graphically summarised. Each graph displays work rate intensities, showing times spent (ordinate) within zones of different physiological strain (abscissa) during the simulation. Thus, moving from the left (zone 1: lowest intensity) to the right side of the graph (zones 5 or 6: highest intensity) reflects progressive increments in work rate, but with the times within any one zone (intensity) being taken from work performed across the entire simulation. These data complement and extend those presented within Table 19.

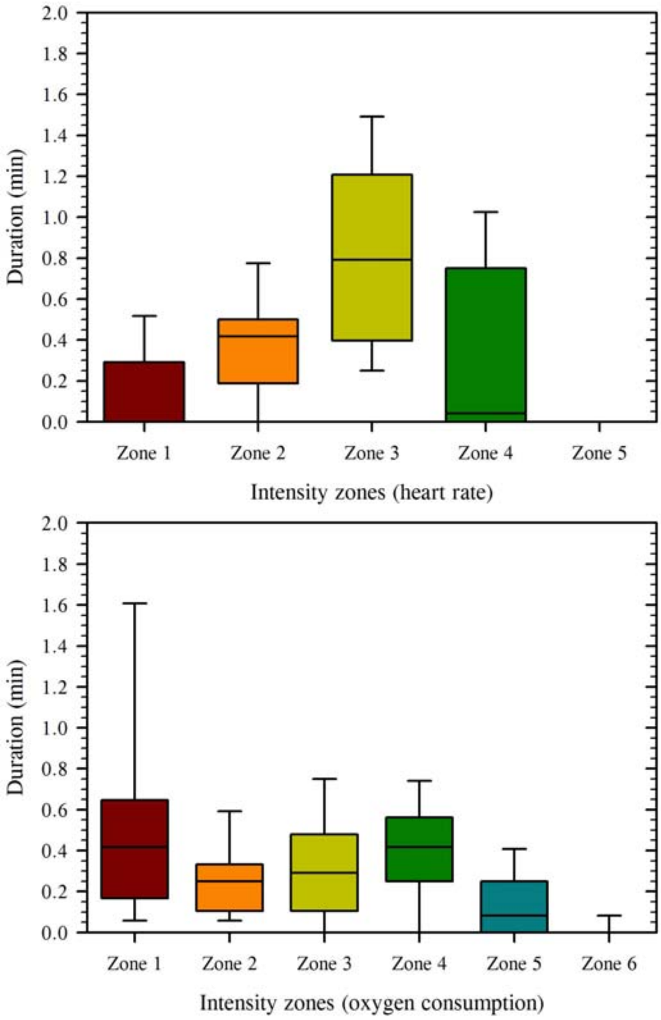

Figure 29: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the hose roll-out (bowling 70 mm) simulation. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

Temporal information for cardiovascular and metabolic strain for this simulation are revealed within Figure 29[24] across the entire simulation, which averaged 1.68 min.

[24] A detailed description of these box plots is contained within the hazmat simulation.

Attention should primarily be direct to the medians[25] (horizontal lines), and how these varied across the zones of strain. For instance, the highest median identifies the zone in which firefighters spent most time during the simulation. For this occupational task, that was zone three for heart rate, but the variations for absolute oxygen consumption were equally distributed across zones one to four. Therefore, this short-duration activity did not impose a particularly heavy cardiovascular or metabolic burden upon the firefighters. Instead, this task would seem to rely more heavily upon strength, power and skill than upon cardiorespiratory endurance.

3.3.3 Observational summary

Outcomes from the final stage of this analysis, an overall evaluation of the simulation, are summarised in Table 16. The aim of this was to identify the fitness classifications essential to each occupational task, to analyse the movements within the activity, including muscle actions, and to summarise the cardiovascular and metabolic strain.

Table 20: Overall occupational task assessment: rolling out 70-mm hose.

Attribute	Evaluation
Primary fitness classification (%)	Power: 60-70%
Secondary fitness classification (%)	Strength: 30-40%
Tertiary fitness classification (%)	- - -
Primary movement action	Squat with underarm throw, followed by walk and carry
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Throw (upper body)
Primary postural classification	Upright
Minor postural classification	---
Dominant body region	Upper body
Major muscle groups involved	*Shoulder flexors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions
Dominant mode of carriage	Unilateral
Individual or team	Individual

[25] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

Attribute	Evaluation
Load	16.6 kg of rolled 70-mm hose 5 kg 70-mm wide breach
Approximate position of load and percentage of task time in that position	60% waist (80-100 cm) 30% ground (0-80 cm) 10% chest (100-150 cm)
Average task duration (min)	1.68 (range: 1.25-2.42)
Average task heart rate (beats.min^{-1})	144 (range: 126-168)
Cardiovascular impulse (beats)	241.62
Cardiovascular load (arbitrary units)	2.66
Perceived exertion (6-20)	11.6 (range: 9-15)
Average oxygen cost (L.min^{-1})	1.58 (range: 0.90-2.01)
Peak oxygen cost (L.min^{-1})	2.51 (range: 1.43-3.02)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	15.21 (range: 7.86-20.66)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	24.13 (range: 12.46-32.27)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	70.27 (range: 37.61-94.78)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	111.60 (range: 59.61-144.31)

3.4 Simulation four: Coupling hoses (individual)

3.4.1 Example experimental data

This occupational task invariably follows the previous task at a fire, and it too was short (lasting 1.14 min) and skill-related. However, on this occasion, there can also be a significant strength component related to successfully completing the hose coupling, particularly for individuals with smaller hands. Accordingly, it was anticipated that the cardiovascular and metabolic strain may not be high. However, as the time-series responses for one firefighter demonstrate, this was not realised: heart rate (Figure 30), absolute oxygen consumption (Figure 31), ventilation (Figure 32).

The coloured bands within these Figures define zones of increasing strain, moving from the lower left to the upper right corners. For the individual shown, significant cardiovascular, metabolic and ventilatory strain were evident, even though the simulation lasted only 70 s for this firefighter. Since all simulations were required to be performed under realistic operational conditions, there was a sense of urgency associated with this activity, for any delay in this tasks would prevent firefighters from actively fighting a fire. Thus, one may

anticipate that the criticality of the task was reflected in these data, and in particular the cardiovascular response.

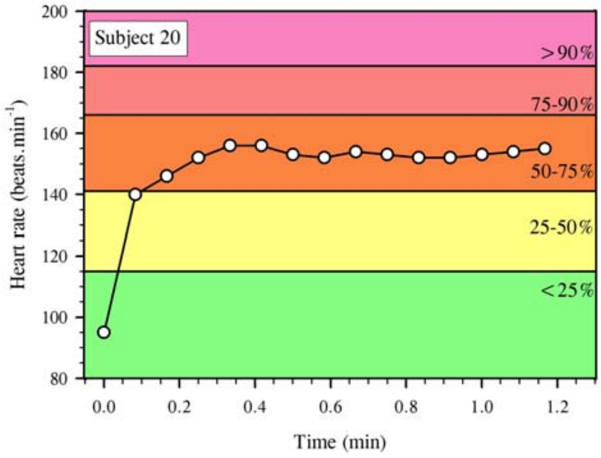

Figure 30: Heart rate response of one firefighter during the hose-coupling simulation.

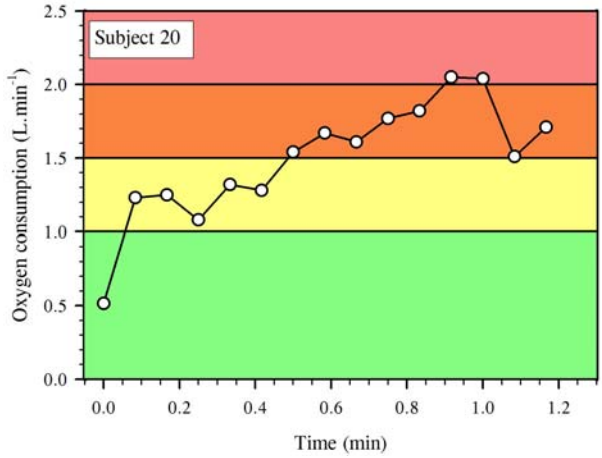

Figure 31: Oxygen consumption response of one firefighter during the hose-coupling simulation.

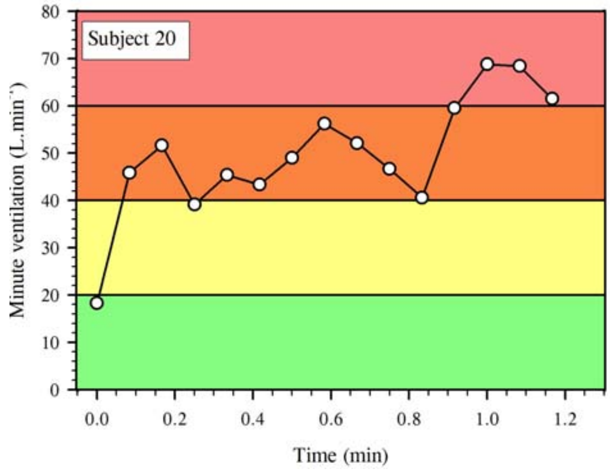

Figure 32: The ventilatory response during the hose-coupling simulation.

3.4.2 Physiological and psychophysical strain

Table 21 summarises the physiological strain, across five indices, experienced by the firefighters performing the hose-coupling simulation. Average data are presented for rest and for the task simulation. In the latter state, the range parameters (minimal and maximal) define the lower and upper boundaries of strain. Oxygen consumption data are presented as absolute values, but also as data normalised to the total firefighter mass (body mass, protective clothing and equipment, data acquisition hardware). During this simulation, the mean heart rate had a 95% probability of falling between 128-142 beats.min^{-1}. Similarly, the mean absolute oxygen consumption would be within the range 1.25-1.55 L.min^{-1}.

Table 21: Summary parameters for physiological strain in firefighters (*N*=16) performing a hose-coupling simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (11)	135 (13)	98	165	7
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	1.40 (0.31)	0.33	2.59	0.15
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	13.49 (2.87)	2.88	23.33	1.41
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.94 (5.21)	62.39 (12.95)	13.76	106.22	6.34
Minute ventilation (L.min^{-1})	18.15 (5.21)	49.57 (13.46)	14.19	119.55	6.60
Tidal volume (L)	0.90 (0.22)	1.72 (0.34)	0.75	2.76	0.17
Breathing frequency (breaths.min^{-1})	21 (4)	29 (6)	12	52	3

Figure 33 summarises these heart rate and absolute oxygen consumption responses, but now with respect to zones of increasing physiological strain across the whole occupational simulation. These data complement and extend those presented within Table 21. Within each graph, varying work rate intensities are displayed, such that the times spent (ordinate) within physiological strain zones (abscissa) are indicated. Moving from the left (zone 1: lowest strain) to the right side of the graph (zones 5 or 6: highest strain) reflects progressive increments in work rate. However, the times within any one zone have been taken from

work performed across the entire simulation.

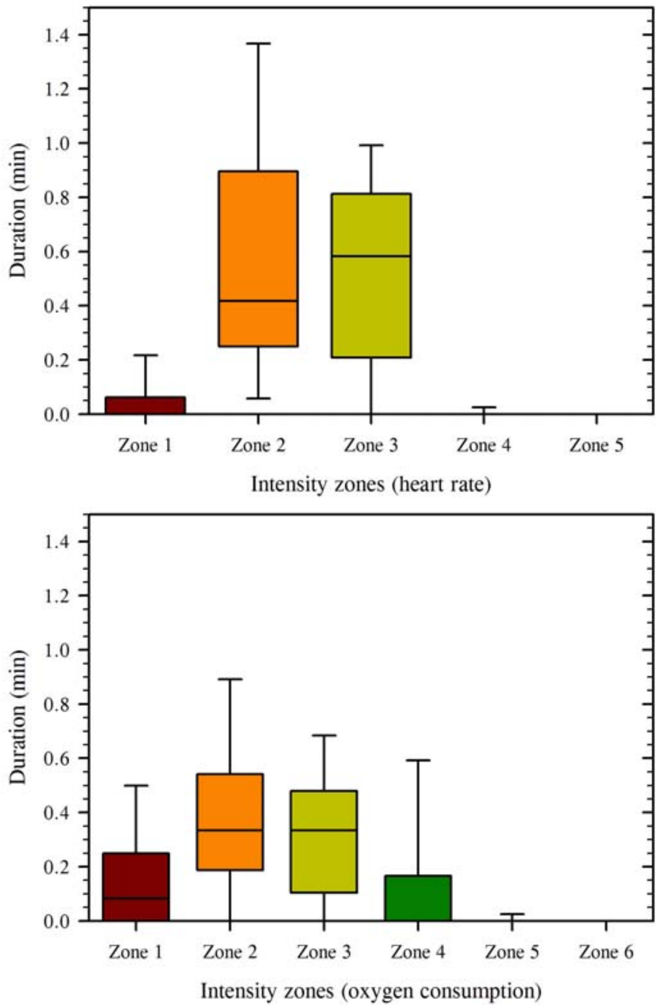

Figure 33: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the hose-coupling simulation. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

Readers should direct their attention to the medians[26] (horizontal lines) contained within Figure 33[27]. The position of each median across the different strain zones, reveals the variability in physiological strain experienced by these firefighters, and it shows the fractional time spent within each strain level. For instance, the highest median identifies the region within which firefighters spent most their time. In this simulation, that was zones two and three for both heart rate and absolute oxygen consumption. Clearly, significant cardiovascular and metabolic burdens were experienced by these individuals, even though the task lasted only about 75 s.

[26] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

[27] A detailed description of these box plots is contained within the hazmat simulation.

3.4.3 Observational summary

Table 22 summarises the final stage of analysis for this activity. The aim of this analytical stage was to identify the essential fitness classifications for each task, to analyse the movement patterns, including muscle actions, and to summarise the principal indices of physiological strain.

Table 22: Overall occupational task assessment: coupling hoses.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 100%
Secondary fitness classification (%)	- - -
Tertiary fitness classification (%)	- - -
Primary movement action	One- or two-handed grip, hold and rotate in squatting or kneeling position, followed by a short walk
Primary movement classification	- - -
Minor movement classification	- - -
Primary postural classification	Kneel and crouch
Minor postural classification	Upright
Dominant body region	Hands
Major muscle groups involved	*Wrist supinators:* concentric and isometric actions *Wrist extensors:* isometric action *Elbow flexors*: isometric action
Dominant mode of carriage	- - -
Individual or team	Individual
Load	Resistive force provided by the couplings: not quantified
Approximate position of load and percentage of task time in that position	100% ground (0-80 cm)
Average task duration (min)	1.14 min (range: 0.75-1.83)
Average task heart rate (beats.min^{-1})	135 (range: 109-154)
Cardiovascular impulse (beats)	153.93
Cardiovascular load (arbitrary units)	1.70

Attribute	Evaluation
Perceived exertion (6-20)	9.6 (range: 6-14)
Average oxygen cost ($L.min^{-1}$)	1.40 (range: 0.76-2.01)
Peak oxygen cost ($L.min^{-1}$)	1.95 (range:1.19-2.59)
Average specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	13.49 (range: 6.61-17.75)
Peak specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	18.79 (range:10.37-23.33)
Average specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	62.39 (range: 31.64-79.37)
Peak specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	86.86 (range:49.61-106.22)

3.5 Simulation five: Locating and connecting hydrant to appliance (individual)

3.5.1 Example experimental data

To successfully perform this operationally critical activity, firefighters needed to carry a considerable load (Table 5: 20+ kg in addition to the hose), either in one (70 m) or two trips (210 m) over a 70-m course (Figure 6). As with the two previous simulations, this simulation needed to be completed quickly, but under control, and these objectives were reflected within the physiological strain indices: heart rate (Figure 34), absolute oxygen consumption (Figure 35) and ventilation (Figure 36). Within each graph, the coloured bands define zones of increasing strain, moving (over time) from the lower left to the upper right corners of each Figure.

Unlike simulations three and four, cardiovascular, metabolic and ventilatory strain was progressively rising throughout the simulation. Thus, in the firefighter used to illustrate these responses, heart rate entered zone four (75-90% of the heart rate reserve) whilst the absolute oxygen consumption data averaged more than 2.0 $L.min^{-1}$ for more than 40% of the simulation.

3.5.2 Physiological and psychophysical strain

Summaries of the physiological strain experienced by firefighters performing this simulation are contained within Table 23. Average data are presented for the resting and simulation states, with the range parameters defining the lower and upper boundaries of strain. Oxygen consumption data are presented in absolute values, but also normalised to the total mass of each firefighter (body mass, protective clothing and equipment, and data acquisition hardware worn). During this rescue simulation, the mean heart rate had a 95% probability of falling between 142-158 $beats.min^{-1}$. Similarly, the mean absolute oxygen consumption will lie within the zone 1.37-1.75 $L.min^{-1}$.

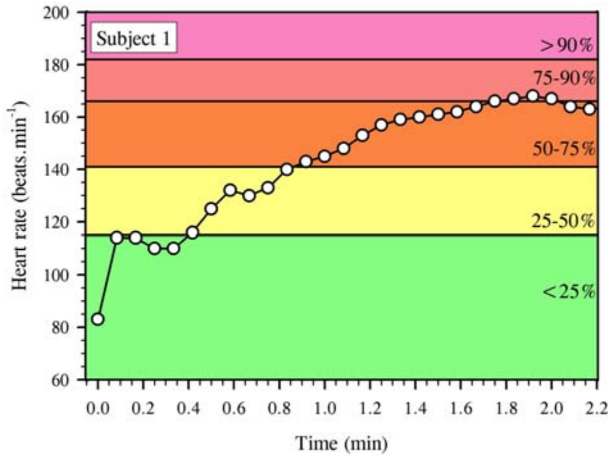

Figure 34: Heart rate response of one firefighter during the fire-hydrant connection simulation.

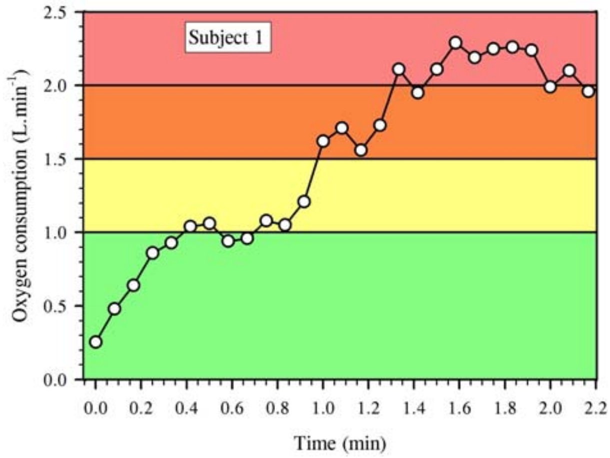

Figure 35: Oxygen consumption response of one firefighter during the fire-hydrant connection simulation.

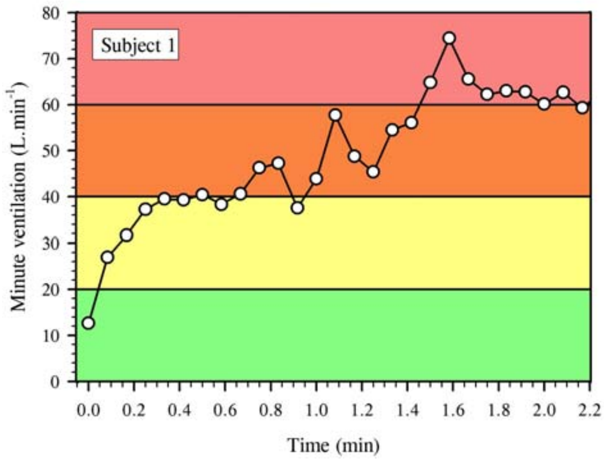

Figure 36: The ventilatory response during the fire-hydrant simulation.

Table 23: Summary parameters for physiological strain in firefighters (N=16) performing a hydrant connection simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (11)	150 (17)	86	186	8
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	1.56 (0.39)	0.29	3.21	0.19
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	14.95 (3.56)	2.80	31.77	1.75
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.94 (5.21)	69.14 (16.18)	12.94	145.71	7.93
Minute ventilation (L.min^{-1})	18.15 (5.21)	58.55 (16.88)	17.44	127.24	8.27
Tidal volume (L)	0.90 (0.22)	1.83 (0.42)	0.62	3.19	0.20
Breathing frequency (breaths.min^{-1})	21 (4)	32 (6)	17	58	3

These observations are graphically summarised in Figure 37 for heart rate and absolute oxygen consumption, extending and complementing those presented in Table 23. These graphs show work rate intensity zones, and reveal the times spent (ordinate) at different levels of physiological strain (abscissa) during this occupational simulation. Moving from the left (zone 1: lowest intensity) to the right side of the graph (zones 5 or 6: highest intensity) will reflect a gradual increase in work rate. However, the time within each intensity zone has been accumulated from across the entire simulation.

Readers should direct their attention to the medians[28] (the horizontal lines) within Figure 37[29]. These lines provide temporal information concerning physiological strain. For instance, whilst this activity averaged just 2.78 min, this time was distributed across the full range of intensities, and the position of each median communicates this information. Thus, whilst metabolic strain climbed during the course of this task, it was evenly dispersed across zones one to four, while cardiovascular strain was displaced towards the higher intensities

[28] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

[29] A detailed description of these box plots is contained within the hazmat simulation.

(zones three and four). Therefore, the successful completion of this task would be heavily dependent upon muscular strength and endurance due its load-carriage nature, but it would also reply upon cardiorespiratory endurance.

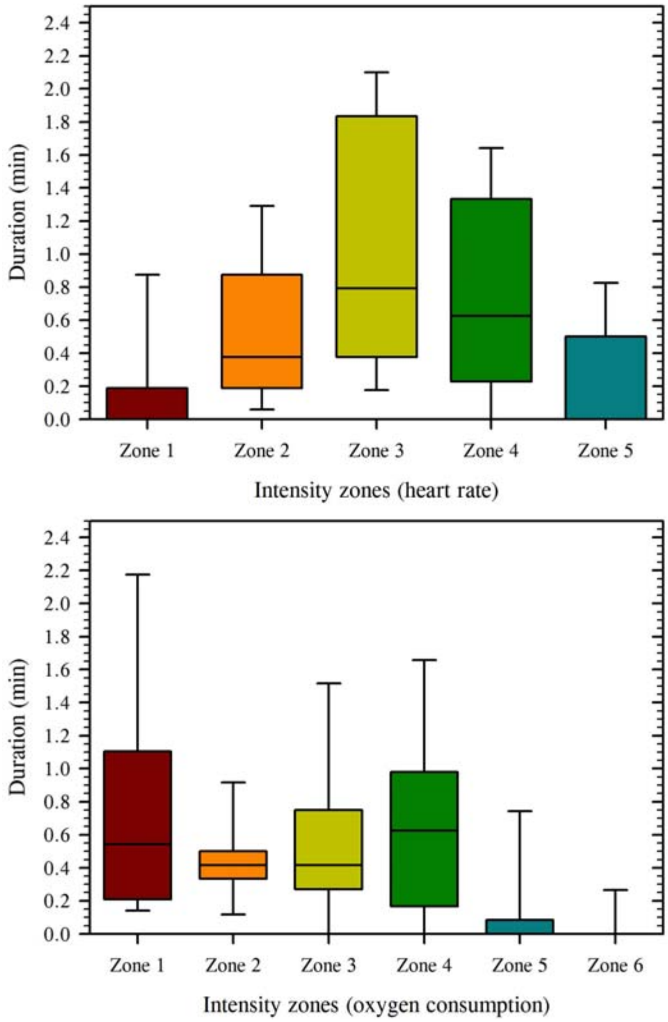

Figure 37: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the fire-hydrant connection simulation. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

3.5.3 Observational summary

The final stage of this analysis involved an overall evaluation of the simulation (Table 24). The aim was to identify the essential fitness classifications for this task, to analyse the movement patterns (including muscle actions), and to summarise cardiovascular and metabolic strain.

Table 24: Overall occupational task assessment: locating and connecting a fire hydrant.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 40-50%

Attribute	Evaluation
Secondary fitness classification (%)	Muscular endurance: 35-45%
Tertiary fitness classification (%)	Cardiorespiratory endurance: 10-20%
Primary movement action	Static carry with loads in both hands while walking on level ground
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Lift and place (upper body)
Primary postural classification	Upright
Minor postural classification	Kneel, squat, crouch
Dominant body region	Upper body
Major muscle groups involved	*Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Unilateral
Individual or team	Individual
Load	16.6 kg of rolled 70-mm hose Hydrant Standpipe: 8 kg Hydrant delivery elbow: 7.1 kg Hydrant bar: 1.8 kg
Approximate position of load and percentage of task time in that position	80% ground to waist (0-100 cm) 20% above shoulder (150+ cm)
Average task duration (min)	2.78 (range: 1.50-4.33)
Average task heart rate (beats.min^{-1})	150 (range: 107-166)
Cardiovascular impulse (beats)	418.35
Cardiovascular load (arbitrary units)	4.62
Perceived exertion (6-20)	14.1 (range: 11-17)
Average oxygen cost (L.min^{-1})	1.56 (range: 0.91-2.25)
Peak oxygen cost (L.min^{-1})	2.31 (range: 1.33-3.21)

Attribute	Evaluation
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	14.95 (range: 7.89-19.80)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	22.13 (range: 12.20-31.77)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	69.14 (range: 37.75-88.56)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	102.38 (range: 58.36-145.71)

3.6 Simulation six: Dragging charged 70-mm hose (lateral: individual)

3.6.1 Example experimental data

The Research Team was advised that this occupational activity, along with simulation twelve (prolonged use of 70-mm hose) would place a significant physiological encumbrance upon firefighters. However, this was not realised. Certainly within the data shown in Figures 38-40, strain was minimal. Moreover, unlike each of the previous simulations, these time-series data are clearly reflective of steady-states for heart rate (Figure 38), absolute oxygen consumption (Figure 39) and ventilatory responses (Figure 40). Where these indices had previously moved upwards through the bands that defined zones of increasing strain, for this activity, they were at a stable, low intensity across the simulation.

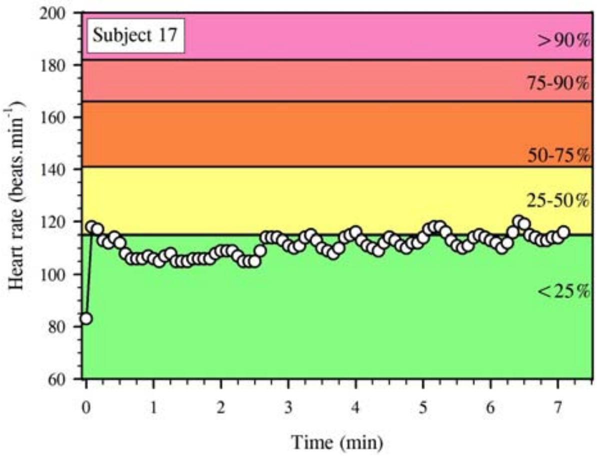

Figure 38: Heart rate response of one firefighter during the lateral movement of a charged 70-mm hose.

3.6.2 Physiological and psychophysical strain

In Table 25, firefighter strain during this simulation is summarised. Average data are presented for the resting and simulation states. In the latter state, the range parameters (minimal and maximal) define the lower and upper boundaries of physiological strain observed. Oxygen consumption data are presented in absolute values, but also normalised to the total mass of each firefighter (body mass, protective clothing and equipment, and data acquisition hardware worn). During this activity, the mean heart rate had a 95% probability

of falling between 127-145 beats.min^{-1}. Similarly, the mean absolute oxygen consumption would be found within the zone 0.72-0.94 L.min^{-1}.

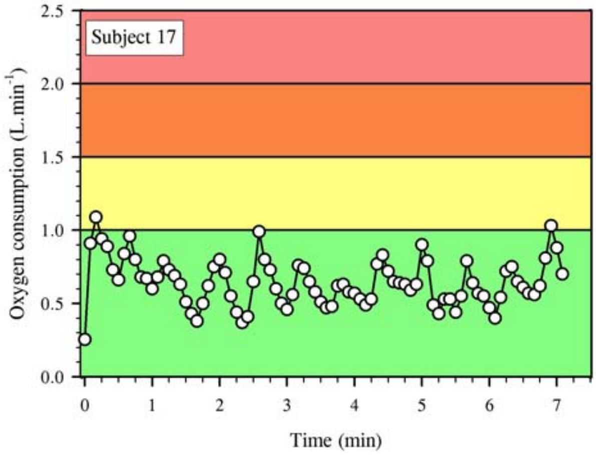

Figure 39: Oxygen consumption response of one firefighter during the lateral movement of a charged 70-mm hose.

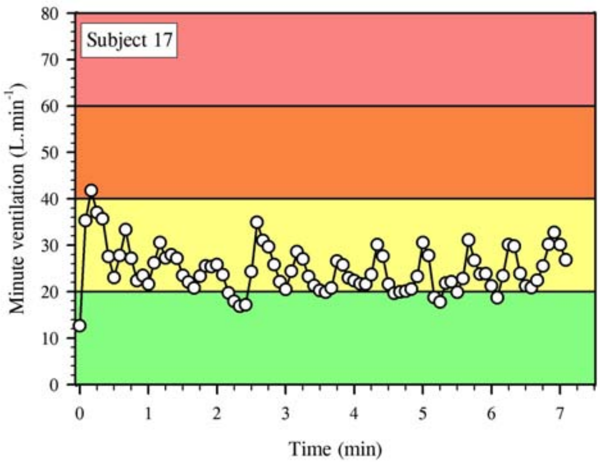

Figure 40: The ventilatory response of one firefighter during the lateral movement of a charged 70-mm hose.

Table 25: Summary parameters for physiological strain in firefighters (N=16) moving a charged 70-mm hose (laterally). Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (12)	136 (18)	105	172	9
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	0.83 (0.23)	0.24	2.15	0.11

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Specific oxygen consumption ($mL.kg^{-1}.min^{-1}$)	4.45 (1.20)	7.98 (2.37)	2.44	22.44	1.16
Specific oxygen consumption ($mL.kg^{-0.67}.min^{-1}$)	18.94 (5.21)	36.83 (10.51)	11.67	100.35	5.15
Minute ventilation ($L.min^{-1}$)	18.15 (5.21)	34.04 (9.31)	13.05	78.88	4.56
Tidal volume (L)	0.90 (0.22)	1.27 (0.28)	0.45	2.32	0.14
Breathing frequency ($breaths.min^{-1}$)	21 (4)	27 (5)	14	53	3

In Figure 41, these observations for heart rate and absolute oxygen consumption are graphically summarised. Each graph displays work rate intensities, showing times spent (ordinate) within zones of different physiological strain (abscissa) during the simulation. Thus, moving from the left to the right side of the graph reflects progressive increments in work rate, but with the times within any one zone (intensity) being taken from work performed across the entire simulation. Thus, Figure 41[30] provides temporal information for physiological strain across the entire simulation, which averaged 7.09 min. Attention should be directed to the medians[31] (the horizontal lines) within each graph, and how the position of each varies across the strain zones. In this task, that was zones two and three for heart rate, and zone one for absolute oxygen consumption. Therefore, the performance of this occupational task would not be a function of cardiorespiratory endurance.

3.6.3 Observational summary

The final stage of this analysis involved an overall evaluation of the simulation, with the aim being to identify the fitness classifications essential to each occupational task, to analyse the movement patterns, including muscle actions, and to summarise the principal cardiovascular and metabolic strain measures. The outcomes from these observations for this activity are summarised in Table 26.

[30] A detailed description of these box plots is contained within the hazmat simulation.

[31] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

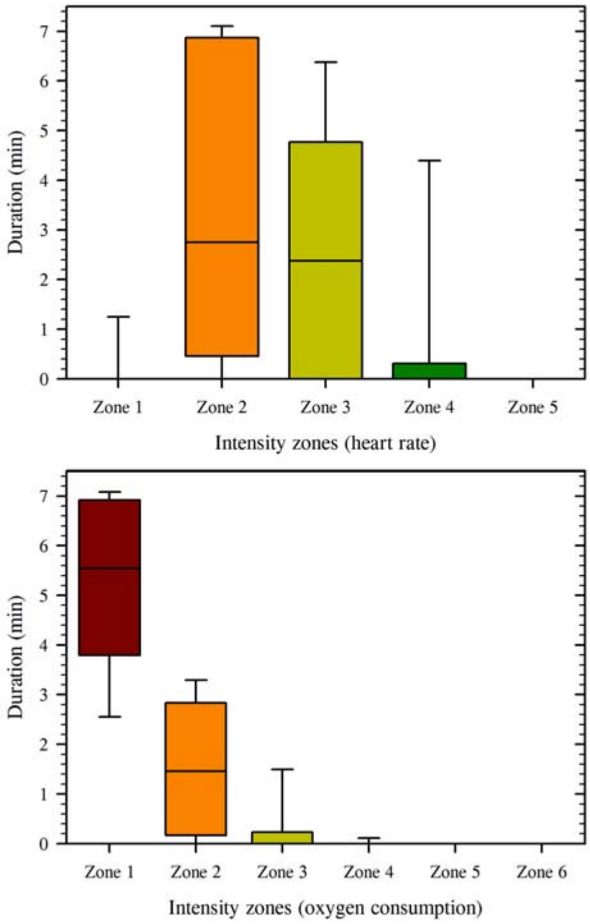

Figure 41: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the lateral movement of a charged 70-mm hose. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

Table 26: Overall occupational task assessment: dragging charged 70-mm hose.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 50-60%
Secondary fitness classification (%)	Strength: 30-40%
Tertiary fitness classification (%)	Power: 10-20%
Primary movement action	One-sided pull with uneven centre of gravity, then with intermittent periods of walking
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Push, pull, drag (upper and lower body)
Primary postural classification	Upright

Attribute	Evaluation
Minor postural classification	- - -
Dominant body region	Upper body
Major muscle groups involved	*Shoulder flexors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions [all actions are predominately isometric]
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	70-mm hose: ~115 kg, 7-8 kg off the ground
Approximate position of load and percentage of task time in that position	100% waist to shoulder (100-150 cm)
Average task duration (min)	7.09 (range: 7.08-7.17)
Average task heart rate (beats.min^{-1})	136 (range: 111-167)
Cardiovascular impulse (beats)	961.53
Cardiovascular load (arbitrary units)	10.62
Perceived exertion (6-20)	10.5 (range: 6-13)
Average oxygen cost (L.min^{-1})	0.83 (range: 0.39-1.18)
Peak oxygen cost (L.min^{-1})	1.39 (range: 0.61-2.10)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	7.98 (range: 4.63-12.66)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	13.42 (range: 7.85-22.44)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	36.83 (range: 21.30-56.36)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	62.00 (range: 33.02-100.35)

3.7 Simulation seven: Fire attack (in pairs)

3.7.1 Example experimental data

The fire-attack simulation lasted, on average, 4.16 min, and it elicited mid-range physiological strain, as is evident within the time-series responses for firefighter 28 for heart rate (Figure 42), absolute oxygen consumption (Figure 43) and ventilation (Figure 44). The coloured bands within these Figures define zones of increasing strain, moving from the lower left to the upper right over time.

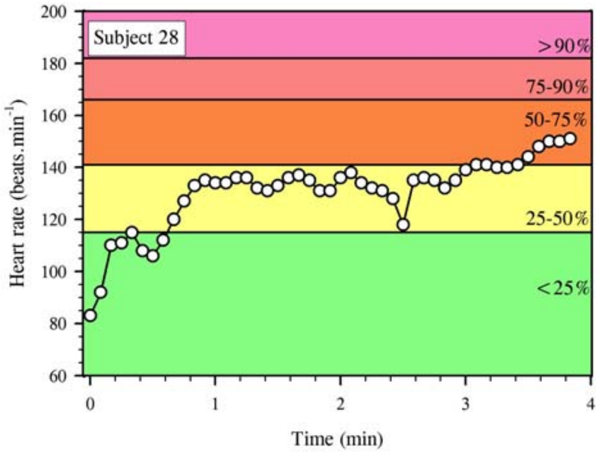

Figure 42: Heart rate response of one firefighter during the fire-attack simulation.

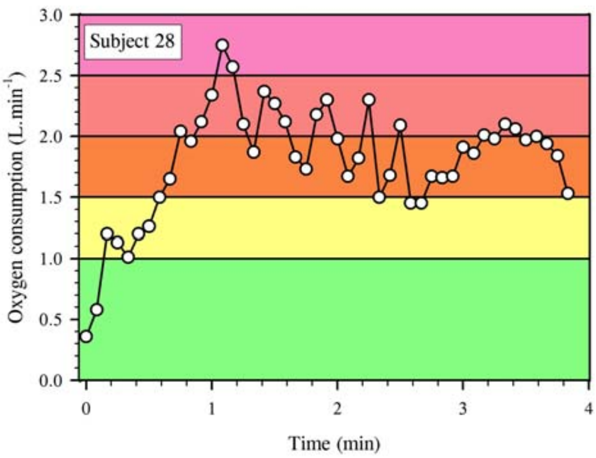

Figure 43: Oxygen consumption response of one firefighter during the fire-attack simulation.

3.7.2 Physiological and psychophysical strain

Table 27 summarises this strain for five key physiological indices, and across all firefighters performing the fire-attack simulation. Average data are presented for the resting and the simulation stages of these trials. In the latter instance, the minimal and maximal parameters describe the lower and upper level of strain observed. Oxygen consumption data are presented in both absolute and normalised formats. The latter reflect the combined influence of the body and equipment masses (body mass, protective clothing and equipment, data acquisition hardware). During this task, the mean heart rate had a 95% probability of falling

between 135-151 beats.min^{-1}. Similarly, the mean absolute oxygen consumption could be expected to fall within the zone 1.34-1.72 L.min^{-1}.

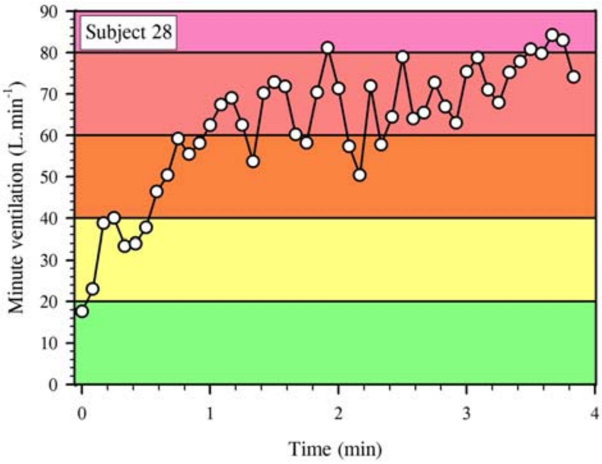

Figure 44: The ventilatory response of one firefighter during the fire-attack simulation.

Table 27: Summary parameters for physiological strain in firefighters (*N*=16) performing the fire-attack simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (12)	143 (17)	91	189	8
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	1.53 (0.38)	0.28	3.01	0.19
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	14.76 (3.75)	3.18	29.38	1.84
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.94 (5.21)	68.19 (16.84)	15.16	134.85	8.25
Minute ventilation (L.min^{-1})	18.15 (5.21)	58.21 (13.53)	14.23	116.05	6.63
Tidal volume (L)	0.90 (0.22)	1.61 (0.36)	0.35	3.23	0.18
Breathing frequency (breaths.min^{-1})	21 (4)	37 (6)	18	60	3

The observations for heart rate and absolute oxygen consumption are graphically summarised in Figure 45[32], with graphs displaying different work rate intensities (abscissa), and showing how long firefighters spent (ordinate) within each zone during the simulation. As one moves from left (zone 1) to right (zones 5 or 6), physiological strain progressively increases. However, the times within any one zone are taken from work performed across the entire simulation. It is recommended that attention be primarily directed at the medians[33] shown on each graph (the horizontal lines within each box). The relative position of each line provides an evaluation of variations in strain throughout the simulation. In this scenario, most time was spent within zone three for both heart rate and absolute oxygen consumption. Whilst this task involved significant materials handling (dragging charged 38-mm hose: two people), and could therefore be described as a muscular strength and endurance task, it was also associated with a cardiorespiratory endurance component.

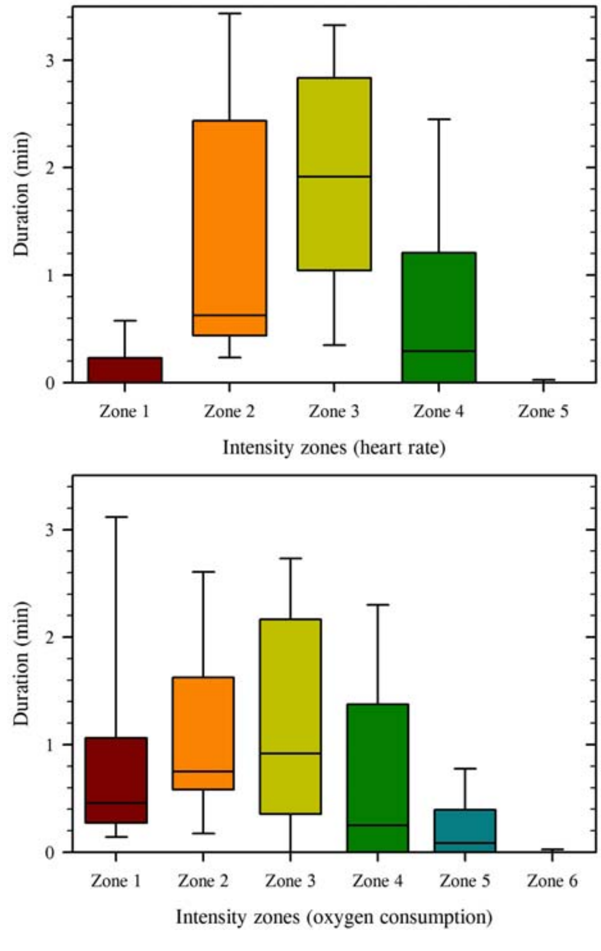

Figure 45: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the fire-attack simulation. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

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[32] A detailed description of these box plots is contained within the hazmat simulation.

[33] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

3.7.3 Observational summary

Finally for this simulation, an overall task analysis was completed. The purpose of this was to identify the essential fitness classifications for this activity, to analyse patterns of movement and muscle actions, and to summarise cardiovascular and metabolic strain. The outcomes from these analyses are summarised in Table 28.

Table 28: Overall occupational task assessment: fire-attack simulation.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 30-40%
Secondary fitness classification (%)	Strength: 40-50%
Tertiary fitness classification (%)	Cardiorespiratory endurance: 20%
Primary movement action	Extended squat and crab-crawl, with one-sided pull and uneven centre of gravity
Primary movement classification	Push, pull, drag (whole body)
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Kneel, squat, crouch
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Shoulder flexors*: concentric and isometric actions *Elbow flexors*: isometric action *Knee flexors*: concentric action *Hip flexors*: concentric and isometric actions *Back extensors*: concentric and isometric actions *Trunk Stabilisers*: isometric actions
Dominant mode of carriage	Unilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	100% ground to waist (0-100 cm)
Average task duration (min)	4.16 (range: 3.42-5.25)
Average task heart rate (beats.min^{-1})	143 (range: 110-163)
Cardiovascular impulse (beats)	593.89

Attribute	Evaluation
Cardiovascular load (arbitrary units)	6.56
Perceived exertion (6-20)	13.4 (range: 9-17)
Average oxygen cost ($L.min^{-1}$)	1.53 (range: 0.88-2.10)
Peak oxygen cost ($L.min^{-1}$)	2.27 (range: 1.17-3.01)
Average specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	14.76 (range: 8.79-20.39)
Peak specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	21.77 (range: 11.72-29.38)
Average specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	68.19 (range: 40.17-94.14)
Peak specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	100.70 (range: 53.54-134.85)

3.8 Simulation eight: Firefighter down: one-person rescue (individual)

3.8.1 Example experimental data

The single most critical occupational activity identified within the first phase of this research (Taylor *et al.*, 2012) was the one-person rescue of a fallen firefighter during the course of a fire attack or a structural search and rescue. Data from firefighter 32 are used to illustrate this simulation: heart rate (Figure 46), absolute oxygen consumption (Figure 47) and ventilation (Figure 48). Within each graph, the coloured bands define zones of increasing strain, moving (over time) from the lower left to the upper right corners.

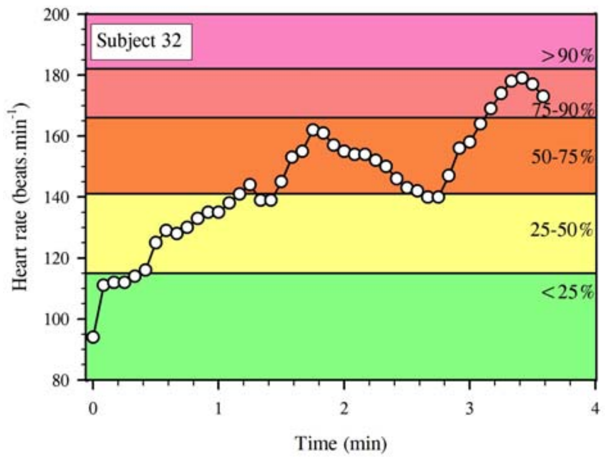


Figure 46: Heart rate response of one firefighter during the one-person firefighter rescue simulation.

For this simulation, every firefighter rescued the same individual (85.15 kg plus 19-20 kg of protective equipment and breathing apparatus: total mass = 106.57 kg). Each rescue was performed as rapidly as possible, but at a disciplined pace. Contrary to expectations, the

perceived difficulty of this task was not so definitively reflected within these data, although the absolute oxygen consumption (Figure 47) and particularly minute ventilation were significantly elevated (Figure 48).

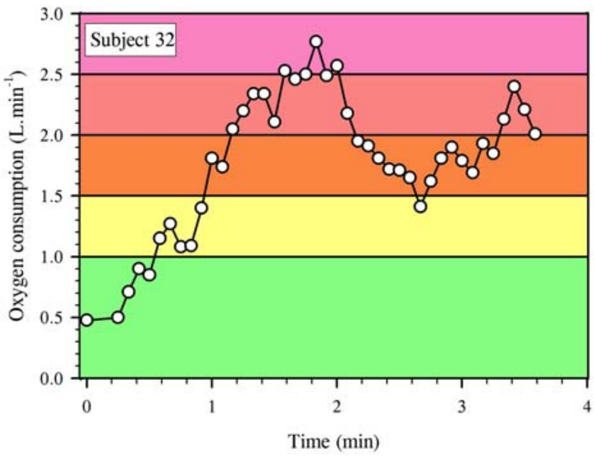


Figure 47: Oxygen consumption response of one firefighter during the one-person firefighter rescue simulation.

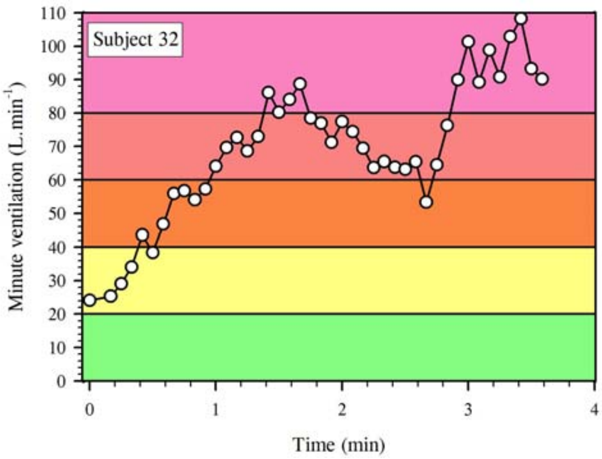


Figure 48: The ventilatory response of one firefighter during the one-person firefighter rescue simulation.

3.8.2 Physiological and psychophysical strain

Parameters summarising the physiological strain are presented in Table 29 as averages for the resting and simulation conditions. For the latter state, observed data ranges (minimal and maximal) describe the lower and upper boundaries of strain, with oxygen consumption data being presented in both absolute values and normalised (specific) formats (body mass, protective clothing and equipment, and data acquisition hardware worn). During this simulation, the mean heart rate had a 95% chance of falling between 153-169 beats.min^{-1}, whilst the mean absolute oxygen consumption could be found within the zone ranging from 1.44-1.92 L.min^{-1}.

Table 29: Summary parameters for physiological strain in firefighters (N=16) performing a one-person firefighter rescue. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (12)	161 (16)	97	188	8
Absolute oxygen consumption (L.min^{-1})	0.36 (0.12)	1.68 (0.46)	0.32	2.90	0.24
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	16.22 (4.58)	2.84	28.20	2.40
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.79 (5.57)	67.91 (17.92)	10.01	129.92	9.39
Minute ventilation (L.min^{-1})	18.15 (5.21)	70.22 (14.10)	26.64	116.62	6.91
Tidal volume (L)	0.90 (0.22)	1.84 (0.42)	0.60	3.67	0.21
Breathing frequency (breaths.min^{-1})	21 (4)	39 (5)	24	71	2

Figure 49[34] provides complementary data for heart rate and absolute oxygen consumption, extending this form of presentation into physiological strain zones (abscissa) that reflect variations in the times spent (ordinate) within work rate of different intensities. Moving from the left (zone 1: lowest intensity) to the right side of each graph (zones 5 or 6: highest intensity), there is a progressive increase in strain. However, the cumulative time within any one zone (intensity) was taken from work performed across the entire simulation, which averaged 3.84 min. The horizontal lines within each box plot show the median[35] times within each zone. Thus, the highest median, but not the height of the boxes, reveals the region within which firefighters spent most time during this simulation. For heart rate, these times are shifted rightward (more stressful) relative to the previous occupational simulations. This trend was less evident within the absolute oxygen consumption data, although strain was still high. The final stage of this analysis involved an overall evaluation of each fire-fighting simulation (including movement and muscle action analyses). The outcomes from this are summarised in Table 30.

[34] A detailed description of these box plots is contained within the hazmat simulation.

[35] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

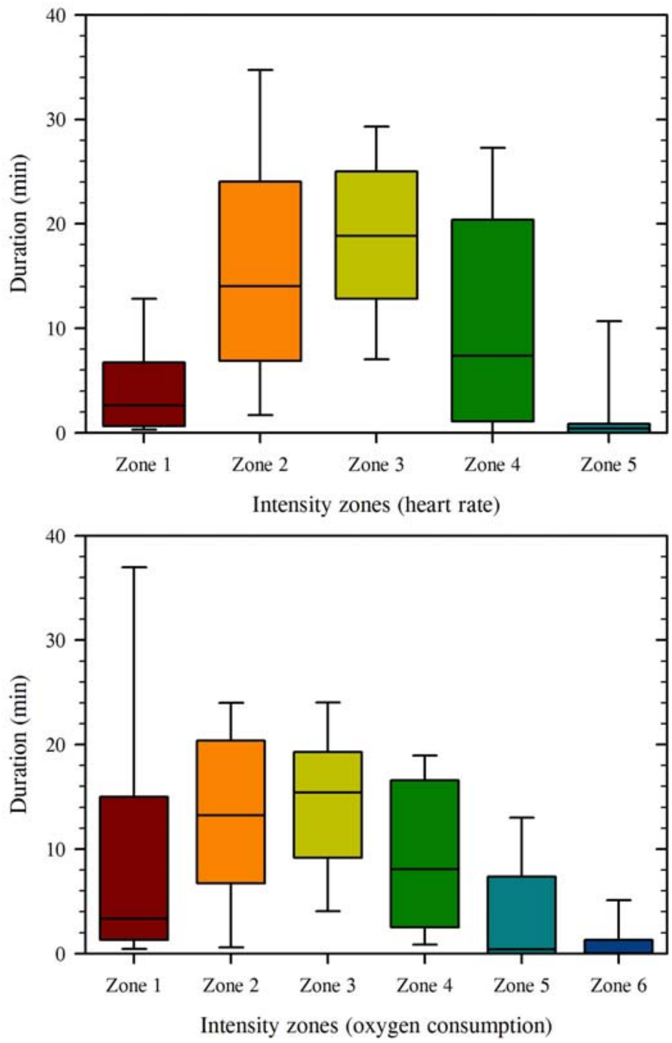


Figure 49: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the one-person firefighter rescue simulation. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

3.8.3 Observational summary

Table 30: Overall occupational task assessment: fire-fighter rescue simulation (one person).

Attribute	Evaluation
Primary fitness classification (%)	Strength: 50-60%
Secondary fitness classification (%)	Power: 30-40%
Tertiary fitness classification (%)	Dynamic balance: 10-20%
Primary movement action	Isometric hold with backward walking on level ground
Primary movement classification	Push, pull, drag (lower body)

Attribute	Evaluation
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Kneel, squat, crouch
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Elbow flexors*: isometric action *Knee flexors*: concentric action *Hip extensors*: concentric action *Back extensors*: isometric action *Trunk Stabilisers*: isometric action
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	Firefighter with full protective ensemble: 106.57 kg
Approximate position of load and percentage of task time in that position	80% ground to waist (0-100 cm) 20% waist to chest (100-150 cm)
Average task duration (min)	3.84 (range: 2.92-5.17)
Average task heart rate (beats.min^{-1})	161 (range: 126-176)
Cardiovascular impulse (beats)	617.46
Cardiovascular load (arbitrary units)	6.82
Perceived exertion (6-20)	17.0 (range: 13-19)
Average oxygen cost (L.min^{-1})	1.68 (range: 0.86-2.41)
Peak oxygen cost (L.min^{-1})	2.21 (range: 1.50-2.90)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	16.22 (range: 8.44-23.41)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	21.29 (range: 14.82-28.20)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	67.91 (range: 37.22-95.64)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	98.26 (range: 70.84-129.92)

3.9 Simulation nine: Bushfire (dragging charged hose forwards: individual)

3.9.1 Example experimental data

Time-series responses for firefighter 33 performing the bushfire simulation are presented within Figures 50-52, with the coloured bands defining zones of increasing strain.

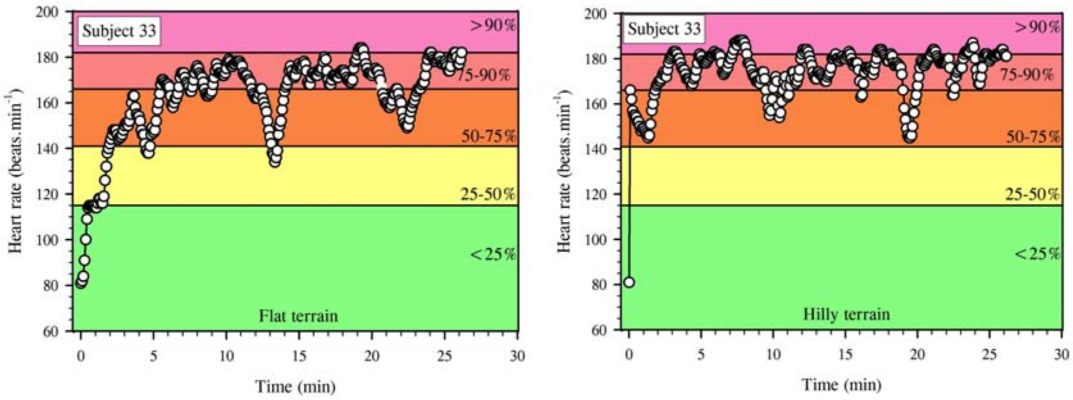


Figure 50: Heart rate response of one firefighter during the bushfire (hose-drag) simulation: flat (left) and hilly terrain.

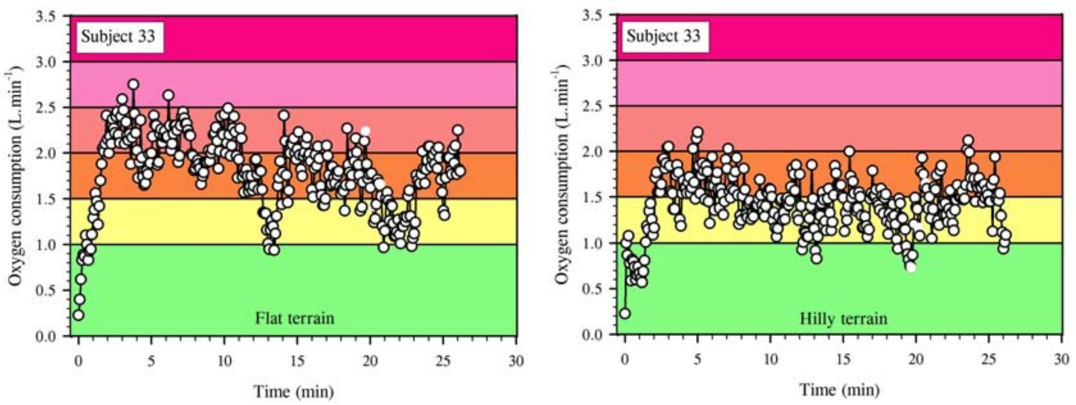


Figure 51: Oxygen consumption response of one firefighter during the bushfire (hose-drag) simulation: flat (left) and hilly terrain.

3.9.2 Physiological and psychophysical strain

During this occupational simulation, the mean heart rate had a 95% probability of falling between 135-151 beats.min^{-1}. Similarly, the mean absolute oxygen consumption would be expected to fall within the zone 1.41-1.85 L.min^{-1} (Table 31). This Table shows data for all firefighters performing the simulation, with averages being presented for both the baseline (resting) and working stages of the simulation. When working, the range parameters (minimal and maximal) define the lower and upper boundaries of physiological strain observed during the simulation. Oxygen consumption data are presented in absolute values, but also normalised to the total mass of each firefighter (body mass, protective clothing and equipment, and data acquisition hardware worn).

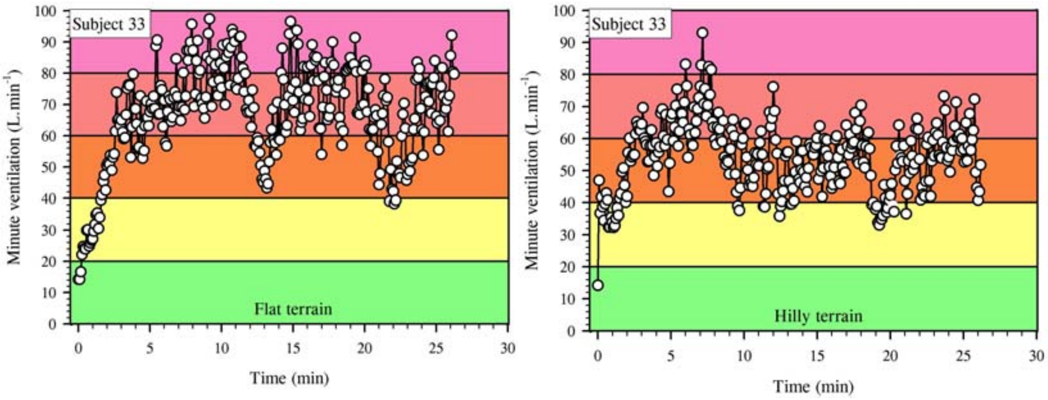


Figure 52: The ventilatory response of one firefighter during the bushfire (hose-drag) simulation: flat (left) and hilly terrain.

Table 31: Summary parameters for physiological strain in firefighters (*N*=16) performing a bushfire (hose-drag) simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (11)	143 (15)	77	189	8
Absolute oxygen consumption (L.min^{-1})	0.37 (0.11)	1.63 (0.44)	0.23	3.83	0.22
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.52 (1.09)	18.10 (4.23)	2.98	44.40	2.07
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	19.21 (4.84)	79.69 (19.08)	12.51	193.28	9.35
Minute ventilation (L.min^{-1})	17.81 (5.34)	58.65 (12.64)	12.91	127.96	6.19
Tidal volume (L)	0.93 (0.22)	1.70 (0.32)	0.47	3.89	0.16
Breathing frequency (breaths.min^{-1})	20 (4)	35 (4)	13	79	2

In Figure 53, the observations for heart rate and absolute oxygen consumption are graphically summarised. Each graph displays work rate intensities, showing times spent (ordinate) within zones of different physiological strain (abscissa) during the simulation.

Thus, moving from the left to the right side of the graph reflects progressive increments in work rate, but the times within any one zone (intensity) were drawn from work performed across the whole simulation.

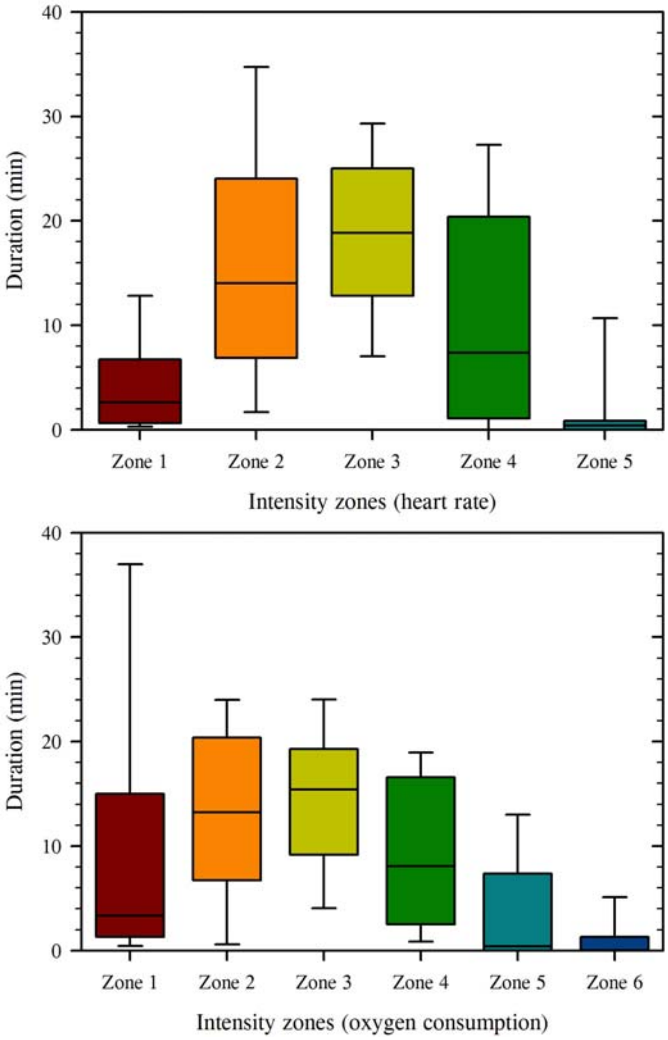


Figure 53: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the entire bushfire (hose-drag) simulation. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

The simulation lasted 52.33 min (Figure 53)[36], with most of the time spent working in zone three for both heart rate and absolute oxygen consumption. This temporal information is indicated by the position of the median[37] (horizontal line) within each box (strain zone); the higher the median, the longer was the duration at the corresponding intensity. For this activity, there was a significant reliance upon cardiorespiratory endurance, and this is reflected within Table 32, which summarises the overall evaluation of the bushfire hose-drag task. During this evaluation, the Research Team considered the fitness classifications

[36] A detailed description of these box plots is contained within the hazmat simulation.

[37] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

essential to the task, they analysed the movement patterns, including muscle actions, and they summarised the principal cardiovascular and metabolic strain measures.

3.9.3 Observational summary

Table 32: Overall occupational task assessment: bushfire (hose-drag) simulation.

Attribute	Evaluation
Primary fitness classification (%)	Cardiorespiratory endurance: 50-60%
Secondary fitness classification (%)	Strength and power: 20-30%
Tertiary fitness classification (%)	Muscular endurance: 10-20%
Primary movement action	One-sided pull on uneven and hilly terrain
Primary movement classification	Push, pull, drag (lower body)
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Shoulder extensors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	60% waist (80-100 cm) 20% ground (0-80 cm) 20% waist to shoulder (100-150 cm)
Average task duration (min)	52.33
Average task heart rate (beats.min^{-1})	143 (range: 114-168)
Cardiovascular impulse (beats)	7461.9
Cardiovascular load (arbitrary units)	82.18

Attribute	Evaluation
Perceived exertion (6-20)	12.8 (on flat terrain) 13.8 (on hilly terrain)
Average oxygen cost ($L.min^{-1}$)	1.63 (range: 0.91-2.44)
Peak oxygen cost ($L.min^{-1}$)	2.94 (range: 1.63-3.83)
Average specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	18.10 (range: 12.51-27.36)
Peak specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	32.84 (range: 23.86-44.40)
Average specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	79.69 (range: 53.32-120.42)
Peak specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	144.42 (range: 100.30-193.28)

3.10 Simulation ten: Stair climb dragging charged hose (forwards: in pairs)

3.10.1 Example experimental data

The successfully performance of this critical activity required firefighters to drag a charged 38-mm hose while ascending 64 stairs (4 storeys: 16.8 m). The leading firefighter was positioned on the branch, with the second (supporting) firefighter assisting, but remaining approximately one hose length behind. Data for one lead firefighter are presented: heart rate (Figure 54), absolute oxygen consumption (Figure 55) and ventilation (Figure 56). Within each graph, the coloured bands define zones of increasing strain.

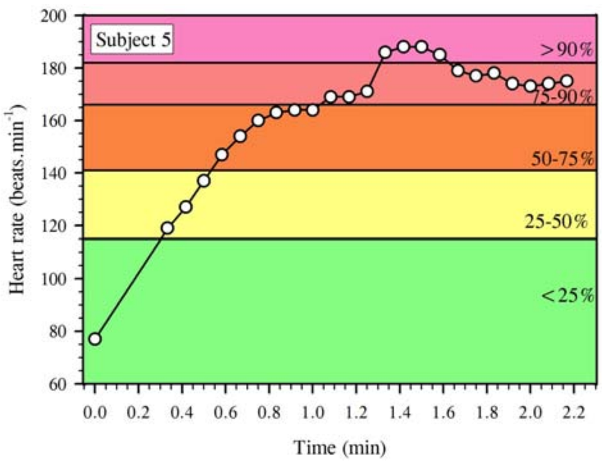


Figure 54: Heart rate response of one firefighter during the stair-climb simulation dragging a charge 38-mm hose (leading firefighter).

It is clear from Figure 54 that leading firefighters experienced a rapid elevation in cardiovascular strain. This was accompanied by equally dramatic increases in absolute oxygen consumption (Figure 55) and minute ventilation (Figure 56). Thus, in the firefighter

used to illustrate these responses, heart rate was within the two most stressful zones for 50% of the task (75-90% and >90% of the heart rate reserve), whilst the absolute oxygen consumption exceeded 3.0 L.min^{-1} for the same duration.

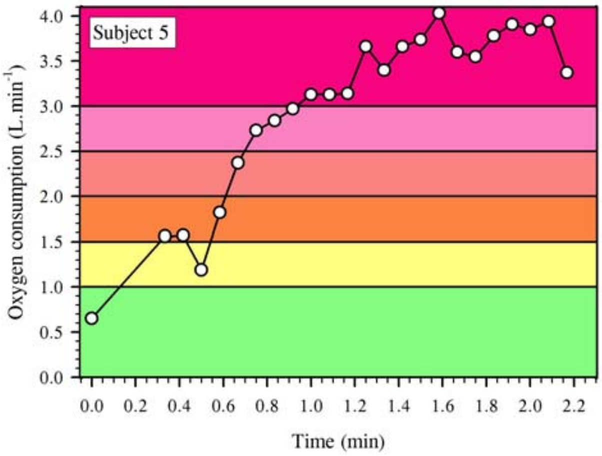


Figure 55: Oxygen consumption response of one firefighter during the stair-climb simulation dragging a charge 38-mm hose (leading firefighter).

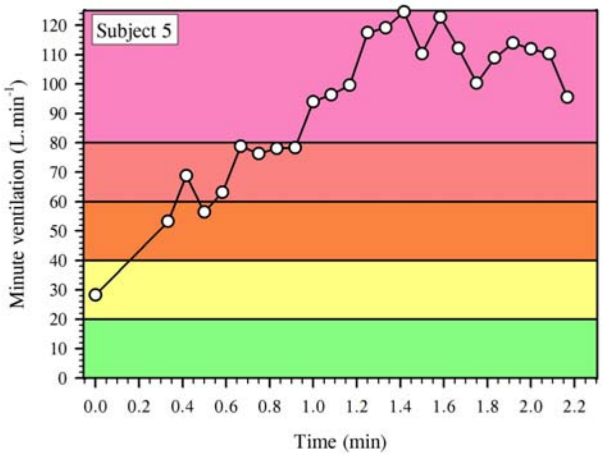


Figure 56: The ventilatory response of one firefighter during the stair-climb simulation dragging a charge 38-mm hose (leading firefighter).

3.10.2 Physiological and psychophysical strain

In Tables 33 (lead firefighter) and 34 (support firefighter), overall physiological strain is summarised across five indices. Average data are presented for the resting and simulation states, with oxygen consumption are presented as absolute values, but also normalised to the total mass of each firefighter (body mass, protective clothing and equipment, and data acquisition hardware worn). The minimal and maximal parameters define the boundaries of strain observed during this task. However, the mean heart rate for the leading firefighter had a 95% probability of falling between 149-163 beats.min^{-1}, whilst the mean absolute oxygen consumption could be expected to fall within the range from 1.68-2.26 L.min^{-1}. These data are consistent with significant muscular, cardiovascular and metabolic demands imposed by this task, even though its average duration was only 2.46 min.

Table 33: Summary parameters for physiological strain in firefighters (N=17) performing a stair climb, dragging a charged 38-mm hose (leading firefighter). Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	79 (10)	156 (15)	95	188	7
Absolute oxygen consumption (L.min^{-1})	0.33 (0.11)	1.97 (0.61)	0.43	4.03	0.29
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.79 (1.26)	17.81 (5.04)	3.80	33.90	2.40
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.46 (5.40)	84.04 (23.84)	18.10	163.91	11.33
Minute ventilation (L.min^{-1})	17.12 (5.78)	81.99 (16.11)	18.79	138.93	7.66
Tidal volume (L)	0.82 (0.18)	2.02 (0.35)	0.63	3.34	0.17
Breathing frequency (breaths.min^{-1})	21 (6)	41 (6)	21	65	3

Table 34: Summary parameters for physiological strain in firefighters (N=17) performing a stair climb, dragging a charged 38-mm hose (support firefighter). Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	78 (10)	158 (14)	82	190	7
Absolute oxygen consumption (L.min^{-1})	0.32 (0.11)	1.84 (0.68)	0.20	3.94	0.32

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Specific oxygen consumption ($mL.kg^{-1}.min^{-1}$)	3.74 (1.23)	16.78 (6.00)	1.77	31.88	2.85
Specific oxygen consumption ($mL.kg^{-0.67}.min^{-1}$)	16.26 (5.35)	78.97 (28.07)	8.42	154.13	13.34
Minute ventilation ($L.min^{-1}$)	16.87 (6.04)	83.79 (15.80)	16.66	134.94	7.51
Tidal volume (L)	0.82 (0.19)	2.07 (0.41)	0.57	3.87	0.19
Breathing frequency ($breaths.min^{-1}$)	21 (6)	41 (6)	20	64	3

Temporal information for heart rate and absolute oxygen consumption changes observed across the entire simulation are illustrated within Figure 57[38]. Each graph displays work rate intensities, such that the times spent (ordinate) within each physiological strain zone (abscissa) are indicated by moving from the left to the right side of each graph. However, times within any one zone were taken from work performed across the entire simulation. Medians[39] are shown as horizontal lines within each box. In this case, cardiovascular strain was predominantly located within the three most stressful zones, whilst metabolic strain was more evenly distributed. Instead, this task would seem to rely more heavily upon muscular endurance and strength than upon cardiorespiratory endurance.

3.10.3 Observational summary

The final stage of this analysis involved an overall evaluation of each of the two positions taken up by firefighters: leading and support. The objective of these analyses was to identify the fitness classifications essential to these tasks, to analyse the movement patterns of firefighters, including muscle actions, and to summarise cardiovascular and metabolic strain. The outcomes from these analyses are summarised in Table 35A and 35B.

[38] A detailed description of these box plots is contained within the hazmat simulation.

[39] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

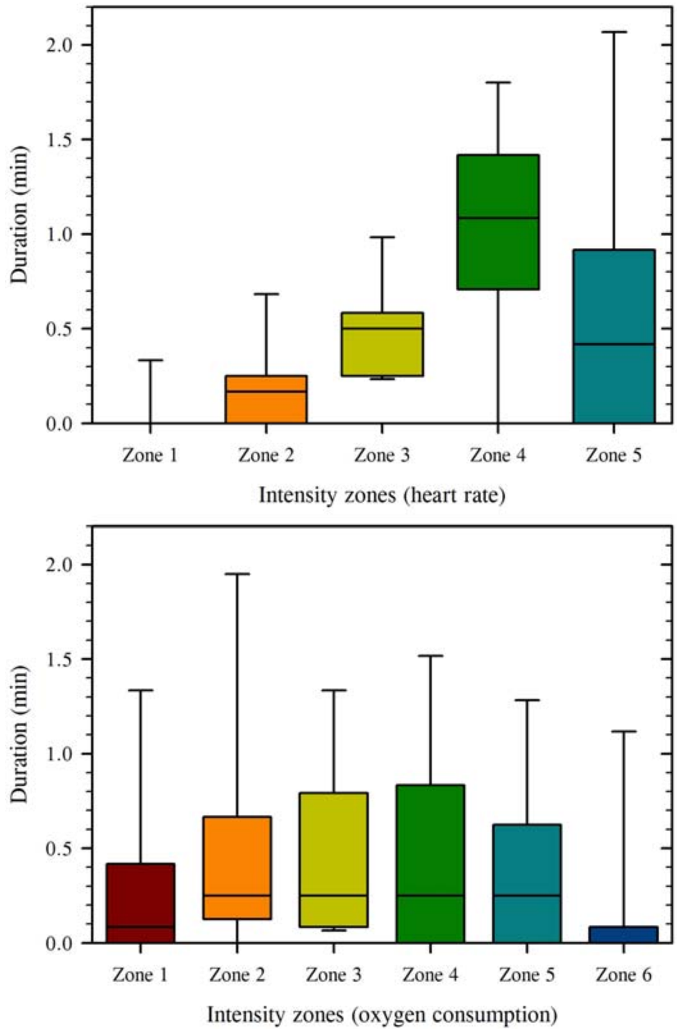


Figure 57: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the stair-climb simulation dragging a charge 38-mm hose (leading firefighter). *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

Table 35A: Overall task assessment: stair climb with charged 38-mm hose: lead position.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 40-50%
Secondary fitness classification (%)	Power: 25-35%
Tertiary fitness classification (%)	Strength endurance: 15-35%
Primary movement action	Stair climb with one-sided pull, and uneven centre of gravity
Primary movement classification	Push, pull, drag (lower body)

Attribute	Evaluation
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Shoulder flexors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	50% chest to shoulder (100-150 cm) 25% waist (80-100 cm) 25% ground (0-80 cm)
Average task duration (min)	2.46 (range: 1:00-4.33)
Average task heart rate (beats.min^{-1})	156 (range: 124-172)
Cardiovascular impulse (beats)	383.46
Cardiovascular load (arbitrary units)	4.83
Perceived exertion (6-20)	15.2 (range: 13-18)
Average oxygen cost (L.min^{-1})	1.97 (range: 0.85-3.08)
Peak oxygen cost (L.min^{-1})	2.66 (range: 1.30-4.03)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	17.81 (range: 7.47-24.15)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	23.95 (range: 11.50-33.90)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	84.04 (range: 35.58-114.87)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	113.07 (range: 54.72-163.91)

Table 35B: Overall task assessment: stair climb with charged 38-mm hose: support.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 40-50%
Secondary fitness classification (%)	Power: 25-35%
Tertiary fitness classification (%)	Strength endurance: 15-35%
Primary movement action	Stair climb with one sided pull, and uneven centre of gravity
Primary movement classification	Push, pull, drag (lower body)
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Stoop and forward bend
Minor postural classification	Upright
Dominant body region	Lower body
Major muscle groups involved	*Shoulder flexors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	40% waist (80-100 cm) 35% ground (0-80 cm) 25% chest to shoulder (100-150 cm)
Average task duration (min)	3.50 (range: 2.58-6.08)
Average task heart rate (beats.min^{-1})	158 (range: 130-178)
Cardiovascular impulse (beats)	552.36
Cardiovascular load (arbitrary units)	7.04
Perceived exertion (6-20)	15.6 (range: 12-19)
Average oxygen cost (L.min^{-1})	1.84 (range: 0.47-3.00)
Peak oxygen cost (L.min^{-1})	2.60 (range: 0.85-3.94)

Attribute	Evaluation
Average specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	16.78 (range: 4.12-25.39)
Peak specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	23.61 (range: 7.52-31.88)
Average specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	78.97 (range: 19.65-122.18)
Peak specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	11.25 (range: 35.78-154.13)

3.11 Simulation eleven: Prolonged use of 38-mm hose (lateral movements: individual)

3.11.1 Example experimental data

Time-series responses for heart rate (Figure 58), absolute oxygen consumption (Figure 59) and ventilation (Figure 60) reveal that this simulation imposed minimal physiological strain upon firefighters, even though it averaged 15.36 min.

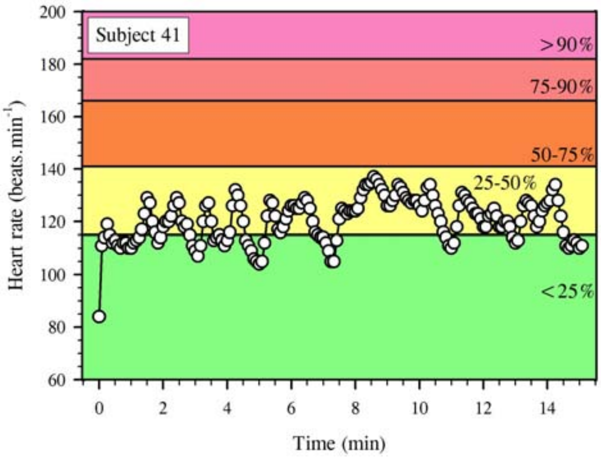


Figure 58: Heart rate response of one firefighter during the prolonged use of a 38-mm hose.

3.11.2 Physiological and psychophysical strain

Table 36 summarises the strain experienced by firefighters performing this extended hose-use simulation. Data are presented for both the resting and simulation states, with the range parameters (minimal and maximal) defining the lower and upper boundaries of strain observed during the simulation. Oxygen consumption data are presented in absolute values, but also normalised to the total mass of each firefighter (body mass, protective clothing and equipment, and data acquisition hardware worn). During this activity, the mean heart rate had a 95% probability of falling between 102-124 beats.min^{-1}. Similarly, the mean absolute oxygen consumption data were not much above the resting state, falling within the range from 0.46-0.64 L.min^{-1}. In Figure 61, these heart rate and absolute oxygen consumption observations are summarised in box plots, which show the times spent across zones of increasing physiological strain (abscissa).

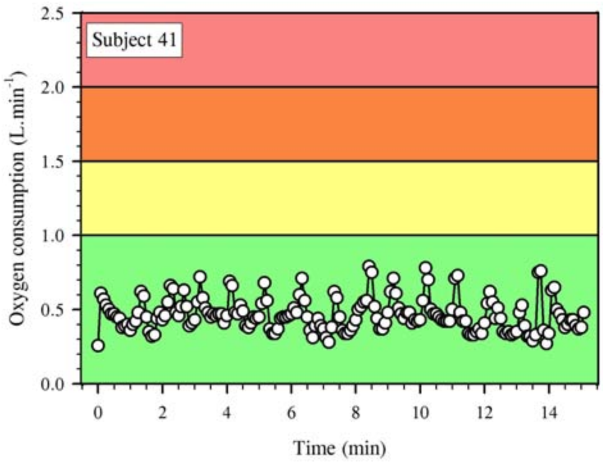


Figure 59: Oxygen consumption response of one firefighter during the prolonged use of a 38-mm hose.

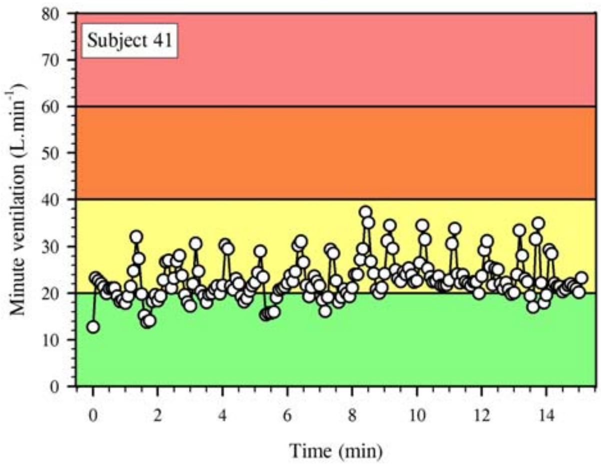


Figure 60: The ventilatory response of one firefighter during the prolonged use of a 38-mm hose.

Table 36: Summary parameters for physiological strain in firefighters (*N*=14) using a 38-mm hose for a prolonged duration. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	113 (20)	74	172	11
Absolute oxygen consumption (L.min^{-1})	0.33 (0.12)	0.55 (0.17)	0.13	2.26	0.09

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Specific oxygen consumption ($mL.kg^{-1}.min^{-1}$)	3.76 (1.28)	4.92 (1.40)	1.15	16.47	0.74
Specific oxygen consumption ($mL.kg^{-0.67}.min^{-1}$)	16.45 (5.88)	23.30 (6.59)	5.47	83.56	3.45
Minute ventilation ($L.min^{-1}$)	17.53 (6.31)	26.30 (5.12)	10.64	66.41	2.68
Tidal volume (L)	0.83 (0.18)	0.91 (0.14)	0.37	2.35	0.07
Breathing frequency ($breaths.min^{-1}$)	22 (6)	30 (6)	8	68	3

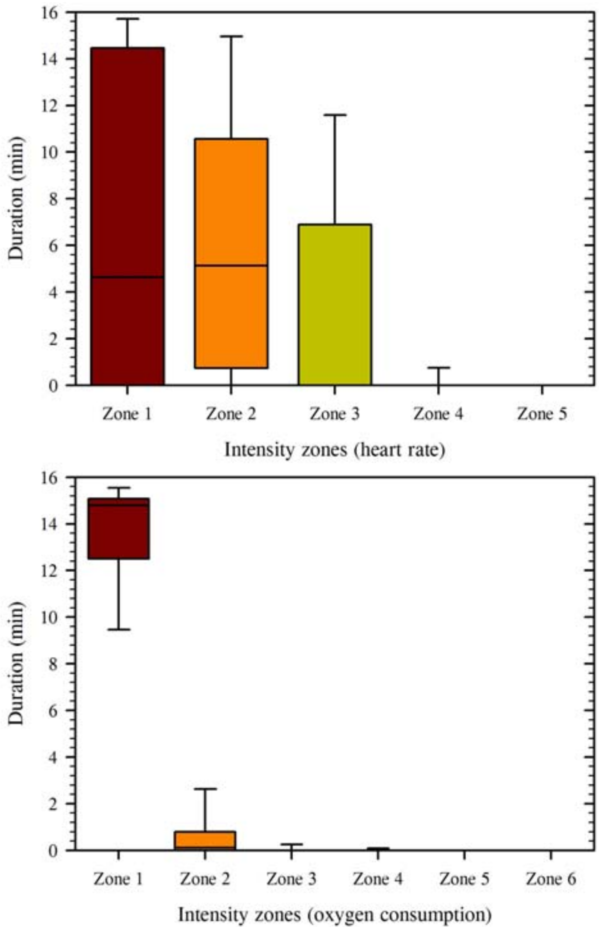


Figure 61: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the prolonged use of a 38-mm hose. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

3.11.3 Observational summary

Finally, this simulation was analysed to identify the key fitness classifications, to analyse the movement patterns (including muscle actions) and to summarise the principal cardiovascular and metabolic strain measures. These outcomes are summarised in Table 37.

Table 37: Overall task assessment: prolonged hose-use simulation: 38-mm hose.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 70-80%: minimal strain
Secondary fitness classification (%)	Strength: 20-30%: minimal strain
Tertiary fitness classification (%)	- - -
Primary movement action	Static, two-handed hold in upright position
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Push, pull, drag (upper body)
Primary postural classification	Upright
Minor postural classification	- - -
Dominant body region	Upper body
Major muscle groups involved	*Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action *[minimal muscular work in this task]*
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	100% waist to chest (100-150 cm)
Average task duration (min)	15.36 (range: 15.08-16.00)
Average task heart rate (beats.min^{-1})	113 (range: 86-154)
Cardiovascular impulse (beats)	1733.40
Cardiovascular load (arbitrary units)	21.61
Perceived exertion (6-20)	10.3 (range: 7-15)

Attribute	Evaluation
Average oxygen cost (L.min^{-1})	0.55 (range: 0.25-0.90)
Peak oxygen cost (L.min^{-1})	1.12 (range: 0.60-2.26)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	4.92 (range: 2.18-6.67)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	9.86 (range: 5.31-16.47)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	23.30 (range: 10.34-33.11)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	47.40 (range: 25.26-83.56)

3.12 Simulation twelve: Prolonged use of 70-mm hose (stationary: in pairs)

3.12.1 Example experimental data

This simulation lasted 15.40 min. However, the time-series responses for heart rate (Figure 58), absolute oxygen consumption (Figure 59) and ventilation (Figure 60) indicate that it too imposed minimal physiological strain upon these firefighters.

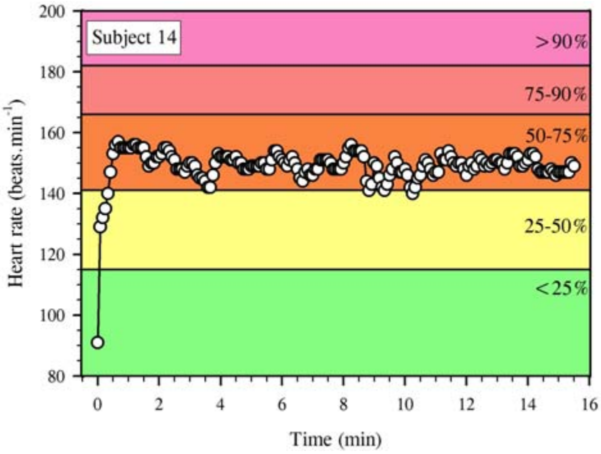


Figure 62: Heart rate response of one firefighter during the prolonged use of a 70-mm hose.

3.12.2 Physiological and psychophysical strain

Table 38 summarises the strain experienced by firefighters performing this extended hose-use simulation. Data are presented for both the resting and simulation states, with the minimal and maximal values defining strain boundaries observed during the simulation. Oxygen consumption data are presented in absolute values, but also normalised to the total mass of each firefighter (body mass, protective clothing and equipment, and data acquisition hardware worn). During this activity, the mean heart rate had a 95% probability of falling between 113-133 beats.min^{-1}, whilst the absolute oxygen consumption data were again not much greater than at rest: 0.48-0.64 L.min^{-1}. In Figure 65, these heart rate and absolute

oxygen consumption observations are summarised in box plots, which show the times spent across zones of increasing physiological strain (abscissa).

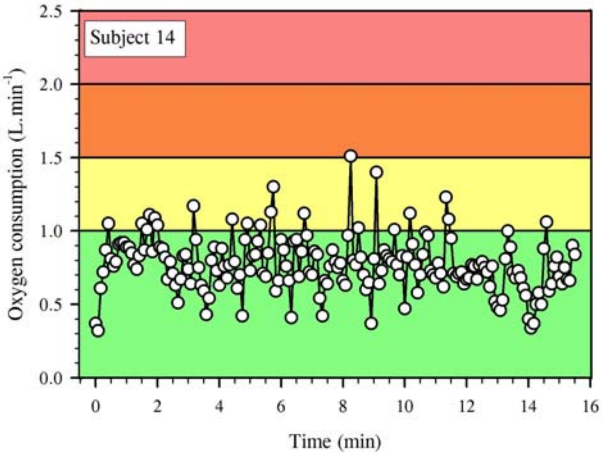


Figure 63: Oxygen consumption response of one firefighter during the prolonged use of a 70-mm hose.

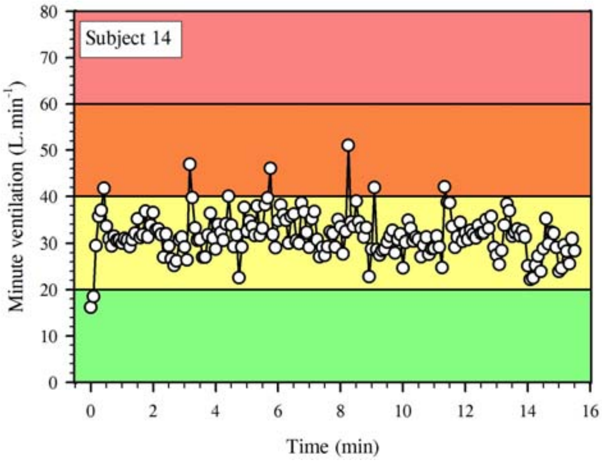
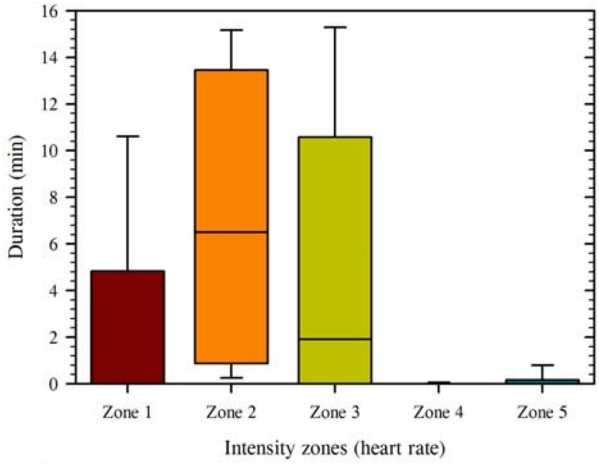


Figure 64: The ventilatory response of one firefighter during the prolonged use of a 70-mm hose.

Table 38: Summary parameters for physiological strain in firefighters (*N*=13) using a 70-mm hose for a prolonged duration. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	123 (19)	60	157	10
Absolute oxygen consumption (L.min^{-1})	0.34 (0.13)	0.56 (0.13)	0.14	1.51	0.08

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Specific oxygen consumption ($mL.kg^{-1}.min^{-1}$)	3.75 (1.45)	4.94 (1.39)	1.20	13.43	0.79
Specific oxygen consumption ($mL.kg^{-0.67}.min^{-1}$)	16.49 (6.32)	23.40 (6.12)	5.76	63.81	3.46
Minute ventilation ($L.min^{-1}$)	17.64 (6.66)	26.45 (5.77)	11.06	59.76	3.14
Tidal volume (L)	0.83 (0.20)	0.88 (0.14)	0.44	2.06	0.08
Breathing frequency ($breaths.min^{-1}$)	22 (6)	31 (5)	14	64	3



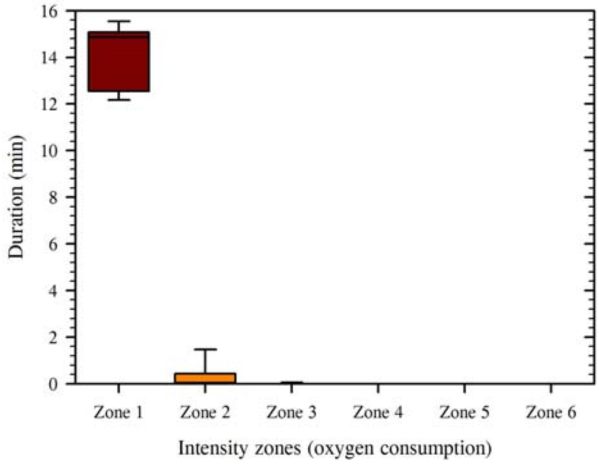


Figure 65: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the prolonged use of a 70-mm hose. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

3.12.3 Observational summary

Finally, this simulation was analysed to identify the key fitness classifications for the task, to analyse the movement patterns (including muscle actions) and to summarise cardiovascular and metabolic strain. These outcomes are summarised in Table 39.

Table 39: Overall task assessment: prolonged hose-use simulation: 70-mm hose.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 70-80%
Secondary fitness classification (%)	Strength: 20-30%
Tertiary fitness classification (%)	- - -
Primary movement action	Static, two-handed hold in upright position
Primary movement classification	Carry and hold (upper body)
Minor movement classification	- - -
Primary postural classification	Upright
Minor postural classification	- - -
Dominant body region	Upper body (shoulders)
Major muscle groups involved	*Shoulder flexors and abductors:* concentric and isometric actions *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action [all muscles predominately isometric]
Dominant mode of carriage	Bilateral
Individual or team	Team
Load	70-mm hose: ~115 kg
Approximate position of load and percentage of task time in that position	70% waist to chest (100-150 cm) 30% at shoulder level (~150 cm)
Average task duration (min)	15.40 (range: 15.08-15.67)
Average task heart rate (beats.min^{-1})	123 (range: 90-149)
Cardiovascular impulse (beats)	1892.46
Cardiovascular load (arbitrary units)	23.68

Attribute	Evaluation
Perceived exertion (6-20)	10.7 (range: 7-15)
Average oxygen cost ($L.min^{-1}$)	0.56 (range: 0.37-0.77)
Peak oxygen cost ($L.min^{-1}$)	1.05 (range: 0.71-1.51)
Average specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	4.94 (range: 3.19-7.87)
Peak specific oxygen cost ($mL.kg^{-1}.min^{-1}$)	9.24 (range: 6.63-13.43)
Average specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	23.40 (range: 15.37-34.47)
Peak specific oxygen cost ($mL.kg^{-0.67}.min^{-1}$)	43.84 (range: 30.56-63.81)

3.13 Simulation thirteen: Ladder use (10.5 m: in pairs)

3.13.1 Example experimental data

Figures 66-68 present heart rate, absolute oxygen consumption and ventilation data during a ladder under-run (rasing a ladder to the vertical position) and a ladder ascent. The coloured bands define zones of increasing strain, moving (over time) from left to right.

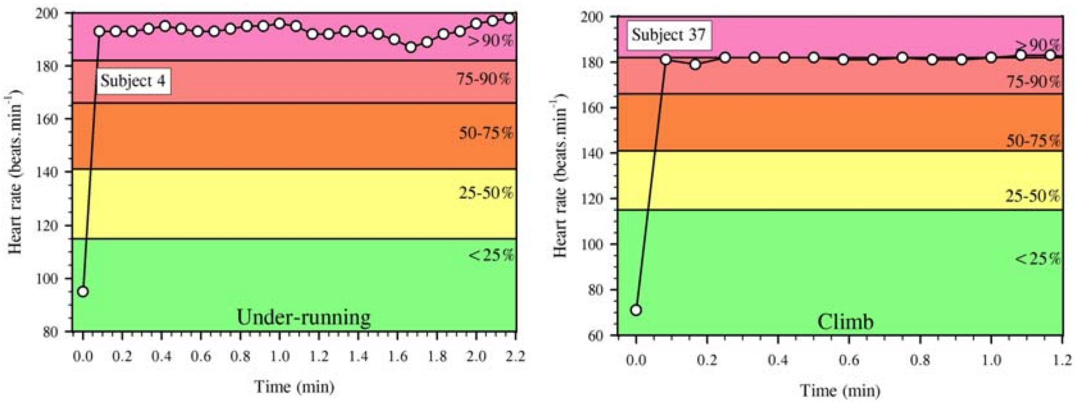


Figure 66: Heart rate response of two firefighters during two ladder-use simulations: under-running (left) and a ladder ascent.

3.13.2 Physiological and psychophysical strain

Tables 40-43 summarise physiological strain for the more active (non-supporting) firefighters across the entire ladder simulation (Table 40), during the ladder under-run phase (Table 41), during the ladder ascent (Table 42) and during the ladder restow onto an appliance (Table 43). Data are presented for the resting and simulation states, with the range parameters (minimal and maximal) defining the lower and upper boundaries of strain. Oxygen consumption data are presented in both absolute and normalised formats. During the ladder under-run simulation, the mean heart rate had a 95% probability of falling between 155-173 $beats.min^{-1}$, whilst the absolute oxygen consumption would fall within the

zone 0.98-1.48 L.min^{-1}. During the ladder ascent, the corresponding values were: 148-174 beats.min^{-1} and 1.28-1.94 L.min^{-1}.

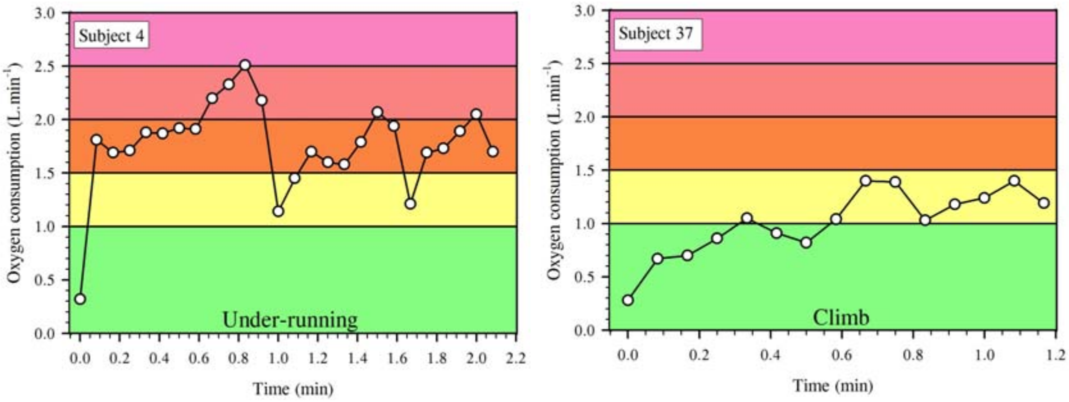


Figure 67: Oxygen consumption response of two firefighters during two ladder-use simulations: under-running (left) and a ladder ascent.

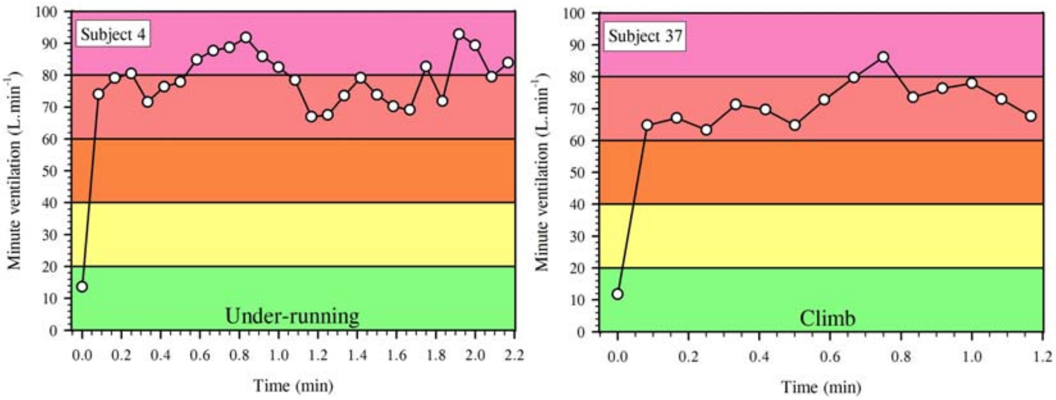


Figure 68: The ventilatory response of two firefighters during two ladder-use simulations: under-running (left) and a ladder ascent.

Table 40: Summary parameters for physiological strain in firefighters (N=15) performing the entire 10.5-m ladder simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	159 (19)	75	198	10
Absolute oxygen consumption (L.min^{-1})	0.33 (0.12)	1.44 (0.46)	0.28	3.47	0.24
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.92 (1.22)	12.95 (3.84)	2.39	28.93	2.01

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Specific oxygen consumption ($mL.kg^{-0.67}.min^{-1}$)	16.56 (5.34)	61.15 (18.23)	11.52	134.41	9.55
Minute ventilation ($L.min^{-1}$)	17.35 (6.12)	70.48 (12.77)	20.04	122.03	6.46
Tidal volume (L)	0.82 (0.18)	1.80 (0.33)	0.41	3.13	0.16
Breathing frequency ($breaths.min^{-1}$)	22 (6)	40 (4)	19	75	2

Table 41: Summary parameters for strain in firefighters (*N*=15) performing a 10.5-m ladder under-run simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimum	Maximum	95% confidence interval
Heart rate ($beats.min^{-1}$)	80 (11)	161 (20)	75	198	10
Absolute oxygen consumption ($L.min^{-1}$)	0.33 (0.12)	1.40 (0.50)	0.28	3.05	0.26
Relative oxygen consumption ($mL.kg^{-1}.min^{-1}$)	3.92 (1.22)	12.77 (5.06)	1.59	23.93	2.40
Specific oxygen consumption ($mL.kg^{-0.67}.min^{-1}$)	16.56 (5.34)	59.90 (21.42)	11.52	128.19	11.22
Minute ventilation ($L.min^{-1}$)	17.35 (6.12)	72.08 (16.77)	25.11	122.03	8.49
Tidal volume (L)	0.82 (0.18)	1.85 (0.40)	0.63	3.13	0.20
Breathing frequency ($breaths.min^{-1}$)	22 (6)	40 (5)	19	65	2

Table 42: Summary parameters for physiological strain in firefighters (*N*=15) performing a 10.5-m ladder ascent simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimum	Maximum	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	161 (27)	75	196	13
Absolute oxygen consumption (L.min^{-1})	0.33 (0.12)	1.66 (0.66)	0.28	3.47	0.35
Relative oxygen consumption (mL.kg^{-1}.min^{-1})	3.92 (1.22)	14.99 (5.88)	2.39	28.59	3.08
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.56 (5.34)	70.68 (27.41)	11.52	128.30	14.36
Minute ventilation (L.min^{-1})	17.35 (6.12)	76.10 (21.47)	26.26	122.03	10.87
Tidal volume (L)	0.82 (0.18)	1.97 (0.56)	0.69	3.13	0.28
Breathing frequency (breaths.min^{-1})	22 (6)	39 (6)	24	62	3

Table 43: Summary parameters for strain in firefighters (*N*=15) performing a 10.5-m ladder carry and restow simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	169 (11)	112	197	6
Absolute oxygen consumption (L.min^{-1})	0.33 (0.12)	1.48 (0.52)	0.32	2.94	0.27
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.92 (1.22)	14.75 (6.11)	2.43	28.59	3.20

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Specific oxygen consumption ($mL.kg^{-0.67}.min^{-1}$)	16.56 (5.34)	62.95 (19.98)	12.17	116.38	10.47
Minute ventilation ($L.min^{-1}$)	17.35 (6.12)	70.31 (14.92)	27.79	115.70	7.82
Tidal volume (L)	0.82 (0.18)	2.04 (0.35)	0.75	3.08	0.18
Breathing frequency ($breaths.min^{-1}$)	22 (6)	39 (5)	19	64	3

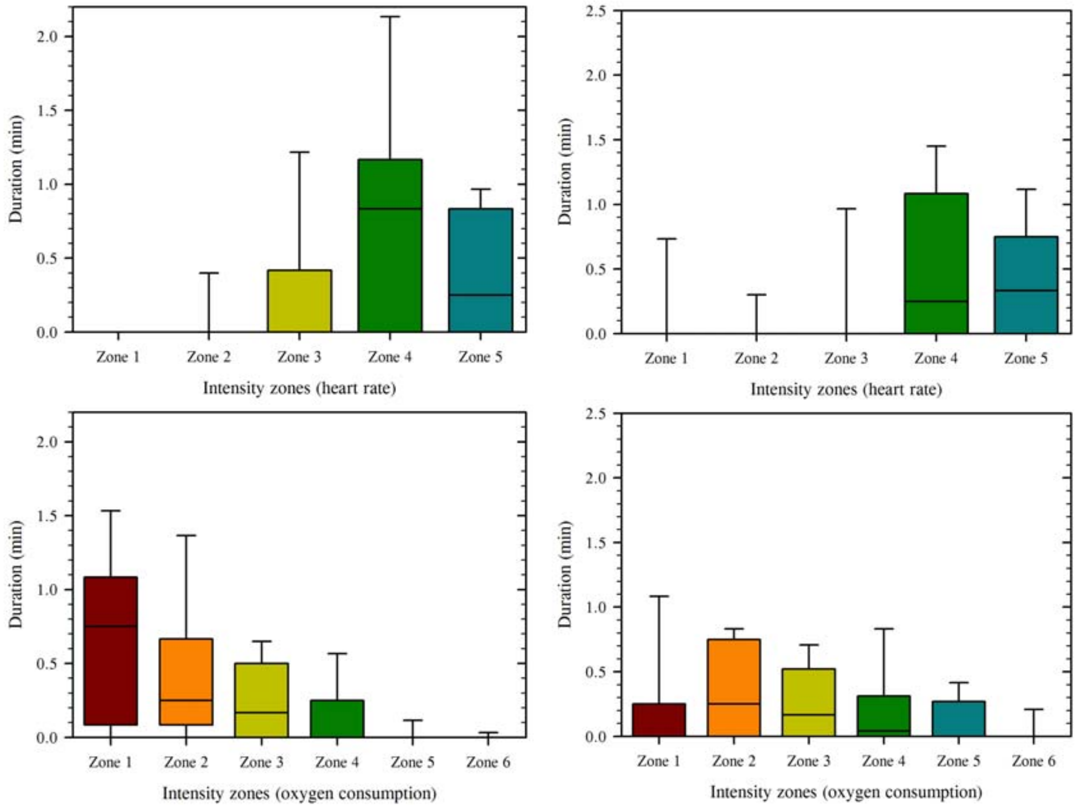


Figure 69: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during two ladder-use simulations: under-running (left) and a ladder ascent. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

In Figure 69[40], these observations for heart rate and absolute oxygen consumption are graphically summarised, with each graph displaying work rate intensities (abscissae) and

[40] A detailed description of these box plots is contained within the hazmat simulation.

times spent within these zones (ordinates). Readers should primarily direct attention to the median[41] within each box (horizontal line), and how these lines vary across the zones of strain: the highest median reveals the region within which firefighters spent most time. For the ladder ascent, the cardiovascular burden fell within the two most stressful zones.

3.13.3 Observational summary

The final stage of this analysis involved an overall evaluation of each fire-fighting simulation, with the aim being to identify the fitness classifications essential to each occupational task, to analyse the movement patterns, including muscle actions, and to summarise the principal cardiovascular and metabolic strain measures. The outcomes from these analyses are summarised in Table 44.

Table 44: Overall occupational task assessment: 10.5-m ladder use simulation.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 30-40%
Secondary fitness classification (%)	Muscular endurance: 30-40%
Tertiary fitness classification (%)	Agility and balance: 20-30%
Primary movement action	One-handed carry on level ground, and two-handed actions during raise and lower, and whilst climbing the ladder
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Lift and place (upper body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Upper body
Major muscle groups involved	*Shoulder flexors:* concentric, eccentric and isometric actions *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Both unilateral and bilateral
Individual or team	Team

[41] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

Attribute	Evaluation
Load	Ladder (extension): 49.6 kg
Approximate position of load and percentage of task time in that position	40% waist (80-100 cm) 30% above shoulder (150+ cm) 20% chest (100-150 cm) 10% ground (0-80 cm)
Average task duration (min)	7.28 (range: 5.50-10.25)
Average task heart rate (beats.min^{-1})	159 (range: 105-182)
Cardiovascular impulse (beats)	1157.52
Cardiovascular load (arbitrary units)	14.47
Perceived exertion (6-20)	13.2 (range: 7-17)
Average oxygen cost (L.min^{-1})	1.44 (range: 0.82-2.27)
Peak oxygen cost (L.min^{-1})	2.35 (range: 1.45-3.47)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	12.95 (range: 6.89-18.86)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	21.15 (range: 11.79-28.93)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	61.15 (range: 33.73-89.70)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	99.86 (range: 57.70-134.41)

3.14 Simulation fourteen: Carrying ventilation fan up stairs (in pairs)

3.14.1 Example experimental data

The ventilation fan currently used by Fire & Rescue NSW has a mass of 35-kg, and it must be moved by two firefighters. Thus, each individual may be expected to carry approximately 17.5 kg. However, the distribution of this load between firefighters is rarely equal, since this carriage often occurs along narrow corridors and up narrow stairs. In this simulation, both of those conditions existed (Figure 14) as the firefighters negotiated 64 stairs over four storeys (horizontal distance = 38.9 m; vertical displacement = 16.6 m). On average, this occupational simulation was completed in 1.51 min. Data from firefighter 43 are used to illustrate this simulation: heart rate (Figure 70), absolute oxygen consumption (Figure 71) and ventilation (Figure 72). Within each graph, the coloured bands define zones of increasing strain, moving (over time) from the lower left to the upper right corners.

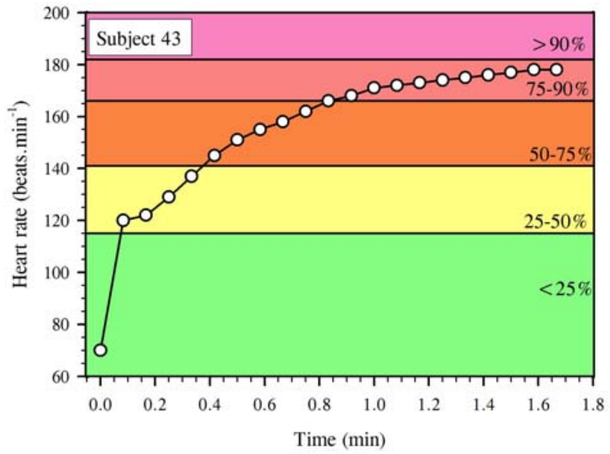


Figure 70: Heart rate response of one firefighter during the ventilation fan carry simulation (up stairs).

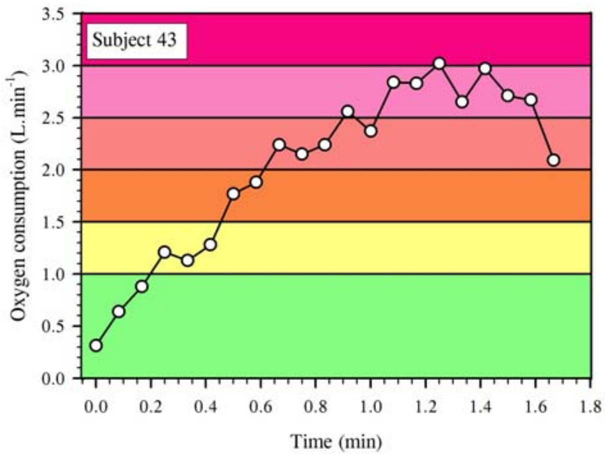


Figure 71: Oxygen consumption response of one firefighter during the ventilation fan carry simulation (up stairs).

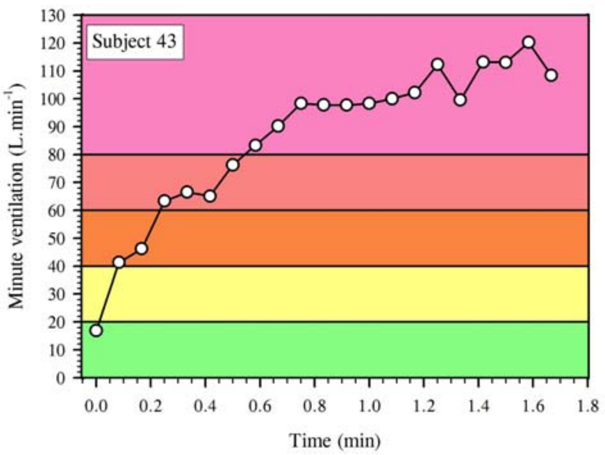


Figure 72: The ventilatory response of one firefighter during the ventilation fan carry simulation (up stairs).

3.14.2 Physiological and psychophysical strain

Table 45 summarises the physiological strain experienced by firefighters performing this simulation, with average data presented for the resting and simulation states. The minimal and maximal values define the outer boundaries of this strain. During this task, the mean heart rate had a 95% probability of falling between 152-162 beats.min^{-1}. Similarly, the mean absolute oxygen consumption will lie within the zone 1.23-1.75 L.min^{-1}.

Table 45: Summary parameters for strain in firefighters (*N*=17) performing a ventilation fan carry simulation (up stairs). Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (12)	157 (11)	99	192	5
Absolute oxygen consumption (L.min^{-1})	0.34 (0.11)	1.49 (0.53)	0.31	3.38	0.26
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.85 (1.23)	13.29 (4.89)	2.61	28.55	2.40
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.86 (5.30)	62.93 (22.60)	12.64	137.82	11.07
Minute ventilation (L.min^{-1})	17.40 (5.86)	76.87 (11.89)	25.11	130.44	5.83
Tidal volume (L)	0.83 (0.19)	1.86 (0.32)	0.64	3.59	0.16
Breathing frequency (breaths.min^{-1})	22 (6)	41 (7)	20	70	3

Figure 73[42] provides temporal information for strain across the entire simulation. Medians[43] are shown as horizontal lines within each box, with the highest median revealing the zone within which firefighters spent most time during this activity.

[42] A detailed description of these box plots is contained within the hazmat simulation.

[43] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

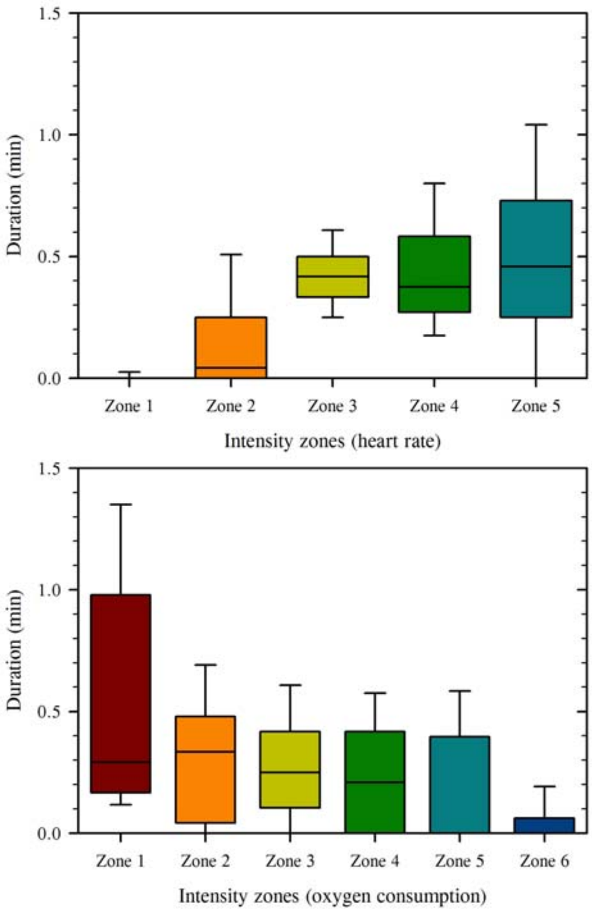


Figure 73: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the the ventilation fan carry simulation (up stairs). *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

3.14.3 Observational summary

Finally, analysis involved an overall evaluation of this simulation, with the aim being to identify the fitness classifications essential to each occupational task, to analyse the movement patterns, including muscle actions, and to summarise the principal cardiovascular and metabolic strain measures (Table 46).

Table 46: Overall occupational task assessment: ventilation fan carry simulation.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 50-60%
Secondary fitness classification (%)	Cardiorespiratory endurance: 20-30%
Tertiary fitness classification (%)	Dynamic balance: 10-20%
Primary movement action	Stair climb with one-, and possibly two-handed carry

Attribute	Evaluation
Primary movement classification	Carry and hold (whole body)
Minor movement classification	Lift and place (upper body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Unilateral
Individual or team	Team
Load	Ventilation fan: 35 kg
Approximate position of load and percentage of task time in that position	80% ground to waist (0-100 cm) 20% above shoulder (150+ cm)
Average task duration (min)	1.51 (range: 1.08-2.33)
Average task heart rate (beats.min^{-1})	157 (range: 127-176)
Cardiovascular impulse (beats)	237.32
Cardiovascular load (arbitrary units)	2.97
Perceived exertion (6-20)	15.3 (range: 11-17)
Average oxygen cost (L.min^{-1})	1.49 (range: 0.61-2.36)
Peak oxygen cost (L.min^{-1})	2.21 (range: 0.84-3.38)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	13.29 (range: 5.39-20.94)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	19.69 (range: 7.40-28.55)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	62.93 (range: 26.35-99.60)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	93.34 (range: 36.21-137.82)

Human Performance Laboratories (Australia)

3.15 Simulation fifteen: Using sledge axe to gain entry (individual)

3.15.1 Example experimental data

Figures 74-76 illustrate the physiological strain (heart rate, oxygen consumption, minute ventilation) experienced by one firefighter performing this activity. Within each graph, the coloured bands define zones of increasing strain, moving (over time) from the lower left to the upper right corners of each Figure. Since it was anticipated that some firefighters may gain immediate access through the metal door and locking mechanism used for this task, the simulation was deliberately extended in an attempt to represent a more resistant entry. This simulation was always performed as rapidly as possible, and this is reflected across all data.

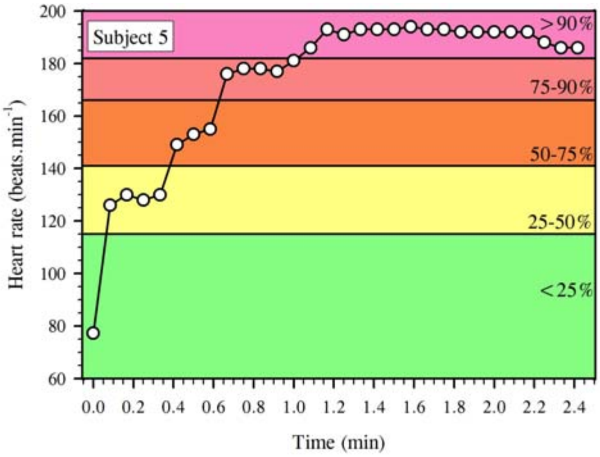


Figure 74: Heart rate response of one firefighter during the sledge axe door entry simulation.

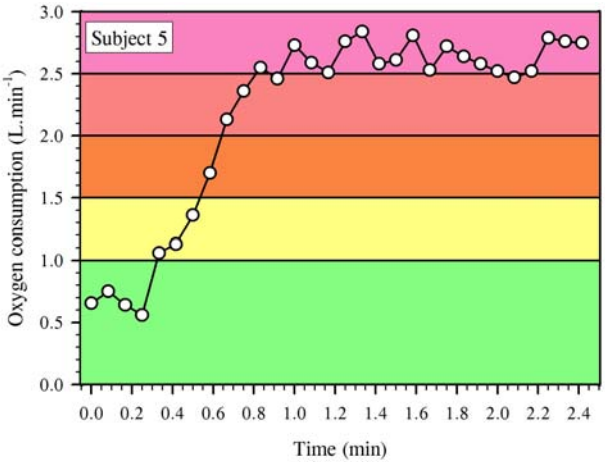


Figure 75: Oxygen consumption response of one firefighter during the sledge axe door entry simulation.

3.15.2 Physiological and psychophysical strain

Table 47 summarises the physiological strain experienced by firefighters performing this simulation. From these data, one can be 95% certain that the true mean heart rate would fall between 159-171 beats.min^{-1}. Similarly, the mean absolute oxygen consumption will lie within the zone 1.37-1.73 L.min^{-1}.

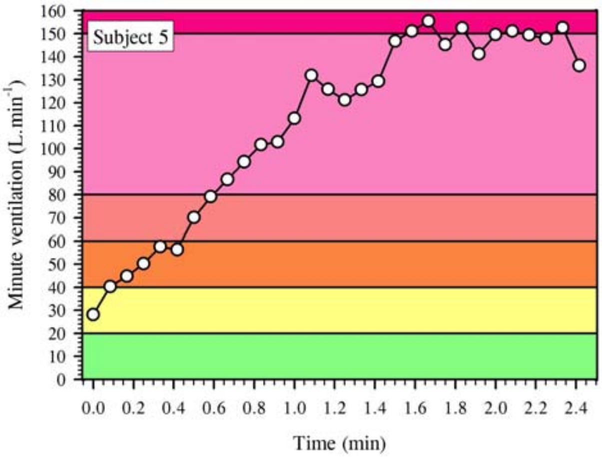


Figure 76: The ventilatory response of one firefighter during the sledge axe door entry simulation.

Table 47: Summary parameters for strain in firefighters (*N*=16) performing a sledge axe forced entry simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	79 (11)	165 (13)	110	196	6
Absolute oxygen consumption (L.min^{-1})	0.35 (0.11)	1.55 (0.35)	0.30	3.37	0.18
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.94 (1.29)	13.95 (3.22)	2.28	28.64	1.69
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	17.13 (5.59)	65.93 (14.49)	11.41	137.41	7.59
Minute ventilation (L.min^{-1})	17.40 (5.86)	82.07 (16.39)	16.12	155.44	8.03
Tidal volume (L)	0.83 (0.19)	1.91 (0.32)	0.40	3.52	0.16
Breathing frequency (breaths.min^{-1})	22 (6)	43 (7)	19	74	3

Figure 77[44] provides temporal information for physiological strain across the whole simulation. Readers should primarily direct their attention to the median[45] within each box (the horizontal lines), and how the position of each line varies across the zones of strain: the highest median reveals the region within which firefighters spent most time during this simulation. These data complement and extend those presented within Table 47, and show that the cardiovascular strain for this task mainly occupies the most stressful region.

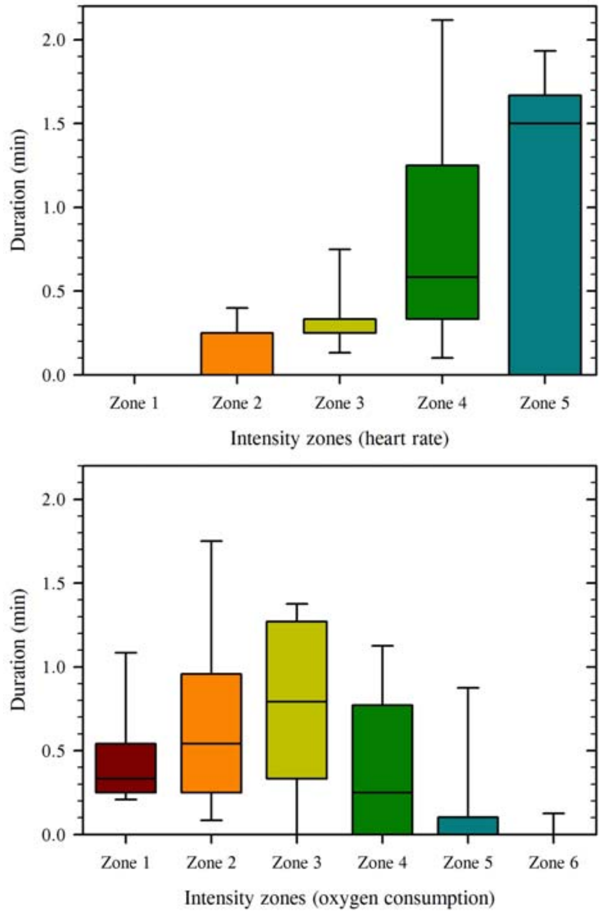


Figure 77: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the sledge axe door entry simulation. *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

3.15.3 Observational summary

Table 48 summarises the complete analyses for this simulation, in which the essential fitness classifications were identified, movement patterns (including muscle actions) were analysed, and the principal cardiovascular and metabolic strain measures summarised.

[44] A detailed description of these box plots is contained within the hazmat simulation.

[45] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

Table 48: Overall occupational task assessment: sledge axe entry simulation.

Attribute	Evaluation
Primary fitness classification (%)	Power: 35-45%
Secondary fitness classification (%)	Cardiorespiratory endurance: 35-45%
Tertiary fitness classification (%)	Muscular endurance: 15-25%
Primary movement action	Two-handed rotation (swing)
Primary movement classification	Upper-body rotation (swing)
Minor movement classification	Twist and turn (upper body)
Primary postural classification	Upright
Minor postural classification	---
Dominant body region	Upper body
Major muscle groups involved	*Shoulder flexors, abductors and rotators:* concentric and eccentric actions *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee extensors*: concentric and isometric actions *Back extensors*: concentric, eccentric and isometric actions *Trunk stabilisers*: concentric, eccentric and isometric actions
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	Sledge axe: 4.7 kg
Approximate position of load and percentage of task time in that position	100% waist to above shoulder (80+ cm)
Average task duration (min)	2.50 (range: 2.33-2.83)
Average task heart rate (beats.min^{-1})	165 (range: 132-186)
Cardiovascular impulse (beats)	412.61
Cardiovascular load (arbitrary units)	5.26
Perceived exertion (6-20)	15.4 (range: 10-19)
Average oxygen cost (L.min^{-1})	1.55 (range: 0.88-2.22)

Attribute	Evaluation
Peak oxygen cost (L.min^{-1})	2.24 (range: 1.29-3.37)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	13.95 (range: 7.18-19.59)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	20.10 (range: 10.49-28.64)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	65.93 (range: 35.12-85.79)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	92.84 (range: 51.33-137.41)

3.16 Simulation sixteen: Structural search and rescue (hot-fire cell: in pairs)

3.16.1 Example experimental data

3.16.1.1 Hot conditions (simulation one)

Body core temperature data (gastrointestinal pill) for all eight firefighters who participated within both stages of this fire-fighting stimulation are presented in Figure 78. These simulations averaged only 25.64 min, yet every fire-fighter terminated the activity with a deep-body temperature greater than 39°C. Figure 79 shows the heart rate response for firefighter 44 (identified as subject one in Figure 78).

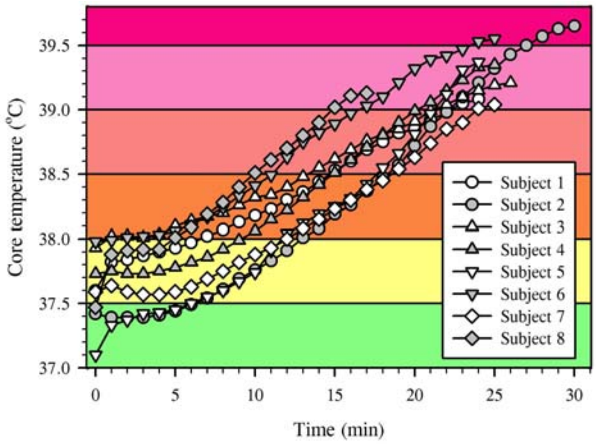


Figure 78: Core temperature response of all eight firefighters during the first (heated) structural search and rescue simulation.

It is evident that each firefighter was warm before commencing the task. However, each was well rested and hydrated, so this pre-exposure elevation was wholly due the wearing of the personal protective clothing. It is also clear that, once the core temperature started to rise, the response of each firefighter was linear. Indeed, the mean rate of rise was 0.08°C.min^{-1} (SD 0.02). This linear response permitted an extrapolation of these data to predict the time taken to reach a core temperature of 40°C. There is nothing magical about this number, as there is considerable variability in heat tolerance among healthy individuals. However, it could realistically be seen as a temperature beyond which firefighters may become seriously impaired, incapacitated or even suffer from heat illness. When the time

taken to reach this temperature was predicted for each firefighter, it was found to average just 10.6 min (SD 4.9; range: 4.0-15.0 min).

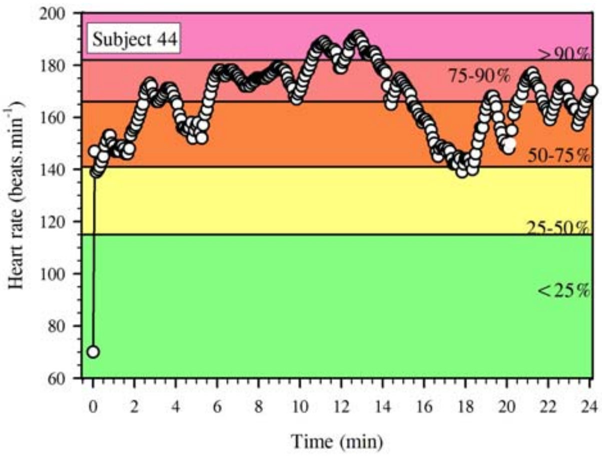


Figure 79: Heart rate response of one firefighter during the first (heated) structural search and rescue simulation.

3.16.1.2 Temperate conditions (simulation two)

As noted earlier, the structural search and rescue was comprised of several tasks that had already been evaluated within this series of simulations. However, the simulation was added at the request of the Research Team, since it provided an opportunity to join several tasks into a single simulation with high ecological validity[46]. In addition, it would provide a cross-validation of the fire-attack simulation (Table 27), *albeit* using data collected from another pool of firefighters. Time-series data for one firefighter for heart rate (Figure 80), absolute oxygen consumption (Figure 81) and ventilation (Figure 82) are provided below, with the coloured bands defining zones of strain.

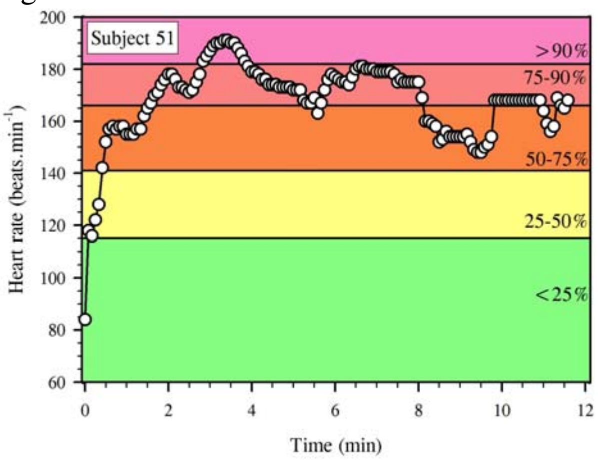


Figure 80: Heart rate response of one firefighter during the second (temperate) structural search and rescue simulation.

[46] Ecological validity refers to research methods, materials and settings that replicate real-life situations, such that those employed within the job, and external observers, would consider the simulation to approximate an occupational task as it might be performed under realistic conditions.

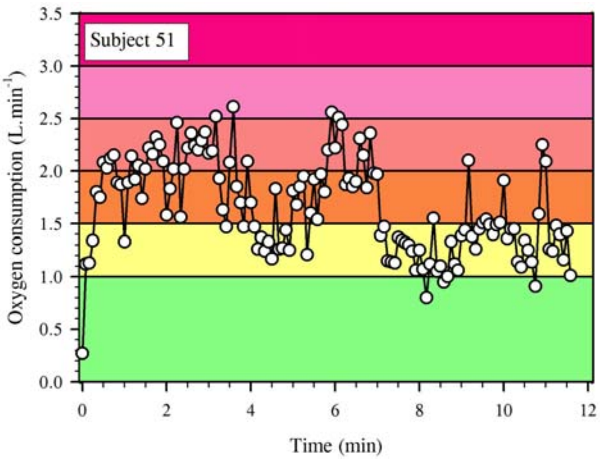


Figure 81: Oxygen consumption response of one firefighter during the second (temperate) structural search and rescue simulation.

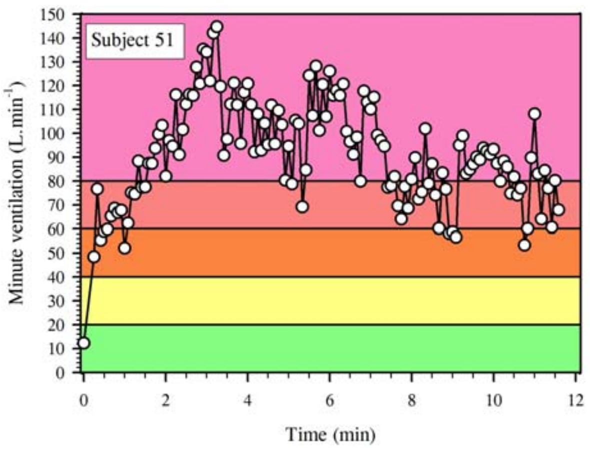


Figure 82: The ventilatory response of one firefighter during the second (temperate) structural search and rescue simulation.

3.16.2 Physiological and psychophysical strain

Table 49 summarises physiological strain observed during this simulation. Across all firefighters, the mean heart rate had a 95% probability of falling between 135-163 beats.min^{-1}. Similarly, the mean absolute oxygen consumption would lie within the zone from 1.41 to 1.81 L.min^{-1}. In comparison with the fire-attack simulation (Section 3.7, Table 27), these range data displayed considerable overlap, with the mean heart rate falling within the range from 135 to 151 beats.min^{-1}, whilst the mean absolute oxygen consumption fell between 1.34-1.72 L.min^{-1}. Moreover, the averages derived for specific oxygen consumption, minute ventilation, tidal volume and breathing frequency were quite comparable across the two simulations. This provides the Research Team with confidence that, between simulations seven and sixteen, a valid characterisation of this occupational activity has been obtained.

Table 49: Summary parameters for physiological strain in firefighters (N=8) performing the second (temperate) structural search and rescue simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	79 (15)	149 (20)	91	194	14
Absolute oxygen consumption (L.min^{-1})	0.32 (0.09)	1.61 (0.29)	0.38	3.37	0.20
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.83 (0.79)	15.09 (2.17)	4.05	30.39	1.51
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.41 (3.63)	70.52 (10.61)	18.11	143.73	7.35
Minute ventilation (L.min^{-1})	13.98 (2.43)	67.71 (14.49)	20.85	144.65	10.04
Tidal volume (L)	0.74 (0.08)	1.79 (0.25)	0.52	3.55	0.17
Breathing frequency (breaths.min^{-1})	19 (3)	37 (7)	14	66	5

In Figure 83[47], observations for heart rate and absolute oxygen consumption are summarised. Graphs display work rate intensities, showing times spent (ordinate) within zones of different physiological strain (abscissa) during the simulation, which lasted 19.57 min. The medians[48] within each box (horizontal lines) show the times spent within each strain zone.

3.16.3 Observational summary

The final analysis involved an overall evaluation of the two primary part of this simulation: the host-drag and dummy-drag activities. The aim of these analyses was to identify the critical fitness classifications for each task, to analyse the movement patterns, including muscle actions, and to summarise the principal cardiovascular and metabolic strain measures. The outcomes from these analyses are summarised in Table 50.

[47] A detailed description of these box plots is contained within the hazmat simulation.

[48] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

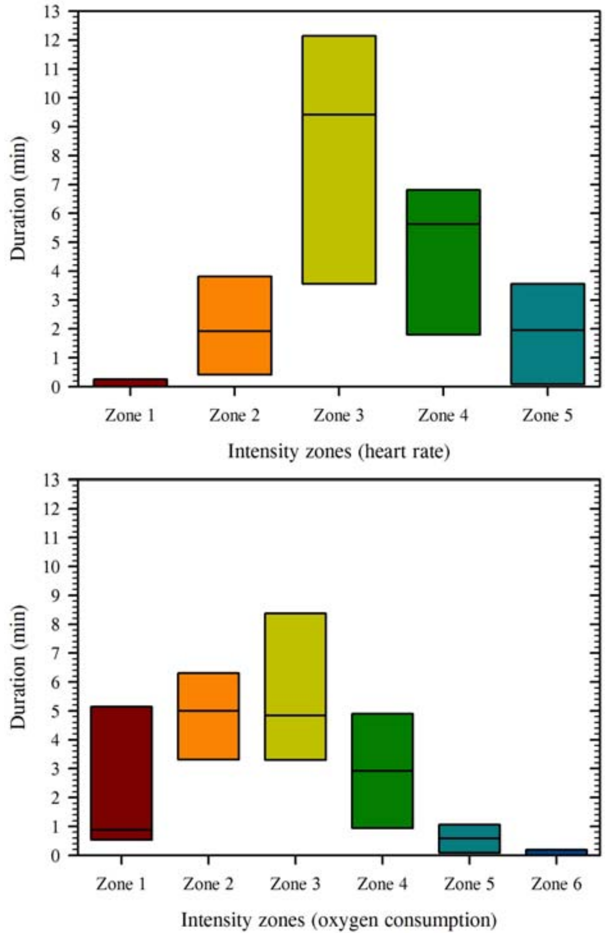


Figure 83: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the second (temperate) structural search and rescue simulation (whiskers were not calculated due to the smaller sample size). *[See Figure 21 caption for details concerning zone definitions and box plot interpretations.]*

Table 50: Overall occupational task assessment: second (temperate) structural search and rescue simulation.

Attribute	Evaluation
Primary fitness classification (%)	Hose-drag tasks: Muscular endurance 50% Dummy-drag tasks: Strength 30-40%
Secondary fitness classification (%)	Hose-drag tasks: Cardiorespiratory endurance 30-40% Dummy-drag tasks: Muscular endurance 30-40%
Tertiary fitness classification (%)	Hose-drag tasks: Power 10-20% Dummy-drag tasks: Cardiorespiratory endurance 20-30%

Attribute	Evaluation
Primary movement action	Hose-drag tasks: Stair climb with one-sided pull, and uneven centre of gravity Dummy-drag tasks: Isometric hold with backwards walking down stairs
Primary movement classification	Both tasks: Push, pull, drag (whole body)
Minor movement classification	Both tasks: Carry and hold (upper body)
Primary postural classification	Hose-drag tasks: Upright Dummy-drag tasks: Kneel, squat, crouch
Minor postural classification	Hose-drag tasks: Stoop and forward bend Dummy-drag tasks: Upright
Dominant body region	Lower body
Major muscle groups involved	**Hose-drag tasks:** *Shoulder extensors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions **Dummy-drag tasks:** *Elbow flexors*: isometric action *Knee flexors*: eccentric action *Hip extensors*: eccentric action *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Both bilateral
Individual or team	Individual
Load	Hose-drag tasks: 38 mm hose: ~ 35 kg Dummy-drag tasks: 50 kg and 70 kg dummies
Approximate position of load and percentage of task time in that position	**Hose-drag tasks:** 50% upper torso (100-150 cm) 25% waist (80-100 cm) 25% ground (0-80 cm) **Dummy-drag tasks:** 60% waist (80-100 cm) 20% upper torso (100-150 cm) 20% ground (0-80 cm)

Attribute	Evaluation
Average task duration (min)	19.57 (range: 11.58-23.42)
Average task heart rate (beats.min^{-1})	149 (range: 113-173)
Cardiovascular impulse (beats)	2913.90
Cardiovascular load (arbitrary units)	37.11
Perceived exertion (6-20)	13.1 (range: 8-17)
Average oxygen cost (L.min^{-1})	1.61 1.11-1.87)
Peak oxygen cost (L.min^{-1})	2.71 (range: 2.11-3.37)
Average specific oxygen cost (mL.kg^{-1}.min^{-1})	15.09 (range: 11.70-17.42)
Peak specific oxygen cost (mL.kg^{-1}.min^{-1})	25.40 (range: 22.03-30.39)
Average specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	70.52 (range: 52.63-78.99)
Peak specific oxygen cost (mL.kg$^{-0.67}$.min^{-1})	118.49 (range: 99.65-143.73)

3.17 The distillation of occupational simulations

The final analysis for this Phase of the project had two aims. Firstly, from the fifteen occupational activities investigated, the Research Team endeavoured to derive a sub-set of tasks that would impose meaningful, yet broadly representative levels of physiological strain when performed by operational firefighters from across a wide range of experience and skill levels. Since the next Phase of this project is centred upon the development of physiological screening tests for possible use within recruiting, and since it would be inefficient to consider using all fifteen activities within such screening, the Research Team set about excluding tasks if efficiencies could be gained without compromising the integrity of the process. Therefore, the second aim was to establish a filtration process through which some activities could be culled to minimise the duplication of movement patterns and loads within this sub-set of tasks.

To achieve these aims, a decision-analysis approach was adopted (Howard, 1966), and an algorithm was developed through which each occupational task was evaluated (Figure 84). The resulting decision tree (flow chart) first permitted the separation of strength- and endurance-related activities. Subsequent steps within strength-related activities resulted in the classification of tasks according to the body region involved, the primary movements performed and the loads carried. Endurance activities were also sub-divided on the basis of load carriage. Before a task was eliminated from further consideration, its criticality was first assessed. The results of this algorithm are presented in Table 51.

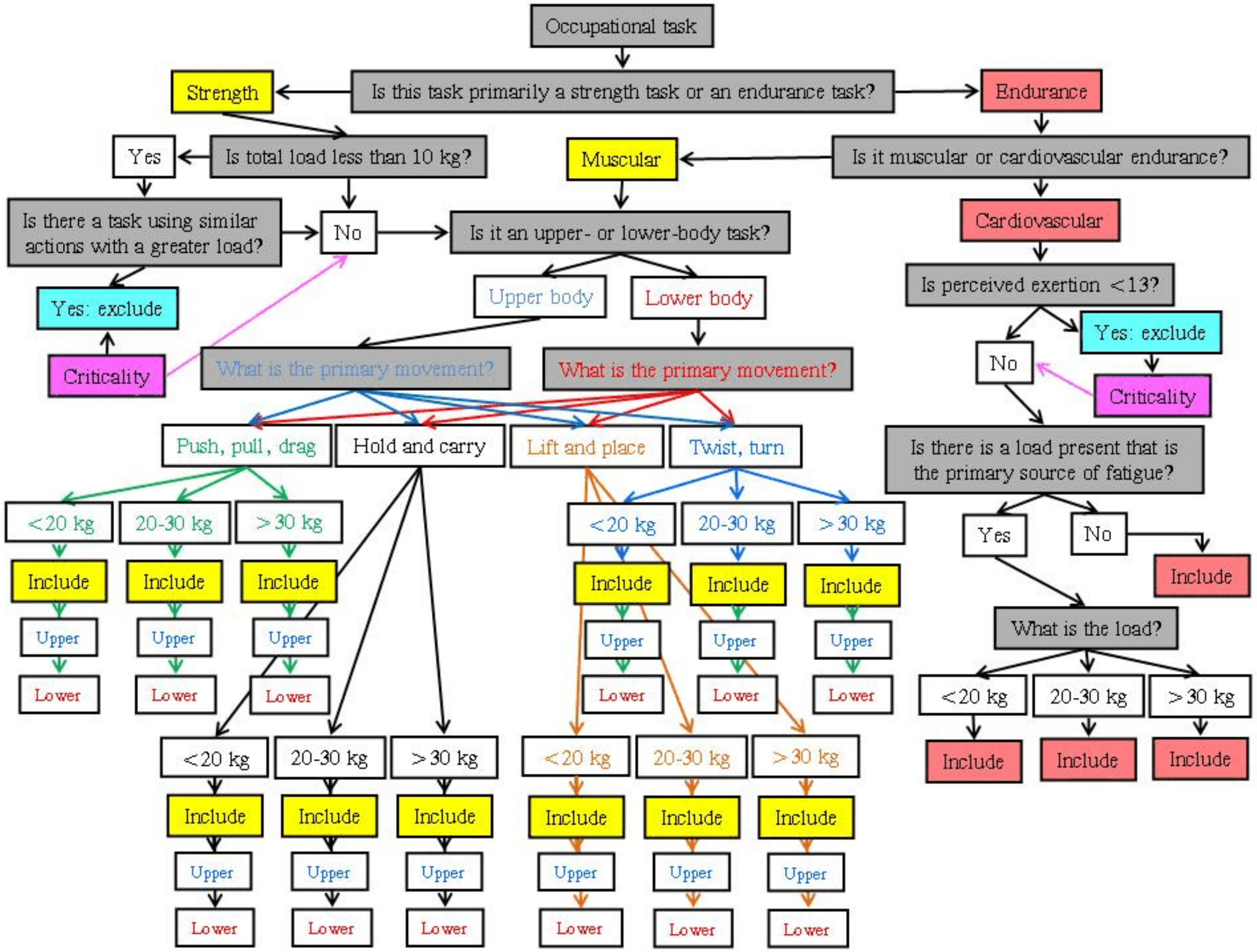


Figure 84: A flow chart (decision tree) for the distillation of occupational tasks into activities that reflect the breadth of physically demanding tasks that impose meaningful levels of physiological strain upon workers.

Table 51: Occupational task (simulation numbers 1-15) classifications based upon the analysis algorithm presented in Figure 84. Where a task appears within more that one cell, it has been deemed to be a whole-body activity (*i.e.* tasks 8, 10 and 14).

<table>
<tr><th colspan="6">Strength and muscular-endurance activities</th><th colspan="3">Cardiorespiratory-endurance activities</th></tr>
<tr><th colspan="3">Upper-body activities</th><th colspan="3">Lower-body activities</th><th colspan="2">Loaded</th><th>Unloaded</th></tr>
<tr><td rowspan="3">Push, pull, drag</td><td>< 20 kg</td><td></td><td rowspan="3">Push, pull, drag</td><td>< 20 kg</td><td></td><td rowspan="4">< 20 kg</td><td rowspan="4">15</td><td rowspan="12"></td></tr>
<tr><td>20-30 kg</td><td></td><td>20-30 kg</td><td>7</td></tr>
<tr><td>> 30 kg</td><td>8, 10</td><td>> 30 kg</td><td>8, 10</td></tr>
<tr><td rowspan="3">Hold and carry</td><td>< 20 kg</td><td>2, 3, 5, 11</td><td rowspan="3">Hold and carry</td><td>< 20 kg</td><td></td></tr>
<tr><td>20-30 kg</td><td>1, 6, 12, 13, 14</td><td>20-30 kg</td><td>14</td><td rowspan="4">20-30 kg</td><td rowspan="4"></td></tr>
<tr><td>> 30 kg</td><td></td><td>> 30 kg</td><td></td></tr>
<tr><td rowspan="3">Lift and place</td><td>< 20 kg</td><td></td><td rowspan="3">Lift and place</td><td>< 20 kg</td><td></td></tr>
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3.18 A commentary on cardiorespiratory endurance standards

At present, the minimal endurance fitness standard used by Fire & Rescue NSW is based upon the ability of potential recruits to consume oxygen at a rate equal to, or greater than, 45 $mL.kg^{-1}.min^{-1}$. This is evaluated in an unloaded state using the 20-m, multi-stage, shuttle-run test (Léger and Lambert, 1982) performed in standard exercise clothing.

At face value, this practise would seem appropriate, since the shuttle-run test is a valid procedure through which to estimate cardiorespiratory endurance via the prediction of maximal aerobic power (maximal oxygen consumption: Léger and Lambert, 1982; Paliczka *et al.*, 1987; Ramsbottom *et al.*, 1988; Cooper *et al.*, 2005). Furthermore, a number of investigators have recommended, based upon their task characterisation experiments, that the maximal aerobic power standard for firefighters should be between 39-45 $mL.kg^{-1}.min^{-1}$ (Lemon and Hermiston, 1977; O'Connell *et al.*, 1986; Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001b). Thus, this valid field test, in combination with an experimentally supported standard, would appear to be well justified. Indeed, this approach is widely accepted internationally, and, at least to the knowledge of the present authors, it appears not to have been challenged. However, the current authors recommend that this practise should cease, and the following text provides the justification that has lead to this recommendation.

Gledhill and Jamnik (1992a) reported an average specific oxygen consumption of 23.4 $mL.kg^{-1}.min^{-1}$ for 90% of the fire-fighting tasks they studied. They also assumed tasks that lasted 1-2 hours could not be tolerated unless firefighters operated at intensities of about 50% of maximal aerobic power. Thus, working for these durations may require a maximal aerobic power two-fold higher (46.8 $mL.kg^{-1}.min^{-1}$). Thus, 45 $mL.kg^{-1}.min^{-1}$ became their recommended minimal standard. However, these data were derived by normalising absolute oxygen consumption using only the body mass of the firefighters (personal communication). It has been established herein that the resting metabolic rate, and the metabolic demand of ambulatory tasks, are a function of both body mass and the load that is carried on the body (Section 3.1.3; Appendix Two). In the current simulations, this involved the personal protective clothing and equipment. Thus, whilst it may be argued that it is only the body that is metabolically active, one cannot ignore the burden of load carriage, just as one cannot ignore a change in body mass due to increasing adiposity. Therefore, in the current project, all normalisation involved the combined body and protective equipment masses.

To illustrate the significance of these two approaches, we shall revisit steady-state data collected by the current authors during walking and bench stepping, with and without the personal protective clothing and equipment used by Fire & Rescue NSW (Taylor *et al.*, 2012b). When such data are used, the inter-individual variability (noise) present within all field-trial data is minimised. This noise is associated with variations in firefighter performance due to differences in the self-selected work rate, terrain, performance technique and efficiency, the simulation sequence and so forth. In Figure 85, six graphs are presented, two for each exercise mode, in the form of absolute (A and B) and specific oxygen consumption (C and D), and also as residuals relative to the averages for each exercise mode (E and F). Strong linear relationships are evident for walking (r^2=0.67) and bench stepping (r^2=0.67), although insufficient data are available, with respect to both sample size and mass range, to fully evaluate other curve-fitting functions.

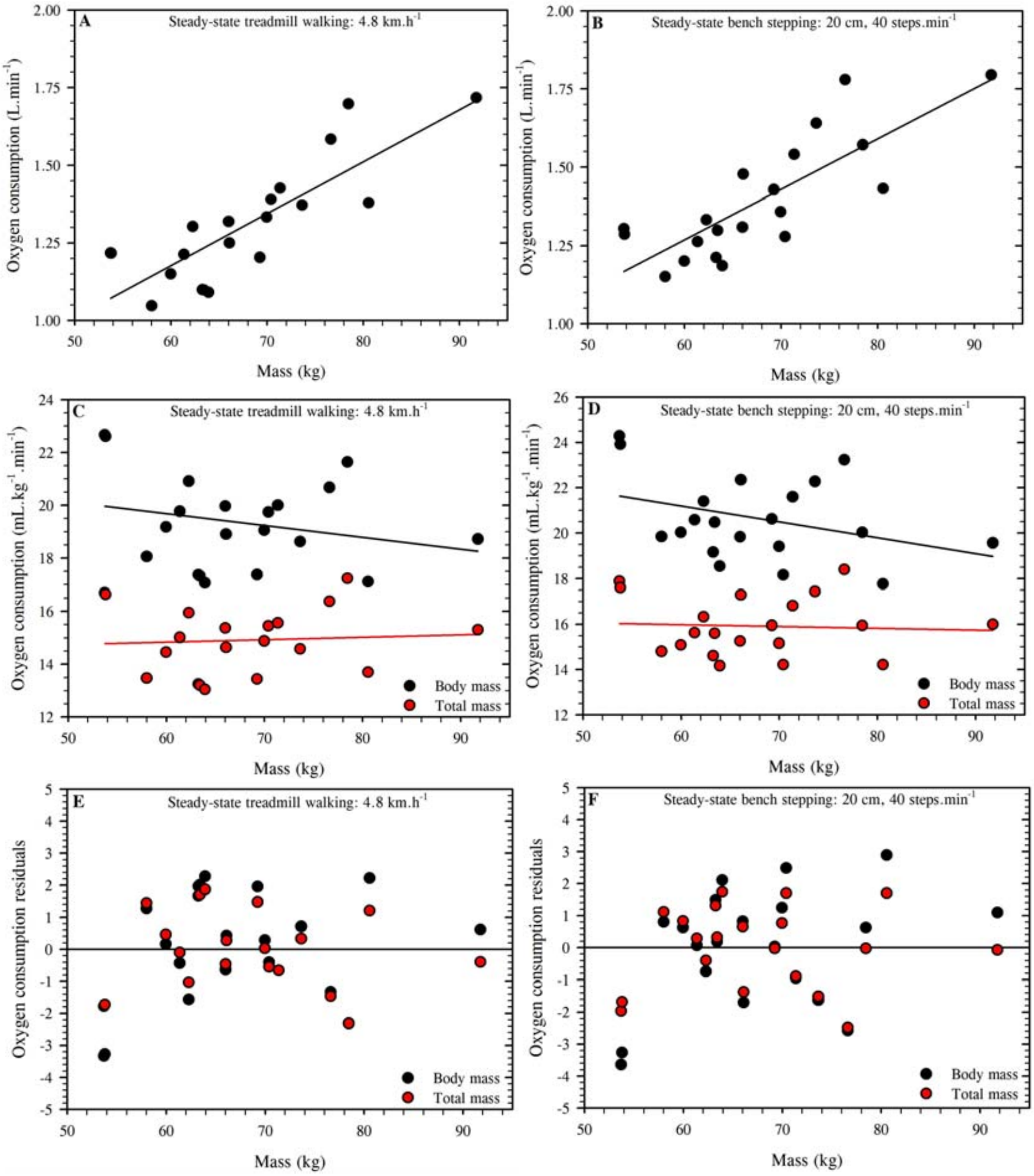

Figure 85: Steady-state oxygen consumption during walking and stepping (*N*=20; ten males and ten females), with and without the personal protective clothing and equipment (Taylor *et al.*, 2012b). Points are values for different individuals in absolute units (A and B), and then normalised to both body mass, and the body plus the protective clothing and equipment masses (total mass: specific oxygen consumption: C and D). Finally, data are presented as residuals, with specific oxygen consumption values individually subtracted from the group mean specific oxygen consumption (E and F).

In Figures 85C and 85D, the impact of the two normalisation strategies is immediately evident. Firstly, normalising for total mass elicits a lower specific oxygen consumption. This is an entirely predictable consequence of changing any denominator. However, if one was to base a cardiorespiratory endurance standard upon data so obtained, then one must determine which normalisation strategy is more appropriate, for the resultant standard is inextricably linked with that choice.

Secondly, as others have demonstrated for maximal aerobic power (Taylor *et al.*, 1981; Schmidt-Nielsen, 1984; Åstrand and Rodahl, 1986; Nevill *et al.*, 1992), there is a negative relationship between specific oxygen consumption and body mass during each of these controlled, steady-state exercise modes (black symbols of Figures 85C and 85D). Although not strong (walking: $r^2=0.06$; bench stepping: $r^2=0.13$), this trend is evident, and it results in an over-correction of data for individuals of greater body mass, and a higher specific oxygen consumption for lighter subjects. That is, when one compares Figure 85A with 85C, and 85B with 85D, this normalisation method has changed the relationship between metabolic demand and mass from a positive (85A and 85B) to a negative slope (85C and 85D). However, when employment standards are being developed, one should endeavour to remove bias. To achieve this, normalisation should convert these slopes into flat, mass-independent relationships. Thus, when standards are developed for employment categories in which loads are carried on the body, as is the case for fire fighting, the possibility exists that the minimal standard may suffer from a mass bias if data are normalised to the body mass only, and also if the standard is developed using individuals drawn from a range of body sizes that inadequately represent that of the sub-population from which recruits may be drawn.

Thirdly, for each exercise mode, normalising to the total mass (body plus clothing and equipment) resulted in a flattening of these specific oxygen consumption to mass relationships (Figures 85C and 85D). This was also predictable, for it is well established that the metabolic impact of a constant load carriage is greater on smaller people (Taylor *et al.*, 1980), changing in direct proportion to the change in the specific load. Thus, a 5% increase in the total load is accompanied by a 5% elevation in metabolic demand. For lighter individuals, the combined mass of the protective clothing and equipment represented a greater relative mass change, and therefore a greater metabolic burden, and the impact of the mass-dependence of load carriage is evident. However, when the absolute oxygen cost was normalised to the total mass, this impact was partially removed, and the corresponding relationships with mass levelled off (red symbols of Figures 85C and 85D). In this case, it appears as though this normalisation procedure minimised the mass bias.

If one now compares these different relationships within Figures 85C and 85D, it becomes apparent that the regression lines for the two normalisation methods converge on a theoretical body mass of 145-150 kg for each exercise mode. At this point, the protective clothing and equipment mass (~20 kg) would be less than 3% of the body mass, and since this is within the resolution of the measurement equipment, it would not be detectable. One can extend these analyses to the current simulations, in which firefighters worked whilst wearing protective clothing and equipment. In this case, ambulatory simulations were chosen to represent walking on a flat surface (Figure 86A: hydrant simulation), moving up

an incline (Figure 86B: carrying the ventilation fan up stairs) and a vertical climb (Figure 86C: ladder climb). This choice allowed for an evaluation of these normalisation procedures across the broadest possible range of mass-dependent locomotion. Whilst these data are inherently noisy, as noted above, mass-dependence is present once more, and a similar converging trend exists, with the regression lines again coming together at a theoretical body mass of 140-150 kg.

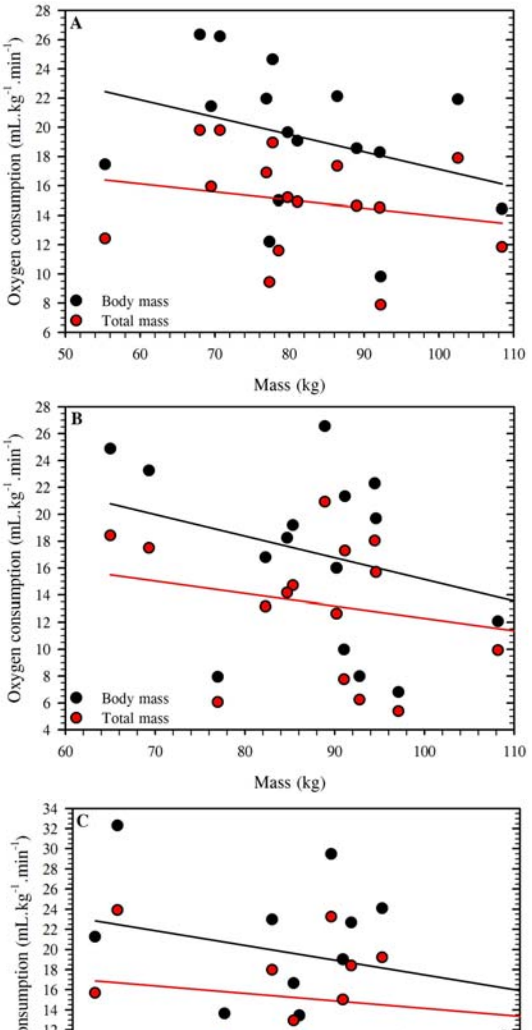

Figure 86: Specific oxygen consumption data for firefighters performing a hydrant simulation (A; Simulation 5: N=16), carrying a ventilation fan (35 kg) up stairs (B; Simulation 14: N=16) and a vertical ladder climb (C; Simulation 13: N=14). Each simulation was performed whilst wearing full personal protective clothing and equipment (~20 kg).

The next analysis of these data provides a statistical justification for choosing one normalisation procedure over another. In Figures 85E and 85F, data are presented as

residuals, with the specific oxygen consumption for each individual subtracted from the group mean for these steady-state walking and stepping activities (respectively). The mean specific oxygen consumption is important, since it would be used for setting an employment standard, if the activities in question were criterion tasks. Both Figures reveal the same trend. That is, the residuals are smaller when these metabolic data were normalised to the total mass, and these differences were statistically significant ($P < 0.05$). Therefore, a statistically superior employment standard should result from the normalisation to total mass when load carriage on the body forms an integral characteristic of the working conditions.

To this point, we have only been considering linear (arithmetic) normalisation procedures. Yet we know that such an approach is frequently inappropriate (Section 3.1.3), since a one-to-one relationship between oxygen consumption and body mass does not exist (Kleiber, 1932; Tanner, 1949; Taylor *et al.*, 1981; Schmidt-Nielsen, 1984; Åstrand and Rodahl, 1986; Nevill *et al.*, 1992). Thus, curvilinear normalisation appears to be more valid for circumstances in which the oxygen cost of an activity is mass dependent. A more complete discussion on this point is contained within Appendix Two.

Finally, we have seen from Table 51 that none of the simulations investigated within the current project could be classed as unloaded, cardiorespiratory endurance activities. Indeed, every activity involved firefighters wearing protective clothing and equipment in some form. Thus, when load carriage is an important occupational constraint, then one must evaluate physiological function under loaded situations (Vanderburgh and Flanagan, 2000; Bilzon *et al.*, 2001a; Vanderburgh, 2008; Vanderburgh *et al.*, 2011). The shuttle-run test fails to meet this criterion, and is likely to provide an unreliable prediction of load-carriage performance (Bilzon *et al.*, 2001a).

One may summarise this commentary as follows:

- Standards derived for load-carriage occupations that do not normalise data to the total mass of the participants, and their protective clothing and equipment masses, are artificially inflated.
- Where possible, mass bias needs to be removed from employment standards, and this cannot occur unless the total mass is appropriately considered.
- Since linear normalisation is fallacious, then nonlinear approaches need to be thoroughly investigated from an occupational perspective (such data have been incorporated into existing data summary Tables [Table 15 onwards]).
- Unloaded endurance tests are unreliable screening methods for occupations in which load carriage is an integral part of the working requirement.

If one accepts these points, then one must also arrive at two conclusions. Firstly, the minimal cardiorespiratory endurance standard of 45 $mL.kg^{-1}.min^{-1}$ may be artificially inflated, due to an artefact arising during its derivation. Secondly, considering the requirement for firefighters to perform predominantly loaded activities, the use of an unloaded endurance test to predict the ability of recruits to meet this standard is now found to be lacking in scientific support.

4. CONCLUSION

The observations arising from these sixteen investigations have been built upon three solid foundations. Firstly, focus-group sessions at eleven Fire Stations, involving 106 firefighters, identified the fifty most physically demanding tasks performed by contemporary firefighters employed by Fire & Rescue NSW. Secondly, in consultation with Executive Staff and high-level, subject-matter experts, this list was consolidated and reduced to thirty-one tasks. Thirdly, firefighters from all ranks and employment classifications were invited to participate in a survey concerning these tasks. More than 1,000 firefighters participated, and, based upon their subjective ratings of task importance, difficulty and performance frequency, a final list of fifteen fire-fighting activities was identified (Taylor *et al.*, 2012a). These were the tasks studied within the current research Phase, with the ultimate aim being to identify valid criterion tasks that may be used to develop screening tests that could be used to identify capable and robust potential fire-fighting recruits.

Task durations ranged from 1.14 min through to 52.33 min, with eight of the simulations being less than 5 min, two were within the 5-10 min range, one simulation fell within the 10-15 min time frame, whilst five tasks lasted 15 min or longer. Since these occupational tasks are valid representations of the most physically demanding duties performed by contemporary firefighters (Taylor *et al.*, 2012a), then one may, at least from a superficial perspective, conclude that at least 50% of these tasks relied on physiological attributes other than whole-body endurance (cardiorespiratory) fitness. A further 30% were dependent upon whole-body fitness, either in the form of cardiorespiratory or muscular endurance.

The occupational task evaluation algorithm (Figure 84) was designed to first cull the least demanding of these activities, and then to group tasks that shared common movement characteristics and physiological attributes. However, only one task was culled using the algorithm: simulation four (coupling hoses). Whilst this is a critical task, it was eliminated for three reasons: loads handled were <10 kg, tools existed to help those with small hands or low grip strength, and other activities were identified that could provide an assessment of this capacity, but under more stressful conditions. This last consideration was important, and has been applied elsewhere, since screening efficiencies can be gained through the elimination of activities that evaluate common physiological or physical attributes. When such instances were found, the more difficult occupational task has been selected for retention.

> **4.1 Recommendation one:** It is recommended that occupational task four (the coupling of hoses) not be included within the list of criterion tasks for fire fighting.

Examination of the shaded cells within Table 51 reveals that, of the fifteen occupational tasks evaluated, none involved unloaded cardiorespiratory endurance. Moreover, no strength or muscular-endurance activities performed with either the upper- or lower-body involved the movement classes of lifting and placing, or twisting and turning. The immediate implication of this first main outcome is that recruit screening should not involve assessment items that focus upon these movements or physiological attributes. For instance, it is well known that unloaded evaluations of cardiorespiratory endurance make unreliable predictors of performance when load carriage is involved (Bilzon *et al.*, 2001a;

Vanderburgh, 2008). Since, at least to the knowledge of the Research Team, a thorough scientific analysis of this occupation has not been recently performed, then this is the first time that Fire & Rescue NSW has been made aware of this fact. It is therefore recommended that the current endurance test used by Fire & Rescue NSW to screen recruits be discontinued (*i.e.* the 20-m, multi-stage, shuttle-run test [Léger and Lambert, 1982]), and, if appropriate, that it be replaced by a test that better reflects the demands of contemporary fire fighting.

> **4.2 Recommendation two:** It is recommended that the current endurance test (shuttle-run) be discontinued and replaced, once appropriate screening tests have been identified (research Phase three) and validated (research Phase four).

Within Table 51, four cells contain more than one occupational task. Similarly, within the separate upper- and lower-body movement classes, several different tasks are listed, but with different loads. These horizontal and vertical relationships provided immediate opportunities to fine tune this task list by culling activities that evaluate common physiological or physical attributes, if a more difficult occupational task exists.

> **4.3 Recommendation three:** It is recommended that occupational task six (lateral dragging of 70-mm charged hose) not be included within the list of criterion tasks for fire fighting, since a more demanding task exists that would evaluate equivalent physiological attributes.

> **4.4 Recommendation four:** It is recommended that task eleven (prolonged use of 38-mm hose) not be included within the list of criterion tasks, since a more demanding task exists that would evaluate equivalent physiological attributes.

> **4.5 Recommendation five:** It is recommended that task twelve (prolonged use of 70-mm hose) not be included within the list of criterion tasks, since a more demanding task exists that would evaluate equivalent physiological attributes.

From Table 51, it also becomes clear that these occupational tasks are dominated by activities in which the holding and carrying of objects dominates the movement patterns. Furthermore, there exists a clear bias across these activities towards a reliance upon upper-body strength or muscular endurance.

> **4.6 Recommendation six:** It is therefore recommended that occupational tasks one (hazmat), two (motor-vehicle rescue), three (rolling out 70-mm hose), five (hydrant location and connection), thirteen (ladder use) and fourteen (ventilation fan carry) be treated as a pool of similar, upper-body criterion tasks upon which may be developed either generic or occupation-specific screening tests. This development will occur within the next Phase of this project.

When cardiorespiratory fitness is important within contemporary fire fighting, it was found to be associated with load carriage, with greater demand being found within occupational task nine: the dragging of a charged 38-mm hose over uneven terrain in the simulation of

fighting a bushfire.

4.7 Recommendation seven: It is recommended that occupational task nine (dragging charged 38-mm hose [uneven terrain]) should become one of the criterion tasks upon which a generic or occupation-specific screening test may be developed.

A second task relied upon cardiorespiratory fitness, but also upon upper-body muscular endurance. This was task fifteen: using a sledge axe to gain entry into a building.

4.8 Recommendation eight: It is recommended that occupational task fifteen (using a sledge axe to gain entry) also be included as a criterion task, leading to the development of either a generic or an occupation-specific screening test.

Finally, three occupational tasks involved movement patterns dominated by the pushing, pulling or dragging of objects >20 kg in mass. Whilst two of these activities could be classed as being whole-body in their demands, each had a heavy reliance upon lower-body strength or muscular endurance.

4.9 Recommendation nine: It is recommended that occupational tasks seven (fire attack), eight (firefighter rescue) and ten (stair climb dragging a charged hose) be treated as a pool of similar, predominantly lower-body criterion tasks upon which may be developed either generic or occupation-specific screening tests. This development will occur within the next Phase of this project.

On the basis of these analyses, the following criterion fire-fighting tasks have been grouped into four activity classes that are recommended to be carried into the next research Phase:

- **Class one:** tasks one (hazmat), two (motor-vehicle rescue), three (rolling out 70-mm hose), five (hydrant location and connection), thirteen (ladder use) and fourteen (ventilation fan carry)
- **Class two:** task nine (dragging charged 38-mm hose [uneven terrain])
- **Class three:** task fifteen (using a sledge axe to gain entry)
- **Class four:** tasks seven (fire attack), eight (firefighter rescue) and ten (stair climb dragging a charged hose).

4.10 Verification and approval of the criterion task list

The above criterion list of fire-fighting tasks was submitted to the Project Management Team for consideration, endorsement and validation. Approval to progress to the next research Phase (screening test development)[49] was also sought at this meeting. These outcomes were each achieved at the Project Management Team meeting held on May 21st (2012: Appendix Three of this report).

[49] Groeller, H., Fullagar, H.H.K.F., Sampson, J.A., and Taylor, N.A.S. (2012). Physiological employment standards for firefighters: *Report 3:* Staged screening tests for contemporary firefighters. *UOW-CHAP-HPL-Report-048.* Human Performance Laboratories, University of Wollongong, Australia. For: Fire and Rescue NSW, Sydney, Australia.

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6. APPENDICES

APPENDIX ONE: Meeting to approve the fire-fighting simulation list for Phase Two

MEETING: Project Management Team:
Date: 27/2/12
Location: Board Room Head Office (FRNSW).
Present: Chair: Alison Donohoe (FRNSW), Darren Husdell (FRNSW), Jim Hamilton (FRNSW), Ken Murphy (FRNSW), Geoffrey Parkes (FRNSW), Brendan Mott (FRNSW), Megan Smith (FRNSW), Nigel Taylor (UOW).
Summary:
(1) Introductions and welcome (AD).
(2) NT gave a very brief overview of the PAT review to date:
During focus groups performed at 11 stations across NSW, 50 physically demanding tasks were identified. 106 FF participated in the focus groups, from 11 stations that were nominated by JH (DRO) & MB (DGMO) to give a good cross section of the organisation's population, considering gender, age, experience etc. The project management team and subject matter experts then looked at the 50 tasks to determine overlap and duplication etc. and the task list was subsequently reduced to 30 tasks for inclusion in the survey. The survey went out to the organisation and we received approximately 250 paper based responses and 750 electronic responses. The survey amongst other things asked staff to rank tasks according to frequency, critical importance, and difficulty involved. The results of the survey were then analysed using a filtration process which was detailed by NT utilising the Executive Summary for this phase of the research. The results of the filtration process identified 15 tasks for detailed task analysis. The 15 trade tasks were tabled as Appendix A for approval by all members of the Project Management team.

A minor amendment to the wording requested by JH, “Ladder use (10.5m) 1-person, under run and stabilise” to “Ladder use (10.5m) 1-person, under run”. JH expressed that this is required as the person footing the ladder is also assisting with the stabilisation.

The agreed task list is as follows:

1. Rolling out uncharged hose lines: 70 mm
2. Hydrant: Locating and connecting
3. Coupling and uncoupling hoses
4. Drag 70-mm charged hose: horizontal
5. Stair climb with PPE, BA and Hose
6. Prolonged use of 38-mm hose
7. Prolonged use of charged hose: 70-mm (two people)
8. Fire attack: prolonged crawl, kneel, crouch and squat
9. Ladder use (10.5 m) 1-person, under run
10. Rescue FF with PPE and BA: 1 person
11. Using spreaders and shears
12. Using sledge hammer to gain entry
13. Carry: ventilation fan (up stairs): 2 people
14. Hazmat: walking, manual handling (encapsulated)

15. Bush: drag charged hose (hilly, sloped and uneven)

This list was endorsed by the committee as the 15 tasks that should be used as the basis for the development of the physical employment standard.

NT provided overview of analysis performed on the tasks to date including explanations of the photos taken on the field testing, and that will appear in the report for phase 2 of the project. NT outlined that his team were able to borrow from the Department of Defence physiological monitoring devices which allowed the field studies to collect essential data. The limited access to this equipment was the reason for commencing task analysis prior to final task list endorsement. The expectation that not all 15 identified tasks will be in the final standard was discussed.

It was acknowledged that a tiered approach to retained firefighter PATs would be considered based on job demands at a various locations. The FRNSW Resource Allocation Model may be able to be utilised in this regard. It was discussed that DRO Jim Smith had expressed out of session that he would discuss this with the Senior Planner ORU LLC, plus a risk assessment would be conducted on each station to facilitate this process.

ACTION: NT to provide report detailing final endorsed task list developed during phase 1 of the project.

(3) It was unanimously agreed to have the wording “Trade” removed from in front of “task” throughout the report. The title on the report is also to be amended to “The essential, physically demanding tasks of contemporary firefighting”.

ACTION: NT to make necessary amendment to report.

(4) NT: In the next phase UOW will utilise the data obtained during the task analysis to develop screening tests. Once these tests are developed FF will be involved in completing the screening test to receive feedback on appropriateness.

APPENDIX TWO: Allometric considerations of mass within occupational standards.

The aim of this Appendix is to provide a theoretical justification for using power functions in the normalisation of oxygen consumption to body mass. We will commence this exercise with a consideration of a uniform geometric shape (the sphere), and explore the dimensional relationships among 15 spheres, each with a radius 1 cm larger than its predecessor. From this analysis, we are able to assemble several fundamental facts. For instance, for equal increments in radius (L)[50], their surface areas (L*L or L^2) will increase in a curvilinear manner (Figure A2-1A), such that doubling the radius results in a four-fold increase in surface area[51]. Thus, area increases as a square function of radius. The volumes (L*L*L or L^3) of these spheres also increase nonlinearly (Figure A2-1B), so that doubling the radius produces an eight-fold increase in volume[52]; volume is a cube function of radius. Therefore, these spheres are geometrically similar, or isometric objects (Schmidt-Nielsen, 1984). However, similar relationships can also be used to describe objects of varying size, but with a uniform shape that does not follow these simple geometric (isometric) patterns.

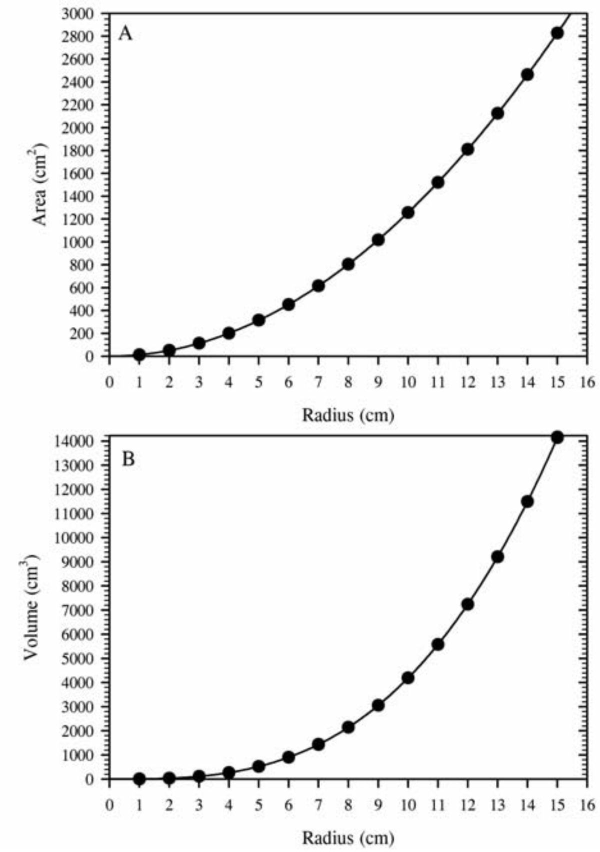

Figure A2-1: The relationships between area and volume, and the radii of spheres.

[50] For dimensional analyses, three symbols will be used: M (mass), L (length) and t (time).

[51] Surface area of a sphere = 4 * Pi * radius^2

[52] Volume of a sphere = 4/3 * Pi * radius^3

For example, humans are broadly similar in shape, so one may expect that body surface areas would change in proportion to the square of some linear dimension, as would be the case for an isometric object. However, this is not observed. Instead, human body surface areas, which are almost universally obtained using the DuBois and DuBois (1916) derivation[53], increase approximately 75 cm^2 for each cm of height gained, if mass remains constant (Figure A2-2A). This is far from a square function, since a two-fold increase in height yields only a 1.65-fold change in surface area. Moreover, when considered with respect to body mass (which is dimensionally equivalent to volume: L^3), surface area increases approximately 100 $cm^2.kg^{-1}$ of mass change, if height is held stable (Figure A2-2B). Thus, doubling the mass increases surface area by a factor of approximately 1.35.

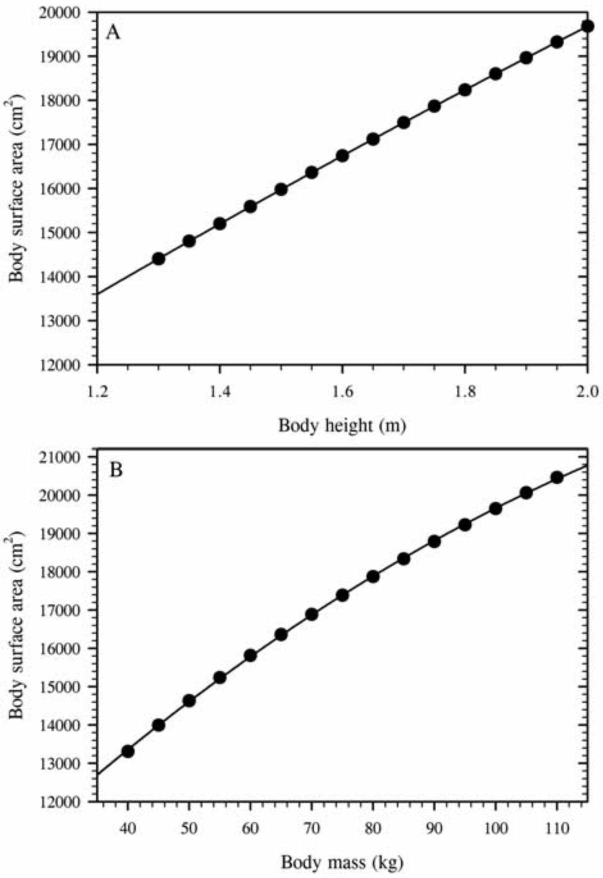

Figure A2-2: The relationships between human body surface area and height when mass is held constant (65 kg; Figure A2-2A), and with mass when height is held constant (1.55 m; Figure A2-2B).

Thus far, we have considered surface area and volume only with respect to linear dimensions. So let us now contemplate the inter-relationship between surface area and volume. This relationship for spheres[54] is illustrated in Figure A2-3A, for which the surface area to volume ratio is the smallest (most efficient) of any three-dimensional object. It is evident that the surface area is not linearly related to volume, unless this relationship is

[53] Body surface area = $0.202 * mass^{0.425} * height^{0.725}$ (DuBois and DuBois, 1916).

[54] Surface area of a sphere = $4.836 * volume^{0.67}$

plotted using logarithmic co-ordinates for both variables, as it is in Figure A2-3B. When such scales are used, linearity is evident, and the slope (exponent) of this line will be +0.67. This means that areal increases of a sphere are proportional to the 0.67 power of volume (volume$^{2/3}$). Moreover, the relationship between surface area and volume varies as a function of the size of the sphere, such that when the ratio of these variables is plotted against spherical volume (Figure A2-3B), it decreases with increments in size, and the slope of this line will be -0.33 (volume$^{-1/3}$; Schmidt-Nielsen, 1984)[55]. Thus, smaller spheres have greater relative surface areas. These relationships (rules) hold true for all isometric objects (Schmidt-Nielsen, 1984).

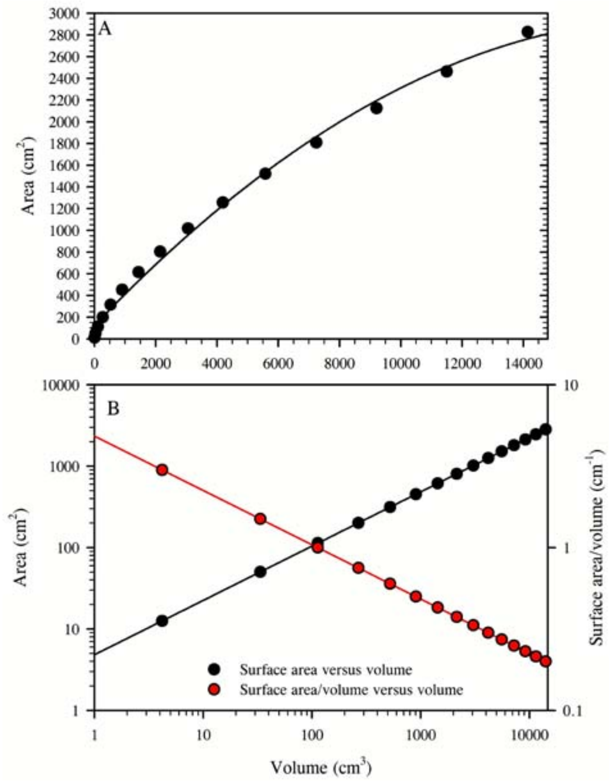

Figure A2-3: The relationships between the surface areas and volumes of spheres plotted using linear (A) and logarithmic co-ordinates (B).

Let us now return to humans, and consider how anatomical and physiological characteristics may change with increments in body surface area or volume. Whilst humans come in different shapes and sizes, we are all of a similar configuration (generic shape). But we do not possess isometric body shapes. In fact, as humans grow, we do so allometrically. That is, we retain the same general shape, but not the same segmental proportions[56]. The classical example of this is evident for the head, which grows much faster during the first decade of

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[55] Positive exponents reveal that variable *y* increases with increments in variable *x*, whilst negative exponents signify inverse relationships.

[56] If humans grew isometrically, then segmental proportions *in utero* would be retained throughout life, but this does not occur. Objects and organisms with isometric scaling possess the following characteristics: surface area will vary as a function of the square of some linear dimension (L^2 or the second power), and volume will change as a cube function of that dimension (L^3 or the third power; Schmidt-Nielsen, 1984).

life than do the other body segments. Because of this allometric growth, the isometric relationships of spheres (Figures A2-1 and A2-3) do not obtain in humans with the same rigidity. However, an awareness of these relationships is critical to understanding and evaluating how absolute values may differ among individuals, simply on the basis of size variations. To address these variations, one may normalise[57] the size of various anatomical structures (brain, heart, lungs) or physiological functions (stroke volume, blood volume, oxygen consumption) to some index of body size (body mass or surface area), so that individuals of varying size can be more readily compared. Whenever body mass, which is an analogue of volume, is the denominator of choice, the resultant output is known as a specific[58] variable (*e.g.* specific oxygen consumption; Royal Society, 1975).

In the resting state, the absolute oxygen consumption of any individual is function of body size, with perhaps the most useful anthropometric indices being the body surface area (Sarrus and Rameaux, 1839; Rubner, 1883; Seltzer, 1940) and body mass (Richet, 1889; Kleiber, 1932, 1947, 1961). These relationships hold true across all mammals. For instance, the absolute resting oxygen consumption of men and women differs, but when it is normalised to either body mass or surface area ($mL.kg^{-1}.min^{-1}$ or $mL.m^{-2}.min^{-1}$), this difference becomes minimal. Thus, the absolute values are correctly interpreted to mean that the resting oxygen consumption of men and women differed mainly because of variations in body size. Therefore, differences between resting men and women are merely gender-related, since men tend to be larger, but they are not gender-dependent.

During exercise, body mass has long been known to correlate better with oxygen consumption than body surface area (Seltzer, 1940). Thus, exercising oxygen consumption data are often normalised to body mass. However, this normalisation is based upon a linear (arithmetic) assumption, such that, across the entire range of body sizes, the simple division of body mass into the absolute oxygen consumption will always permit one to compare the relative impact of a given physical activity upon different individuals, with the affect of body mass now being completely removed (body mass-independence). Notwithstanding its popular use, the significance of the difference between the absolute and specific oxygen consumption derived in this manner is often misunderstood, and the following discussion provides a more complete treatment of this topic, with a view to facilitating an understanding of the data presented within this, and subsequent reports.

Whilst this linear mass normalisation is widely used and accepted, it does not mean that it is appropriate. For instance, it fails to account for all of the inter-individual variability in

[57] Normalising involves dividing the index of interest (*e.g.* oxygen consumption) by some variable that is tightly correlated with that index (*e.g.* surface area or mass). Thus, the absolute oxygen consumption ($L.min^{-1}$) is converted to a relative (specific) oxygen consumption ($mL.m^{-2}.min^{-1}$ or $mL.kg^{-1}.min^{-1}$). In these examples, it is assumed that the relationship between the index of interest and the chosen divisor is always linear.

[58] The word "specific" designates any quantity normalised to (divided by) body mass (Royal Society, 1975).

oxygen consumption[59]. Moreover, the coefficient of variation for oxygen consumption will often exceed that for body mass[60]. This means that a wider range of exercising observations may be found within the oxygen consumption than within the mass data, such that a simple one-to-one relationship between oxygen consumption and body mass does not exist. These facts have also long been known (Kleiber, 1947; Tanner, 1949; Taylor *et al.*, 1981; Schmidt-Nielsen, 1984; Åstrand and Rodahl, 1986), and, if ignored, can lead to specious data interpretation when normalising oxygen consumption during both resting and exercising states, and particularly if one considers masses beyond the normal adult range Tanner (1949).

In the case of maximal exercise (*e.g.* peak aerobic power), one can observe a positive relationship between the peak absolute oxygen consumption and body mass, but a negative relationship is simultaneously evident between peak specific oxygen consumption ($mL.kg^{-1}.min^{-1}$) and body mass (Taylor *et al.*, 1981; Schmidt-Nielsen, 1984; Åstrand and Rodahl, 1986; Nevill *et al.*, 1992; Bilzon *et al.*, 2001a). Indeed, the same relationship was demonstrated within resting animals almost a century earlier (Richet, 1889), it is predictable on a first-principles basis[61] and it follows the dimensional characteristics of spheres (Figure A2-3B). Thus, normalising maximal exercise data for mass will disadvantage larger individuals, whilst potentially inflating data for some smaller people (Åstrand and Rodahl, 1986; Nevill *et al.*, 1992). These outcomes are artefacts of this form of normalisation. Therefore, the injudicious division of mass into oxygen consumption can be invalid in many circumstances.

There is no doubt that normalising for body mass may help to explain some of the variability among individuals in either the absolute resting and exercising oxygen consumption. However, a significant amount of this variation will remain unexplained[62] (Kleiber, 1932). Normalising for body surface area will dramatically improve this state[63] at rest, and it was suggested that the surface area relationship may be associated with the need to balance metabolic heat production against heat loss, with the latter being a function of body surface area (Rubner, 1883). This area-specific procedure has been adopted as a clinical convention for resting individuals, but it too is imperfect, whilst normalising for body mass remains the method of preference within disciplines associated with exercise. However, neither of these denominators is correct.

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[59] Less than 25% of the variation in the resting, absolute oxygen consumption can be explained on the basis of variations in either body surface area (r=0.505) or body mass (r=0.412). However, during moderate exercise, the predictive power of body mass is increased, and it can now explain about 60% of this variation, whilst during heavy exercise, it can account for about 75% of this variability (Seltzer, 1940). Nonetheless, there remains considerable unexplained variability, so the relationship is imperfect.

[60] Data from 20 individuals (Taylor *et al.*, 2012b): coefficient of variation for mass (kg) = 15.2; coefficients of variation for oxygen consumption ($L.min^{-1}$): rest = 27.5, steady-state walking (4.8 $km.h^{-1}$) = 18.4.

[61] Absolute oxygen consumption = $a * mass^{0.75}$ (Kleiber, 1932).
Specific oxygen consumption = absolute value / mass or $a * mass^{0.75}$ / mass.
Thus: specific oxygen consumption = $a * mass^{-0.25}$.

[62] The coefficient of variability for the resting metabolic rate normalised to body mass was about 80% for animals ranging in mass from 150 g to 679 kg (Kleiber, 1932).

[63] The coefficient of variability for the resting metabolic rate normalised to body surface area was about 34% for animals ranging in mass from 150 g to 679 kg (Kleiber, 1932).

Firstly, it is an inherent assumption of this normalising procedure that the linear function describing the relationships between absolute oxygen consumption and either body mass or surface area pass through the origin. That is, at zero body mass, the specific oxygen consumption of an individual will also be zero. Of course, this must hold true. However, the natural extension of this assumption is that this linear relationship, which has almost invariably been derived from experiments conducted using adults, will remain valid across the entire range of body masses. This is not correct. Indeed, when body mass or surface area standards for a variety of physiological functions are applied to individuals falling on either side of the mean obtained from the population sample used to construct the standard (*e.g.* cardiac function, oxygen consumption, plasma volume (Tanner, 1949)), then those individuals appear to deviate from normal purely on the basis of the difference between their size and that of the sample mean. This artefact increases as individuals approach the extremes of body size (*i.e.* the confidence intervals widen; Schmidt-Nielsen, 1984), and so the extrapolation of such regression relationships beyond the range of primary observations is fallacious (Tanner, 1949; Schmidt-Nielsen, 1984).

Secondly, Kleiber (1932) found that normalising using body mass raised to the 0.75 power[64] provided a far superior explanation for variations in resting metabolism[65]. That is, the relationship was not arithmetically linear (one-to-one), but only became linear when graphed on logarithmic scales (*e.g.* Figure A2-3). Thus, for one to compare the mass-independent resting oxygen consumption of individuals of different sizes, one must derive specific oxygen consumption as a power[66], and not as a linear function. Moreover, one must absolutely base this relationship upon data obtained across the widest possible physiological range. The methods used by Kleiber (1932: mice to cattle) satisfy both of these criteria.

Some 50 years after this relationship was established for body mass and resting oxygen consumption, Taylor *et al.* (1981) undertook an evaluation of its efficacy during maximal exercise. Peak aerobic power was measured across a very wide range of body masses in animals (7.2 g to 263 kg), and it too was found to be proportional to the 0.75 power of body mass[67]. Not surprisingly, subsequent confirmations of this power function have been provided within maximally exercising humans (Åstrand and Rodahl, 1986; Nevill *et al.*, 1992), although the exponents have not always been 0.75. When such normalising is applied, the bias that is inherent within the linear normalisation procedure disappears (Åstrand and Rodahl, 1986). Indeed, it appears that, while the 0.75 power function is appropriate across mammalian species (Kleiber 1932; Taylor *et al.* 1981; Schmidt-Nielsen, 1984), within a species, and during resting and exercising states, the exponent may be closer to 0.67 (Heusner, 1982; Schmidt-Nielsen, 1984)[68]. Therefore, whilst it is well established that size is important, it is absolutely critical that we apply the correct scaling

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[64] Also known as the "3/4-power law".

[65] The coefficient of variability for resting metabolic rate normalised to the 0.75 power of body mass was 7% for ten groups of mammals (Kleiber, 1932).

[66] Resting oxygen consumption ($mL.s^{-1}$) = 0.188 * $mass^{0.75}$ (Kleiber, 1961).

[67] Peak aerobic power ($mL.s^{-1}$) = 1.94 * $mass^{0.79}$ (Taylor *et al.*, 1981).

[68] Biologists continue to debate the veracity of the 3/4-power law. For a recent discussion, see Glazier (2008).

function (power), rather than the more convenient (linear) function. Accordingly, this convention has been adopted herein ($mL.kg^{-0.67}.min^{-1}$).

Let us now explore why these relationships should exist. Schmidt-Nielsen (1984: Pp. 83-86) presented the case for this in considerable detail. Whilst a full reiteration of this is beyond the scope of the current work, some key features are noted below for the reader, and these are presented using the nomenclature of dimensional analysis[69].

Muscle force = tensile stress * cross-sectional area * shortening distance

Power = [tensile stress] * cross-sectional area * [shortening distance / time]

Power = $[M * L^{-1} * t^{-2}] * L^2 * [L / t]$ Power = $M * L^2 * t^{-3}$

However, instead of the first dimensional equation being simplified to the second (as shown above), the two parenthetical terms within this equation can be discounted, since they behave as physiological constants. In the first instance, the maximal tensile stress developed by skeletal muscle is a characteristic that is constant across species. It is independent of the size of an animal. Instead, it is determined by the actin and myosin filaments themselves, which are similar across species, as are the number of cross-bridges (Schmidt-Nielsen, 1984). Thus, muscle force is wholly dependent upon the cross-sectional area of the myocyte generating the force. Furthermore, the length and speed of muscle shortening will vary minimally across species (Schmidt-Nielsen, 1984). Thus, these terms become constants (k), and the equation for skeletal muscle power may be re-written as:

Power = $k_1 * L^2 * k_2$

This simplification is well known to muscle physiologists. However, it may be stated another way. Maximal muscle power is a function of muscle diameter squared (L^2), and it is proportional to body mass to the power 0.38 (Schmidt-Nielsen, 1984)[70].

Diameter is proportional to body mass$^{0.38}$

L^2 is therefore proportional (body mass$^{0.38}$)^2 or body mass$^{0.75}$

Power = $k_1 * M^{0.75} * k_2$

From this derivation, it can be seen that muscular power is related to body mass with an exponent of 0.75 (Schmidt-Nielsen, 1984).

Since exercise involves the extensive activation of skeletal muscles, then one can apply this generalisation to the entire, exercising musculoskeletal system and the consumption of oxygen to fuel that exercise (Schmidt-Nielsen, 1984). Thus, metabolic rate during exercise should be normalised to the 0.75 power of body mass, just as it was at rest. This is because it is an accepted convention to approximate metabolic rate from measures of oxygen consumption (Kleiber, 1947), because this oxygen is used in the liberation of stored chemical energy. This energy, in turn, enables the performance of work. Since both the absolute and specific units for oxygen consumption are time derivates, then we are actually obtaining an approximation of metabolic power[71], which has the same dimensional units developed above for muscular power:

Force = mass * acceleration Force = $M * L * t^{-2}$

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[69] For dimensional analyses, three symbols will be used: M (mass), L (length) and t (time).

[70] Elastic criteria, which dictate the relationships between body mass and muscle dimensions, require the diameter of a muscle to conform to the 0.38 power of body mass (Schmidt-Nielsen, 1984).

[71] Power = work / time or Power = energy use / time

Work = force * displacement　　Work = $M * L * t^{-2} * L = M * L^2 * t^{-2}$
Power = work / time　　Power = $M * L^2 * t^{-2} / t = M * L^2 * t^{-3}$.

From this treatment, one may conclude that variables related to power must be scaled using a power function of body mass. Across mammalian species, the exponent would be 0.75 (Kleiber, 1947; Schmidt-Nielsen, 1984), but within a species, the exponent approximates 0.67 (Heusner, 1982; Åstrand and Rodahl, 1986; Nevill *et al.*, 1992). As an extension of this, Schmidt-Nielsen (1984) further demonstrated that variables related to frequency (*e.g.* heart rate, breathing frequency) should be scaled to the -0.25 power of body mass.

APPENDIX THREE: Meeting to report on, and approve the completion Phase Two research activities

Date: 21/5/12
Location: Board Room Head Office (FRNSW).
Present: Alison Donohoe (FRNSW), Darren Husdell (FRNSW), Megan Smith (FRNSW), Brendan Mott (FRNSW), Jim Hamilton (FRNSW), Jim Smith (FRNSW), Nigel Taylor (U0W), Lee Barlow (FRNSW)
Apologies: Gray Parks (FRNSW).
Summary:
(1) Previous Minutes of 27 February 2012 were accepted by all (AD).
(2) BM gave a general overview of the project to date and the purpose of this project management team meeting. The UOW research team is seeking the endorsement of Phase 2 of the research, specifically the 9 recommendations arising from the simulations conducted across the state. The UOW research team is also seeking approval from the project management team to progress to phase 3 of the research project.
(3) NT discussed the Phase 2 report detailing and highlighting areas of importance for the project management team.

NT reinforced that the research and reports need to be robust and scientifically valid to withstand legal challenges and the UOW study is structured to provide this level of protection.

NT noted that, at present, the “Shuttle Run” is a valid field-based test for assessing cardiovascular fitness, but it is not necessarily a defensible test for the physical screening of firefighters. NT advised it is likely that his team would be making a recommendation to replace this with a more appropriate test in the FRNSW physical employment standard.

NT also stated that there is the possibility that some of the existing PAT test components could be included in the new physical employment standard, however, this would need to be investigated in the next phase (phase 3) of the research.

NT provided the details of the data collected during the phase 2 simulations, and the methodology used to determine the physically demanding tasks that impose meaningful levels of physiological strain upon firefighters.

All 9 of the recommendations leading to the list of criterion firefighting tasks were discussed in detail. The criterion tasks were broken down into 4 classes detailed in the Executive Summary.

AD called for the endorsement of the criterion task list by all members of the project management team present. All agreed.

AD also called for the UOW research team to be provided with approval to progress to phase 3 of the project (development of physical screening tests). All agreed.

JS asked that the inclusion of the sledge axe criterion task in any physical screening assessment be carefully considered in light of the availability of alternative tools to assist with this task.

BM reinforced that the results of the focus groups and survey has led to the inclusion of the sledge axe task. NT advised that the cross-over between all tasks will be analysed in the remaining phases of the research.

It was also noted that the scope of this project is to provide recommendations on physical employment standards. Tasks including mechanical reasoning and assessment of claustrophobia etc., while outside the scope of the work may be integrated into the pre-employment process, and may sit alongside the physical employment standard.

The high temperatures experienced during summer at different locations throughout NSW, and the potential effects on physical performance were discussed. NT agreed to consider this during the next phase of the research, however, he explained that the degree of variability in environmental conditions could be difficult to control for during physical screening assessments.

The question of age and gender scaling was raised by JH. It was explained that it was important that physical employment standards were age- and gender-neutral.

It was also discussed that a tiered approach to physical screening between metropolitan and regional stations depending on the job requirements would be considered in the next phases of the project. This requires further discussion and investigation, including the use of the resource allocation model.

ACTIONS

(1) It was agreed to endorse the phase 2 report including the nine recommendations and criterion task list.
(2) It was agreed that the UOW research team would proceed to Phase 3 of the research.
(3) Communication to the organisation to request Firefighters to assist in the testing phase.