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**PHYSIOLOGICAL EMPLOYMENT STANDARDS
FOR FIREFIGHTERS: *REPORT 3*: PHYSICAL
APTITUDE TESTS FOR CONTEMPORARY
FIREFIGHTERS.**

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Physiological employment standards for firefighters: *Report 3: Physical aptitude tests for contemporary firefighters.*

EXECUTIVE SUMMARY

Background:

During emergency operations, heavy physical demands are placed upon firefighters. Employees within these roles are expected to possess the necessary physical and physiological attributes for this occupation. Thus, the identification of individuals with such attributes would simultaneously increase the capability of the workforce whilst minimising the risk of injuries to both firefighters and members of the community. One strategy that might facilitate these outcomes is the development of legally defensible physical employment standards.

The current investigators have been tasked with developing screening tools and physiological standards to facilitate the identification of capable and robust recruits for Fire & Rescue 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 both the number unsuitable recruits chosen, and the number of suitable candidates who might be rejected. 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 form 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

Project phase	Step	Description
3	11	Develop defensible physiological screening tests
	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 the current Research Phase was to develop legally defensible physiological screening tests for firefighters. In this report, the methods and outcomes of the Third Phase of this large project are described, leading to the identification of valid and approved screening tests that may be used to screen potential fire-fighting recruits.

The observations arising from these investigations have been built upon three solid foundations arising from Research Phase One of this project (Taylor *et al.*, 2012a):

- Focus-group sessions (106 firefighters) identified the fifty most physically demanding (occupational) tasks performed by contemporary firefighters.
- Consultation with Executive Staff and high-level, subject-matter experts from Fire & Rescue NSW consolidated these tasks into thirty activities.
- A survey of firefighters (> 1,000 participants) concerning these tasks permitted the identification of fifteen fire-fighting tasks deemed to be the most demanding, most critical and most frequently performed: these became the critical physical activities of fire fighting (Table E-2).

Table E-2: The fifteen critical physical tasks of fire-fighting (Taylor *et al.*, 2012a).

Critical fire-fighting tasks
Critical task 1: Hazmat task
Critical task 2: Motor-vehicle rescue
Critical task 3: Rolling out hose (70 mm)
Critical task 4: Coupling hoses
Critical task 5: Locating and connecting to hydrant
Critical task 6: Drag charged 70-mm hose (lateral)
Critical task 7: Fire attack
Critical task 8: Firefighter down (rescue)

Critical fire-fighting tasks
Critical task 9: Dragging charged 38-mm hose (uneven terrain)
Critical task 10: Stair climb dragging charged hose
Critical task 11: Prolonged use of hose (38 mm)
Critical task 12: Prolonged use of hose (70 mm)
Critical task 13: Ladder use (10.5 m)
Critical task 14: Stair climb with ventilation fan
Critical task 15: Using sledge axe to gain entry

Note: The critical task numbers match those used in Taylor *et al.* (2012b) to identify the fifteen simulations investigated in that Research Phase.

From Research Phase Two of this project, a sub-set of tasks was sought 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 it would be inefficient to consider using all fifteen activities within such screening, the Research Team excluded tasks if efficiencies could be gained without compromising the integrity of the process:

- A filtration schema permitted the culling of tasks to minimise the duplication of movement patterns and loads.
- Four critical tasks from Table E-2 were eliminated during this step:
 - Critical task 4: Coupling hoses
 - Critical task 6: Drag charged 70-mm hose (lateral)
 - Critical task 11: Prolonged use of hose (38 mm)
 - Critical task 12: Prolonged use of hose (70 mm).
- The remaining tasks became the criterion physical activities of fire fighting (Taylor *et al.*, 2012b), and were carried into the next Research Phase.

Methods:

The first step in this process was an overall evaluation of these criterion tasks. Since there were movement pattern similarities across these tasks, then each criterion task was classified into one of four different movement categories. These are presented in Table E-3.

Table E-3: Criterion task movement classifications.

Criterion task class	Class descriptions	Criterion tasks
1	Single-sided carrying tasks	Hazmat task
		Rolling out hose (70 mm)
		Locating and connecting to hydrant
		Drag charged 70-mm hose (lateral)
		Ladder carriage (10.5 m)

Criterion task class	Class descriptions	Criterion tasks
		Prolonged use of hose (38 mm)
		Prolonged use of hose (70 mm)
		Stair climb with ventilation fan
2	Overhead push and holding tasks	Motor-vehicle rescue
		Ladder under-run (10.5 m)
		Using a sledge axe to gain entry
3	Cardiorespiratory dragging tasks	Fire attack
		Dragging charged hose (38 mm)
4	Crucial strength tasks	Stair climb with charged hose
		Firefighter down (rescue)

Each of these criterion tasks was then reviewed with respect to three exclusion criteria:

- a low relative, whole-body physiological (metabolic) demand,
- movement task duplication, or
- the availability of suitable substitution tasks.

Should any task satisfy one or more of these characteristics, it was considered for elimination. In this way, efficiencies within the proposed assessment battery could be found, without compromising either the sensitivity or specificity of the task battery.

Following these classifications, six constraints of practical or logistical significance were considered when determining the suitability of each task, or a modification thereof, for inclusion within an occupation-specific physical aptitude test.

- environmental constraints: locations and facilities for test administration, and climatic variations
- equipment constraints: personal protective clothing and equipment
- the height of the operating posture (below the neutral plane) for firefighters to avoid excessive heat and smoke exposure
- the structures and surfaces used during ambulatory and load-carriage tasks
- the mass to be used for the crucial strength task (firefighter mass)
- the correlation of generic lifting and locomotor activities with criterion tasks.

Proposed physical aptitude test (PAT):

On the basis of this distillation process and the task constraints noted above, the Research Team suggested a preliminary format for these firefighter assessments. It is proposed that these physical tests (physical aptitude test: PAT) be conducted in the form of an activity sequence (circuit) involving the following five components:

- single-sided (unilateral) carriage task or tasks
- holding task or tasks (above and below shoulder height)

- hose drag
- fire attack
- firefighter rescue.

Proposed physical assessment circuit

The Research Team recommends that the physical aptitude test be performed as an uninterrupted sequence of tasks (Figure E-1) that target each of the criterion task classes identified in Table E-3. It is further recommended that satisfactory performance would be determined on the basis of the total time required to complete the circuit test. The minimal time standard would be determined in the next Research Phase of this project, and it would be dependent upon the minimal acceptable work tempo for the tasks within the circuit, as determined by Fire & Rescue NSW, and as performed by existing operational firefighters within fire-fighting simulations (Taylor *et al.*, 2012b). This circuit-style approach for the performance of multiple critical assessment tasks is well established, and has been validated within the literature for other emergency service and military occupations (Considine *et al.*, 1976; Brownlie *et al.*, 1985; Jamnik *et al.*, 2010a and 2010b; Taylor *et al.*, 2003). Moreover, such an approach would simulate the physical demands and the required task sequence that may realistically be encountered at an incident, in which there would be preparation prior to engaging the fire, fire fighting and the performance of a search and rescue.

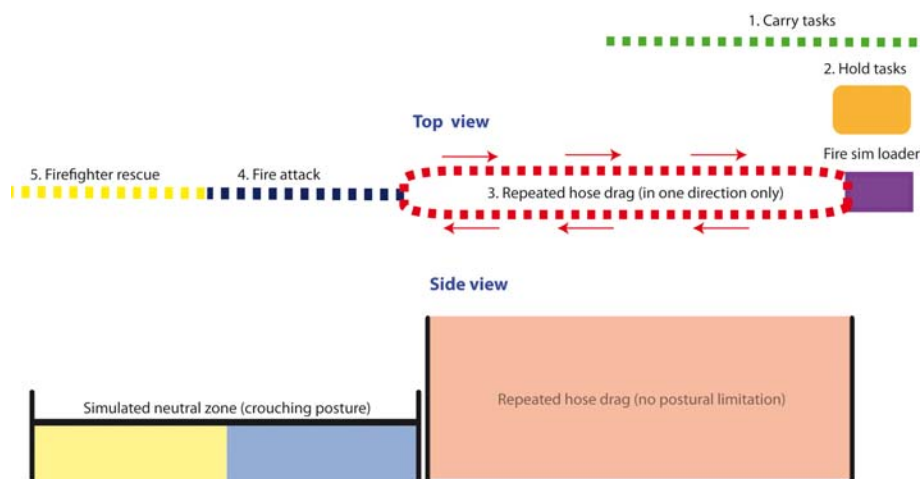


Figure E-1: Proposed test physical aptitude test (circuit) for assessing criterion firefighter tasks. It is recommended this test series be performed in the following order: single-sided (unilateral) carriage task, holding task, hose-drag task, fire-attack task and a firefighter rescue simulation.

It is proposed that an operational height restriction be imposed for the fire-attack and rescue tasks. Since these activities are typically performed with firefighters adopting a semi-crouched posture to minimise the risk of heat and smoke exposure, then this posture should form an integral test component, permitting an assessment of manual handling within somewhat confined spaces. The lower-left half of Figure E-1 shows this height restriction.

Discussion and recommendations:

The Research Team proposes that, if an individual could satisfactorily complete all of the activities within each the criterion task classes of Table E-3, then this person would possess the minimal physiological attributes desired of a contemporary firefighter. However, under operational scenarios, these tasks are performed without rest, and typically above some minimal acceptable speed. Therefore, an elapsed-time standard for this circuit (physical aptitude test) is recommended, as this will allow for individuals of varying physiological attributes to successfully complete the test. Thus, whilst a slow overall performance may not be deemed acceptable, recruits who may be weaker in one test area can compensate by possessing greater abilities on other tasks.

Recommendations and requests for further information

The following recommendations and information requests are tendered to the Project Management Team concerning the proposed physical aptitude test:

Recommendation one: It is recommended that the physical aptitude test be performed as an uninterrupted sequence of tasks (circuit), such that the test replicates the likely intensity and physical demands of a range of activities that may realistically be conducted at an incident. In addition, it would be required that these tasks be completed without rest.

Recommendation two: It is recommended that the physical fitness assessment circuit be developed with full consideration of the operational constraints that exist for Fire & Rescue NSW. Thus, the assessment battery must be able to be deployed consistently across the entire State.

Recommendation three and request one: It is recommended that the physical aptitude test (circuit) be completed with participants wearing about 20 kg of added mass. This is designed to simulate the combined mass of the personal protective clothing and equipment currently used by Fire & Rescue NSW. There is no need for the personal protective equipment to be deployed, but the protective clothing (with the exception of the boots) must be worn during testing (including the helmet), as this ensemble significantly influences flexibility, ranges of joint motion, the performance of heavy exercise (Taylor *et al.*, 2010), and the metabolic demand of locomotion (Taylor *et al.*, 2012c). It is recommended that all test participants wear the standard protective clothing used by Fire & Rescue NSW. It is further recommended that an additional mass, equal to the combined average masses of standard-issue boots, the self-contained breathing apparatus and other standard equipment used during structural fire fighting, be added to each test participant. If required, this equipment load could be simulated through the use of a weighted vest. It is requested that Fire & Rescue NSW determines this mass, and then provides this specification to the Research Team.

Recommendation four: It is recommended that further investigation be undertaken (Phase Four of this project) to assess the ability of simple lifting tasks to predict performance on more complex fire-fighting activities. For example, it is possible

that some highly reproducible, and easily performed tests may reliably predict this performance, and thereby enable a simplification of the criterion holding task. It is also possible that more than one lifting task could be incorporated into the test.

Recommendation five and request two: For the holding task of the aptitude test (item two), the Research Team requires advice from subject-matter experts. It is requested that Fire & Rescue NSW determines whether this holding task is to be performed at a fixed absolute or at some relative height? If the former is adopted, then the Research Team needs to know this height. If the latter is chosen, then the Research Team needs to know this in the form of a percentage of each participant's standing height.

Recommendation six: It is recommended that the frictional loads for the dragging tasks (hose drag, fire attack and firefighter rescue) be applied through a custom-made resistance device: a line and reel resistance loader. The Research Team will investigate appropriate frictional (braking) devices that may satisfy this requirement, whilst ensuring that all such tests are reliable, reproducible and legally defensible.

Recommendation seven and request three: Within the fire-attack and firefighter-rescue tasks, it is recommended that all participants be required to adopt safe operating postures (below the neutral plane) to simulate the avoidance of excessive heat and smoke exposure. The resulting semi-crouched position will be determined so that each participant keeps his/her helmet below the same fixed height. This will also facilitate an assessment of each participant's ability to operate within somewhat confined spaces. It is requested that Fire & Rescue NSW determines the height of this neutral plane, and then provides this specification to the Research Team.

Recommendation eight: It is recommended that further investigation be undertaken (Phase Four of this project) to establish a correlation between load-carriage tasks that require the negotiation of stairs, and those that are performed on predominately flat surfaces. Since access to stairs for recruit testing may not be possible across the State, then this evaluation is aimed at permitting the prediction of load carriage on stairs from load-carriage performance on flat ground.

Recommendation nine and request four: For the one-person, firefighter-rescue task of the aptitude test, it is proposed that a dummy not be dragged, as this can introduce frictional variations across test days and sites. Instead, it is recommended that a fixed resistance be applied through the use of a bespoke line and reel resistance loader. However, for the loading of this device to be set appropriately and at a defensible level, Fire & Rescue NSW must determine the standard mass for this task. Factors that must be considered here relate to the anticipated person to be rescued, and the clothing and equipment worn by that person. It is requested that Fire & Rescue NSW determines this mass, and then provides this specification to the Research Team.

Verification and approval of the staged screening tests

These screening tests were submitted to the Project Management Team for consideration, endorsement and validation. Approval to progress to the final research Phase (development of physiological employment standards for firefighters) was also sought at this meeting. These outcomes were each achieved at the Project Management Team meeting held on 22nd of June (2012: Appendix Three of this report).

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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.

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1. INTRODUCTION

Numerous occupations around the world place high, and sometimes excessive physical demands on the body. Indeed, fire fighting is recognised globally as a physically demanding occupation, requiring attributes such as high endurance (aerobic) fitness and muscular strength (Davis *et al.*, 1982; Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001). A contemporary firefighter is expected to fulfil numerous roles in addition to fire suppression, including responding to transport accidents, natural disasters, rescue and hazardous materials incidents. Many of these roles place firefighters under significant physiological and physical strain. 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).

It is therefore crucial the employee possesses the necessary medical profile (Hocking, 2010), as well as the physical and physiological attributes to tolerate the subsequent demands of the profession. Such employees are most likely to undertake the essential fire-fighting tasks in a safe and productive manner, and are well suited to coping with such extremes of physiological strain. Accordingly, numerous physically demanding occupations now require employees to pass *bona fide* physical fitness standards (Gledhill and Jamnik, 1992a; Taylor and Groeller, 2003; Doherty *et al.*, 2007). 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 process of recruitment and subsequent training must deliver a well-skilled and capable workforce. Given the high injury rates of firefighters (170.5 injuries per 1,000 full time firefighters per annum (Taylor and Kerry, 2010)), Fire & Rescue NSW have a legal obligation to identify those individuals who are less capable of performing the physically demanding fire-fighting tasks, and who, during the performance of various fire fighting roles, would be exposed to an unacceptable risk of injury. Pre-employment screening can serve this need. Moreover, stronger employees are clearly associated with fewer injuries in fire fighting (Cady *et al.*, 1985) and other manual-handling occupations (Chaffin, 1974), such as the Navy (Marcinik, 1986). Nevertheless, the employer must also ensure that no individuals, or groups of individuals, are discriminated against or treated less favourably.

This project involves five discrete Research Phases, with the research reported herein representing the Third Phase of the investigation, in which screening tests were developed that may be used to select appropriate individuals as potential firefighters. Following the completion of Phase Two, in which operational firefighters were studied whilst performing a broad range of physically, critical demanding fire-fighting tasks, the Research Team developed suitable screening test recommendations for firefighters, and this report summarises those recommendations.

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 framework for the overall project. The current research is focussed upon steps eleven to thirteen of Phase Three.

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
	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

Project phase	Step	Description
	18	Implement pre-employment screening
		Review the screening process and its outcomes: ongoing

1.2 Considerations for screening tests

At a superficial level, the current Fire & Rescue NSW physical aptitude test (PAT) appears to be relevant to the tasks performed by firefighters. Despite having appropriate face validity with fire fighting, there is, at present, insufficient scientific evidence to support either the chosen assessment components or the minimum standards of performance used to recruit firefighters. Moreover, the current screening tests used by Fire & Rescue NSW were based upon standards that were determined almost 20 years ago (Gledhill and Jamnik, 1992a). During the ensuing years, significant operational and equipment changes were necessary to ensure that Fire & Rescue NSW remained both a contemporary and an effective organisation. With these changes, the physical and physiological demands of fire fighting were modified. Within Phases One and Two and of this large project, the focus was upon identifying and evaluating the critical tasks that imposed the greatest physiological burden upon firefighters. In this Third Research Phase, attention is directed to the development of task-specific assessments of potential firefighters, whilst ensuring that the full demands of the occupation were adequately represented in the provision of valid screening tests that have of a predictive capacity for occupational performance. This will be achieved through the targeting of key physiological attributes related to this unique job. These screening tests are designed to reflect the key physiological demands that are performed and experienced on the fire ground, leading to the selection of appropriate individuals to become firefighters.

Three key limitations within this process are personal safety, the financial burden of testing on the employer and task performance skill. Given the high reward for passing a screening test (*i.e.* employment), there is an increased likelihood for highly motivated participants to injure themselves during testing (Ayoub *et al.*, 1982), especially if these tests include high-capacity, manual-handling tasks (Snook *et al.*, 1978). Secondly, screening tests can be expensive to implement if administered State wide. The added cost of transporting equipment or the necessity to use different test locations may place a significant financial burden on the organisation. Thirdly, consideration must be given to the level of skill included within some screening tests (Equal Employment Opportunity, 1978; Constable and Palmer, 2000). Whilst there is no doubt that a significant skill element is present in many fire-fighting tasks, the degree to which the skill dictates the successful completion of the task must be carefully managed. However, given that firefighter-specific skills form a critical part of training, and that these skills can be taught after recruitment, employment screening tests should primarily target physiological attributes that can be evaluated independently of skill or task performance proficiency. Such an approach will identify people who are well suited to undertake fire-fighting tasks in a safe and productive manner, and who are able to tolerate the physiological strain associated with fire fighting.

Due to these limitations, it is important to investigate, where applicable, alternative

approaches to the mere duplication or simulation of critical fire-fighting tasks. For instance, when a strong relationship between a basic physical test (*e.g.* grip-strength test) and a critical work task (*e.g.* using a sledge axe) can be identified, such a generic test can be substituted, as it will possess criterion validity, and can be used to predict occupational task performance (Equal Employment Opportunity, 1978). Strong correlations with strength measures and manual-handling task performance, especially with progressions in resistance training, are known to exist (Sharp *et al.*, 1993a; Kraemer *et al.*, 2001). Thus, the use of more generic tests would not only be justified, but these would help to alleviate some limitations to testing. Therefore, when grouping and filtering fire-fighting tasks into possible screening tests, the Research Team deliberately categorised tasks into classes in which such correlations would be likely to exist, and this grouping was based upon shared common movement characteristics and physiological attributes.

1.3 Research aims

The aim of this Research Phase was to develop screening tests that might be used to select appropriate fire-fighter recruits. A primary consideration during test development was the capacity of each test to be administered across the State, and without the need for extensive equipment, support personnel or resources. These tests were designed to be performed with participants wearing the full thermal protective ensemble, plus a load equivalent to the combined mass of the personal protective equipment. These tests should also incorporate the physical characteristics of the fifteen critical fire-fighting tasks previously identified (Taylor *et al.*, 2012b; Table 2).

Table 2: The fifteen critical physical tasks of fire-fighting (Taylor *et al.*, 2012a).

Critical fire-fighting tasks
Critical task 1: Hazmat task
Critical task 2: Motor-vehicle rescue
Critical task 3: Rolling out hose (70 mm)
Critical task 4: Coupling hoses
Critical task 5: Locating and connecting to hydrant
Critical task 6: Drag charged 70-mm hose (lateral)
Critical task 7: Fire attack
Critical task 8: Firefighter down (rescue)
Critical task 9: Dragging charged 38-mm hose (uneven terrain)
Critical task 10: Stair climb dragging charged hose
Critical task 11: Prolonged use of hose (38 mm)
Critical task 12: Prolonged use of hose (70 mm)
Critical task 13: Ladder use (10.5 m)
Critical task 14: Stair climb with ventilation fan
Critical task 15: Using sledge axe to gain entry

Note: The critical task numbers match those used in Taylor *et al.* (2012b) to identify the fifteen simulations investigated in that Research Phase.

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
Jim Smith	Acting Deputy Commissioner Emergency Management (FRNSW)	Steering Committee Member
Rick Griffiths	Acting Director Regional Operations (FRNSW)	Steering Committee Member
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 Methodological overview

2.2.1 Characterisation of critical fire-fighting tasks

The occupational task analysis conducted within Phase Two of this project (Taylor *et al.*, 2012b) achieved several essential outcomes:

- characterisation of the physiological and physical demands associated with performing the fifteen critical tasks of fire fighting (Table 2)
- elimination of four less demanding critical tasks from this Table:
 - Critical task 4: Coupling hoses
 - Critical task 6: Drag charged 70-mm hose (lateral)
 - Critical task 11: Prolonged use of hose (38 mm)
 - Critical task 12: Prolonged use of hose (70 mm)

- this elimination resulted in eleven tasks being carried into the current Research Phase: these are the criterion tasks of fire fighting (Table 4).

Table 4: The eleven criterion physical tasks of fire-fighting (Taylor *et al.*, 2012b).

Criterion fire-fighting tasks	Strength-muscle endurance	Cardiorespiratory endurance
Hazmat task	hold and carry (upper body)	
Motor-vehicle rescue	hold and carry (upper body)	
Rolling out hose (70 mm)	hold and carry (upper body)	
Locating and connecting to hydrant	hold and carry (upper body)	
Fire attack	push, pull, drag (lower body)	
Firefighter down (rescue)	push, pull, drag (upper body)	
Dragging charged hose (38 mm: uneven terrain)		loaded upper-body task
Stair climb dragging charged hose	push, pull, drag (upper body)	
Ladder use (10.5 m)	hold and carry (upper body)	
Stair climb with ventilation fan	hold and carry (upper body)	
Using sledge axe to gain entry		loaded upper-body task

Also within the previous Research Phase, these tasks were categorised into two broad groups based on the predominant physical fitness attribute upon which each task was dependent. The first group was comprised of the strength and muscular endurance tasks, which made up 73% (eight of the eleven) of the tasks (Table 4). These tasks were then classified into upper- or lower-body activities, and finally sub-divided according to the dominant movement characteristics:

- pushing, pulling and dragging actions: three tasks (27%)
- holding and carrying actions: six tasks (55%)
- lifting and placing actions: no tasks
- twisting and turning actions: no tasks.

The second group of tasks relied upon whole-body (cardiorespiratory) endurance.

2.2.2 Selecting criterion fire-fighting tasks for physical aptitude testing

The current Research Phase (Phase Three) required the re-appraisal of each of the criterion tasks to determine its suitability for use, or modification, within an occupation-specific physical aptitude test (PAT). The first stage of this evaluation commenced with a meeting (May 21st, 2012) between the Research Team and the Project Liaison Officer of Fire & Rescue NSW (Brendan Mott).

The first purpose of this meeting was to present and evaluate a preliminary proposal for the classification of the criterion tasks. Since there were movement pattern similarities across these tasks, then each criterion task was classified into one of four different movement categories. During these discussions, it was decided to sub-divide the ladder task into two parts (carrying and under-running) as it was considered to fall within each of two different movement classes. These classifications are presented in Table 5. The second aim was to identify operational constraints that may subsequently influence test selection, design and implementation. Finally, criteria were discussed upon which individual tasks may be eliminated from the list, since it was considered that some duplication may exist among these criterion tasks, and a culling would increase testing efficiency.

Table 5: Criterion task movement classifications.

Criterion task class	Class descriptions	Criterion tasks
1	Single-sided carrying tasks	Hazmat task
		Rolling out hose (70 mm)
		Locating and connecting to hydrant
		Drag charged 70-mm hose (lateral) ¹
		Ladder carriage (10.5 m)
		Prolonged use of hose (38 mm) ¹
		Prolonged use of hose (70 mm) ¹
		Stair climb with ventilation fan
2	Overhead push and holding tasks	Motor-vehicle rescue
		Ladder under-run (10.5 m)
		Using a sledge axe to gain entry
3	Cardiorespiratory dragging tasks	Fire attack
		Dragging charged hose (38 mm)
4	Crucial strength tasks	Stair climb with charged hose
		Firefighter down (rescue)

Six constraints of practical or logistical significance were identified and discussed in detail:

- environmental constraints: locations and facilities for test administration, and

¹ Three tasks that had previously been removed in Research Phase Two (dragging charged 70-mm hose; prolonged use of 38-mm and 70-mm hoses: indicated with yellow highlighting) were returned to the pool of fire-fighting activities. The effect of this re-evaluation, should they be eliminated again, was that FRNSW could then have confidence in the validity of these filtration stages, should this process later be challenged.

climatic variations

- equipment constraints: personal protective clothing and equipment
- the height of the safe operating posture (below the neutral plane) for firefighters to avoid excessive heat and smoke exposure
- the structures and surfaces used during ambulatory and load-carriage tasks
- the mass to be used for the crucial strength task (firefighter mass)
- the correlation of a “lift and place” activity with tasks that required the holding of variously sized objects.

Each constraint was carefully considered when determining the suitability of any criterion task, or a modification thereof, for inclusion within the physical aptitude test.

Three exclusion criteria were identified:

- a low relative, whole-body physiological (metabolic) demand
- movement task duplication
- the availability of a suitable substitution task or tasks.

Should any task satisfy one or more of these characteristics, it was considered for elimination by Research Team. In this way, efficiencies within the proposed fire-fighter physical aptitude test could be found, without compromising either the sensitivity or specificity of the proposed task battery.

2.2.2.1 Exclusion criterion one: low-level physiological demand

On the basis of a low-level, whole-body physiological (metabolic) demand, one critical task (coupling hoses) had been eliminated within Phase Two of this project (Taylor *et al.*, 2012b). In this Third Research Phase, three further tasks were eliminated from further consideration on the basis of this criterion: rolling out hose (70 mm); prolonged use of a hose (38 mm); prolonged use of a hose (70 mm).

Rolling out hose (70 mm): The average task heart rate (144 beats.min⁻¹) and absolute oxygen consumption (1.58 L.min⁻¹) were similar to values observed during other simulations (Taylor *et al.*, 2012b). However, from the feedback of focus groups (Taylor *et al.*, 2012a) and the low ratings of perceived exertion (mean 11.6; scale 6-20), this task was considered to be both low in difficulty and overall physiological demand.

Prolonged use of hoses: Using both the 38-mm and 70-mm fire hoses resulted relatively low physiological strain, with mean working heart rates of 113 and 123 beats.min⁻¹, and average absolute oxygen consumption of 0.55 and 0.56 L.min⁻¹ (respectively: Taylor *et al.*, 2012b). Since the ladder-use tasks and the hazmat simulation shared common movement patterns and muscle activation characteristics, and since they both yielded much greater physiological strain and ratings of perceived exertion (Taylor *et al.*, 2012b), then these two tasks were considered to be of sufficiently low physiological (metabolic) demand to warrant exclusion.

2.2.2.2 Exclusion criterion two: movement task duplication

The primary movement characteristics of each task was studied in detail. This revealed that six of the criterion tasks could be described as possessing “hold and carriage” movement

requirements (Table 4). Within this movement requirement, tasks were identified for which there may have been movement duplication or strong movement similarities. For example, a duplicate task may have a similar loaded mass, duration, posture, points of anchorage (*e.g.* grip with the object), load bearing (bilateral or unilateral), and horizontal or vertical displacement.

Prolonged use of a hose (38 mm): Using these criteria, three tasks were identified: prolonged use of a hose (38 mm); the hazmat simulation and the stair climb carrying the ventilation fan. These entailed prolonged holding and carrying actions. Each was an upper-body task with predominately a unilateral anchorage. Given that tasks two and three were of similar duration, postures and anchorage points, but used heavier loads, task one was again recommended for elimination.

2.2.2.3 Exclusion criterion three: availability of a substitution task

A suitable substitution task is one in which the movement pattern is very similar to another criterion task, but the load that is carried may be heavier, or the task duration longer.

Dragging charged 70-mm hose (lateral movement): This criterion task was a prolonged upper-limb, loaded and strength-based “hold and carry” activity. As such, it was deemed to share common movement characteristics with the ladder use and stair climb with ventilation fan tasks. Given the low physiological demand of moving a charged 70-mm hose laterally (at least within the simulations provided for the Research Team: heart rate 136 beats.min⁻¹, oxygen consumption 0.83 L.min⁻¹ and perceived exertion 10.5 (Taylor *et al.*, 2012b)), it was proposed that this task could be substituted by either the ladder use and stair climb with ventilation fan tasks, as both of these tasks elicited greater physiological strain. Therefore, it was assumed that, if a firefighter could adequately perform either of these harder tasks, then he/she would be able to perform the hose drag task. On this criterion, this task was recommended for elimination.

Stair climb dragging a charged hose: The firefighter-rescue task possesses similar attributes to the stair climb whilst dragging a charged hose. Both tasks entail significant upper- and lower-body strength, and there were similarities in their movement patterns. The loaded vertical displacement component of this stair-climb task would also be observed within the stair climb when carrying the ventilation fan, which also possessed a similar lower-body strength requirement. Thus, if an individual could perform the more demanding of these tasks, then this person could be deemed to be capable of performing both tasks. Moreover, it was deemed that the firefighter rescue was an operationally more critical activity. Therefore, it was recommended that the stair climb with a charged hose could be eliminated on the basis of multiple task substitution.

Using these processes, five criterion tasks were removed (Table 6), with the remaining tasks forming the basis for the physical aptitude test (Table 7).

Table 6: Criterion fire-fighting tasks recommended for elimination.

Criterion tasks	Reason for exclusion
Rolling out hose (70 mm)	Low physiological demand
Dragging charged 70-mm hose	Task Substitution
Stair climb dragging charged hose	Task Substitution
Prolonged use of a 38-mm hose	Low physiological demand and task duplication
Prolonged use of a 70-mm hose	Low physiological demand and task substitution

Table 7: Criterion tasks recommended for the physical aptitude test.

Criterion tasks
Hazmat task
Motor-vehicle rescue
Locating and connecting to hydrant
Fire attack
Firefighter down (rescue)
Dragging charged 38-mm hose (uneven terrain)
Ladder use (10.5 m): carriage and under-running
Stair climb with ventilation fan
Using a sledge axe to gain entry

2.2.3 A closer examination of load-carriage tasks

Due to the high representation of “hold and carriage” tasks within the operational roles of the firefighter, a more detailed assessment of the load-carriage activities was undertaken. In the first instance, these tasks were further sub-classified into the following groups:

- Tasks that were predominately holding activities:
 - Motor-vehicle rescue (typical load: 20 kg)
 - Ladder under-running (10.5 m: 25 kg)
 - Using a sledge axe to gain entry (4.7 kg)
- Tasks that were predominately load-carriage activities:
 - Hazmat task (typical load: 27 kg)
 - Locating and connecting to hydrant (20 kg)
 - Ladder carriage (10.5 m: 25 kg)
 - Stair climb with ventilation fan (single person: 17.5 kg).

2.2.3.1 Lifting and holding above shoulder height

Two criterion tasks required firefighters to lift and hold loads above shoulder height: the ladder under-run and the motor-vehicle rescue. These tasks require special consideration.

It was observed within Phase Two of this investigation, that many holding tasks not only had an obvious static component, where the mass of the object required support for a fixed time, but these holding positions occurred across a range of postures, such that loads were held close to the ground and also above the shoulder. During the Fire Station visits conducted within Phase One of this project, firefighters reported that above-shoulder activities were the among most difficult tasks to perform (Taylor *et al.*, 2012a). This view is consistent with our understanding of the mechanical loading of the body. Indeed, when maximal lifting tasks require lifts to heights above the shoulder, the maximal load that can be successfully lifted is significantly lower (Ayoub *et al.*, 1979, Mital, 1984). This is due to these actions forcing movements to occur over movement ranges where strength is lower due to changes in lever length and stability (Warwick *et al.*, 1980). This possibly explains the high prevalence of injuries in long-duration, manual-handling tasks performed in awkward work postures (Ljunberg *et al.*, 1989).

2.2.3.2 Unilateral load carriage

Four criterion tasks required the unilateral (single-sided) carriage of a load. Each task demanded a single-sided anchorage with the load (*e.g.* ventilation fan). Two of these activities (ventilation fan and ladder carry) required two-person lifts. It has been assumed that the loads associated with each task were equally distributed between the lifters. This assumption allows for improved comparisons to be made between these load-carriage tasks.

Whilst occupational standards for one-person lifting and load-carriage activities are sometimes simply doubled for two-person tasks (Military Standard 1472 U.S., 1989), the sum of the combined individual lifts has been reported to exceed that for paired or team lifts (Karwowski and Mital, 1986; Karowski *et al.*, 1988; Sharp *et al.*, 1993b). That is, people are often unable to exert maximal force when lifting with another person. Furthermore, relative loads borne by individuals in team lifts vary according to the characteristics of the object that is lifted, and they also vary dynamically during the course of the lift, particularly when differences in stature exist between members of the lifting team.

2.2.3.3 Dragging tasks

Three criterion tasks remained for further consideration: the fire attack, the firefighter rescue and dragging a charged 38-mm hose over uneven terrain. Each of these tasks is characterised by its primary movement being the dragging of loads. However, the duration of each task varied markedly, with the dragging of a charged 38-mm hose (bushfire simulation) lasting approximately 13 times longer than either of the other tasks. This dictated that this criterion task needed to be simulated within the physical aptitude test. Furthermore, since both the fire attack and the firefighter rescue were considered to be critical and mandatory tasks, then these too needed to be evaluated within the aptitude test.

2.2.4 Recommendations for the physical aptitude test

Following this filtration process, nine criterion tasks remained, one of which had been subdivided into two activities (ladder use). These tasks, and their corresponding movement classifications are listed in Table 8. The Research Team proposes that, if an individual could satisfactorily complete all of the activities within each the criterion task classes of Table 8, then this person would possess the minimal physiological attributes desired of a

contemporary firefighter.

2.2.5 Key points requiring decisions and recommendations from Fire & Rescue NSW

2.2.5.1 Environmental constraints to physical aptitude testing

In the development of a physical aptitude test, the Research Team discussed with Fire & Rescue NSW the physical and environmental constraints of deploying the assessment battery. It became apparent that standardising the test environment would be challenging, and the several environmental constraints were identified, defined and considered during the development of the assessment battery.

Table 8: Criterion task movement classifications.

Criterion task class	Class description	Criterion tasks
1	Single-sided carrying tasks	Hazmat task
		Locating and connecting to hydrant
		Ladder carriage (10.5 m)
		Stair climb with ventilation fan
2	Overhead push and holding tasks	Motor-vehicle rescue
		Ladder under-run (10.5 m)
		Using a sledge axe to gain entry
3	Cardiorespiratory dragging tasks	Fire attack
		Dragging charged hose (38 mm)
4	Critical strength task	Firefighter down (rescue)

Test venue: Fire & Rescue NSW advised that testing needed to occur within towns across the State. It was suggested that indoor halls or sporting fields could be used, or that testing could be modified to suit the specific constraints at each Fire Station.

Test surface: Access to uniform flat and open spaces throughout the State would not be likely. This limitation could render it almost impossible to deploy a valid and reproducible physical aptitude test throughout NSW. It was suggested that local sporting fields may be suitable.

Access to stairs: Some criterion tasks were stair-climbing activities. To evaluate these tasks, access to consistent flights of stairs would be required. However, since this would not be possible across the State, then this limitation would also adversely affect the validity and reproducibility of the physical aptitude test across venues.

Operational equipment: Concerns were raised regarding the use of specific fire-fighting equipment within operational Fire Stations, such that testing may reduce

the operational capability of some Stations.

Climatic variations: It was noted that a lack of control over climatic conditions may affect test outcomes at some venues. In the opinion of the Research Team, this environmental consideration, whilst important, would be almost impossible to manage consistently. However, it is recognised that significant variations in ambient conditions will influence the performance of strenuous physical tasks (Sköldström, 1987). Thus, some standardisation of the ambient conditions is required. The Research Team believes tests standards could be implemented to minimise the effects of variations ambient temperature on test performance, although the research that may be require to validate this may be both expensive and time consuming. It is therefore proposed that an upper air temperature limit be set for conducting these assessments. This could be set by Fire & Rescue NSW in consultation with experts in this fields and subject-matter experts with Fire & Rescue NSW.

2.2.5.2 Incorporating safe operating postures (below neutral plane) into aptitude testing

The Research Team understands that firefighters are instructed to adopt safe operating postures (below the neutral plane) to avoid excessive heat and smoke exposure. This results in firefighters working a semi-crouched position, and this will significantly affect the performance of physically demanding tasks. Thus, it is recommended that some aspects of the physical aptitude test be undertaken within a clearly defined height limitation. Such a limitation could be easily and consistently applied within a test battery, through the use of vertical markers or horizontal lines set at the appropriate height, and forcing participants to perform some test items within this defined zone. However, the height of this neutral plane will vary, being dependent upon the intensity and temperature of the fire, prevalence of gases in the surrounding atmosphere, the height of the room or surroundings, and, to some extent, the stature of the firefighters. It is proposed that this height must be standardised, such that same height would be used at all test venues. It is further proposed that this height be set by subject-matter experts within Fire & Rescue NSW.

2.2.5.3 Clothing and equipment constraints to physical aptitude testing

Fire & Rescue NSW provided the following clarification regarding the use of personal protective clothing and equipment during physical aptitude testing:

- standard protective clothing will be made available for testing
- this will include: helmet, flash hood, structural fire-fighting ensemble and gloves, but not boots.

It is proposed that physical aptitude testing be conducted with individuals wearing the full personal protective clothing ensemble (t-shirt, trousers, overpants, tunic, flash hood, gloves, helmet). This is deemed necessary since this protective clothing significantly influences flexibility, ranges of joint motion and the performance of maximal exercise, both under controlled laboratory conditions and on a fire-fighting obstacle course (Taylor *et al.*, 2010). In addition, this ensemble has a powerful affect on the metabolic demand of locomotion (Taylor *et al.*, 2012c). Fire & Rescue NSW indicated that boots could not be supplied to the applicants for assessment purposes. Therefore, for simplicity, the use of boots can be omitted, even though they also have a significant metabolic impact (Taylor *et al.*, 2012c). It

is recommended that test participants provide their own footwear.

It is further proposed that testing should be completed with participants wearing at about 20 kg of added mass. This is designed to simulate the combined mass of the personal protective clothing and equipment currently used by Fire & Rescue NSW. Thus, in addition to the protective clothing, an additional mass, equal to that of standard-issue boots, self-contained breathing apparatus and other standard items, needs to be added to each test participant. This equipment load would be simulated through the use of a weighted vest. It is requested that Fire & Rescue NSW determines this mass for the Research Team.

With regard to the physical aptitude test itself, several further equipment constraints were identified, and these include:

- very limited access to laboratory-based test items
- the test needed to be deployed throughout the state
- the test should require minimal equipment
- testing should not reduce the functional capability of Fire Stations
- testing should be easily deployed by one person at the test venue, and without creating a significant manual-handling hazard for the assessor
- testing should not require specific medical or exercise physiology qualifications.

Three criterion tasks were identified that required the dragging of heavy objects (fire attack, dragging charged hose over uneven terrain and firefighter rescue). Due to the environmental and equipment constraints identified above, several task simulation would prove impractical:

- the dragging of a charged hose over a consistent surface and distance
- the dragging of a dummy over a consistent surface and distance

To overcome these constraints, several possible equipment alternatives were considered, including a weighted sled and a torque reel.

A weighted sled (1-1.5 m long) would permit almost infinite load adjustments. It could be easily dragged and it could be adjusted to simulate the loads encountered within the three criterion tasks. Furthermore, such devices are commonly used within sports training settings, and they are also commercially available. However, the limitation with a sled is that the drag forces will vary across different test surfaces, and these needed to be standardised. This drag force is primarily dependent on the frictional forces between the sled and the operating surface. Thus, a sled that is dragged on dirt or concrete will have significantly higher drag loads than an identical sled dragged on a wetted grass surface. Therefore, the standardisation of this drag force in the deployment of this type of test around the State was deemed to most unlikely, and this option was abandoned.

The second option sought to remove, or at least to minimise, the impact of these drag forces. This could be achieved via a line and reel (drum) configuration engineered to be braked at a range of frictional loads (Figure 1). Since the reel would be cylindrical, then the line could only be drawn away from the reel by the application a force sufficiently large enough to overcome this resistance, and cause the reel to rotate. Such turning forces are

know as torques², and these forces could be used to simulate the drag loads encountered within each of the three criterion tasks. Unlike the sled, the system would be stationary, and a high-tensile, non-stretch line would be spooled around the drum (Figure 1: blue line). This line could be pulled away from the reel if a sufficient turning force (torque) was applied to the reel through the line. By passing this line from the large reel to a smaller flywheel set closer to the ground, the line of force application could be made to simulate the direction and height of the drag forces encountered in these three criterion tasks. On the reel, a range of torque settings could be achieved by adjusting the braking force applied to the reel (Figure 1: markers 1 or 2). Thus, the drag load could be easily varied. Various fire-fighting components would be attached to the end of the line. For instance, to better resemble the dragging of a charged hose, a sand-filled section of 38-mm hose, complete with its branch, would be attached to the line. To simulate the rescuing of a firefighter, a modified harness from the self-contained breathing apparatus could be attached to the line. These attachments would allow for the test to more closely approximate operational conditions and equipment.

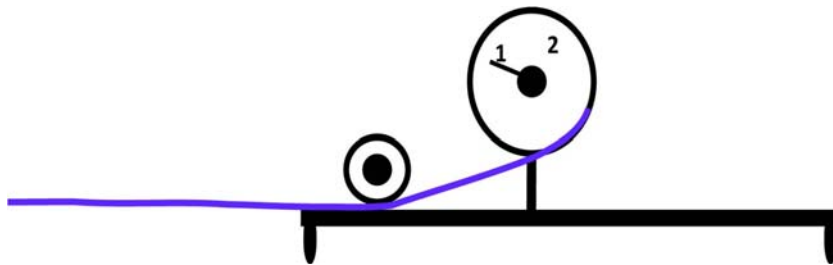


Figure 1: The line and reel resistance loader. The upper reel (drum) shows two torque settings. The blue line passes under a lower flywheel to control both the direction and the angle of the force applied by the participant.

The advantage of this system is that the force that must be applied to pull line away from the reel can be precisely standardised, irrespective of the test venue. Furthermore, the line can be marked at intervals to allow for drag distances to be accurately measured. Therefore, the Research Team recommends that a resisted reel device be used to during the performance of the criterion drag tasks within the physical aptitude test. However, this will require the measurement of the actual drag forces required to move a charged hose on uneven terrain, to perform a fire attack and to successfully rescue a firefighter.

2.2.5.4 Specifications for load-carriage within the physical aptitude test

The critical strength task for the physical aptitude test is the one-person firefighter rescue activity. It is proposed that a dummy not be dragged, as this can introduce frictional variations across test days and sites. Instead, it is recommended that a fixed resistance be applied through the use of a bespoke line and reel resistance loader (Figure 1). However, for the loading of this device to be set appropriately, and at a defensible level, Fire & Rescue NSW must determine the standard mass for this task. Factors that must be considered here relate to the anticipated person to be rescued, and the clothing and

² Torque is defined as tendency of a force to cause an object to rotate about its central axis.

equipment worn by that person. To help with this determination, the following points are offered for consideration. However, it is emphasised that this task is aimed at simulating the one-person rescue of a collapsed firefighter, and not the standard two-person rescue of a civilian. Since this is a firefighter rescue, then to this mass must be added the combined mass of the personal protective clothing and equipment worn during structural fire fighting.

Consideration 1 - The average Australian adult: The future composition of the workforce will be a blend of men and women from diverse cultural backgrounds. These backgrounds have size and stature implications. If one assumes a gender distribution of one female to every nine males, then the average mass of future firefighters could be determined using 90% of the average Australian male mass, plus 10% of the average Australian female mass. This method provides an indicative average mass of 82.01 kg (Australian Bureau of Statistics, 2005).

Consideration 2 - The average firefighter: This mass could be based upon the current average mass of Fire & Rescue NSW employees. However, the Research Team has been advised that obtaining reliable data with sufficient statistical power, would be difficult within the organisation's current operational framework. Thus, the Research Team suggests proceeding with Option 1.

It is now important to highlight that, by using an average population mass, approximately 50% of rescues will be performed on individuals with a mass that exceeds the average. This may be unacceptable to Fire & Rescue NSW, particularly for a task that is deemed the most critical of all fire-fighting tasks (Taylor *et al.*, 2012a). Thus, Fire & Rescue NSW must determine two matters:

“Is it acceptable that firefighters beyond a certain mass might not be able to be rescued by one person?”

“What threshold will be used to set that mass (e.g. 95th percentile)?”

2.2.5.5 Identifying well-correlated substitute tests within the physical aptitude test

Due to a lack of consistent access to stairs, the physical aptitude test will need to be conducted on standardised flat terrain. Thus, the test would aim to predict satisfactory load carriage on stairs from a load-carriage task performed on flat ground. For this to be both valid and legally defensible, predictive correlations between the relative performance of stair-climbing tasks and tasks conducted on flat terrain need to be established. For instance, Cateneo *et al.* (2010) demonstrated that stair climbing ability and a six-minute walk time test (flat ground) showed similar accuracies, sensitivities and predictive capabilities. Significant correlations have been established between stair climbing speed and maximal oxygen consumption during cycle ergometry (Koegelenberg *et al.*, 2008). However, stair climbing ability is a specific form of locomotion, with improvements in climbing power being elicited from climbing training regimen, but not level walking (Bean *et al.*, 2002).

Furthermore, given the multiple trip nature of hazmat carriage tasks, it will also be important to evaluate correlates of load carriage. For example, the Research Team need to evaluate whether or not a single, 70-m load carriage of approximately 27 kg would be sufficient to assess performance for hazmat activities.

Three tasks were identified that required the holding of objects. While replication of one of these criterion tasks, for example, the motor-vehicle rescue, would help maintain high face validity, the Research Team is concerned that twisting and turning of the trunk at speed, and under load (19.5 kg), could represent an increased injury risk for some individuals. Given the high reward for passing a screening test (*i.e.* employment), there is an increased likelihood for highly motivated participants to injure themselves during testing (Ayoub *et al.*, 1982), especially if these tests include high-capacity, manual-handling tasks (Snook *et al.*, 1978). Therefore, the Research Team will investigate whether an alternate activity may exist that would be predictive of the ability to hold an object at a range of fixed heights and anchorage points, such as those experienced within the motor-vehicle rescue.

It is recommended that further study be performed to see if a single-lift task, or a repetitive lift and placement performance, might represent an adequate substitute for criterion tasks that required holding actions. To effectively complete this research, the Research Team requires advice from the subject-matter experts. Are these holding tasks typically performed at some fixed absolute or relative height? For example, during a motor-vehicle rescue, is it anticipated that all firefighters should be able to hold the 20-kg shears at a minimum height, or at some relative height (shoulder height)? Given that task demands may change significantly between individuals of different stature, when performing a task at an absolute height, it is critical that the final selection of a height (or heights), either absolute or relative, be determined solely on the basis of operational demands and procedures.

3. PHYSICAL APTITUDE TEST DESCRIPTION AND DISCUSSION

The Research Team proposes that, if an individual could satisfactorily complete all of the activities within each the criterion task classes of Table 7, then this person would possess the minimal physiological attributes desired of a contemporary firefighter. On the basis of the distillation process undertaken, and the above task constraints, it is proposed that the physical aptitude test (PAT) include the following five components:

- single-sided (unilateral) carriage task or tasks
- holding task or tasks (above and below shoulder height)
- hose drag
- fire attack
- firefighter rescue.

3.1 Single-sided unilateral carriage task

Phase Four of this investigation will determine the final mass and the movement distance required to faithfully reflect the following criterion tasks: hazmat task, locating and connecting to a hydrant, ladder use and stair climb with ventilation fan. Furthermore, in Phase Four, the Research Team will also determine the effect substituting the stair climb with a task performed on flat terrain.

3.2 Holding task

Phase Four of this investigation will determine the final mass and the movement distance required to faithfully reflect the following criterion tasks: motor-vehicle rescue, ladder under-run and using a sledge axe to gain entry. Further investigation will involve assessing the correlation between a single-lift test and a repetitive box lift and placement activity with

the motor-vehicle rescue task. This analysis will permit a comparison of the relative physical demands of each of these activities and their correlations.

3.3 Simulated hose drag

This task was chosen due to its high physiological (metabolic) demand. Phase Four of this investigation will determine the final load and the movement distance required to faithfully reflect the dragging of charged 38-mm hose over uneven terrain. This task will be performed using the line and reel resistance loader (Figure 1).

3.4 Simulated fire attack

This task was chosen due to its criticality, its high physiological (metabolic) demand and its face validity. Phase Four of this investigation will determine the final load and movement distance required to faithfully reflect a fire attack. This task will be performed using the line and reel resistance loader (Figure 1), and it will also have a postural constraint that forces participants to remain below the neutral plane (minimum helmet height).

3.5 Simulated firefighter rescue

This task was chosen due to its high physiological (metabolic) demands, its face validity and the critical nature of this task. Phase Four of this investigation will determine the final load and the movement distance required to faithfully reflect a firefighter rescue. This task will also be performed using the line and reel resistance loader (Figure 1), and it will again have a postural constraint that forces participants to remain below the neutral plane (minimum helmet height).

3.6 Proposed physical aptitude test (circuit)

The Research Team recommends that the physical assessment battery (physical aptitude test: PAT) be performed as an uninterrupted sequence of tests (Figure 2) that target each of the criterion task classes identified in Table 8. It is further recommended that satisfactory performance would be determined on the basis of the total time required to complete the circuit test. The minimal time standard would be determined in the next Research Phase of this project (Phase Four), and it would be dependent upon the minimal acceptable work tempo for the tasks that are performed within the circuit, as determined by Fire & Rescue NSW, and as performed by existing operational firefighters within fire-fighting simulations (Taylor *et al.*, 2012b). This circuit-style approach for the performance of multiple critical assessment tasks is well established, and has been validated within the literature for other emergency service and military occupations (Considine *et al.*, 1976; Brownlie *et al.*, 1985; Jamnik *et al.*, 2010a and 2010b; Taylor *et al.*, 2003). Moreover, such an approach would simulate the physical demands and possible task sequence at an incident, in which there would be preparation prior to engaging the fire, fire fighting and the performance of a search and rescue.

Under operational scenarios, these tasks are generally performed without rest, and typically above some minimal acceptable speed. Within this circuit test, there should also be changes in work tempo, as this will occur at the fire ground. For example, upon arrival, firefighters would perform tasks that require the carriage or holding of equipment, and the gaining of entry into a building or motor vehicle. Upon completion of these tasks, endurance-related

activities, such as the dragging or holding charged hoses would be performed. Finally, after these activities, firefighters should still have sufficient physiological reserve to successfully engage in a fire attack, to enact a search and rescue and to perform a one-person firefighter rescue. Whilst a well-rested person may be able to successfully perform each of the tasks in isolation, in an operational scenario, isolated task performances would rarely occur, and firefighters need to possess strength, muscular and whole-body endurance. Indeed, some individuals who could complete each task separately, may fail to complete all tasks when performed sequentially, due to the cumulative and fatiguing effects of successive physical tasks. Such individuals would not have sufficient physiological capacity to meet the most physically demanding and critical tasks of fire fighting, and this would constitute a failure of the physical aptitude test. This view is consistent with the approach used for physical employment standard development within other occupations (Jamnik *et al.* 2010a and 2010b; Taylor *et al.*, 2003).

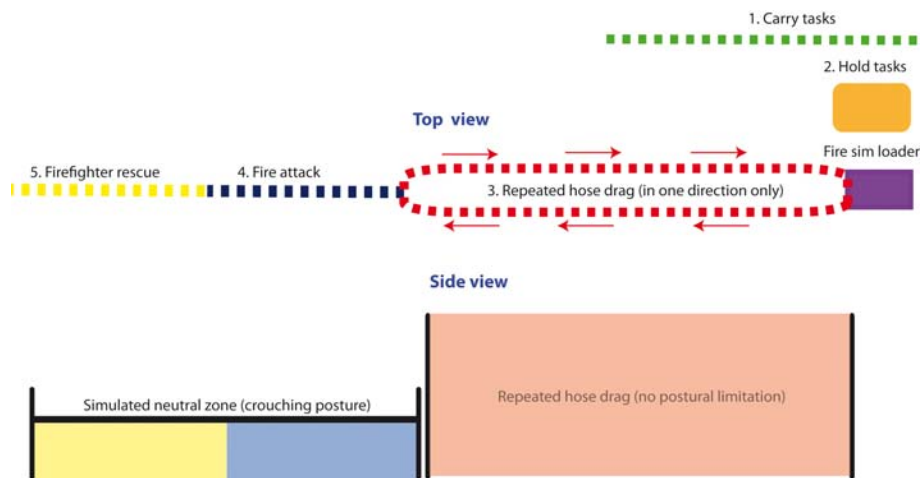


Figure 2: Proposed physical aptitude test (circuit) for assessing criterion firefighter tasks. It is recommended this test series be performed in the following order: single-sided (unilateral) carriage task, holding task, hose-drag task, fire-attack task and a firefighter rescue simulation.

The Research Team proposes that an elapsed-time standard for this circuit (physical aptitude test) be adopted, as this will allow for individuals of varying physiological attributes to successfully complete the circuit. Thus, whilst a slow overall performance may not be deemed acceptable, recruits who may be weaker in one test area can compensate by possessing greater abilities on other tasks. The minimal time standard would be determined in the next Research Phase of this project (Research Phase Four), and it would be dependent upon the minimal acceptable work tempo for the tasks within the circuit, as determined by Fire & Rescue NSW, and as performed by existing operational firefighters within fire-fighting simulations (Taylor *et al.*, 2012b).

4. RECOMMENDATIONS AND INFORMATION REQUESTS

The following recommendations and information requests are tendered to the Project Management Team concerning the proposed physical aptitude test (circuit).

4.1 Recommendation one: It is recommended that the physical aptitude test be performed as an uninterrupted sequence of tasks (circuit), such that the test replicates the likely intensity and physical demands of a range of activities that may realistically be conducted at an incident. In addition, it would be required that these tasks be completed without rest.

4.2 Recommendation two: It is recommended that the physical fitness assessment circuit be developed with full consideration of the operational constraints that exist for Fire & Rescue NSW. Thus, the assessment battery must be able to be deployed consistently across the State.

4.3 Recommendation three and request one: It is recommended that the physical aptitude test (circuit) be completed with participants wearing about 20 kg of added mass. This is designed to simulate the combined mass of the personal protective clothing and equipment currently used by Fire & Rescue NSW. There is no need for the personal protective equipment to be deployed, but the protective clothing (with the exception of the boots) must be worn during testing (including the helmet), as this ensemble significantly influences flexibility, ranges of joint motion, the performance of heavy exercise (Taylor *et al.*, 2010), and the metabolic demand of locomotion (Taylor *et al.*, 2012c). It is recommended that all test participants wear the standard protective clothing used by Fire & Rescue NSW. It is further recommended that an additional mass, equal to the combined average masses of standard-issue boots, the self-contained breathing apparatus and other standard equipment used during structural fire fighting, be added to each test participant. If required, this equipment load could be simulated through the use of a weighted vest. It is requested that Fire & Rescue NSW determines this mass, and then provides this specification to the Research Team.

4.4 Recommendation four: It is recommended that further investigation be undertaken (Phase Four of this project) to assess the ability of simple lifting tasks to predict performance on more complex fire-fighting activities. For example, it is possible that some highly reproducible, and easily performed tests may reliably predict this performance, and thereby enable a simplification of the criterion holding task. It is also possible that more than one lifting task could be incorporated into the test.

4.5 Recommendation five and request two: For the holding task of the aptitude test (item two), the Research Team requires advice from subject-matter experts. It is requested that Fire & Rescue NSW determines whether this holding task is to be performed at a fixed absolute or at some relative height? If the former is adopted, then the Research Team needs to know this height. If the latter is chosen, then the Research Team needs to know this in the form of a percentage of each participant's standing height.

4.6 Recommendation six: It is recommended that the frictional loads for the dragging tasks (hose drag, fire attack and firefighter rescue) be applied through a custom-made resistance

device: a line and reel resistance loader. The Research Team will investigate appropriate frictional (braking) devices that may satisfy this requirement, whilst ensuring that all such tests are reliable, reproducible and legally defensible.

4.7 Recommendation seven and request three: Within the fire-attack and firefighter-rescue tasks, it is recommended that all participants be required to adopt safe operating postures (below the neutral plane) to simulate the avoidance of excessive heat and smoke exposure. The resulting semi-crouched position will be determined so that each participant keeps his/her helmet below the same fixed height. This will also facilitate an assessment of each participant's ability to operate within somewhat confined spaces. It is requested that Fire & Rescue NSW determines this neutral plane height, and then provides this specification to the Research Team.

4.8 Recommendation eight: It is recommended that further investigation be undertaken (Phase Four of this project) to establish a correlation between load-carriage tasks that require the negotiation of stairs, and those that are performed on predominately flat surfaces. Since access to stairs for recruit testing may not be possible across the State, then this evaluation is aimed at permitting the prediction of load carriage on stairs from load-carriage performance on flat ground.

4.9 Recommendation nine and request four: For the one-person, firefighter-rescue task of the aptitude test, it is proposed that a dummy not be dragged, as this can introduce frictional variations across test days and sites. Instead, it is recommended that a fixed resistance be applied through the use of a bespoke line and reel resistance loader. However, for the loading of this device to be set appropriately and at a defensible level, Fire & Rescue NSW must determine the standard mass for this task. Factors that must be considered here relate to the anticipated person to be rescued, and the clothing and equipment worn by that person. It is requested that Fire & Rescue NSW determines this mass, and then provides this specification to the Research Team.

4.10 Verification and approval of the staged screening tests

These screening tests were submitted to the Project Management Team for consideration, endorsement and validation. Approval to progress to the final research Phase (development of physiological employment standards for firefighters) was also sought at this meeting. These outcomes were each achieved at the Project Management Team meeting held on 22nd of June (2012: Appendix Three of this report).

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6. APPENDICES

APPENDIX ONE: Meeting to report on, and approve the completion of 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 (UOW), 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.

APPENDIX TWO: Meeting to discuss possible physical aptitude test options for the approved criterion trade tasks arising from Phase Two

Date: 21/05/12

Location: Deans Meeting Room (University of Wollongong).

Present: Brendan Mott (FRNSW), Nigel Taylor (UOW), Herb Groeller (UOW), John Sampson (UOW), Hugh Fullagar (UOW).

Summary:

The first purpose of this meeting was to present and evaluate a preliminary proposal for the classification of the criterion tasks. Since there were movement pattern similarities across these tasks, then each criterion task was classified into one of four different movement categories.

During these discussions, it was decided to sub-divide the ladder task into two parts (carrying and under-running) as it was considered to fall within each of two different movement classes. The second aim of this meeting was to identify operational constraints that may subsequently influence test selection, design and implementation. Finally, criteria were discussed upon which individual tasks may be eliminated from the list, since it was considered that some duplication may exist among these criterion tasks, and task culling would increase testing efficiency.

Six constraints of practical or logistical significance were identified and discussed in detail:

- environmental constraints: locations and facilities for test administration, and climatic variations
- equipment constraints: personal protective clothing and equipment
- the height of the operating posture (below the neutral plane) for firefighters to avoid excessive heat and smoke exposure
- the structures and surfaces used during ambulatory and load-carriage tasks
- the mass that would be used within the crucial strength task (patient mass)
- the correlation of a “lift and place” activity with critical tasks that require the holding of variously sized objects.

Each was carefully considered when determining the suitability of any criterion task, or a modification thereof, for inclusion within an occupation-specific physical aptitude test.

Three exclusion criteria were identified:

- a low relative, whole-body physiological demand
- movement task duplication
- the availability of suitable substitution tasks.

Should any task satisfy one or more of these characteristics, it would be considered for elimination by Research Team. In this way, efficiencies within the proposed fire-fighter physical aptitude test could be found, without compromising either the sensitivity or specificity of the proposed task battery.

APPENDIX THREE: Meeting to approve physical aptitude test options arising from Phase Three

MEETING: Project Management Team:

Date: 22/6/12

Location: Board Room Head Office (FRNSW).

Present: Chair: Brendan Mott (FRNSW), Alison Donohoe (teleconference connection: FRNSW), Darren Husdell (FRNSW), Jim Hamilton (FRNSW), Jim Smith (FRNSW), Rick Griffiths (FRNSW), Brendan Mott (FRNSW), Megan Smith (FRNSW), Herbert Groeller (UOW), Nigel Taylor (UOW).

Summary:

(1) Previous Minutes of 21 May 2012 were accepted by all.

(2) BM indicated since last meeting further discussion had occurred between himself and UoW research team regarding some of the recommendations for the testings, location of where testing would be held, who would conduct assessments etc.

(3) NT reiterated how the research team came about identifying the 15 tasks that were then assessed. The project is now up to completing report number 3 of 4 reports and needs the committees input to determine if the tests created are practical, transportable and have face validity.

(4) HG went through the attached pages and explained the information detailed on each page. Minutes are to be read in conjunction with documents handed out at the meeting and attached to these minutes.

Table 1: This outlined the 15 tasks that were assessed in Phase 2 of the project.

Table 2: This outlined those tasks that were no longer formally considered in Phase 4 of the project. More specifically:

Simulation 3: this task had very low oxygen consumption, was short duration compared to other tasks tested.

Simulation 6: low physiological demand compared to other tasks which would require 40-50% greater demand.

Simulation 10: the same physiological demands can be replicated by other tasks.

Simulation 11: low demand physiologically and can be substituted.

Simulation 12: this can be substituted with Simulation no 14.

JH raised concerns that some hose drag tasks were removed, but was reassured by HG other tasks remaining met the same physiological demands.

Table 3: Outlined the tasks now remaining which are recommended as part of the fitness assessment.

Table 4 and 5: Breaks down the tasks into those that have a holding and those with a carry characteristic.

Table 6: Breaks down all tasks into 4 classes, with a few tasks generally under each class. HG believes this is the minimum number of classes that needs to be included in the assessment battery. It is felt this number will assist in keeping it simple but also test appropriately to the correct level. BM reinforced any battery of tests needed to also show face validity.

AD asked whether tasks that may have a skill component will be altered to a generic task replicating the movement required. For example, if the ladder raise is still to be included, that it may need to be performed in a simulated capacity eg unilateral shoulder raise. HG advised may be able to use other equipment to simulate the ladder being raised to and above shoulder height. NT advised they may utilise university students to test different ways of testing tasks such as the ladder raise task, and to determine the load given by assistance of the person stabilising the ladder vs underrunning the ladder.

The assessment constraints page outlines the guidelines the researchers are taking into consideration when developing the battery of tests. Any equipment that will be required to perform testing: will need to consider its weight (*e.g.* if a dummy is used), cost and portability.

(5) HG and NT explained the recommendations:

Recommendation 1: To determine what would be the average mass of firefighters in the Australian population (taking into account the same gender mix in FRNSW). HG advised this could be 82 kg. With the addition of PPE and boots, this would equate to 102 kg for firefighter rescue. Although this task may be rarely performed, it is highly critical. Of the 55 firefighters who performed the simulations as part of the research, the average weight of the participants was 83 kg.

To determine the load required for simulation 8 (firefighter down- rescue) UOW need to determine how to create a load that can be consistent. The research team initially thought of a sled, but this would not work due to different surfaces test may be performed on *e.g.* grass versus vs concrete. It was agreed that an alternate to using dummies would be ideal.

Recommendation 2: All agreed that the test would need to be portable across the state, and hence an email was circulated out of session identifying some of the possible constraints that may need to be considered.

Recommendation 3: It was discussed that the approximate weight of PPE is 20 kg (minus boots) but this could be added with a weight vest or belt etc. to mimic the mass of boots.

Recommendation 4: A picture of a mock frictional force device (Fire Sim Loader) is on Figure 1. Creating a device like this will make the test transportable and reduce manual handling risks to the assessors, as the device will be lightweight.

Recommendation 5: Researchers want to know what height will be considered the 'neutral plane' to maintain a crouch posture with certain tests *e.g.* firefighter rescue. See also figure

2. Needs to be determined how this height can be consistent *e.g.* laser level, poles at a certain height placed by assessor.

Recommendation 6: To make the test portable, would consider use of a step activity to mimic negotiation of a stairwell.

Recommendation 7: The committee will need to determine whether they want to use an absolute or relative height for lifting tasks. There will also have to be tasks that assess ability to lift to shoulder height and above shoulder height as single or repetitive lift.

Recommendation 8: This relates to Figure 2. No time frame has been determined as yet as to how long the course will run for, or individual tasks will run for. Some participants may be able to pass individual elements *e.g.* the carry and hold tasks, but with all tasks combined in a sequence may not be able to complete the course. It will require FRNSW to make a determination of the duration of individual tasks and whole assessment time.

(6) ACTIONS:

UOW will send out a formal letter of request asking for answers to key questions raised from their recommendations. This will be done within the next week. Answers are to be provided back from the Committee to help the UOW further streamline the battery of tests that make up the PAT.

APPENDIX FOUR: Requests for additional information from Fire & Rescue NSW

Request one:

It is recommended that the screening circuit be completed with participants wearing about 20 kg of added mass. It is recommended that all test participants wear the standard protective clothing used by Fire & Rescue NSW. It is further recommended that an additional mass, equal to the combined average masses of standard-issue boots, the self-contained breathing apparatus and other standard equipment used during structural fire fighting, be added to each test participant. This equipment load will be simulated through the use of a weighted vest.

It is requested that Fire & Rescue NSW determines this mass, and then provides this specification to the Research Team.

Request two:

For the holding task of the aptitude test (item two), the Research Team requires advice from subject-matter experts.

It is requested that Fire & Rescue NSW determines whether this holding task is to be performed at a fixed absolute or at some relative height?

If the former is adopted, then the Research Team needs to know this height.

If the latter is chosen, then the Research Team needs to know this in the form of a percentage of each participant's standing height.

Request three:

Within the fire-attack and firefighter-rescue tasks, it is recommended that all participants be required to adopt safe operating postures (below the neutral plane) to simulate the avoidance of excessive heat and smoke exposure. The resulting semi-crouched position will be determined so that each participant keeps his/her helmet below the same fixed height. This will also facilitate an assessment of each participant's ability to operate within somewhat confined spaces.

It is requested that Fire & Rescue NSW determines the height of this neutral plane, and then provides this specification to the Research Team.

Request four:

For the one-person, firefighter-rescue task, it is proposed that a dummy not be dragged, as this can introduce frictional variations across test days and sites. Instead, it is recommended that a fixed resistance be applied through the use of a bespoke line and reel resistance loader. However, for the loading of this device to be set appropriately and at a defensible level, Fire & Rescue NSW must determine the standard mass for this task. Factors that must be considered here relate to the anticipated person to be rescued, and the clothing and equipment worn by that person.

It is requested that Fire & Rescue NSW determines this mass, and then provides this specification to the Research Team.