Physical Employment Standards for UK Firefighters: Minimum Muscular Strength and Endurance Requirements

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Conflicts of interest

The authors express no conflict of interest

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PHYSICAL EMPLOYMENT STANDARDS FOR UK FIREFIGHTERS: MINIMUM MUSCULAR STRENGTH AND ENDURANCE REQUIREMENTS

Running title: Strength requirements for UK firefighters

ABSTRACT

Objective: To assess sensitivity and specificity of surrogate physical ability tests as predictors of criterion firefighting task performance and to identify corresponding minimum muscular strength and endurance standards. Methods: Fifty-one (26 male; 25 female) participants completed three criterion tasks (ladder lift, ladder lower, ladder extension) and three corresponding surrogate tests (One-repetition maximum (1RM) seated shoulder press; 1RM seated rope pull-down; repeated 28 kg seated rope pull-down). Surrogate test standards were calculated that best identified individuals who passed (sensitivity; true positives) and failed (specificity; true negatives) criterion tasks. Results: Best sensitivity/specificity achieved were 1.00/1.00 for a 35 kg seated shoulder press, 0.79/0.92 for a 60 kg rope pull-down and 0.83/0.93 for 23 repetitions of the 28 kg rope pull-down. Conclusions: These standards represent performance on surrogate tests commensurate with minimum acceptable performance of essential strength-based occupational tasks in UK firefighters.

Key Words: Physical employment standards; firefighting; muscular strength; muscular endurance; physical fitness; sensitivity and specificity.

INTRODUCTION

Firefighting is a strenuous occupation requiring high levels of physical fitness[1, 2]. Inadequate levels of physical ability can put firefighters at risk of over-exertion and injury[3, 4] and could increase risk to the public[5-7]. While many UK firefighters are subjected to routine fitness monitoring to ensure appropriate levels of fitness are maintained, a wide variation exists in the methods of testing and monitoring, the components of fitness assessed and the application of physical employment standards.

Evidence into the causes of on-duty fatalities from coronary heart disease in both US[8-10] and UK[11] firefighters has highlighted the importance of regular physical training and the maintenance of appropriate levels of fitness to help protect firefighters from the vigorous demands of the job[12, 13]. Much of the research into minimum fitness standards for serving firefighters, however, has tended to focus more on cardiorespiratory fitness requirements [1, 14-17] than on other components of physical fitness, such as muscular strength and endurance. This is despite a number of studies identifying their importance for safe and effective firefighting performance[2, 18, 19]. In the UK, minimum cardiorespiratory fitness standards for firefighters were recently identified and recommended[7], but strength and muscular endurance standards for safe and effective performance of essential firefighting tasks remain unclear.

Studies comparing firefighting task performances with both laboratory[20] and gym-based tests of strength and muscular endurance[21-23], have shown that physical ability tests can be used to predict firefighting performance. However, few investigations have both identified suitable surrogate tests (gym-based, easily replicable) and/or determined performance standards on these tests that are associated directly with minimal acceptable job performance. One study determined that a combination of three surrogate tests were able to predict performance on a fire suppression task[24]. A combined test score was then validated against minimum acceptable performance standards previously identified through a job analysis process[24]. The authors identified that the derived cut score would correctly identify 89% of the ‘successful’ task performances and 72% of the ‘unsuccessful’ performances within the workforce. However, this study was conducted on firefighters from a single municipal fire service in the USA and, to our knowledge, there are no other studies of this kind in other firefighter populations. In the UK, there is a lack of research investigating the minimum muscular strength and endurance requirements for performing the critical and most arduous firefighting tasks and/or using gym-based physical ability tests from which to derive physical employment standards.

The aim of this study was therefore to assess the sensitivity and specificity of common and replicable gym-based physical ability tests to predict performance of criterion operational firefighting tasks that require the largest application of physical strength and muscular endurance. To our knowledge, this will be the first study to identify and recommend minimum muscular strength and endurance tests and standards associated with minimal acceptable task performance for UK firefighting tasks.

METHODS

Task Development

This study was completed as part of a UK wide project to develop physical employment standards for incumbent UK firefighters. A task analysis process, using a best practice methodology[(25)], identified the critical and most physically demanding generic tasks using muscular strength and endurance performed by all UK firefighters through consultation with a 'technical panel' of subject matter experts[(26)]. Pilot testing was conducted at South Wales Fire & Rescue Service Training and Development Centre (Cardiff, UK) to determine the forces required to perform each of the identified tasks to a minimum acceptable standard[(26)], using standard fire service equipment. An analogue force dynamometer (Model 5002, Takei, Japan) was used to measure the force required to overcome inertia on each piece of fire service equipment involved in the individual tasks. Following this, criterion tasks were either designed using these force measures or identified from previous research projects[27] to simulate one individual firefighter's (single-person) requirement within each task. Best practice guidelines were adhered to in order that each task was performed safely and replicated the actual nature of the job[28].

To correspond with each criterion task, a gym-based physical ability test was identified. The criteria for selection of these tasks was that they used similar movements and/or application of force as their corresponding criterion tasks, used commonly available gym equipment and could be easily monitored (and safely controlled and/or 'spotted') by a practitioner. The criterion (occupational) tasks are described later, followed by their corresponding gym-based physical ability tests.

Participants

Twenty-six male (age 24 ± 5 y; mass 83 ± 15 kg; height 179 ± 7 cm; BMI 26 ± 4 kg/m^2; body fat 16 ± 5 %) and 25 female (age 24 ± 6 y; mass 63 ± 6 kg; height 165 ± 6 cm; BMI 23 ± 3 kg/m^2; body fat 26 ± 6 %) participants volunteered for this study and, after obtaining written and verbal explanation of the test procedures, provided informed consent to participate. Participants were recruited from two local universities as well as from support staff of South Wales Fire & Rescue Service. Since the tasks required no specialist skill or technique, operational firefighters were not recruited. The recruitment of civilians (non-firefighters) allowed similar proportions of male and female participants with divergent physical capabilities to be recruited. Participants completed a physical activity readiness questionnaire (Par-Q+) to ensure their safety to complete the physical tasks.

Protocol

Participants attended South Wales Fire & Rescue Service's Training and Development Centre, Cardiff, UK to complete the series of firefighting tasks and gym-based physical ability tests. Upon arrival, anthropometric measurements (body mass, height, estimated body fat (Bodystat 1500, Bodystat Ltd., UK)) were recorded for each participant. Following this, participants completed the occupational tasks and physical ability assessments in a randomised order with adequate recovery between each task. All operational firefighting tasks were completed while wearing a standard firefighting ensemble (fire tunic, leggings, boots, helmet and gloves) to replicate the demands of working in firefighting equipment. The physical ability tests were performed in loose fitting gym clothing.

Criterion Tasks

Ladder lift task – The ladder lift task was completed using a bespoke fire service ladder lift simulator[27]. Participants performed the task by lifting a bar on a pivot arm from hip height to a height of 1.82 m, replicating half of the weight of the head of a 13.5 m fire service ladder (approximately 29 kg at the mid-lifting point). Participants completed a set routine corresponding to lift weights of 14 kg, 19 kg and finally 29 kg with two minutes rest between lifts. Task performance was recorded as a pass / fail to successfully lift the 29 kg to the required 1.82 m height in one compete motion.

Ladder lower task – The ladder lower task was completed using a wall-mounted PowerSport ladder simulator (PowerSport Fitness Ltd, Bridgend, UK). Participants were required to perform a single downward pull on the ladder rope with both hands from a vertically extended position to chest height in order to simulate the unhooking of the weight of a 13.5 m fire service ladder (approximately 42 kg)[26].

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Ladder extension task – The ladder extension task was completed using a wall-mounted PowerSport ladder simulator (PowerSport Fitness Ltd, Bridgend, UK). Participants were required to fully extend a 10.5 m fire service ladder at a set speed of 70 pulls per minute[26] by continuously pulling (using a hand-over-hand action) on the ladder rope weighing approximately 28 kg.

Gym-based Physical Ability Tests

All physical ability tests were preceded by a standardised warm up procedure[29] and were separated by an adequate recovery period. Maximal performance on the physical ability tests that required a single transfer of force were assessed by one-repetition maximum (1RM) and for tests that required repetitive motion, performance was assessed by number of continuous repetitions until volitional failure at a given load:

Seated shoulder press – The seated shoulder press exercise (surrogate for the ladder lift task) was completed on a Body Solid power rack (Body Solid Ltd, Illinois, USA) using a standard Olympic bar with standard Olympic size weights in 2.5 kg increments. Participants were required to perform a 1RM overhead press whilst maintaining proper posture in an upright, seated position. The heaviest weight successfully pressed overhead was recorded.

Seated rope pull-down (single) – The seated rope pull-down exercise (surrogate for the ladder lower task) was completed on a commercial seated cable lat-pull down machine (Life Fitness Ltd, Illinois, USA). The lat-pull down bar was replaced by a section of standard fire service rope used for the extension of fire service ladders. Participants were required to perform a 1RM single pull down on the rope with both hands from a fully extended overhead position to chest level. The highest weight successfully pulled to chest height was recorded.

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Seated repeated rope pull-down (repeated) – The repeated seated rope pull-down exercise (surrogate for the ladder extension task) was completed on a commercial seated lat-pull down machine (Life Fitness Ltd, Illinois, USA) using a set weight of 28 kg (corresponding to the weight of a 10.5 m fire service ladder). The lat-pull down bar was replaced by a section of standard fire service rope used for the extension of fire service ladders. Participants were required to repeatedly pull down on the rope with both hands to chest level and return to the starting position at a speed indicated by audible bleeps from a metronome, until failure. To correspond with the criterion ladder extension task, participants were instructed to time each downward pull and each return to starting position with a bleep set to 70 beats per minute (the minimum performance requirement identified by the technical panel), which equated to 35 downward pulls per minute. The test was stopped (and the number of repetitions recorded) when the participant was unable to complete a full repetition in time with the metronome or the participant could no longer maintain their grip on the rope.

Statistical Analyses

Independent t-tests were performed to identify the existence of significant differences in maximal performance in the physical ability tests between those who passed and failed the criterion tests and between males and females. Significance was identified as $p < 0.05$. For each criterion task the binary result (pass/fail) was plotted against the participants' maximal performance in the corresponding physical ability test. For each test, sensitivity (true positive rate) and specificity (false positive rate) were calculated at several hypothetical performance standards set at regular increments. Sensitivity, the ability of the predictive physical ability test to correctly identify those who passed the criterion test, was calculated using the following formula:

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

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

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

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

where TN denotes true negatives and FP denotes false positives.

Accuracy was then determined by summing the number of true positives and true negatives and dividing by the total number in the population sample. Receiver-operating characteristic (ROC) curves were then plotted using the range of performance standards, with sensitivity on the y-axes and 1-specificity on the x-axes to determine the performance standard that was mathematically closest to maximising both specificity and sensitivity (perfect classification would be where both have a value of 1). Where applicable, this value was rounded to the nearest whole increment suitable for that performance measure.

RESULTS

Thirty-one of the 51 participants (61%; 26 male, 5 female) successfully completed the ladder lift task. Thirty-nine (77%; 26 male, 13 female) successfully completed the criterion ladder lower task and 36 participants (71%; 25 male, 11 female) successfully completed the ladder extension task (Table 1). Significant differences in muscular strength were identified between the successful and unsuccessful groups in the ladder lift task (53 ± 13 kg vs. 25 ± 5 kg respectively; $p < 0.01$) and the ladder lower task (79 ± 20 kg vs. 48 ± 9 kg respectively; $p <$

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0.01) and in muscular endurance on the ladder extension task (41 ± 22 repetitions vs. 13 ± 9 repetitions respectively; $p < 0.01$).

[Table 1]

While male participants successfully completed all criterion tasks to the required standard apart from one individual who failed to complete the ladder extension task, a higher proportion of female participants failed to complete the ladder lift (80%), ladder lower (52%) and ladder extension (56%) tasks than those who were successful. The male participants in this study demonstrated significantly greater maximal strength compared to their female counterparts on the seated shoulder press exercise (55 ± 13 kg vs. 28 ± 8 kg; $p < 0.01$) and on the seated rope pull-down exercise (91 ± 14 kg vs. 52 ± 9 kg; $p < 0.01$) and greater muscular endurance compared to their female counterparts in the seated repeated rope pull-down exercise (49 ± 20 repetitions vs. 16 ± 9 repetitions respectively).

Figures 1-3 (below) show individual performances (pass/fail) in the criterion tasks (ladder lift, ladder lower and ladder extension, respectively) versus maximal performances in the corresponding physical ability test (Panel A) and corresponding ROC curve derived from these data (Panel B).

[Figure 1]

On the seated shoulder press, a performance standard of 35 kg represents ideal sensitivity and specificity where both are equal (i.e. 1). At this performance level accuracy is 100%, representing a perfect predictor of criterion performance.

[Figure 2]

A performance standard of 60 kg on the seated single rope pull-down test represents the closest value to ideal classification (specificity and sensitivity of 1). At this performance standard sensitivity is 0.79, specificity is 0.92 (1-specificity = 0.08), and accuracy is 82%.

[Figure 3]

A performance standard of 23 repetitions of 28 kg on the seated repeated rope pull-down test elicited the closest value to the ideal specificity and sensitivity of 1. At this point sensitivity and specificity are 0.83 and 0.93 (1-specificity = 0.07), respectively, and accuracy is 86%.

DISCUSSION

This study sought to assess the sensitivity and specificity of gym-based physical ability tests to predict performance in critical firefighting tasks that required the largest application of physical strength and muscular endurance. This was completed in an attempt to identify minimum muscular strength and endurance standards to ensure UK firefighters are able to perform generic tasks safely and effectively. Performance standards of 35 kg in the seated shoulder press test (surrogate for the ladder lift task), 60 kg in the seated maximal single rope pull-down test (surrogate for the ladder lower task) and 23 repetitions of 28 kg (at 35 pulls per minute) in the seated repeated rope pull-down test (surrogate for the ladder extension task) represented the optimal achievable balance of specificity and sensitivity for the respective criterion tasks. The gym-based surrogate physical ability tests and standards identified are effective at

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predicting the readiness of UK firefighters to perform essential occupational tasks requiring physical strength and muscular endurance.

This study applied a rigorous task analysis process which followed best practice guidelines[25] and used highly experienced firefighters as subject matter experts to: (i) determine the critical and most arduous muscular strength and endurance tasks performed by all UK firefighters and; (ii) identify the minimum acceptable performance requirements[26]. This ensured that the tasks identified in the research would be directly related to the critical activities of UK firefighting. Since the tasks did not require technical skill, it was possible to use civilian participants for this study. This gave a mixture of resistance trained and untrained individuals with a wide range of physical abilities. This approach likely increased the number of participants failing to complete various tasks, thus improving the predictive validity of the physical ability tests. The measures of sensitivity and specificity would have been more difficult to determine if incumbent/trained firefighters had been recruited as participants where the vast majority of participants (if not all) could have successfully achieved all tasks.

This investigation identified that common gym-based physical ability assessments are effective at predicting performance on associated criterion tasks identified for this population, which is consistent with previous findings comparing firefighting task performance with surrogate physical ability tests[20, 22-24]. However, very few of these studies identified any minimum acceptable performance standards associated with these tests. This information is a critical step for fire services when applying these surrogate tests to ensure appropriate levels of physical strength and muscular endurance for the role. The findings of this research are therefore of great benefit to fitness trainers, occupational health physicians and nurses, as well as human resource policy makers working within the UK fire and rescue services.

The only other study to identify minimum performance standards for firefighters in conjunction with muscular strength and endurance tests was conducted in a municipal fire department in the USA[24]. A large sample of 153 serving firefighters were recruited, with 15 (10%) of those participants being female. Whilst this sample was representative of the fire department from which they were recruited, this highlights a limitation when conducting research using firefighters, since the proportion of females in the role is often relatively small. However, a noteworthy advantage of using incumbents was that the authors were able to model the impact of imposing the proposed minimum performance standards on the workforce. The authors reported that 83% of the workforce would be able to meet the minimum standards identified. Additionally, the authors indicated that the minimum cut score would identify 89% of successful performers (sensitivity) along with 72% of unsuccessful performers (specificity).

The ability to model the pass/fail rates (of any proposed standards) on the existing workforce is highly valuable to quantify possible adverse impact to specific demographic groups. However, it has to be assumed that, in terms of task performance, the sample is representative of the wider population of operational firefighters. Whilst it is well recognised that the introduction of physical employment standards may indirectly and disproportionately affect certain demographic groups, particularly based on age or sex[5, 7, 19], this information can be used to develop support mechanisms (such as physical training programmes) to minimise adverse impact to individuals and groups within an organisation. While this was not possible within the current study, it would be useful to assess the impact of implementing these standards within the UK fire and rescue services in future.

The position of each minimum performance standard in the current study was identified using ROC curves to determine the most statistically balanced combination of highest sensitivity (correctly identifying those that passed) and highest specificity (correctly identifying those that failed). This attempts to minimise the error associated with the predictive test, but typically false positives and false negatives cannot be entirely mitigated. It is possible that a standing pull-down or standing shoulder press test may have improved the likelihood of achieving higher test predictive power by closer mimicking the criterion test conditions, however this study aimed both to use standard gym based fitness equipment and to use exercises easily safeguarded by a practitioner in order to maximise the applicability of this research to fire and rescue services. In addition, while the optimum position of a standard can be determined using this analysis, there may be a requirement for a statistically determined 'borderline' category for tests of this nature. This would produce a lower, secondary standard and a boundary for those who may (or may not) have sufficient readiness for work. Unfortunately, there are no established guidelines for the production of these boundaries in physical employment standards research so has not been evaluated here. However, in the context of this particular study, it may be that the lowest weight increment that still maintains, for instance, 85 or 90% specificity or sensitivity could be selected as a borderline category but would depend on the specific requirements of the organisation in question, as expanded upon below.

Several limitations of this work are that without periodically implementing these tests and associated standards in the UK Fire & Rescue Service, it is not possible to understand the true impact on the workforce or the test-retest reliability of the tests. Sensitivity and specificity are in direct opposition, where sensitivity increases, specificity decreases and vice versa. Consequently, in the likely event that a test does not achieve a perfect predictive classification (i.e. sensitivity and specificity of 1), an organisation may choose a sub-optimal balance of these two variables. Consequently, researchers, practical end-users and/or managers would need to agree and justify the reasons for preferentially electing for higher specificity or sensitivity in a

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performance standard for an organisation. For example, where one might want to minimise the adverse impact on employees during a fitness test (i.e. incorrectly classifying an employee as unfit), the sensitivity of the test could be increased to reduce the possibility of this error, resulting in a lower performance standard and a higher pass rate. However, if one felt that it was important to be extremely confident in an employee's ability to perform the task appropriately (i.e. reducing the chance of an employee incorrectly passing a fitness test), a higher specificity could be adopted, resulting in a higher performance standard and a lower pass rate. It could be that in an emergency service occupation (such as firefighting), where the impact of an employee not being able to perform the job may put lives at risk, a test that favours higher specificity may be appropriate. To the authors' knowledge, there are no globally-accepted guidelines that navigate these issues when determining physical employment standards for physically demanding or safety-critical occupations. Research focusing on repeated measures implementation of standards and tests in a workforce, and subsequent collection of impact and reliability data could help identify suitable recommendations for this, and other public safety occupations.

Cardiorespiratory performance, muscular strength and endurance are all important components of physical fitness recognised as being critical for performing firefighting duties safely and effectively. This study identified strength and muscular endurance standards on easily-replicable gym-based exercises commensurate with minimum acceptable performance requirements for essential tasks in UK firefighting. These performance standards should be applied to all UK firefighters, as part of a routine fitness assessment, to ensure that firefighters are physically able to safely carry out their work and to preserve public safety.

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Table legends

Table 1. Performance on the criterion tasks and the corresponding maximal performances (mean ± SD) during the physical ability test(s).

Figure legends

Figure 1. Individual performances (Pass/Fail) in the criterion ladder lift task against 1RM in the seated shoulder press test (A), and corresponding ROC curve (B) derived from these data.

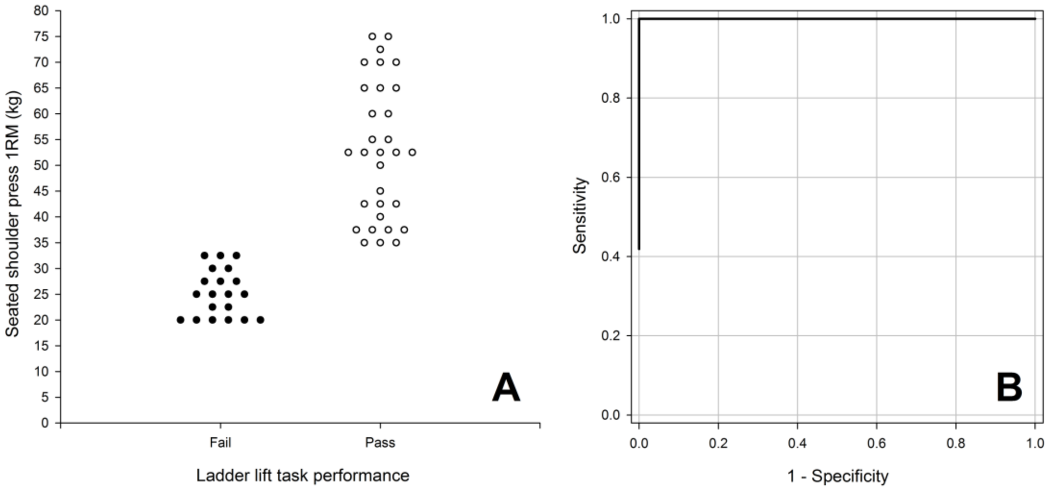
Figure 2. Individual performances (Pass/Fail) in the criterion ladder lower task against 1RM in seated maximal rope pull-down (A) and corresponding ROC curve (B) derived from these data.

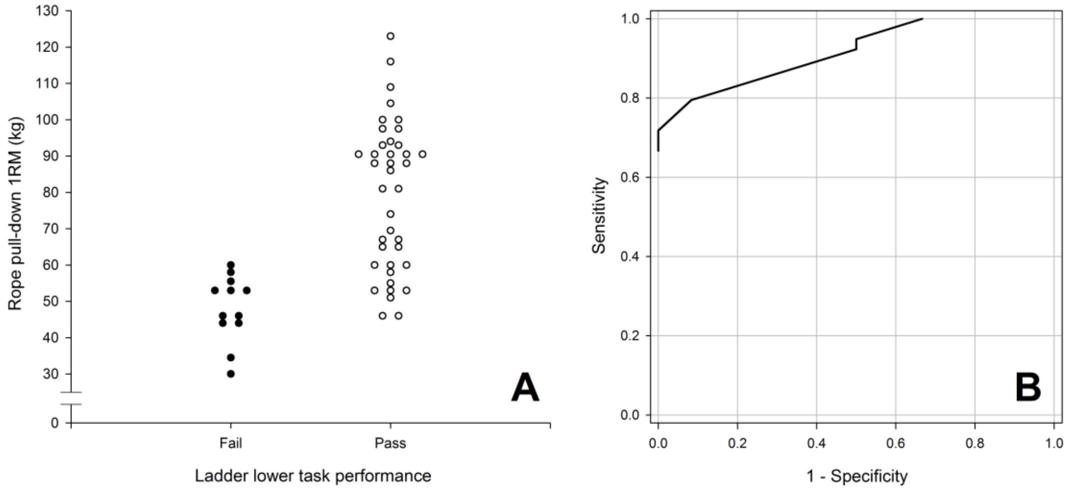
Figure 3. Individual performances (Pass/Fail) in criterion ladder extension task against the number of repetitions to failure during the repeated rope pull-down at 35 pulls·min^{-1} (A) and corresponding ROC curve (B) derived from these data.

Table 1. Performance on the criterion tasks and the corresponding maximal performances (mean ± SD) during the physical ability test(s).

Criterion task	Ladder Lift		Ladder Lower		Ladder Extension	
	Pass	Fail	Pass	Fail	Pass	Fail
n	31	20	39	12	36	15
Male	26	0	26	0	25	1
Female	5	20	12	13	11	14
Shoulder press 1RM (kg)	53 ± 13	25 ± 5*	-	-	-	-
Seated pull 1RM (kg)	-	-	79 ± 20	48 ± 9*	-	-
Repeated pull (reps)	-	-	-	-	41 ± 22	13 ± 9*

* - Significantly different from those that passed the criterion task.





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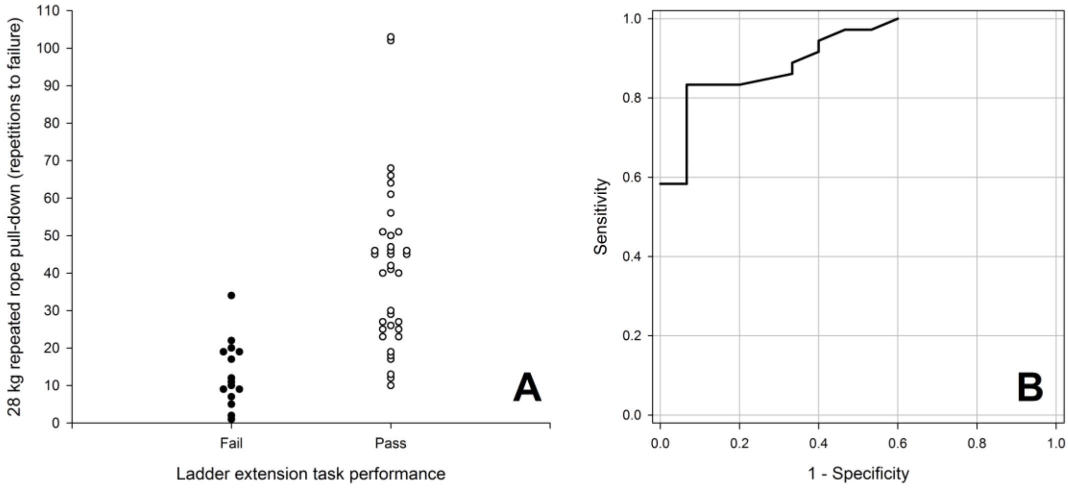

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