THE EFFECT OF PERSONAL PROTECTIVE EQUIPMENT ON FIREFIGHTER OCCUPATIONAL PERFORMANCE

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THE EFFECT OF PERSONAL PROTECTIVE EQUIPMENT ON FIREFIGHTER
OCCUPATIONAL PERFORMANCE

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DISSERTATION

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A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Education
at the University of Kentucky

By
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Lexington, KY

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ABSTRACT OF DISSERTATION

THE EFFECT OF PERSONAL PROTECTIVE EQUIPMENT ON FIREFIGHTER OCCUPATIONAL PERFORMANCE

Firefighting is a strenuous occupation that requires high-intensity work, resulting in prolonged periods of stress and physical exertion. The physical demand of performing firefighting tasks is augmented by the weight of personal protective equipment (PPE) worn (i.e., load carriage: LC) and the use of a self-contained breathing apparatus (SCBA). These factors have been shown to increase metabolic demand at submaximal workloads and decrease maximal aerobic capacity in laboratory settings. However, there is limited research evaluating the effects of these factors on occupational performance. Therefore, the primary purpose of this study was to quantify the detrimental effect of LC only and LC+SCBA on firefighter occupational performance. In addition, it is important to identify fitness characteristics and physiological outcomes that are correlated to the decrement in performance produced by the PPE. This information will guide practitioners in selecting appropriate training strategies to effectively prepare firefighters to perform occupational tasks in gear. Thus, a secondary aim was to evaluate the relationships between fitness and pulmonary outcomes versus the decrement in occupational performance produced by the PPE. Twenty-one male firefighter recruits (Age: 28.6 ± 4.3 yr; Height: 178.6 ± 7.2 cm; Mass: 94.1 ± 15.4; Body Fat: $17.8 \pm 8.4\%$) participated in this study. Occupational physical ability was assessed by time to complete a simulated fire ground test (SFGT). The SFGT was composed of the following tasks: stair climb, charged hose drag, equipment carry, ladder raise, forcible entry, search, and victim rescue. The recruits participated in six testing sessions. First, two SFGT familiarization trials were performed on separate days. During the next three testing sessions, the firefighter recruits performed the following SFGT conditions in a randomized order: control condition (PT clothes), LC only condition, and PPE+SCBA (SCBA) condition. Baseline and post-SFGT pulmonary and physiological data were collected. To describe within group differences between SFGT conditions, relative difference scores were calculated as follows: % difference = (([experimental trial outcome – PT trial outcome] / PT trial outcome) x 100). Statistical differences between the SFGT conditions were

assessed with repeated measures ANOVA. To evaluate the relationship between fitness outcomes versus the decrement in SFGT performance, fitness testing data were obtained from the recruit academy and included: 1.5 mile run time, maximal push-ups, maximal sit-ups, maximal pull-ups, and prone plank time. In addition, the recruits completed a battery of fitness tests in their sixth testing session. The absolute difference in time to complete the SFGT between conditions was calculated as: experimental SFGT time - PT time. Bivariate correlations were used to assess the relationship between the absolute difference in SFGT time versus fitness outcomes. The LC+SCBA trial took $44.5 \pm 15.5\%$ longer (345.9 ± 43.7 s; $p < .001$) and the LC only trial took $38.3 \pm 12.6\%$ longer (331.2 ± 39.3 s; $p < .001$) to complete the SFGT than the PT trial (241.0 ± 33.3 s). The LC+SCBA trial took longer to complete the SFGT than the LC only trial ($p = .046$). Post-SFGT RPE was higher in the LC+SCBA trial (6.7 ± 1.7) and LC only trial (6.3 ± 1.5) compared to the PT trial (4.6 ± 1.8; $p < .001$). Absolute aerobic capacity, lower body power, anaerobic power and capacity, abdominal muscular endurance, and upper body strength were significantly correlated to the decrement in SFGT performance on some tasks caused by the PPE. In summary, PPE increases the intensity of performing fire ground tasks. To enhance occupational performance, it is imperative that firefighters optimize specific physical fitness attributes to reduce the relative stress produced by the PPE.

KEYWORDS: Firefighter, Tactical Performance, Occupational Performance, Load Carriage, Fitness Outcomes

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THE EFFECT OF PERSONAL PROTECTIVE EQUIPMENT ON FIREFIGHTER
OCCUPATIONAL PERFORMANCE

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CHAPTER I

INTRODUCTION

Structural firefighters are required to perform physically strenuous occupational tasks while working in unfavorable conditions and wearing cumbersome Personal Protective Equipment (PPE) (94, 101, 104). The public, their colleagues, and their own lives depend on their ability to complete these tasks successfully. Firefighters' PPE consists of boots, coat, pants, hood, helmet, gloves and a Self-Contained Breathing Apparatus (SCBA), which collectively weigh 20 kg (101). Although PPE is necessary for protection, it increases the physiological burden during occupational performance due to the extra load carriage, increased work of breathing from the SCBA and the microclimate created by the thermal barriers of the bunker gear (32, 94, 101, 104). To perform occupational tasks safely and effectively a certain level of physical fitness is required to compensate for these physiological challenges (23, 69, 84, 90).

Load carriage and respirator use are two of the most prominent factors that negatively affect firefighter physical ability (32, 101). The physiological impacts of load carriage include decreased exercise tolerance, capacity, and efficiency, and thus firefighters experience a decrease in maximal measures of workload, oxygen consumption, and power output (6, 28, 94, 98, 101, 104). Load carriage also elicits increased submaximal effects including rate of perceived exertion, oxygen consumption and overall metabolic burden and physiological strain (6, 28, 94, 98, 101, 104). In addition, load carriage requires increased muscular work, which is associated with an earlier onset of fatigue and decreased exercise tolerance and capacity (6, 28, 94, 98, 101, 104). Performing load carriage at submaximal intensities elicits elevated heart rate,

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breathing discomfort, leg fatigue and RPE (80). The overall metabolic cost of activity, as demonstrated by oxygen consumption, is increased with load carriage, but it is dependent on several factors including the intensity of activity, body-size, location of the load carriage, and fitness level (78, 101, 104). These factors lead to an increase in metabolic burden at submaximal and maximal intensities and decreased work output. In brief, more energy is required to sustain the increased mass, allowing less energy to contribute to performing external work (104).

The SCBA is a necessary piece of equipment that negatively affects firefighter physical ability. The SCBA is comprised of a regulator attached to an oxygen tank. The deleterious effects of the SCBA are twofold. First, the SCBA is carried on the firefighter's back and is secured to the torso with a harness system that uses shoulder and waist straps, similar to a backpack. The restrictive forces applied by the harness system have been shown to restrict chest wall movement and limit ventilation (32, 78, 80). Second, the SCBA utilizes a positive pressure system. Thus, the SCBA regulator requires the firefighter to produce a greater expiratory pressure to exhale. Eves et al. (2005) reported that during a graded exercise test (GXT), the combination of wearing a cylinder and breathing through the SCBA decreased VO_{2max} by 14.9% compared to a performing a GXT without gear and while breathing in ambient conditions. Specifically, the respirator decreased VO_{2max} by 13.1%, whereas carrying the cylinder decreased VO_{2max} by 4.8%.

Although the SCBA provides the necessary protection from smoke and other air pollutants, it has been shown to alter breathing patterns, increase the work of breathing, and significantly decrease maximal exercise performance, while increasing submaximal cardiorespiratory responses (16, 32, 104). This is likely due to a combination of the

following factors: increased sensation of breathlessness, lung hyperinflation, increased competition for available cardiac output (especially at maximal exercise) between respiratory muscles and contracting skeletal muscles, which leads to a reduction in peripheral blood flow and skeletal muscle fatigue (16, 50). This resultant skeletal muscle fatigue can result in decreased exercise capacity and increased RPE (16, 104). Interestingly, in clinical environments, firefighters have demonstrated greater forced expiratory volume in 1s (FEV1), forced vital capacity (FVC) and increased maximum expiratory peak pressure (MEP_{peak}), which are perhaps respiratory adaptations to chronic SCBA use (26, 89). Both thoracic load carriage and SCBA use, individually, have demonstrated acute decreases in maximal inspiratory and expiratory pressures, suggesting respiratory muscle fatigue is a culprit for unfavorable respiratory responses (36). Despite the deleterious effects of SCBA use, Eves et al. reported an inverse relationship between the change in ventilation with the SCBA versus absolute VO_{2max}, suggesting that firefighters with increased cardiorespiratory fitness levels tend to experience a lesser decrement in performance due to PPE (32). In summary, SCBA use negatively effects cardiorespiratory responses, however, greater cardiorespiratory fitness may attenuate the decrement in performance in laboratory settings.

Firefighters' PPE has been shown to negatively affect physiological responses to work and exercise in laboratory settings (6, 32, 94, 98, 104). Similar to the responses observed during laboratory exercise, PPE has a negative impact on firefighter performance (101). Firefighter occupational performance is often assessed by timing the completion of occupational tasks. However, the several studies that have evaluated occupational performance either did not use PPE, used parts of it, did not utilize a control

condition, and/or did not recruit firefighters (69, 84, 90, 101). Thus, there is a need to evaluate the effect of PPE on occupational performance in a controlled yet applied setting.

Considering the aforementioned challenges of performing fire ground tasks with PPE, it is also important to identify physical fitness characteristics that are associated with the PPE-induced performance decrement. Identifying predictive characteristics will guide tactical strength and conditioning practitioners' exercise prescription to enhance firefighters' occupational readiness. An increased level of fitness will reduce the relative physiological stress, allowing for enhanced occupational performance with less risk of adverse events, thereby increasing the safety of the firefighter, their colleagues and the public (92). Therefore, the primary purpose of this study was to determine the effect of load carriage and respirator use (SCBA) on Simulated Fire Ground Test (SFGT) performance. The secondary aim of the study was to identify fitness attributes and physiological outcomes that are correlated to the decrements in SFGT performance produced by the load carriage only and load carriage plus SCBA use. We hypothesized that the load carriage plus SCBA condition would elicit a bigger decrement in SFGT performance than load carriage alone. We also hypothesized that upper body strength and anaerobic power and capacity would be related to the decrement in performance.

Assumptions

Assumptions of this study include the following:

1) All participants gave maximal effort during all of the tests.

2) All participants were well rested prior to performing physical assessments.

Delimitations

The study was delimited to the following:

1) Current Fire Department recruits who were cleared for duty by a physician.

2) Occupational physical ability was defined by the tasks included in the simulated fire ground test.

Definitions

Load Carriage: Full turnout gear including standard issued helmet, hood, coat, pants, gloves, boots, as well as the self-contained breathing apparatus and full cylinder.

Peak Expiratory Flow Rate (PEFR): Measure of speed of maximal expiratory flow ($L \cdot min^{-1}$).

Forced Vital Capacity (FVC): volume of air exhaled in a full breath (L).

Forced Expiratory Volume in 1 second (FEV1): Volume of air exhaled in first second of spirometry maneuver (L).

HR_{max}: Age predicted maximum heart rate (220 - years in age).

Heat Index: A measure of how hot the ambient temperature feels when relative humidity is factored in to the temperature, as calculated by the National Weather Service.

RPE: Rating of perceived exertion based on a 0-10 category-ratio scale (11).

Thermal Sensation: Rate of feeling of temperature, based on 0-5 Omni Scale (20).

CHAPTER II

REVIEW OF LITERATURE

Introduction

Firefighters must complete physically strenuous tasks while working in unfavorable conditions and wearing heavy Personal Protective Equipment (PPE) (22, 92, 94-96, 101-104). The public, their colleagues and their own lives depend on their ability to complete these tasks effectively. Firefighter turnout gear, or bunker gear, consists of boots, coat, pants, hood, helmet, gloves and a Self-Contained Breathing Apparatus (SCBA) (10, 101). The mass of this gear has changed over the years with advances in technology but still weighs about 20 kg (10, 101, 104). In addition to the PPE, firefighters often carry tools such as hammers, flashlights and radios(10). The coats and pants consist of three layers: the inner layer is a thermal barrier, followed by a moisture barrier and thermal shell which collectively protect from burns, cuts and moisture buildup (10). This creates a very hot microclimate that can limit cooling and further increase the work intensity (21, 40, 94, 96-98, 101, 104). The SCBA creates a pressure that increases the resistance required to exhale. By maintain a higher pressure inside the mask than outside of the mask, inward flow of possibly contaminated air is prevented in the event of a leak. (16, 21, 32, 33). The mask mounted regulator delivers air into the face mask just above the ambient air pressure of 14.7 psi after being reduced from 4500 psi from the cylinder with the primary pressure reducer (24). While necessary for protection, the PPE collectively increases the physiological burden during occupational performance due to the extra load carriage, increased work of breathing from the SCBA and the microclimate created by the thermal barriers of the bunker gear (2, 6, 28, 32, 94, 98, 101, 104). To

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perform occupational tasks safely and effectively a certain level of physical fitness is required (18, 23, 59-61, 69, 84, 90, 111). In order to properly train firefighters for optimal performance it is important to understand the independent and collective decrement in performance produced by the PPE. In addition, it is meaningful to identify fitness characteristics that are associated to the PPE-induced performance decrement to guide appropriate exercise prescription to prepare firefighters for occupational demands.

PHYSIOLOGICAL EFFECTS OF PERSONAL PROTECTIVE EQUIPMENT

The Role of Load Carriage

Personal protective equipment negatively impacts firefighter ability and performance by altering biomechanics and increasing metabolic demand and it can also increase risk of injury (101). It has been shown that PPE has a significant negative effect on both physiological and physical performance measures, but these decrements cannot fully be explained by the mass of the equipment (104). It should be noted that the shape of the load (i.e., a backpack vs. protective clothing) as well as the placement of the load has an impact (101, 104).

The first issue to be considered is the mass of the load, irrespective of placement (52, 101, 104). Firefighters wear personal protective equipment with an approximate mass of 20kg, which may be close to 40% of a smaller firefighter's body mass (57, 63, 101, 104). This is excluding any additional pieces of equipment that the firefighter may have to carry depending on the situation, which may add another 20kg (101, 104). This may include equipment such as hydraulic cutting and spreading tools (104). The physiological impacts of load carriage include decreased exercise tolerance, capacity and efficiency, decreased maximal measures of workload, oxygen consumption and power

output but increased submaximal effects including rate of perceived exertion, oxygen consumption and overall metabolic burden and physiological strain (14, 57, 63, 78, 85, 101, 104). In summary, less external work can be accomplished because more available energy is being used to support and move the additional load on the body (104). While overall metabolic cost of activity is increased with load carriage, the cost is dependent on several factors including intensity of activity, body-size of the individual and body location of the load carriage, as well as fitness levels of the individual (52, 78, 104). The performance decrement and cardiovascular strain due to load carriage are exacerbated in smaller, less fit individuals (38, 76, 78, 104).

Many studies have been conducted to evaluate the effects of the weight of the PPE on the physical abilities of firefighters. Maximal physical abilities have been shown to be lowered during load carriage conditions (57, 63, 78, 101, 104). Studies have shown significant decreases in time to exhaustion on maximal exercise tests (57, 63, 77, 78). Phillips et al. (2016) investigated the effects of heavy load carriage during graded exercise using healthy male subjects familiar with load carriage (78). The loaded condition consisted of subjects wearing a 25 kg backpack compared to the control condition where they wore the same physical training (PT) clothes but were unloaded. Power output was calculated by using the equation [mass (including the load) x speed x grade]. Power output at ventilatory threshold was reduced by 23.5% to 174 ± 5 W in the loaded condition compared to 133 ± 5 W in the unloaded condition (78). Power output at maximal exercise was decreased by 11.1% to 264 ± 11 W in the loaded condition compared to 297 ± 7 W in the unloaded condition and there was a 29.8% deduction in time to exhaustion 971 ± 15 s compared to 1383 ± 21 s (78). Other studies have reported

decreases in time to exhaustion of 46.6% during 45 kg load carriage (77). Oxygen uptake (VO_2) is also found to be reduced at ventilatory threshold in loaded conditions (32, 78). The decrease in exercise performance due to the increased weight carried is well established in the literature.

Maximal oxygen uptake (VO_{2max}) is also decreased at maximal exercise during load carriage (32, 57, 77). Carrying excess weight requires an increase in energy to support the load and increases baseline metabolic function, therefore decreasing the amount of available energy to perform the required task (14, 78, 101, 104). Load carriage also requires increased muscular work, which often results in faster fatigue leading to decreased exercise tolerance and capacity (32, 74, 78, 104). It has been suggested that exercise performance may be reduced by 1% for every 1 kg of external load (64, 77). At maximal exercise, there is no difference in heart rate, rate of perceived exertion or respiratory exchange ratio (RER) shown between loaded and unloaded conditions (32, 76, 78) During submaximal load carriage, heart rate is elevated compared to an unloaded condition in line with the increased oxygen consumption (80). Thomas et al. (2015) reported that load carriage resulted in a 7.8% increase in time to complete an obstacle course in SWAT operators (105). The literature reports no change in rate of perceived exertion (RPE) or lactate at maximal exercise during load carriage compared to unloaded conditions (32, 74, 78, 80, 105). This is likely due to the fact that subjects are terminating tests and/or reaching maximal levels at a lower workload (32, 78, 80).

Ventilatory variables are altered at maximal levels during load carriage as well (32, 78, 80). For instance, the volume of CO_2 exhaled (VCO_2) is decreased at maximal exercise, thus given the concurrent reduction in VO_2 the maximal respiratory exchange

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ratio (RER) is unchanged (32, 77, 78, 80). At maximal exercise intensities, breathing frequency is elevated while tidal volume (Tv), minute ventilation (Ve) and Ventilatory Threshold (Vt) are decreased (77, 78, 80). This suggests the use of a more rapid, but shallow breathing pattern which is thought to minimize the increased work of breathing (77, 79). In turn, this strategy also results in increased dead space and minute ventilation, which increases breathing discomfort and exercise RPE (77, 79). Minute ventilation is the volume of air breathed each minute and is calculated as the product of breathing rate and tidal volume (68). Deeper breathing results in less anatomic dead space, which is the air that does not participate in gaseous exchange with the blood (68). Intuitively, dead space increases with an increase in tidal volume, but increased tidal volume still allows for better gaseous exchange as shallow rapid breathing can lead to only dead space air being moved resulting in less alveolar ventilation (68). During progressive exercise, ventilatory threshold occurs at a lower power output during load carriage conditions (77, 78, 80). Ventilatory threshold is defined as the point where there is an increase in $\dot{V}_E/$ $\dot{V}O_2$ while $\dot{V}_E/\dot{V}CO_2$ remains constant (110).

Higher submaximal responses to exercise have also been demonstrated during load carriage. This is also a result of the increased metabolic demand and oxygen consumption necessary to support the excess mass (77, 78, 101, 104). Standing baseline $\dot{V}O_2$ is significantly elevated during 45 kg of load carriage compared to an unloaded condition, ($0.52 \pm .12$ L/min vs. $0.42 \pm .10$ L/min, p <.05 respectively) which reduces the physiological reserve (3.75 ± 0.13 L/min to 3.24 ± 0.11 L/min) (77, 101). Physiological reserve is the difference between $\dot{V}O_{2peak}$ and baseline $\dot{V}O_2$ (77, 101). An increase in baseline metabolic load or a decrease in metabolic load will result in a decrease in

physiological reserve and likely occupational ability (77, 104) Absolute energy

expenditure increases as the amount of load being carried increases (44). However, it has

been shown that those exposed to chronic load carriage may elicit adaptations to slightly

attenuate the increased energy expenditure (44, 91). Grenier et al. (2012) reported a

22.3% ± 16.3% ($j \cdot kg^{-1} \cdot m^{-1}$) increase in the gross energy cost of walking while carrying a

~22.4 kg load and 37.1± 22.9% ($j \cdot kg^{-1} \cdot m^{-1}$) increase while carrying a ~37.9 kg load (44).

The net energy cost of walking was 42.5 ± 29.2% higher while carrying a ~22.4 kg load

and 70.8% ± 43.0% higher while carrying a ~37.9 kg load (44). This increase in energy

required to complete tasks under load carriage results in an increase in several

physiological variables during submaximal conditions (32, 57, 63, 74, 78). Oxygen

consumption has been shown to increase disproportionately to the amount of weight

being carried during incline walking, likely due to biomechanical changes adapted to

stabilize or maintain body position (62, 77, 78, 104). Phillips et al. (2016) reported a

significant increase in absolute oxygen consumption at submaximal intensities during

load carriage of 30 kg and 45 kg, but not 15 kg compared to an unloaded condition (77).

When made relative in terms of body mass + load carried, oxygen consumption was

significantly reduced with a 15 kg load but significantly increased with 45 kg load,

suggesting a nonlinear and mass specific response (77). It seems that the absolute

increase in oxygen consumption was proportionately lower than the increase in mass in

the 15 kg condition, which resulted in a lower oxygen consumption relative to body mass

+ load carriage. Similar findings have been reported in the literature with load carriages

as small as 20 kg. For instance, Taylor et al. (2012) reported a 47% increase in absolute

oxygen consumption during steady state walking (101, 104). Heart rate, breathing

discomfort, leg fatigue and exercise RPE are elevated during submaximal load carriage (62, 80, 85). Dead space ventilation is increased during submaximal exercise with load carriage while $\dot{V}E$ is decreased, and breathing frequency is increased, similar to responses at maximal exercise (80, 85). RER is also unchanged as $\dot{V}CO_2$ also increases with $\dot{V}O_2$ during load carriage (77, 80). Blood lactate levels are less commonly reported and have shown conflicting results at submaximal levels.

The location of the additional load placed on the body can significantly impact its effects. Loads carried closest to the body's center of mass have exhibited the least physiological burden (51, 101, 104). Wearing a double pack (half the load on the front and half on the back) has a lower energy cost than a backpack of the same mass (51). The hands and feet are the least efficient sites for load carriage during normal gait as there is increased work to initiate and terminate the motion that the limbs must go through as well as an increased arc of motion in comparison to the rest of the body (101, 104). This results in further elevated overall metabolic burden on the individual (57, 101, 104). Firefighter PPE is cumbersome and has been shown to increase metabolic burden due to the mass of clothing as well as restriction of movement due to the PPE (93, 104). This restriction in movement from the bulk of the PPE alters gait mechanics, reduces joint efficiency and results in a locomotor hobbling effect (93, 104). An increased trunk lean is often adopted due to the shift in center of gravity further impacting movement. Studies that have shown an increased energy cost disproportionate to the amount of mass worn is likely due to these alterations (78, 93, 104). PPE also has detrimental impacts on functional balance (49). Thoracic load carriage is another common location, which also

has further physiological impacts including increased work of breathing and reduced maximal exercise capacity and tolerance (32, 63, 64, 78, 104).

Demonstrating the inefficiency of peripheral load carriage, Lee et al. (2013) determined the effects of different clothing conditions in two different protocols (57). The authors found that during graded exercise tests, submaximal $\dot{V}O_2$ was 33% and 25% higher during the PPE+ boots and PPE+ shoes conditions, respectively, compared to a physical training (PT) condition with a t-shirt, shorts and socks (57). Time to exhaustion decreased substantially in the boots and shoes conditions compared to the light clothing. This decrease was seen more markedly in the speed protocol (PSP) than the incline protocol (PIP). Extrapolating their results, the authors concluded that time to exhaustion was calculated to decrease by .5 minutes for every 1.5 kg additional mass in the PIP shoes condition and .8 min in the PSP shoes condition compared to 1.3 min decrease in the PIP boots condition and 1.6 min decrease in the PSP boots condition. Wearing boots resulted in a significantly greater VO_2 and heart rate in submaximal exercise than running shoes but $\dot{V}O_{2max}$ was not affected (57) . The rate of increase in oxygen uptake was noticeably greater in the boots than shoes particularly while running (PSP) compared to walking uphill (PIP) (57). This further emphasizes the substantial impact that the location of the load has on various physiological and performance outcomes.

Taylor and colleagues (2012) determined that carrying the breathing apparatus (11.30 kg) imposed a significantly smaller metabolic burden than boots (2.44 kg) during walking but not stepping (101). When broken down by oxygen consumed per kg of mass carried for walking and bench stepping, the boots had the highest (88.75 ml·kg^{-1}·min^{-1} and 72.24 mL·kg^{-1}·min^{-1}) followed by clothing (32.63 ml·kg^{-1}·min^{-1} and 36.45 ml·kg^{-}

$^{1}\cdot min^{-1}$) then the helmet (13.67 ml$\cdot$kg$^{-1}\cdot$min^{-1} and 27.74 ml$\cdot$kg$^{-1}\cdot$min^{-1}) followed by the breathing apparatus (10.21 ml$\cdot$kg$^{-1}\cdot$min^{-1} and 11.36 ml$\cdot$kg$^{-1}\cdot$min^{-1}). The oxygen consumption per kilogram of mass of the equipment was calculated by subtracting the absolute oxygen consumption from the control trial from the experimental trial and normalized to the mass of the equipment (101). When a load is added to the torso it is as if the individual has gained central body mass. If a mass is added to the foot or hand it must be moved around the arc of the range of motion of the joint thus increasing inertial work and muscular work while also affecting center of gravity and balance. This is likely why although the breathing apparatus is four times heavier, it had less of an impact than the boots. The thermal protective clothing is more evenly distributed over the body surface and the increased work due to the increased load is performed by more muscles across all joints. With this being said, wearing thick clothing also elevates joint stiffness and friction within the clothing layers therefore increasing metabolic burden (101, 104).

Thoracic load carriage also elicits specific effects, particularly during heavy exercise (32, 77, 78, 80). It can restrict chest wall movement and therefore ventilation (76, 78, 80). It has been suggested that since inspiratory muscles may be fatigued during endurance exercise and respiratory fatigue is related to reduced oxygen delivery to working muscles that the chest wall restriction involved in thoracic load carriage may explain the reduced exercise tolerance seen during load carriage conditions (32, 76). Peoples et al. (2016) performed a study to compare the effects of load carriage versus chest-wall restriction (76). Exercise tolerance was reduced by 21% in the loaded (22 kg) condition but not in the chest strapping condition, indicating that the load was the primary detriment not the imposed breathing restriction (76). During the load carriage

condition, inspiratory time and expiratory time were significantly reduced even while standing (76). At maximal exercise, load carriage (but not chest strapping) elicited a lower time to exhaustion, slightly lower maximal heart rate, increased RPE and breathing frequency compared to the control (76). Tidal volume was decreased in both load carriage and chest strapping (76). There was no change in maximal voluntary ventilation compared to before the test in any of the conditions, suggesting that it was unlikely that inspiratory muscle fatigue impacted exercise tolerance, although there was a reduced breathing reserve in both load carriage and chest strapping conditions as well as a decreased maximal voluntary ventilation prior to the start of the test (76). Breathing reserve is the difference between maximal voluntary ventilation and the maximal ventilation achieved during the test. It is important to note that the authors used a weighted vest for their load carriage condition which may not elicit the same thoracic loading as is seen in firefighters wearing the SCBA harness. In contrast, Faghy et al. (2014) reported that wearing a 25 kg backpack induced significant inspiratory and expiratory muscle fatigue. Subjects completed a 60 min walk at 6.5 km·hr^{-1} and after 15 minutes of recovery performed a 2.4 km time trial with the load (36). Subjects showed an 11% decrease in maximal inspiratory pressure and a 13% decrease in maximal expiratory pressure following the load carriage trial which was further decreased (5 and 6% respectively) following the 2.4 km time trial (36). Forced vital capacity (FVC) decreased by $4 \pm 13\%$ and forced expiratory volume in 1 sec (FEV1) decreased $1 \pm 9\%$ after load carriage (36). Time trial performance decreased by $30.5 \pm 5\%$ during the load carriage condition (36). There are methodological differences between the two studies, mainly being that Faghy et al. (2014) used a backpack with adjustable shoulder and waist straps

compared to the weighted vest in Peoples et al. (2016). This has been previously supported in the literature showing backpacks having a larger impact than weighted vests (104).

Lung function has been tested in firefighters for a variety of reasons. It has been questioned whether they may have adverse health effects due to the exposure of potentially harmful substances on duty. Studies have shown increased mortality from some cancers but surprisingly the risk of dying from lung disease is equal or lower than compared to the population (89). Studies from 15+ years ago have shown reduced lung function and an accelerated lung function decline, likely due to the working conditions and equipment (89). FEV1, FVC, and forced mid-expiratory flow (FEF$_{25-75}$) are common parameters measured as indicators of lung function (89). FVC is the total amount of volume moved in one breath from maximal inspiration to maximal expiration (68). FEV1 is the same as FVC but more dynamic as it is performed for only one second (68). FEV1/FVC is an indicator of pulmonary expiratory capacity often used for clinical diagnosis and normal healthy individuals tend to have values around 85% (68). Schermer et al. (2010) showed that firefighters had higher FEV1 values (4.39 ± .68 L compared to 3.66 ± .73 L) and FVC values (5.86 ± .83 L compared to 4.50 ± .84 L) compared to matched controls (89). They had a lower FEV1/FVC (%) value (75.0 ± 6.4% compared to 81.4 ± 6.7%) and FEF$_{25-75}$ (3.53 ± 1.7 L·s^{-1} compared to 3.73 ± 1.14 L·s^{-1}) (89). Higher rates of self-reported exposure to dust, smoke and fire were correlated to lower FEV$_1$ and FVC values. Above average FVC values are likely the cause for decreased FEV1/FVC values (89). Low FEF$_{25-75}$ values are indicative of a high rate of small airway obstruction but is also related to FVC as exhaled volume does not increase linearly with time during a forced expiration so this

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information may be another byproduct of high FVC (89). Donovan et al. (1999) found no difference in FVC between firefighters and civilians but did find an increased maximum expiratory peak pressure (MEP_{peak}) in firefighters (254 ± 8 compared to 214 ± 9 cmH_2O). This may be an adaptation elicited from chronic use of the SCBA by means of postural changes eliciting a forward lean and increasing the abdominal wall strength (26). Butcher et al. (2007) found reductions in maximal inspiratory ($12.3 \pm 6.3\%$) and expiratory ($14.0 \pm 10.8\%$) pressures post-exercise wearing the SCBA regulator and PPE. It is suggested that both the load carriage and regulator acutely elicit respiratory muscle fatigue, which is likely compounded with full gear on (17). Respiratory muscle fatigue may increase limb fatigue and impair whole body performance via the metaboreflex. It also may decrease the function of the respiratory musculature to stabilize posture and prevent falls as its main priority is respiration (36). This could result in increased risk of falls especially in unfavorable conditions such as dark buildings with debris and possibly unstable surfaces. The metaboreflex is a sympathetically mediated response from fatigued inspiratory muscles which constricts peripheral vasculature and increases cardiac output by redistributing blood flow and volume which can lead to earlier peripheral muscle fatigue and overall reduced performance (12, 36). Inspiratory muscle training has elicited increased maximal inspiratory pressure, decreased breathing discomfort and heart rate during submaximal load carriage as well as improvement on a time trial post load carriage (37). This suggests that respiratory muscle strength is trainable and may attenuate the metaboreflex, which could be related to the decrements seen in firefighter occupational performance while wearing PPE.

The Role of the SCBA

One of the most hindering aspects of the PPE that firefighters must wear is the Self-Contained Breathing Apparatus or SCBA, which is a mask and regulator attached to an oxygen tank. The SCBA regulator requires a certain expiratory pressure of air flow to allow air to escape. While providing protection from smoke and other air pollutants, the SCBA has been shown to alter breathing patterns and significantly decrease maximal exercise performance (16, 32). Wearing the SCBA has shown that work of breathing during exercise is increased due to the increased expiratory pressure that is required, resulting in an increase in active expiratory resistive work and inspiratory elastic work at higher ventilation rates (16, 32, 33). This has been attributed to the expiratory resistance as well as perhaps the impact of limited chest wall mechanics due to the SCBA's weight, as previously discussed (6, 32, 33, 35, 36). Previous research has shown that using the SCBA with low density gas has attenuated this effect, confirming the effect of increased expiratory resistance (33). It has been discovered that this added resistance also creates a decreased duty cycle and altered breathing pattern with a decreased breathing frequency and increased tidal volume at low ventilation rates with the opposite response occurring at higher ventilations (32). Duty cycle, also called, Ti/Ttot is the inspiratory time divided by the total time for one ventilatory cycle (32). The SCBA may result in competition between respiratory muscles and exercising peripheral muscles for blood flow at maximal exercise which may also lead to reduced venous return and stroke volume, likely impacting cardiac output and leading to a reduction in blood flow to active muscles, ultimately resulting in earlier onset of muscle fatigue (16, 50). During exercise with an SCBA a decrease in oxygen saturation has been observed (32). Besides having a large

physiological impact, it also increases the sensation of breathlessness and lung

hyperinflation, which causes further mental stress in an already stressful situation (16).

The total weight of the SCBA is around 12 kg but even when the load carriage effect is

omitted, studies have shown that the respirator itself limits $\dot{V}O_{2max}$ during a maximal

graded exercise test by limiting ventilation due to the increased breathing resistance (32).

Interestingly, there is a large variety of individual responses to the SCBA. However, there

is an inverse relationship between the change in ventilation with the SCBA (vs. no

SCBA) and the absolute $\dot{V}O_{2max}$ of the participants (32). This suggests that those with

higher aerobic capacity are affected less by wearing the SCBA (32).

Wearing the SCBA and regulator has further physiological impacts compared to

other load carriage (32, 63, 64, 104). It increases inspiratory and expiratory work of

breathing, reduces maximal exercise capacity and tolerance as well as alters breathing

patterns (32, 63, 64, 78, 104). This is likely partially due to the physical limitations

placed on the body by the load (63, 64, 104). The SCBA harness and air cylinder limit

maximal ventilation, which can result in increased dyspnea and RPE as well as fatigue of

the respiratory muscles (104). These impediments in ventilation and breathing alterations

may result in arterial desaturation as well as increased mechanical work on the heart

(104). It has been suggested that the harness straps and air cylinder weight only

minimally restrict ventilation compared to the effects of the actual regulator itself (32).

When thoracic load carriage is combined with increased breathing resistance (SCBA) left

ventricular preloading and reduced end-diastolic filling have been observed, which

further exacerbates the increased work already being placed on the heart, implying

increased downstream vascular resistance that is often seen most pronounced during

resistance training (104). Eves et al. (2005) reported that carrying the SCBA cylinder resulted in a reduction of $4.8 \pm 5.3\%$ in VO_{2max}, confirming that both the mass ($12.1 \pm .5$ kg) and the mechanical restrictions have an impact (32).

The total SCBA (regulator and pack) elicits negative effects at maximal and submaximal physical activity by also increasing cardiorespiratory strain. The increased strain is likely due to the interaction of increased breathing resistance, equipment dead space, weight of the equipment and subjective stress factors (65). Wearing the SCBA results in an increased expiratory pressure for airflow. It has been demonstrated that the SCBA attenuates ventilation during heavy exercise, likely due to the mechanical limitations placed on the chest wall from the pack as well as the increased expiratory pressure required to breathe against the regulator (16, 29, 33, 104). The latter has been suggested to be the main cause (33, 34). Previous research has also found that stepping exercise with the SCBA induced reductions in both inspiratory and expiratory maximal pressures, indicating respiratory muscle fatigue, likely due to its increased inspiratory elastic expiratory resistive and total work of breathing (15). Eves et al. (2003) demonstrated that using a lower density mix of helium and oxygen during an graded exercise test wearing PPE + SCBA increased $\dot{V}O_{2max}$ and maximal $\dot{V}_E$ by alleviating some of the respiratory effort required with the SCBA and perhaps reducing respiratory muscle fatigue (33). This can be explained that since helium and oxygen mixed gas has a lower density, it maintains laminar flow at higher flow rates resulting in less resistance to flow and therefore less muscular effort necessary for exhalation, particularly when breathing against a positive pressure as in the SCBA (13, 33). $\dot{V}O_{2max}$ is decreased while wearing the SCBA (16, 29, 32). An increase in work of breathing can decrease exercise

performance, likely due to the following things: increased sensation of breathlessness, lung hyperinflation, increased competition for available cardiac output (especially at maximal exercise) between respiratory muscles and exercising muscle which leads to a reduction in leg blood flow resulting ultimately in muscle fatigue (16).

Eves et al. (2005) conducted a study to determine the magnitude of ventilatory limitation caused by the SCBA and its overall impact on $\dot{V}O_{2max}$ as well as the impact caused by the individual components of the regulator and the cylinder/harness assembly (32). Subjects completed four graded exercise tests on the treadmill: full SCBA, regulator, cylinder and control. In all conditions the subjects also wore standard turnout gear. The full SCBA condition reduced maximal oxygen consumption ($14.9 \pm 7.1\%$), ventilation and maximal power output ($11.6 \pm 8.2\%$) compared to the control condition. The authors concluded the reduction in ventilation was due to a significant reduction in tidal volume (32). Duty cycle (T_i/T_{total}) also decreased, likely due to the reduction in inspiratory time (T_i) and increase in expiratory time (T_e) (16, 32). Other literature has also shown decreased tidal volume, inspiratory and expiratory times, and increased ventilatory frequency, resulting in an overall altered breathing pattern, further leading to insufficient ventilation and gas exchange (16, 64). Others have reported a decrease in inspiratory time but no change in expiratory time (29). At maximal exercise with the SCBA, the estimated breathing resistance and peak expiratory pressure are significantly increased as is inspiratory elastic work and inspiratory active resistive work (16, 29, 32). There is also a decrease in maximal respiratory flow rate and decreased active expiratory elastic work when wearing the SCBA (16, 29, 32). Inspiratory resistive work is unaffected (16). At high intensities, the increased active expiratory resistive work and

inspiratory elastic work contributes to 13% increase in total work of breathing (16).

Maximal oxygen consumption was reduced significantly in the regulator condition (13.1

± 4.6%) compared to the pack condition (4.8± 5.3%), however only peak power output

was reduced compared to the control (32). Maximal workload has been reported to

decrease by about 35% during a graded exercise test with the SCBA and resulted in

slower recovery than control conditions (64, 65). The regulator decreased ventilation and

inspiratory time while increasing expiratory time without changing tidal volume or

breathing frequency (32). Other literature has reported decreased tidal volume at maximal

exercise (2.62 ± .04 L) compared to PT (3.17 ± .04 L) with increased ventilation at

submaximal levels but lower at maximal exercise (142.8 ± 18.0 L·min^{-1} vs. 167.1 ± 15.6

L·min^{-1}) (29). Dreger et al. (2006) reported the decrease in $\dot{V}O_{2max}$ with SCBA was

related (r = .81) to the decrease in ventilation (29). At maximal exercise, fraction of

expired oxygen (F_EO_2) was shown to be significantly higher (17.43 ± .28% compared to

17.29 ± .20%) and F_ECO_2 was significantly lower (4.07 ± .26% compared to 4.32 ± .26)

with the SCBA compared to the control condition (29). Similarly, at peak exercise

oxyhemoglobin saturation was decreased in the SCBA and regulator trials compared to

the pack and control conditions (32). This is likely due to a decrease in alveolar

ventilation that may occur at high exercise intensities with the SCBA (29). Maximal heart

rate, RPE and perceived respiratory distress were not different across the trials, but the

authors reiterate the fact that these responses occurred at lower power outputs in the

regulator and SCBA trials (32). Butcher et al. (2006) reported no difference in tidal

volume, respiratory rate or heart rate while cycling with the SCBA (16). During heavy

exercise with the SCBA it is likely that an increase in CO_2 results in an increase in

breathing frequency as well (32). RER and $\dot{V}CO_2$ remained very low although maximal

heart rate was attained during the heavy exercise SCBA condition(32). In comparison,

other literature has reported hypoventilation but still a resulting decrease in RER while

wearing a regulator (65).

Donovan et al. (1999) completed a study comparing the ventilatory performance

during exercise while wearing an SCBA in a group of firefighters to a group of civilians

(26). During the first visit, anthropometric measures and measures of strength, power,

flexibility, and lung function were completed. Lung function measures included

spirometry with a portable spirometer, peak static mouth pressures during inspiration and

expiration. The next visits included a "Firetest" which was a submaximal progressive test

designed to simulate firefighter scenarios and included a treadmill walk, carrying

dumbbells, deadlift, step-ups, and shoulder press and lasted 23 minutes. It was done in 2

conditions, PT clothes, and SCBA + PPE (24.3 kg). The civilian group had a third visit

with PPE but no SCBA (4.6 kg) to introduce and familiarize them to turnout gear.

During the test, respiratory air flow was measured, heart rate was recorded and a measure

of breathlessness was completed. The firefighter group on average had a greater peak

expiratory mouth pressure than the civilian group. During the Firefit test with SCBA, the

firefighter group used significantly less air and rated their breathlessness significantly

lower. The percent change between the PT Firefit test and SCBA Firefit test was

significantly higher for the civilian group in air use, $\dot{V}_E$ and tidal volume. The authors

conclude that although there is no significant difference in breathing patterns in PT

clothes, the firefighters have developed different breathing strategies to cope with the

SCBA (26). The firefighter group met the added ventilatory demand by increasing

breathing frequency and reducing total breath duration and maintaining tidal volume. The increased expiratory mouth pressure data suggest the firefighter group has stronger expiratory muscles than the general population (26). It has previously been suggested they may have stronger inspiratory muscles as well (27).

In summary, the increased expiratory resistance caused by the SCBA alters breathing patterns during exercise, especially at higher intensities (16, 29, 33, 104). This can result in respiratory muscle fatigue, decreased exercise capacity and increased RPE and breathlessness (16, 26, 29, 33, 104). It increases submaximal responses and decreases maximal abilities, similar to the pattern seen in load carriage. This overall increases the physiological demand placed on firefighters (16, 21, 29, 33, 104).

The Role of Thermoprotective Equipment

Firefighters must perform physically strenuous work for prolonged periods of time in harsh environments wearing thermal protective equipment in high ambient temperatures (8). Thermal regulation is essential for the body (68). Core temperature is 37 ±1°C and cannot tolerate increases greater than 5°C or decreases greater than 10°C (68). The American College of Sports Medicine defines exertional heat stroke at rectal temperatures greater than 40°C (3). Heat transfer between humans and the environment can occur in four ways: radiation, convection, conduction, and evaporation (45, 68). Dissipating heat is critical during exercise in warm weather. Heat transfer occurs in a high to low gradient. Radiation involves the transfer of heat between two objects, for example the body absorbing heat from the ground or direct sunlight. Conduction is heat exchange through direct contact of two objects -for example water. The body shunts blood to the surface of the skin to dissipate heat. Convection is heat transfer between

body surface and the boundary air layer near the skin. This includes wind or water moving past the skin; if convection occurs slowly, the boundary layer is warm and insulative, if it occurs quickly (i.e., a fan) our insulative boundary layer is constantly being replaced and heat loss increases. Lastly, and likely the most important during exercise is the heat loss that occurs with sweat evaporation. Water vaporizing to the environment exerts a cooling effect on the skin. For all these mechanisms to occur, there must be a favorable gradient. For example, in an extremely humid environment, evaporation cannot occur and will not have a cooling effect on the body (45, 68).

During exercise in the heat the body has increased cardiovascular demands. The working muscles require blood flow to deliver nutrients for metabolism while blood is also being shunted to the periphery to transport metabolic heat for cooling. Evaporation is the main mechanism of cooling which can result in large fluid loss or dehydration. Stroke volume (SV) is generally lowered in the heat due to this loss of fluid and resultant decreased venous return which requires an increase in heart rate to maintain cardiac output (Q). Dehydration can lead to a decrease in blood pressure due to the reduction in stroke volume and increased competition for cardiac output, which with prolonged exercise will also decrease. Eventually blood flow to the working muscles will decrease, ultimately resulting in muscular fatigue. At the same time, the body is producing more heat as a byproduct of metabolism and further exacerbating the issue (40, 67, 68, 93). Therefore, firefighters face a two-part dilemma involving extremely high ambient temperatures coupled with high heat production with an inability to dissipate heat due to the PPE that they must wear (109). This inability to dissipate heat also leads to dehydration due to the amount of sweat lost, which can further impact the issue of

thermoregulation (94). Previous studies have demonstrated that heat stress caused by wearing PPE and dehydration contribute to cardiac strain during exercise with the increase in core temperature having a larger impact on heart rate during exercise than moderate dehydration did (40). The combination of dehydration and increased core temperature further leads to increased cardiovascular strain (93, 94). This can lead to early fatigue and a decrease in performance as well as exacerbating any underlying disease symptoms which could result in a sudden cardiac event (94). Seeing as 45% of on duty fatalities are caused by sudden cardiac events this is a major concern (9).

The increased overall metabolic burden due to wearing PPE is a result of load carriage, ambulatory inefficiency, and increased work of breathing (16, 101, 104). These effects result in an increase in metabolic heat production. Firefighter PPE is made to protect from extreme temperatures and debris, however, this protective layer also results in heat insulation, effectively eliminating the benefits of perspiration in thermal regulation. (94, 97, 104). The ineffective cooling results in a further increased sweat rate as the body attempts to cool itself which is ineffective since evaporation cannot occur and therefore only leads to dehydration (94, 97, 104). This can further impact cardiac output due to decreased venous return and lead to even higher heart rates than due to the increased intensity of load carriage exercise etc.(94, 97, 104). Thermal regulation is yet another component that leads to increased cardiovascular strain during firefighter tasks. Taylor et al. (2012) reported that wearing PPE clothing (4.72 kg) represented a significantly increased burden during steady state walking and stepping as calculated by heart rate response, likely due to the impaired ability to dissipate heat in combination with increased overall cardiovascular strain (101). The processes for heat dissipation

(convection, conduction, evaporation and radiation) are all gradient dependent and unfortunately in the microclimate created by the PPE the gradient is the opposite way for cooling the body and indeed has the opposite effect (94, 104). Dehydration can lead not only to decreased body fluid (decreased venous return and increased work on the heart to maintain cardiac output) but it also can lead to depletion of electrolytes (104). It is suggested that relative VO_{2max} of an activity is increased while wearing PPE due to the heavy weight but also increased thermal impact leading to a significant decrease in work capability and duration as well as premature onset of muscle fatigue (57). The impaired thermal regulation aspect of the PPE has shown decreases in exercise tolerance, capacity and power output as well as increased physiological effects at submaximal conditions likely due to the competition of the working muscles competing for blood flow and the shunting of blood to the skin in an attempt to cool and maintain core temperature (2, 14, 93, 94, 104). The issue of thermal regulation is exacerbated in live fire situations when ambient temperatures become extreme (2). Performing firefighter relevant tasks such as raking debris in hot temperatures (45°C) has shown core temperatures close to 38°C within the first hour of testing (56). Overall the hot temperature resulted in lower performance values and higher levels of thermal stress and exertion (56). An ad libitum increase in water intake led to no changes in body mass or urine specific gravity (USG), likely also due to the frequent breaks in the design of the study (56). Lee et al. (2013) reported peak heart rate during a graded exercise test with PPE was significantly higher $(180 \pm 17 \text{ b·min}^{-1})$ at an ambient temperature of 32°C than 22°C $(168 \pm 18 \text{ b·min}^{-1})$ (57). Other studies have shown decreased $\dot{V}O_{2max}$, decreased time to exhaustion and increased

RPE during hot conditions, likely a combination of the heated environment and resultant dehydration(87, 94, 112).

However, firefighters often face much more extreme temperatures, reaching over 200°C (14). Bruce-Low and colleagues (2007) performed a study using firefighter breathing apparatus instructors to investigate the cardiovascular stress of wearing the weight of the PPE compared to regular PT clothes in live fire training exercise (LFTE) and mock fire training exercises (MFTE) in an attempt to quantify the contributing factors to the intrinsic stress from the weight and permeability of the PPE + SCBA compared to the extrinsic stress wearing PPE + SCBA in a hot environment (14). The subjects were acting as breathing apparatus instructors assisting and supervising drills. Oxygen consumption, heart rate, skin, aural and microclimate temperatures and RPE were all recorded during the trials. The subjects then completed two identical MFTE and LFTEs each spanning 35 ± 2 min. The temperature during the MFTE was 15.1 ± 2.3 °C at 1.2 m above floor and 15.3 ± 3.5 °C at the ceiling compared to LFTES which were 174.8 ± 28.9 °C and 209.6 ± 34.1 °C at ceiling. The mean oxygen cost (estimated by amount of air used in cylinder) was 13.8 ± 2.3 ml·kg^{-1}·min^{-1} during the MFTE which was significantly lower than the 17.4 ± 2.8 ml·kg^{-1}·min^{-1} seen during the LFTE, suggesting the increase in ambient temperature increased oxygen consumption. Heart rate was also significantly higher, likely due to the increased ambient temperature. Heart rate elevated and decreased depending on when they were exposed to live fire and when it was turned off during debriefing sessions. Temperature (skin, aural and microclimate) tended to drift overall with small dips if any, indicating the short debriefs did not alleviate the heat stress. RPE was higher in the LFTE and skin, aural and microclimate temperatures

increased more significantly in the LFTE than the MFTE. In conclusion, the authors

suggest that increased heat storage from the PPE is responsible for the majority of the

increased cardiovascular strain seen. Similarly, Angerer et al. (2008) investigated the

cardiocirculatory and thermal strain during live fire suppression in structural firefighters

(2). The subjects completed a 30-minute simulated fire operation wearing full gear (24

kg) where the temperature 1.5m above the ground was 200 °C and near the ceiling it

reached 700 °C at maximum (2). After the simulation, core temperature significantly

increased from 36.9 °C to 37.7 °C, body weight significantly decreased by .6 kg, both

systolic and diastolic blood pressure significantly decreased by 9 mmHg, and heart rate

was elevated by 24 b·min^{-1} (2). The authors also state that maximum heart rates were

highly variable, likely due to individual and situational factors during a simulated

emergency (2).

Smith and colleagues (2015) conducted a study investigating the effects of heat

stress and dehydration on physiological responses in firefighters while wearing PPE (94).

Twelve physically active, healthy, college aged males participated in the study which

compared three different experimental conditions of heat stress. There was a hydrated

heat stress condition, dehydrated heat stress condition and a control condition of hydrated

but no heat stress. The dehydrated state was defined as a 1-2% loss in body mass by

limited consumption of 1-1.5 L in the 24 hr prior and ~8 ounces water during the trial

with a goal of 3% body weight loss by the end of the trial. Each trial consisted of a 100-

minute intermittent exercise protocol including three 20 minute bouts of walking on the

treadmill at 3.1 mph and 5% grade separated by 20 minutes of rest. The hydrated no heat

stress condition included wearing a cooling shirt, weighted vest and SCBA harness and

drinking enough fluid to prevent dehydration during the trial. The hydrated heat stress

condition consisted of wearing 18.7 kg of PPE including the SCBA harness. The

dehydrated heat stress condition had the same gear but fluid was restricted 24 hours prior

to and during exercise. The dehydrated condition simulated the dehydration that

commonly occurs during occupational tasks and further exacerbates heat stress. All

conditions were conducted in a thermoneutral environment so external heat was not a

factor. During all trials, core temperature rose during exercise and slightly into recovery.

In the control condition, core temperature rose by .61°C by the end of the trial compared

to1.22°C in the hydrated heat stress and 1.5°C in the dehydrated heat stress. Heart rate

similarly increased during exercise and decreased during recovery however to much

different magnitudes. During the control condition, heart rate averaged 105 b·min^{-1}

compared to 152 b·min^{-1} during the hydrated heat stress condition and 158 b·min^{-1} in the

dehydrated heat stress condition. As the authors conclude, since all participants wore the

same load carriage this 50 b·min^{-1} increase in heart rate is not caused from the load

carriage but reflects the effects of the microclimate of the PPE and perhaps increased

effort of walking in cumbersome clothing. During the recovery times, heart rate during

the stress conditions did not fully recover back to baseline and like core temperature,

drifted upwards with each bout. This study clearly demonstrates the thermal effect that

PPE has on firefighters even during ambient conditions (94). A study by Bruce-Low et al.

(2007) reported that at the end of a step test skin temperature was 33.6 ± 0.3 °C in a PT

condition and 33.2 ± 1.4 °C in a weighted PT condition compared to 36.7 ± 1.2 °C in the

PPE condition, showing the microclimate effect of the PPE, unrelated to the additional

load carriage (14). Aural temperatures were not different between trials. Microclimate

temperatures were also significantly increased in the PPE condition at 33.0 ± 0.9 °C and RPE was significantly higher in the weighted PT and PPE conditions (14).

When wearing all aspects of the PPE, the physiological responses that have been described separately, are compounded, resulting in greater decrements in performance. Dreger and colleagues (2006) completed a study to investigate the combined effects of PPE and SCBA on VO_{2max} (29). Twelve healthy males familiar with exercise in firefighting gear volunteered to participate in the study. Subjects completed two graded exercise treadmill tests in randomized order (29). One condition was wearing full PPE and SCBA compared to the control condition of PT clothes and running shoes breathing through a standard low resistance valve (29). Oxygen cost was found to be significantly higher at submaximal levels wearing PPE+SCBA than PT clothes. At peak exercise, VO_2 and VCO_2 were significantly lower in PPE condition, while the power output at VO_{2max} was significantly higher in the PT condition (29). $\dot{V}O_{2max}$ averaged 52.4 ± 8.5 ml·kg^{-1}·min^{-1} during the PT condition compared to 43.0 ± 5.7 ml·kg^{-1}·min^{-1}. (29). It has been said that since VO_{2max} is used as a measure of physical capability but is decreased wearing either PPE or with SCBA, it should be assessed with PPE on for relevant occupations (104).

EFFECTS OF PERSONAL PROTECTIVE EQUIPMENT ON OCCUPATIONAL PHYSICAL ABILITY

The physiological effects caused by the individual pieces of, and total, PPE have been established during controlled laboratory tests. However, this is not specific to firefighter occupational performance and not all studies have used the target population. Similar to the responses seen during exercise, PPE has a negative impact on FF performance. Firefighter occupational performance is often tested in an obstacle course

format, lasting varying amounts of time, completing relevant tasks, like the ability tests required for firefighters (69, 84, 90, 101). Many of the studies conducted regarding occupational performance either do not use PPE, use parts of it or do not use a control trial. This may be important as studies have shown possible pulmonary and thermoregulatory adaptations in incumbent firefighters (55, 89). This is like what is seen in the literature with exercise responses to PPE. Studies in other tactical populations also use similar obstacle courses to determine the occupational performance decrements seen with gear (66, 105).

Overall, a decrease in performance with increased work is seen during obstacle courses wearing gear (54, 66, 101, 105, 106). Performance on a military obstacle course, including firefighter relevant tasks such as a victim drag, produced a decrease of 31% in time to completion when loaded (66). While a military specific anaerobic sprinting task saw decreases in sprint performance by 8.2 ± 1.4 s in a 30 m sprint in 21.6 kg of gear, with the greatest decrement occurring in the first 5 m likely due to the test beginning with rising from a prone position (106). Other studies in military populations have shown that performance continually deteriorates throughout a task and that heavier loads elicit larger decrements (48). Thomas et al. (2015) conducted a study with SWAT operators completing an occupationally relevant obstacle course in both loaded and unloaded conditions (105). The loaded condition consisted of 14.2 ± 2.0 kg and consisted of a ballistic armor vest, helmet, duty belt, weapons, ammunition, communications equipment and medical equipment. The authors found that during the loaded condition, 9 of the 13 tasks were significantly slower and the total time to completion was increased by 7.8%. There were however no differences in blood lactate, heart rate or RPE between trials.

Similarly, Taylor and colleagues (2012) evaluated the difference in firefighter obstacle course performance while wearing full PPE and carrying the SCBA (total 19.86 kg) using healthy non-firefighter males and females (101). The obstacle course consisted of tasks including a hose carry, stair climb, equipment carry, climb over a fence, and victim/dummy drag. The total course covered 281.3 m horizontally and 29.01 m vertically, including 8 flights of stairs. Overall, obstacle course performance decreased by 27% while wearing PPE with males experiencing a slightly smaller decrement of 23% compared to 31% in females. The authors stated that on average the females were 15 kg lighter than the males and therefore the load a greater relative burden on those smaller and less strong individuals (101). Taylor and colleagues quantified, for the first time, the individual burden of each piece of PPE, however they did not use the SCBA and did not correlate fitness characteristics using a firefighter population (101).

There is a gap in the literature regarding the effect of gear on different aspects of occupational performance. Many tactical populations are required to perform a variety of tasks of different physiological nature and there is much left to be learned. Particularly, subject responses such as blood lactate or RPE or thermal stress are lacking (54).

THE EFFECT OF PHYSICAL FITNESS ON OCCUPATIONAL PHYSICAL ABILITY

As with most athletic tasks, firefighting can be broken down to a strength component and a cardiovascular component. There are clear relationships between various fitness characteristics and firefighter occupational performance (18, 23, 59-61, 69, 84, 90, 111). The literature also demonstrates that build or stature may play a role in performance (18, 63, 69, 111). Multiple studies have reported the relationship between fat-free weight and body fat percentage and even height to performance (18, 63, 69, 111).

This is logical as literature on load carriage has demonstrated that smaller individuals are at a greater disadvantage (18, 38, 76, 78, 104). Studies have shown that heavier individuals (more absolute weight) negatively impacts performance as they are already carrying more weight. This is somewhat contradictory as fat-free weight has shown to be beneficial to performance although so is a low body fat percentage [38, 39, 41]. Throughout the literature, there are strong correlations between firefighter occupational performance and upper body strength and endurance, anaerobic power and capacity, aerobic capacity, and body fat percentage (18, 31, 60, 61, 63, 69, 84, 90, 111). A minimal level of absolute muscular strength is necessary to perform some of the common tasks required by firefighters as well as a minimal level of aerobic fitness. It has been established that aerobic capacity plays a part in firefighter occupational performance, with suggested VO_{2max} criterion levels of 40-45 ml·kg^{-1}·min^{-1} or 8-12 METs (22, 30, 61, 69, 99). Muscular strength and endurance have been correlated with occupational performance as well (22, 59, 60, 84, 103, 111). There have also been studies that suggest anaerobic capacity may play a significant role as well due to the intermittent high intensity nature of firefighting (46, 63, 90). Studies in other tactical populations have shown that improvements in load carriage performance can be elicited via upper body resistance training with aerobic training as well as field based training using load carriage (23, 52, 104). It has also been shown that increased levels of fitness can decrease the decrement caused by load carriage (23, 52, 104). Strong correlations have been shown between total time on the military obstacle course and upper body strength, lower body strength, and lower body power (66). Circuit training interventions targeting cardiovascular fitness, muscular strength and endurance improved firefighter

occupational performance demonstrating that an increase in overall fitness is beneficial

(75). The difference in methodology including types of fitness tests, subject population

and equipment worn during the tasks makes it difficult to compare across the literature.

Dreger et al. (2007) and Elsner et al. (2008) both measured $\dot{V}O_2$ during firefighter

specific tasks wearing PPE (30, 31). Dreger et al. (2007) assessed the oxygen cost of the

Canadian Department of National Defense Fire Fit test, a test containing 10 firefighting

tasks that is used to test the fitness of incumbent Canadian Forces firefighters (30). Using

the data, the authors predicted an oxygen cost of 34.1 ml·kg^{-1}·min^{-1} to be associated with

the standard 8-minute completion time (30). The subjects completed one trial of the Fire

Fit test in PPE and carrying the SCBA (total: 23.0 ± 1.80 kg) while breathing through a

portable metabolic system (MMC), and one trial wearing PPE and breathing through the

SCBA (30). The Fire Fit test included a hose carry, ladder carry and raise, hose drag, two

ladder climbs, rope pull, forcible entry, victim rescue, ladder lower and carry, spreader

tool carry (30). The total time was recorded as well as the "work time" during which an

event was being completed and "relief time" during transitions (30). There were no

significant differences in performance time between the SCBA trial and the MMC trial in

either total time, work time, or relief time or RPE thus the authors said the trials were

comparable (30). Subjects worked at an average level of 85% $\dot{V}O_{2peak}$, $90.5 \pm 4.0\%$ of

maximal heart rate and RER was $1.13 \pm .09$, suggesting a high level of physical demand

(30). Elsner et al. (2008) measured $\dot{V}O_2$ in a similar task specific continuous circuit that

included multiple hose advances, a ladder carry and extension, donning an SCBA, using a

simulated Keiser sled, climbing three flights of stairs, pulling hose up to the third story

with a rope, dragging a hose to the third floor and a search and rescue with victim drag,

while wearing PPE and carrying SCBA (total load carriage mass = 27 kg) (31). This circuit was slightly longer than Dreger et al. (2007) with an average completion time of 11.65 ± 2.21 minutes compared to 6.63 ± 1.10, and the results were slightly different (30, 31). Elsner et al. (2008) reported average $\dot{V}O_2$ was 29.10 ± 8.0 ml·kg^{-1}·min^{-1}, average heart rate was 175 ± 7 b·min^{-1} which correspond with 62% $\dot{V}O_{2max}$ and 95% maximum heart rate while $\dot{V}O_{2peak}$ during the test averaged 80% of $\dot{V}O_{2max}$ (31). Dreger et al. (2007) used a mix of male and female firefighters and nonfirefighters, whereas Elsner (2008) only used male firefighters who were currently participating in a department wellness program, which could explain some of the differences found (30, 31).

Michaelides et al. (2011) and Sheaff and colleagues (2010) have conducted similar studies to identify the relationships between various fitness characteristics and firefighting performance on an occupational ability tests while wearing PPE but not the SCBA (69, 90). They both used firefighters, wearing 22.7 kg (69, 90). Michaelides et al. (2011) used an ability test that included 6 consecutive tasks: stair climb, rolled hose lift and move, Keiser sled, hose pull and hydrant hookup, mannequin drag and charge hose advance while wearing PPE (69). Flexibility was measured using the sit and reach test, muscular endurance was calculated with a 1-minute sit-up test and maximal pushup test (69). Strength was assessed using a hand dynamometer and 1-RM bench press and squat while abdominal strength was calculated using an isometric test (69). Lastly, anaerobic power was tested using a 60-second step test and a vertical jump (69). The subjects were separated into two groups based on their Ability Test time, best performers and poorest performers for multiple regression analysis using a backward step method which revealed that 60% of variation observed in the ability test performance was reduced to 5 variables:

abdominal strength, power calculated by the step test, maximum number of push-ups completed, resting heart rate and body fat percentage (69). It was concluded that abdominal strength, upper body muscular endurance, anaerobic power and low body fat percentage are things that should be focused on for improvement on occupational performance (69). While there were no tests of aerobic fitness in this study, the authors state that it has already been established that cardiovascular fitness plays a large role in firefighting performance (69). Sheaff and colleagues (2010) used the Candidate Physical Ability Test (CPAT) which contains 8 firefighting related tasks (stair climb, hose drag, equipment carry, ladder raise and extension, forcible entry, search, rescue and ceiling breach and pull) separated by 25.9 m walk while wearing a load simulating PPE (90). Subjects were similarly separated based on performance on the CPAT (successful defined as completion time ≤ 10 min and 20 sec, or unsuccessful) (90). Group differences between successful and unsuccessful subjects were found in WAnT (Wingate anaerobic cycling test) and $\dot{V}O_{2max}$ in relative and in absolute terms (90). The authors report that absolute $\dot{V}O_{2max}$ in combination with anaerobic fatigue resistance significantly predicts 82% of the variance in CPAT performance (90). Louhevaara et al. (1995) also reported that the anaerobic capacity was important in predicting efficient firefighter occupational work performance (the smallest drop in maximal power output when loaded) (63) .

Rhea et al. performed a similar study, however the subjects were allowed complete rest between each of their tasks (84). The subjects completed a Cooper 12-minute run test, anaerobic power/endurance with a 400-m sprint, muscular strength (5-RM bench press and back squat) and handgrip dynamometer), local muscular endurance (maximal repetitions of bench press, bent over row, bicep curls and seated shoulder

press) (84). The four tasks of the occupational test were hose pull, stair climb while carrying a high-rise hose pack, simulated victim drag and equipment hoist (84). Overall job performance was found to be significantly correlated with muscular strength, muscular endurance and anaerobic endurance (84). There was no correlation between job performance and cardiovascular endurance, unlike many other studies likely due to the methodology of allowing for complete rest between tasks (61, 69, 84). The authors state that this was chosen to allow examination of the individual tasks without the effects of fatigue (84).

Since most fire departments do not have access to a laboratory for testing, Lindberg and colleagues (2013) performed a study to correlate relevant direct laboratory and indirect field tests to provide recommendations on the best field tests to be used (61). The study included common work tasks including cutting, stairs, hose pulling, demolition, victim rescue, vehicle extrication and carrying baskets, however they were completed in regular PT clothes. The authors concluded that best field tests for evaluation of firefighter's work performance time include 500 m rowing time, 3000 m running time relative to body weight and percent of maximal heart rate achieved during a 6 min treadmill walking test (61). Lindberg and colleagues (2014) also completed a study comparing full time firefighters, part time firefighters and civilians and found that laboratory tests of maximal upper body strength and endurance were significantly correlated to work capacity time during the stair, pulling, demolition and rescue tasks in a firefighter specific circuit (60). Simulated work tasks were also found to be significantly correlated with at least nine of fourteen lower body maximal power laboratory tests, which is not as commonly reported in the literature (60, 90). The authors suggest that

based on their results, maximal hand grip strength, bench press, chin ups, dips, standing broad jump, upright barbell row and barbell shoulder press all have strong correlations with one or more simulated work tasks (60).

Strong positive relationships have been reported between average $\dot{V}O_2$ during a firefighting task and $\dot{V}O_{2max}$., suggesting that cardiovascular fitness is an important factor in how fast firefighters can complete their required tasks (31). Hunt et al. (2016) similarly noted that in a military population, initial acceleration and peak velocity were primary determinants of occupational performance when loaded with gear and that large individual responses were seen (48). This further demonstrates that higher levels of physical fitness can reduce the decrement in performance caused by gear (48).

Taylor and colleagues recently stated that it was unlikely to accurately evaluate the working capability of an individual when evaluated in the unloaded state and that relative to occupational testing, the load condition should be reproduced as accurately as possible (104). It is imperative when determining minimal criterion workload for firefighting to realize that an activity involving 70-80% of $\dot{V}O_{2max}$ measured from a typical test would result in 80-90% of $\dot{V}O_{2max}$ wearing PPE (57). It is likely that maximal performance determined from a typical VO_{2max} may overestimate the performance capabilities compared to wearing full PPE (57, 104). It has been said that the additional strain of the SCBA is so high that decisions regarding the use of respirators, rest periods and the individuals physiological work capacity must be carefully considered (65). The impacts of the regulator are seen to a lesser extent during light to moderate intensity activities, however it increases the intensity of the work being performed (32). PPE has a significant negative effect on $\dot{V}O_{2max}$ and when testing firefighters, the impact of PPE

and SCBA on maximal work capacity needs to be taken into consideration (29). Authors have noted large individual differences in ventilation with the SCBA that are possibly explained by the significant inverse relationship between the change in ventilation and absolute $\dot{V}O_{2max}$ values, suggesting that the SCBA has a larger effect on smaller and/or less aerobically fit individuals during high intensity work (32). This evidence further supports determining the impact in firefighter occupational performance due to overall and individual pieces of PPE and the related fitness characteristics would provide insight on how to train to combat these performance decrements.

Conclusion

Firefighting is a challenging profession that involves high intensity work as well as heavy lifting, resulting in prolonged periods of stress and exertion (92, 94, 100, 102, 103). This can involve intense work periods requiring high levels of energy expenditure (i.e., 12 METs) and near maximal heart rates (23, 99). Studies have shown that this can result in decreased cognitive function, judgment, and accuracy as well as increased anxiety (95, 96). The combination of these factors is not ideal to function in an emergency situation. Furthermore, data has shown that 44-49% of fatalities in the line of duty for firefighters are related to sudden cardiovascular or cerebrovascular events (9, 100). If firefighters are not physically fit enough to perform these tasks, overexertion can lead to mental errors, decreased physical ability, and initiation of a cardiovascular event (92, 100). These work demands, in combination with the lack of warm-up and hypohydration increase the potential for a cardiac event (92-94). The fitness profile of the average firefighter is often high in muscular strength but there is a high prevalence of obesity, likely due to the lifestyle factors involved with being in the fire service (92). It

has been shown that the amount of time engaged in leisure-time sport activities was inversely related to physical work capacity as a marker of cardiocirculatory strain during simulated fire operations (2). The authors suggest that a more active lifestyle is advantageous in decreasing the physiological strain seen in firefighters (2). It is necessary to determine the specific fitness characteristics that are unique to firefighter performance in full gear to properly prescribe exercise. A heightened level of fitness will reduce the relative physiological stress being placed on these individuals allowing for better performance with less risk of adverse events, thereby increasing the safety of the individual, their colleagues and the public (92).

CHAPTER III

METHODS

Experimental Design

The purpose of this study was to determine the effect of load carriage and

respirator use (SCBA) on Simulated Fire Ground Test (SFGT) performance. The SFGT is

a relevant indicator of firefighter physical ability (23). The secondary aim of the study

was to identify fitness attributes and physiological outcomes that were correlated to the

decrements in SFGT performance produced by the load carriage only and load carriage

plus SCBA use. This study utilized a repeated measures crossover design. The primary

dependent variable was SFGT time. The independent variables were the load carriage and

load carriage plus SCBA conditions. In the regression analysis, the fitness scores and

physiological outcomes served as the predictor variables, whereas the SFGT difference

scores served as the dependent variables.

Subjects

A convenience sample of 25 metropolitan fire department recruits volunteered to

participate in this study. The recruits' physical characteristics are displayed in Table 1. A

Physical Activity Readiness Questionnaire was given to exclude recruits that have been

diagnosed with cardiovascular, pulmonary, or metabolic disease or reported

contraindicated signs or symptoms of these chronic diseases.   All firefighters provided

written informed consent after a detailed explanation was provided about the aims,

benefits, and risks associated with the investigation. The firefighters were informed that

they were free to withdraw from the study at any time, without penalty. They were told

that their participation in this study did not affect their employment or probationary

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status. All of the procedures used in this study were approved by the University's

Institutional Review Board prior to initiation of the study. Of the 25 firefighters that

provided informed consent, 21 firefighters' data were used for analysis. Of the

firefighters that were not used in the data analysis, two subjects dropped out due to

leaving the academy, one firefighter dropped out due to illness and one firefighter

dropped out due to an incurred injury that was not associated with the study procedures.

The firefighters had been in the academy for 8 weeks before familiarization trials began

and 11 weeks before actual data collection started.

Table 1. Physical characteristics of 21 male firefighter recruits.

	Mean	±	SD	Range		
Body mass (kg)	94.1	±	15.4	65.5	-	117.3
Fat-free mass (kg)	71.7	±	7.7	55.7	-	85.8
Fat mass (kg)	22.3	±	6.1	9.8	-	39.2
Body mass in PPE (kg)	119.8	±	16.2	91.3	-	145.9
Age (yr)	28.6	±	4.3	21	-	36
Height (cm)	178.6	±	7.2	165.4	-	196
PPE mass (kg)	25.7	±	1.6	23.5	-	28.6
Relative body fat (%)	22.9	±	6.1	14.4	-	35.8

PPE: Personal Protective Equipment.

Procedures

This study consisted of 6 testing sessions. All testing sessions took place at the fire department's training center. Session 1 consisted of a familiarization trial on the SFGT that was performed while wearing full PPE and required the firefighter to breathe through the SCBA. Session 2 consisted of a second familiarization trial of the SFGT performed with the respirator and full PPE. During Session 2 three trials of forced expiratory volume in 1s (FEV1), forced vital capacity (FVC) and peak expiratory flow rate (PEFR) were performed using the ChestTest Spirometer (VacuMed, Ventura, CA). The test-retest reliability of these repeated trials was ICC = .882 for FVC and .933 for FEV1. All measurements were taken in accordance with American Thoracic Society Guidelines (70). Three trials of FVC, FEV1 and PEFR were taken with the recruit wearing a nose clip, in a seated position. The recruits were instructed to inhale as much as possible then seal their lips around the spirometer and blow out as hard and as fast as possible while maintaining an upright position. For further analysis, the percentages of each recruits' measured lung function were calculated relative to their predicted FVC, FEV1 and FEV1/FVC, according to age, gender, height and ethnicity using Global Lung Function Initiative equations (81). The order of testing Sessions 3-5 was randomized and included the following SFGT conditions: physical training (PT) clothes and tennis shoes only (Control condition; PT condition), "load carriage only" (i.e., full PPE gear but not breathing through respirator) and "load carriage plus SCBA" use (i.e., full gear and breathing through respirator). Before and after each SFGT, body mass (to account for sweat loss) and blood lactate were assessed. Immediately after completion of the SFGT, rating of perceived exertion (RPE) and thermal sensation were recorded. Heart rate was

monitored continuously with a heart rate monitor strap (Polar Electro Oy, Inc., Kempele, Finland) and transmitted to a device on the recruit's arm (ActiTrainer, Actigraph, Pensacola, FL) throughout the SFGT. Using Actilife software (ActiGraph, Version 6, Pensacola, FL), the number of myocardial contractions per 15 second epochs were recorded and time stamped. These data were multiplied by four to express heart rate per minute. Peak heart rate was the highest heart rate seen throughout the test and average heart rate was calculated throughout the trial. Any dropped data was excluded from calculations of mean heart rate. Urine specific gravity (PAL10S, Atago, Tokyo, Japan) was collected before each trial, as a measure of hydration status.

The SFGT was used as a measure of firefighter occupational physical ability. It was developed in consultation with the Fire Department's training officers. The test-retest reliability of the SFGT was ICC = .929 based on the total completion time of 3 SFGT trials (i.e., 2 familiarization trials and 1 load carriage plus SCBA trial). Previous research has demonstrated this type of test to have similar levels of reliability (ICC = .937) (23). The SFGT was performed with full PPE (NFPA, 1971; standard issued helmet, hood, coat, pants, gloves, and boots) and SCBA (Scott Inc., Monroe, NC) totaling 25.7 ± 1.6 kg. The SFGT was composed of the following tasks, performed in order, to simulate how they are typically performed on the fire ground: stair climb, charged hose drag, equipment carry, ladder raise, forcible entry, search, and victim rescue (23). Total SFGT time and individual task times were taken using a stopwatch (Sportline, Model 461, Hazleton, PA). Recruits began by picking up and carrying one 15.24 m section of $1^{3/4}$"- firehose (mass = 22.2 kg) packaged as a highrise hose pack up 4 flights of stairs (17 steps per flight). The recruit placed the highrise pack on the landing and returned down the 4

flights of stairs, touching each step on the way down. Recruits were allowed to use the handrail for stability purposes only on the stair ascent. The task split time was taken when the recruit's foot touched the ground. The recruit then proceeded 15.24 m to the hose drag task. Next, the firefighter performed a charged (i.e., water pressurized) hose drag task by placing the nozzle end of 1 section of 30.48 m of $1^{3/4}$" fire hose over their shoulder and pulled it 25 m. The split time for the hose drag was taken at the 25 m mark. The firefighter then proceeded 20.7 m and performed an equipment carry task for which they carried 2 department issued 5-gallon foam buckets (mass = 20 kg each) 62 m. The split time for the equipment carry was taken when the buckets were placed on the ground. Next, the firefighter proceeded 11.2 m and performed a ladder raise task. The firefighter raised a 14 ft extension ladder from the ground to a building and lowered it back to the ground using a hand-over-hand technique, touching each rung. The split time for the ladder raise was taken when the ladder was placed on the ground. The firefighter then proceeded 4.4 m and completed a forcible entry task using a Keiser Force Machine Chopping Simulator (Keiser Inc., Fresno, CA, USA). The firefighter was positioned to strike the end of a 72.7 kg steel beam with a 4 kg sledge hammer (Trusty-Cook, Indianapolis, Indiana, USA). The beam was required to move 1.5 m in order to complete the task. Next, the firefighter performed a victim search task by walking or running 7 m and climbing up a flight of 17 stairs, then performing a right hand search by crawling 35 m around the perimeter of an interior room. The search task split time was taken when the firefighter returned back to the cone at the top of the stairs. Lastly, the firefighter performed a victim rescue task by descending back down the flight of 17 stairs and proceeded 15.6 m to a 73 kg mannequin which was dragged 27 m to the task and SFGT

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finish line. The task and total SFGT was completed when the mannequin's feet crossed the finish line.

Blood lactate was measured at rest prior to the SFGT and 5 minutes following the test. A fingerstick and universal precautions were used to obtain the lactate sample. Following the fingerstick, the first drop of blood was wiped away. The second drop of blood was used for the analysis. The calibration of the blood lactate analyzer (LactatePlus, Nova Biomedical Corporation, Waltham, MA) was checked prior to each testing day with low (manufacturer's acceptable range: 1.0-1.6 mmol·L^{-1}) and high (manufacturer's acceptable range: 4.0-5.4 mmol·L^{-1}) control solutions. Ratings of perceived exertion was assessed immediately following the SFGT using the 0-10 category-ratio scale for overall feeling of exertion from the entire SFGT. This scale has been used in previous studies to investigate subjective measures of occupational physical exertion (77, 80). Recruits were assessed for thermal sensation using the Omni Thermal Sensation Scale which has been found valid (r = .77) and reliable (r = .81) (20). Spirometry data were collected immediately after each SFGT trial to determine differences in respiratory muscle fatigue between the trials as well as to determine if pulmonary function was related to the decrement in occupational performance. Oxygen levels from the SCBA tank were measured using the regulator pressure gauge to determine the amount of oxygen consumed during the SCBA trial.

Testing Session 6 consisted of a battery of fitness tests. The Wingate Anaerobic Test was used as a measure of anaerobic capacity. Test-retest reliability of this assessment has been reported to be ICC = 0.862 (82). A Monark^{TM} (Model 894E, Varberg, Sweden) cycle ergometer was used with a relative resistance placed on the

flywheel equal to 7.5% of the recruit's body mass (82) . Recruits were instructed to pedal as fast as possible for the 30 second test duration. Peak power, mean power, and fatigue index were recorded. Relative peak power was defined as the greatest power output $(W \cdot kg^{-1})$ recorded during any of the 5 second sampling periods throughout the 30 second test. Relative mean power was recorded as the average power output $(W \cdot kg^{-1})$ during all of the 5 second intervals throughout the 30 second test. Fatigue index was calculated as the percent decrease in power output from the highest power to the lowest power observed throughout the entire test (7). Next, anthropometric data were collected. Standing height (to the nearest 0.1 cm) was measured without shoes with a portable stadiometer (Road Rod 214 Seca, Hanover, MD, USA). Then, body mass was measured (to the nearest 0.1 kg) without shoes with an electronic scale (TBF-521, Tanita Corporation, Arlington Heights, IL, USA). Body composition was measured with a tetrapolar bioelectric impedance analyzer (BIA; Bodystat 1500, Ventura, CA, USA). Specifically, electrodes were placed on the subjects' wrist, hand, ankle, and foot while lying in the supine position. Height, body mass, age and gender were input. The recruits' fat-free mass was calculated using the following formula:

$FFM = -4.104 + (0.518 \times height^2 (cm) / resistance) + (0.231 \times weight (kg)) +$

$(.130 \times reactance) + 4.229 (*gender)$

*Males = 1; = Females = 0; (r = .986, SEE = 1.72 kg) (53).

Relative body fat percentage was then calculated (to the nearest 0.1%). A vertical jump test was performed to assess lower body peak power. The test-retest reliability of this assessment was calculated at ICC = .995. This test was performed using a Vertec™ apparatus (Vertec Scientific Ltd., Aldermaston, UK). Specifically, the recruit was asked

to reach and touch the highest vane with the dominant arm while standing flat-footed, then perform a countermovement jump for maximal height (no preparatory step was allowed). Vertical jump height was calculated as the difference between the vertical jump height and reach height values (measured to the nearest 1.3 cm). Two practice trials were performed, followed by three official trials, with the highest value being used for analysis. The following formula was used to calculate Peak Power:

Peak power (W) = (51.9) × (jump height [cm]) + 48.9 × (body mass [kg]) – 2007. This prediction of peak power has been validated with an r^2 = .78 and SEE = 561.5 W (88). Upper-body strength was assessed using a handgrip dynamometer (Grip D, model T.K.K. 5401; Takei Scientific Instruments, Tokyo, Japan) (83, 107). Three trials were conducted and the highest measurement for each hand was recorded, with the sum of the highest scores from each hand used for data analysis. The test-retest reliability for hand grip strength has been reported to be r = 0.924 (83). The Fire Academy's Fitness Test data were obtained for the following tests: push-ups, prone plank hold, sit-ups, pull-ups and a 1.5 mile run time. Recruits performed the exercises in the previously listed order with a 5-10 minute break between tasks. Recruits were given two minutes per task to complete as many push-ups, sit-ups, or pull-ups as possible. During the push-up and sit-up tasks, recruits were allowed to pace themselves or take breaks as needed. For the pull-up tasks, recruits were allowed to come down from the bar one time to rest during the two minute test duration. During the plank hold, recruits were on their elbows and were given one corrective warning on form by the training officers before the task was terminated. The test maxed out at 4 minutes. The 1.5 mile run was performed outside around the training center on a two loop course. The fitness data used for analysis were collected in

the beginning of the last week of data collection. Aerobic capacity was estimated using the formula:

$$VO_{2max} \ (ml \cdot kg^{-1} \cdot min^{-1}) \ 88.02 - .1656 \ (kg) - 2.767 \ (min) + 3.716 \ (*gender)$$

*Males = 1; = Females = 0; ($r = 0.90$, SEE = 2.8 $mL \cdot kg^{-1} \cdot min^{-1}$) (42, 47).

Daily resting heart rate and blood pressure data were also taken from the Academy over a one month period. A Physical Fitness Academy Test (PFAT) score was calculated for all individuals based on a scoring system designed by the Department. A score of 0-3 was assigned for a range of scores for each test and were totaled for an overall score out of 30 points.

Statistics

Basic statistics (mean ± standard deviation) were used to describe demographic and outcome variables. One-way repeated measures ANOVAs were used to determine if there were differences in SFGT times, heart rate, blood lactate, RPE, thermal sensation or spirometry data among baseline (PT) and the experimental conditions. Data were visually inspected for normality. The data were also checked for sphericity. If the sphericity assumption was violated a Greenhouse-Geiser correction was used. Least significant differences were used for follow-up pairwise comparisons. Effect size was calculated as partial η^2. Statistical power for comparisons by SFGT condition was assessed through the statistical software package. The level of significance was set a priori at $p < 0.05$ for all statistical analyses.

To describe within group changes in baseline SFGT versus experimental SFGT outcomes, relative difference scores were calculated as follows: % difference = ((([experimental trial outcome – baseline outcome] / baseline outcome) x 100). Delta

scores were also calculated to determine the absolute difference in time between SFGT

conditions as: experimental SFGT trial time - baseline SFGT time. Pearson Product

Moment Correlations were used to assess the relationships between LC and SCBA-

induced SFGT performance decrements versus fitness outcomes. Cronbach's alpha was

used to assess the test-retest reliability of the practice trials of the SFGT and other

pulmonary and fitness test outcomes. Independent sample t-tests were conducted between

fastest and slowest performers in various SFGT conditions, as determined by those in the

top versus bottom quartile SFGT times. The Statistical Package for Social Sciences

(SPSS, Version 22) was used for data analysis.

CHAPTER IV

RESULTS AND DISCUSSION

Results

The fitness characteristics of the recruits are described in Table 2. Recruits had an average 1.5 mile run time of 11.9 ± 1.4 minutes which corresponded with in an estimated VO_{2max} of 43.4 ± 6.0 ml·kg^{-1}·min^{-1} and an absolute VO_{2max} of 4.01 ± 0.32 L·min^{-1}.

Table 2. Fitness and physiological characteristics of 21 male firefighter recruits.

	Mean	±	SD	Range		
1.5 mile run time (min)	11.9	±	1.4	9.3	-	14.1
Push-ups (number completed)	54.7	±	5.0	41	-	61
Pull-ups (number completed)	20.3	±	4.8	9.0	-	30.0
Sit-ups	61.2	±	10.9	38.0	-	80.0
Plank time (min)	3.0	±	0.8	2.0	-	4.0
PFAT score	19.4	±	7.7	4.0	-	30.0
VJ (cm)	53.9	±	10.3	33.0	-	74.9
VJ power (W)	5393.0	±	769.0	4033.2	-	6845.2
Body fat (%)	22.9	±	6.1	14.4	-	35.8
Right handgrip (kg)	62.3	±	7.2	50.0	-	80.0
Left handgrip (kg)	59.5	±	5.5	48.0	-	68.0
Handgrip sum (kg)	121.8	±	12.2	98.0	-	144.0
Wingate peak power (W)	1086.3	±	193.1	790.7	-	1503.3
Wingate average power (W)	762.3	±	117.5	579.8	-	982.1
Wingate fatigue index (%)	57.5	±	7.1	36.3	-	69.2
Wingate peak power-relative ($W \cdot kg^{-1}$)	12.1	±	2.7	7.7	-	21.5
Wingate average power-relative ($W \cdot kg^{-1}$)	8.4	±	1.3	5.5	-	12.1
Estimated VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	43.4	±	6.0	34.7	-	55.0
VJ Power Relative ($W \cdot kg^{-1}$)	57.8	±	5.9	46.4	-	68.1
FVC (L)	5.3	±	1.0	3.5	-	7.5
FEV1 (L)	4.1	±	1.2	1.5	-	6.5
PEFR ($L \cdot s^{-1}$)	8.1	±	3.3	1.9	-	13
Systolic BP (mmHg)	131.7	±	5.3	123.8	-	141.0
Diastolic BP (mmHg)	83.6	±	7.1	75.0	-	109.0
Resting heart rate ($b \cdot min^{-1}$)	74.1	±	14.9	53.4	-	122.4

PFAT: Physical Fitness Academy Test; VJ: vertical jump; FVC: Forced Vital Capacity;

FEV1: Forced Expiratory Volume in 1s; PEFR: Peak Expiratory Flow Rate; BP: Blood

Pressure.

Table 3 describes the amount of time taken to complete the SFGT in all three conditions. There was a significant overall effect of condition on the total SFGT time $(F_{(2,40)}=186.052, p < .001)$. Specifically, recruits took longer to complete the SFGT in the LC condition $(331.2 \pm 39.3$ s, $p < .001)$ and the SCBA condition $(345.9 \pm 43.7$ s, $p < .001)$ compared to the PT condition $(241.0 \pm 33.3$ s). In addition, the SCBA condition took longer to complete than the LC condition $(p = .02)$. There were significant overall effects for condition on all SFGT task times $(p < .001)$. Specifically, compared to the PT condition, recruits took longer to complete the SFGT during the LC and SCBA conditions on all individual tasks. In addition, recruits took longer to complete the stair climb, hose drag, ladder raise, search task and the victim rescue task $(p \leq .047)$ in the SCBA condition compared to the LC condition.

It is important to account for potential differences in environmental conditions across the SFGT trials. To that end, there was a significant overall effect for heat index $(F_{(2,40)}=3.416; p=.043)$. Specifically, the mean heat index during the LC condition $(25.9 \pm 2.4°C)$ was higher than the PT condition $(23.1 \pm 4.2°C)$ $(p = .020)$. There was also a significant overall effect for temperature $(F_{(2,40)} = 4.407; p= .019)$ such that the LC $(25.9 \pm 2.3°C; p= .018)$ and SCBA $(25.0 \pm 4.5°C; p = .049)$ conditions were warmer than the PT condition $(22.9 \pm 4.1°C)$. Finally, there was a significant overall effect for humidity $(F_{(1.26, 25.15)} = 7.229; p = .009)$. Specifically, the relative humidity was higher in the PT condition $(65.9 \pm 19.0\%)$ compared to the LC $(49.9 \pm 13.1\%; p= .019)$ and SCBA $(47.1 \pm 17.2\%; p = .007)$ conditions. Despite differences in the environmental conditions, the decrement in the absolute SFGT time was not correlated to the change in heat index $(r = .116, p = .616)$.

Table 3. Comparison of simulated fire ground test task times across equipment conditions in 21 male firefighter recruits.

	PT			LC			SCBA		
	Mean	±	SD	Mean	±	SD	Mean	±	SD
Total time (s)	241.0	±	33.3	331.2	±	39.3*[b]	345.9	±	43.7*
Stair climb (s)	42.0	±	7.6	66.7	±	10.2*[b]	70.1	±	12.1*
Hose drag (s)	21.5	±	3.7	32.2	±	4.6*[b]	33.5	±	5.3*
Equipment carry (s)	42.5	±	5.6	59.0	±	5.8*	60.6	±	5.8*
Ladder raise (s)	15.7	±	2.4	20.0	±	2.7*[b]	20.8	±	2.9*
Forcible entry (s)	41.4	±	9.2	49.1	±	9.5*	50.7	±	11.1*
Search (s)	43.3	±	9.2	54.8	±	8.2*[b]	57.6	±	9.0*
Victim drag (s)	34.7	±	6.4	49.4	±	7.7*[b]	52.7	±	7.7*
Heat Index (°C)	23.1	±	4.2	25.9	±	2.4*	24.9	±	5.1

*Significant difference compared to the PT condition ($p < .05$). [b]Significant difference between LC vs. SCBA conditions ($p < .05$). PT: Wearing physical training clothes; LC: Wearing full gear but not breathing through SCBA; SCBA: Wearing turnout gear and breathing through respirator.

Table 4 displays the relative difference in time to complete the total SFGT and each individual task between gear conditions. The LC condition took 38.3 ± 12.6% longer to complete the SFGT than the PT condition, whereas the SCBA condition took 44.5 ± 15.5% longer to complete the SFGT than the PT condition. Furthermore, in the SCBA condition the stair climb task, ladder raise task, search task and victim drag task took significantly longer than in the LC condition.

Table 4. Percent change in completion time of simulated fire ground test tasks in gear conditions compared to the PT condition in 21 male firefighter recruits.

	LC			SCBA		
	Mean	±	SD	Mean	±	SD
Total time	38.3	±	12.6	44.5	±	15.5
Stair climb	60.7	±	21.2	69.2	±	26.9
Hose drag	52.1	±	24.4	58.3	±	26.4
Equipment carry	40.3	±	16.2	44.3	±	17.8
Ladder raise	28.0	±	12.9	33.2	±	14.5
Forcible entry	21.9	±	25.3	25.6	±	27.4
Search	29.3	±	18.9	36.1	±	22.2
Victim drag	44.5	±	15.5	54.5	±	23.1

LC: Wearing full gear but not breathing through SCBA; SCBA: Wearing turnout gear and breathing through respirator.

Table 5 describes the pulmonary function values both in absolute term as well as a percentage of their predicted values for baseline measures as well as post-test measures for all conditions. There was no change in absolute terms for FVC, FEV1 or FEV1/FVC between conditions or from baseline. Percent of predicted FVC post SCBA was significantly lower compared to the PT condition ($p = .007$) and baseline ($p < .001$). Percent of predicted FEV1 was significantly higher post SCBA than during baseline ($p < .001$). Lastly, percent of predicted FEV1/FVC was significantly higher post SCBA compared to baseline ($p < .001$) and post PT ($p = .003$). Percent of predicted FEV1/FVC was also higher post LC condition compared to post PT condition ($p < .001$).

Table 5. Comparison of pulmonary function outcomes between gear conditions at baseline and following the simulated fire ground test in 21 male firefighter recruits.

	Baseline	Post PT	Post LC	Post SCBA
FVC (L)	5.27 ± 0.96	5.8 ± 2.0	5.9 ± 3.8	5.2 ± 0.9
FEV1 (L)	4.03 ± 1.18	4.8 ± 1.7	4.7 ± 2.1	4.3 ± 1.2
PEFR (L·s^{-1})	8.04 ± 3.19	9.1 ± 2.9	8.9 ± 2.9	8.9 ± 3.2
FEV1/FVC	0.78 ± 0.19	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.2
%FVC Predicted	96.6 ± 13.91	105.74 ± 36.46	85.48 ± 38.65	78.55 ± 21.13*[b]
%FEV1 Predicted	89.33 ± 23.35	106.01 ± 37.3	130.72 ± 85.78	113.96 ± 17.79[b]
%FEV1/FVC Predicted	91.75 ± 19.9	95.48 ± 25.07	151.15 ± 33.17*	156.33 ± 56.15*[b]

*Significant difference compared to the PT condition (p < .05). [b]Significant difference from baseline (p < .05). LC: Wearing full gear but not breathing through SCBA; SCBA: Wearing turnout gear and breathing through respirator. FVC: Forced Vital Capacity; FEV1: Forced Expiratory Volume in 1 s; PEFR: Peak Expiratory Flow Rate; PT: Physical training clothes condition; LC: Wearing full gear but not breathing through SCBA; SCBA: Wearing turnout gear and breathing through respirator.

Table 6 describes the differences in physiological measures between the 3 gear conditions. There was a significantly higher RPE value $(F_{(2,40)}=18.691, p < .001)$ in the SCBA $(6.7 \pm 1.7, p < .001)$ and LC $(6.3 \pm 1.5, p < .001)$ conditions compared to the PT condition (4.6 ± 1.8). Thermal sensation score was also significantly higher $(F_{(2,40)}=32.884, p < .001)$ in the SCBA $(3.9 \pm 0.8, p < .001)$ and LC $(3.9 \pm 0.6, p < .001)$ conditions compared to the PT condition (2.2 ± 0.9). The amount of body mass lost from the SFGT was significantly higher $(F_{(2,30)} = 3.412, p = .039)$ in the SCBA condition $(.28 \pm .23$ kg, $p = .027)$ and the LC condition $(.26 \pm .28$ kg, $p = .036)$ than the PT condition $(.12 \pm .20$ kg$)$. Despite differences in thermal sensation responses between PT vs. LC and SCBA conditions, the decrement in the absolute SFGT time was not correlated to the change in thermal sensation for LC $(r = .075, p = .745)$ or for SCBA $(r = -.078, p = .736)$. Likewise, the differences in body mass lost and the decrement in the absolute SFGT was not correlated for LC $(r = -.243, p = .289)$ or for SCBA $(r = .123, p = .596)$. The decrement in the absolute SFGT time was not correlated to the change in RPE for LC $(r = -.168, p = .467)$ or for SCBA $(r = .148, p = .523)$.

Table 6. Physiological and psychological measures taken in three conditions of the simulated fire ground test in 21 male firefighter recruits.

	PT			LC			SCBA		
Average heart rate (b·min^{-1})	161.3	±	12.7	161.6	±	11.2	162.8	±	13.4
Average heart rate (%)	84.3	±	5.7	84.3	±	5.0	85.0	±	6.5
Peak heart rate (b·min^{-1})	171.8	±	13.9	173.6	±	12.4	174.7	±	13.4
Peak heart rate (%)	89.8	±	6.1	90.6	±	5.7	91.1	±	6.2*
RPE	4.6	±	1.8	6.3	±	1.5*	6.7	±	1.7*
Thermal Sensation	2.2	±	0.9	3.9	±	0.6*	3.9	±	0.8*
BM lost (kg)	0.12	±	0.20	0.26	±	0.28*	0.28	±	0.23*
Resting Lactate (mmol·L^{-1})	1.4	±	1.2	1.4	±	0.6	1.6	±	0.7
Post Lactate (mmol·L^{-1})	12.4	±	4.2	11.1	±	2.4	11.1	±	2.9

*Significant difference compared to the PT condition ($p < .05$). [b]Significant difference between LC vs. SCBA conditions ($p < .05$). LC: Wearing full gear but not breathing through SCBA; SCBA: Wearing turnout gear and breathing through respirator. RPE: rating of perceived exertion; BM lost: body mass lost.

Table 7 describes the correlation between fitness characteristics and the delta score in SFGT task time in the LC condition compared to the PT condition. There were no significant correlations with the total delta SFGT time, but several characteristics were associated with the hose drag and equipment carry tasks. Estimated relative VO_{2max}, sit-ups, plank time and total PFAT score were negatively correlated with the hose drag. 1.5 mile run time was positively correlated with the hose drag. The equipment carry task was negatively correlated with vertical jump power, left handgrip strength, absolute estimated VO_{2max}, Wingate peak and average power as well as body mass, fat-free mass, height and FEV1. The ladder raise task was negatively correlated with handgrip strength and age. The victim drag was negatively correlated with plank time.

Table 7. Correlation matrix between the difference in time (s) due to load carriage in simulated fire ground test performance versus physical fitness characteristics in 21 male firefighter recruits.

	Total	Stair Climb	Hose Drag	Equipment Carry	Ladder Raise	Keiser Sled	Search Task	Victim Drag
1.5 mile run time (min)	.161	.037	.527*	-.207	.061	.069	-.123	.362
Push-ups (number completed)	-.087	-.433	-.293	.426	-.065	.276	-.222	-.093
Pull-ups (number completed)	-.183	-.363	-.231	.301	.121	.143	-.173	-.378
Sit-ups	-.114	-.088	-.523*	.199	.142	-.147	.054	-.019
Plank time (min)	-.229	-.077	-.520*	.312	-.056	-.141	.043	-.487*
PFAT score	-.172	-.162	-.526*	.353	-.022	-.022	.043	-.374
VJ Power (watts)	-.174	-.197	.168	-.567**	-.084	.144	-.133	-.048
Body fat (%)	-.055	-.152	.244	-.178	-.144	-.174	-.129	.369
Systolic BP (mmHg)	.003	-.121	-.011	-.298	-.206	.325	-.095	.141
Diastolic BP (mmHg)	-.080	-.012	.016	-.445*	-.260	.413	-.145	-.227
Resting heart rate (b·min^{-1})	.050	.155	.089	-.384	-.074	.168	.071	.002
Right handgrip (kg)	-.327	-.359	-.172	-.252	-.389	-.130	-.109	-.015
Left handgrip (kg)	-.304	-.154	-.216	-.458*	-.531*	-.153	.085	-.089
Handgrip Sum (kg)	-.331	-.282	-.200	-.357	-.471*	-.146	-.026	-.050
Wingate peak power (W)	-.218	-.276	.041	-.463*	-.170	-.045	.080	-.032
Wingate average power (W)	-.256	-.421	-.006	-.488*	-.075	.029	.003	.009
Wingate fatigue index (%)	.031	.276	.211	-.376	-.083	-.246	.181	.137
Wingate peak power - relative (W·kg^{-1})	.011	.010	-.032	-.093	-.057	.148	.258	-.284
Wingate average power-relative (W·kg^{-1})	.012	-.076	-.104	-.074	.026	.269	.270	-.339
Estimated VO$_{2max}$ (ml·kg^{-1}·min^{-1})	-.046	.057	-.435*	.326	.022	-.034	.164	-.337
Body Mass (kg)	-.139	-.189	.210	-.443*	-.144	-.026	-.195	.232
Fat free mass (kg)	-.202	-.223	.134	-.575*	-.153	.116	-.217	.045
Fat mass (kg)	-.064	-.133	.244	-.265	-.115	-.144	-.148	.358
Age (yr)	-.177	-.008	-.151	-.286	-.471*	-.081	-.051	.006
Height (cm)	.053	.047	.326	-.442*	.007	.181	.048	.013

Table 7, continued.

FVC (L)	.196	.142	.098	-.311	.333	.305	-.033	.263
FEV1 (L)	-.080	-.113	-.175	-.495*	.160	.083	.028	.218
PEFR	.038	-.004	-.095	-.413	.220	.108	.155	.218
Vertical jump (cm)	-.055	-.016	-.055	-.190	.083	.244	.084	-.397
Absolute Estimated VO_2 ($L \cdot min^{-1}$)	-.406	-.365	-.299	-.451*	-.291	-.005	-.185	-.162

*Significant correlation ($p < .05$). VJ: vertical jump; FVC: Forced Vital Capacity; FEV1: Forced Expiratory Volume in 1s;

PEFR: Peak Expiratory Flow Rate; BP: Blood Pressure PFAT: Physical Fitness Academy Test.

Table 8 describes the correlation between fitness characteristics and the SFGT delta time of the SCBA condition compared to the PT condition. Diastolic blood pressure was positively correlated with SFGT total time and the forcible entry task. 1.5 mile run time was positively correlated with the delta times for the hose drag and ladder raise tasks whereas estimated absolute VO_{2max} was negatively correlated with the hose drag delta time. Fatigue index was positively correlated with the delta time on the stair climb task. Body fat percentage was correlated to the victim drag task delta time.

Table 8. Correlation matrix between the difference in time due to Load Carriage + SCBA in simulated fire ground test versus physical fitness characteristics in 21 male firefighter recruits.

	Total	Stair Climb	Hose Drag	Equipment Carry	Ladder Raise	Keiser Sled	Search Task	Victim Drag
1.5 mile run time (min)	.296	.178	.441*	-.034	.435*	.200	.086	.355
Push-ups (number completed)	-.040	-.423	-.011	.320	-.229	.291	-.079	-.082
Pull-ups (number completed)	-.137	-.370	-.080	.262	-.232	.147	-.046	-.356
Sit-ups	-.225	-.233	-.398	.128	-.112	-.246	-.106	-.042
Plank time (min)	-.261	-.191	-.278	.209	-.363	-.181	-.138	-.420
PFAT score	-.255	-.288	-.314	.210	-.416	-.100	-.093	-.374
VJ Power (watts)	.198	.006	.175	-.198	.298	.267	.286	.189
Body fat (%)	.124	.001	.129	-.059	.190	-.006	.036	.467*
Systolic BP (mmHg)	.179	.109	-.083	-.110	.125	.439	.008	.202
Diastolic BP (mmHg)	.454*	.350	.242	.014	.318	.689**	.302	.089
Resting heart rate (b·min^{-1})	.092	.280	.058	-.303	.207	.057	.065	.022
Right handgrip (Kg)	.051	-.125	-.100	.014	-.202	.142	.184	.129
Left handgrip (Kg)	.038	-.006	-.218	-.187	-.276	.064	.327	.111
Handgrip Sum (Kg)	.047	-.077	-.158	-.076	-.245	.113	.257	.127
Wingate peak power (W)	.172	.016	.098	-.072	.128	.166	.344	.117
Wingate average power (W)	-.046	-.238	-.161	-.252	.038	.081	.212	.102
Wingate fatigue index (%)	.244	.445*	.327	-.090	.305	-.098	.220	.140
Wingate peak power - relative (W·kg^{-1})	.435*	.259	.326	.273	.130	.426	.511*	-.030
Wingate average power-relative (W·kg^{-1})	.318	.077	.153	.189	.023	.450*	.489*	-.096
Estimated VO$_{2max}$ (ml·kg^{-1}·min^{-1})	-.220	-.116	-.299	.127	-.374	-.169	-.061	-.358
Body Mass (kg)	.062	.000	.024	-.243	.208	.087	.011	.293
Fat free mass (kg)	.013	-.028	-.051	-.336	.155	.192	.014	.093
Fat mass (kg)	.095	.023	.085	-.128	.222	-.014	.007	.420

Table 8, continued.

Age (yr)	.162	.057	-.052	-.184	-.071	.219	.157	.401
Height (cm)	.061	.035	-.019	-.424	-.022	.298	.136	.034
FVC (L)	.109	.113	-.244	-.204	.406	.097	.130	.291
FEV1 (L)	-.045	-.012	-.390	-.262	.363	-.179	.165	.273
PERF	.102	.134	-.309	-.136	.406	-.053	.251	.293
VJ (cm)	.198	.009	.216	.059	.134	.260	.394	-.141
Absolute Estimated VO_2 ($L \cdot min^{-1}$)	-.236	-.243	-.450*	-.348	-.205	.023	-.071	-.034

*Significant correlation ($p < .05$). VJ: vertical jump; FVC: Forced Vital Capacity; FEV1: Forced Expiratory Volume in 1s;

PEFR: Peak Expiratory Flow Rate; BP: Blood Pressure PFAT: Physical Fitness Academy Test.

For further analysis, the fitness outcomes were compared between the highest and lowest quintiles of the three SFGT conditions, where the lowest quintile would indicate the fastest performers. When stratified by SFGT time in the PT condition, the lowest quintile of recruits had a higher vertical jump height (58.7 ± 5.4 cm compared to 45.2 ± 9.8, p = .027), higher vertical jump power ($5,766.5 \pm 722.7$ W vs. $4,806.2 \pm 452.4$ W, p = .036), higher handgrip strength (130.8 ± 12.0 kg vs. 111.6 ± 12.6 kg, p = .039), and greater Wingate average power (829.4 ± 103.3 W vs. 645.2 ± 68.6 W, p = .011). When stratified by quintile of the SFGT time in the LC condition, the lowest quintile had a higher handgrip strength (132.4 ± 10.3 kg vs. 111.6 ± 12.6 kg, p = .021) and a higher Wingate average power (792.5 ± 122.9 W compared to 645.2 ± 68.6 W, p = .047). Lastly, when stratified by quintile of the SFGT time in the SCBA condition, the lowest quintile had a higher estimated absolute VO_{2max} ($4.30 \pm .18$ L·min^{-1} compared to $3.88 \pm .23$ L·min^{-1}, p = .012), higher Wingate average power (885.7 ± 43.3 W vs. 721.9 ± 94.7 W, p = .008) and were younger (26.0 ± 3.2 yr vs. 31.6 ± 1.9 yr, p = .010). Recruits were also grouped by the decrement in performance in each condition both in absolute terms as well as percent decrement. There was no difference between group characteristics when separated by SCBA percent decrement. When separated by LC percent decrement, top performers had a higher Wingate average power relative to bodyweight ($8.68 \pm .38$ W·kg^{-1} compared to $8.17 \pm .12$ W·kg^{-1}; p=.038). When stratified by delta times in the LC condition, the lowest quintile had a higher handgrip strength (128.0 ± 8.7 kg vs. 111.2 ± 8.4 kg, p = .015) and a higher estimated absolute VO_{2max} ($4.32 \pm .14$ L·min^{-1} vs. $3.84 \pm .23$ L·min^{-1}, p = .004) than the highest quintile. No significant differences were found when the sample was stratified on the SFGT by delta times in the SCBA condition.

Discussion

The primary aim of this study was to quantify the detrimental effect of load carriage and load carriage plus SCBA use on occupational performance in firefighter recruits. It took recruits significantly longer to complete the SFGT in the LC and SCBA conditions compared to the PT condition, indicating that the mass of the gear and positive pressure respirator inhibited work efficiency. Furthermore, the total SFGT as well as the stair climb, hose drag, ladder raise, search task and victim rescue tasks took longer to complete in the SCBA condition compared to the LC condition, indicating that the respirator produced additional deleterious effects on work efficiency.

The LC condition took $38.3 \pm 12.6\%$ longer than the PT condition, whereas the SCBA condition took $44.5 \pm 15.5\%$ longer. This is similar to the 27% decrement in firefighter physical ability produced by PPE reported by Taylor et al. (2012) (101). Similarly, using a military population loaded with 42 kg of gear, Mala et al. (2015) found a 31% decrease in performance on an anaerobic obstacle course which included a sprint and a victim drag task (66). The current study elicited an average decrement of $1.5 \pm .43\%$ per kg of PPE which is a smaller decrement than has been previously reported in literature suggesting that body armor results in an average of 2.4-3.5% decrement per kg of body armor in military populations in agility and obstacle courses, with a lesser decrement (1.5% per kg) reported in treadmill walking (25, 54, 58). Unfortunately, many of these original sources are not accessible to the public to compare methodologies and results (54). Military tasks are broken down into material handling tasks and movement tasks. Material handling tasks involved more fine motor movements (i.e., rifle firing and loading). A 30% decrement in military task performance, including a grenade throw, with

a 4.5 kg protective vest is attributed to the mass of the vest but that the stiffness of the vest adds to the functional obstruction (25, 43, 54). The smaller relative decrement seen in this study may be due to the SFGT having more walking tasks and less motor skill tasks. In both PPE conditions, the stair climb task was the most affected with a $60.7 \pm 21.2\%$ decrement in performance in the LC condition and $69.2 \pm 26.9\%$ decrement in the SCBA condition. Thomas et al. (2015) reported much lower decrements than the current study in stair climb (14%) and victim drag (15.6%) tasks with SWAT operators (105). The increased decrements reported in the current study are likely due to the greater number of stairs ascended and descended (4 flights vs. 1 flight), the requirement to drag a mannequin a greater distance (27 m vs. 23 m), and the greater load carriage requirement overall (25.7 kg vs. 14.2 kg)(105). In the present study, the search task took $29.3 \pm 18.9\%$ longer in the LC condition, similar to Thomas et al. (2015) who reported a 34.3% decrement (105). These findings support the idea that the decrement in performance with load carriage is task specific and a combination of the mass as well as the placement and material characteristics (i.e., stiffness) (43, 104).

The results from the current study suggest that together, the respirator and load carriage have a compounded effect on performance. This is very similar to what is reported in the literature during laboratory tests. Eves et al. (2005) demonstrated that carrying and breathing through the SCBA decreased peak power output on a maximal treadmill graded exercise test by 11.6% whereas carrying the cylinder itself decreased peak power by 6.4% and breathing through the regulator without the load carriage decreased peak power by 4.8% decrease (32). The subjects in the aforementioned study were not wearing full PPE, which explains the difference in findings when comparing the

decrement of the cylinder condition to this study. However, it is challenging to compare the present study's findings across the literature as the author is not aware of any literature comparing the effects of the SCBA+LC to an LC condition in an occupational task in a sample of recruits.

It is critical to assess the effect of the respirator in a sample of recruits as literature has shown that firefighters tend to have superior pulmonary function compared to the general population (i.e., higher than predicted FEV1 and FVC values than the general population) and firefighters learn and adopt altered SCBA breathing patterns to reduce air use and the feeling of dyspnea (26, 89). The current study found slightly lower FVC and FEV1 values both in absolute terms and percent predicted compared to the firefighter population used in Schermer et al. (2010) but higher values than the described matched civilian control population (89). An FEV1/FVC value in healthy populations should be above 70%, however the proportionately higher increase in FVC in firefighters compared to their increase in FEV1 is likely resulting in this lower FEV1/FVC ratio (89). The FEV1/FVC values in absolute and percent predicted were slightly higher in the current study compared to the firefighters in Schermer et al. (2010) but still slightly lower compared to the civilian matched controls (89). Chronic exercise has been shown to increase FVC with a greater response to anaerobic than aerobic exercise as well as increased FEV1 which may explain why firefighters have higher lung function values (5, 39).

Although there is controversy in the literature about whether all forms of acute exercise result in reduced pulmonary function, percent predicted FVC was lower following the SCBA condition than in the PT condition or at baseline, indicating

respiratory fatigue (39, 73). The opposite effect was seen when comparing FEV1 and FEV1/FVC percent of predicted values post SFGT in the LC and SCBA conditions (73). FEV1 increased significantly compared to baseline in the SCBA condition, which resulted in an increase in FEV1/FVC. This discrepancy could be due to most literature testing lung function 5-10 min post exercise as opposed to immediately following the SFGT in the current study (73). Forbes et al. (2011) found that respiratory muscle training improved respiratory muscle strength as well as respiratory muscle recovery after exercise so perhaps the recruits exposure to the SCBA for several months in the academy enhanced their respiratory muscle strength and recovery (41). Related, swimming has also been shown to elicit improvements in pulmonary function, perhaps due to the increased pressure on the respiratory muscles under water (4). The effect of the SCBA and thoracic load carriage may result in similar improvements. Previous studies with respiratory muscle training devices have shown no difference in pulmonary function values post training. Authors suggest that since respiratory training devices have resistance during expiration but the spirometer does not, any possible improvements of breathing against resistance are not shown in pulmonary function testing (1). Pulmonary function after SCBA use may have similar findings which may explain the lack of difference in absolute measures of pulmonary function between baseline and posttest.

The physiological measures taken during and following the SFGT were relatively similar between the three conditions despite taking longer to complete the SFGT in the PPE conditions. Specifically, recruits' mean and peak heart rate values were similar between conditions in absolute terms (Table 6). When calculated as a percentage of HR_{max}, peak heart rate was slightly higher in the SCBA condition. In addition, the mean

heart rates from the current study in the SCBA condition (162.8 ± 13.4 b·min^{-1}; $85.0 \pm$ 6.5% HR$_{max}$) were similar to Dennison et al (2012) who used a similar SFGT and reported an average heart rate of 165.5 ± 12.5 b·min^{-1} (87.6 ± 5.9% HR$_{max}$) (23). Furthermore, despite similar heart rate values between conditions, RPE and thermal sensation were significantly higher in the SCBA and LC conditions. This finding is supported in the literature, where research indicates that the same task is perceived as being more difficult to complete while wearing gear, due to increased metabolic demand as well as increases in skin and microclimate temperatures (14, 28, 101).

Thermal regulation is yet another component of PPE that leads to increased cardiovascular strain during firefighter tasks. Heat transfer is gradient dependent, and the hot microclimate created by the PPE does not allow heat to dissipate effectively (94, 104). The higher thermal scores noted in the SCBA and LC conditions demonstrate the reduced ability of the gear to dissipate heat, leading to the development of a hot microclimate (14). The impaired ability to thermoregulate due to the PPE has been shown to decrease exercise tolerance, capacity and power output as well as increase the cardiovascular strain at submaximal conditions, which is likely due to the competition for blood flow amongst the working muscles and the shunting of blood to the skin in an attempt to reduce core body temperature (2, 14, 93, 94, 104). The negative effects of the hot microclimate within the gear was apparent by a significant loss of body mass in the SCBA condition (p = .027), with a similar result in the LC condition (p = .036; Table 6). The recruits lost on average 0.284 kg (range: 0-0.82 kg) in the SCBA condition, which ranged from 0-.99% of their body mass. Similarly, Caldwell et al. (2011) reported subjects lost 1.65-2.19% of their body mass following 2.5 hours of low intensity activity

in a hot humid environment while wearing body armor (19). The amount of body mass

lost due to perspiration in this study is concerning given that the occupational tasks only

took 5-6 minutes to complete. It is suggested that body mass losses of >2% impacts

physical and mental performance (86). Dehydration leads to decreased fluid volume

which can increase cardiovascular strain due to decreased venous return and increased

work of the heart to maintain cardiac output and may result in depletion of electrolytes as

well as increase the risk for heat illnesses (86, 94, 104).

The post-SFGT blood lactate scores were not significantly different across

conditions, suggesting that the recruits were giving the same, presumably maximal effort

across all conditions with the load carriage eliciting a $38.3 \pm 12.6\%$ decrement in

performance, the respirator theoretically eliciting an additional $4.6 \pm 8.2\%$ decrement in

performance (calculated as the difference in the LC and SCBA trials) and the total gear

eliciting a $44.5 \pm 15.5\%$ reduction in occupational performance. Literature has shown

other cases where body armor has increased RPE and decreased work capacity, yet

elicited no difference in blood lactate across conditions (85). The magnitude of the post-

blood lactate values noted in the present study (i.e., 11.1-12.4 $mmol \cdot L^{-1}$) are similar to

those reported in other studies using simulated fire ground tasks. Von Heimburg et al.

(2006) found blood lactate concentrations of 13 ± 3 $mmol \cdot L^{-1}$ after tasks involving stair

climbing and a victim drag and Dennison et al. (2012) found values of 11.80 ± 3.16

$mmol \cdot L^{-1}$ after performing a similar SFGT wearing PPE (23, 108). Collectively, these

findings support the contention that these high intensity tactical activities are rather

anaerobic in nature (46, 63, 66, 105, 108). Harvey et al. (2008) further supported this by

demonstrating that by the end of the first task in a simulated fire ground test, VCO_2 had

already exceeded VO_2, likely due to buffering of hydrogen ions in response to the sustained muscular contractions during such activities (46). The literature is mixed as to the importance of anaerobic power versus capacity as it may be argued in most firefighting operations, which are less than 10 minutes in length, anaerobic capacity may be of less importance than maximal anaerobic power (46, 108). In addition, it has been suggested that having a larger maximal aerobic capacity could allow reduced contribution of anaerobic metabolism (90).

The current study supports the idea that a myriad of fitness characteristics play a role in firefighter occupational performance. It is important to identify the fitness characteristics and physiological outcomes that are correlated to the decrement in performance produced by the PPE. This information will guide practitioners in selecting appropriate training strategies to effectively prepare firefighters to perform occupational tasks in gear. Thus, Aim 2 evaluated the relationships between fitness and pulmonary outcomes versus the decrement in occupational performance produced by the PPE. To evaluate this objective, the absolute difference in SFGT time between conditions (i.e., delta time) was correlated to the battery of fitness characteristics. In addition, the recruits were divided into best and worst performers for each of the three conditions to compare group differences. This need has previously been addressed by Taylor et al. (2016) who reported that performance in an unloaded condition is likely unrepresentative of performance tested in a loaded condition (104). Indeed, not everyone who was a top performer in one condition was a top performer in other conditions. In the SCBA condition there was a between group difference with top performers having superior upper body strength, Wingate average power, age and absolute VO_{2max}. In the LC

condition, there were significant differences in handgrip strength and Wingate average power with top performers producing greater values. In the PT condition, the top performers had superior lower body power, anaerobic power, and handgrip strength. Age, upper body strength and aerobic capacity have previously been shown as divisions between top and poor performers (69, 71, 108). Absolute VO_{2max} was a dividing factor in the top and worst performers for the SCBA condition (3.8 ±.23 $L \cdot min^{-1}$ vs 4.3 ±.18 $L \cdot min^{-1}$) a similar trend noted in the literature (69, 71, 108).

In the current study, absolute VO_{2max} correlated to the delta time for the equipment carry task in the LC condition and the hose drag task in the SCBA condition. In addition, 1.5 mile run time was correlated with the delta score for the hose drag task in both conditions and the ladder raise in the SCBA condition. Since the SCBA decreases maximal aerobic capacity, it would make sense that those with a higher absolute VO_{2max} would be at an advantage during aerobically demanding tasks while wearing the SCBA (29, 32). An increased aerobic capacity also helps account for the increase in blood flow to more musculature involved in supporting the external load during load carriage. A common theme is that while absolute maximal aerobic capacity seems to be a better predictor of tactical performance in this population, suggesting that body mass may play a role, not all the literature demonstrates this direct relationship between body size and performance (90). The current study found several correlations between stature and performance decrement (Table 7). This discrepancy throughout the literature may be due to several factors. Although larger stature may be advantageous as their PPE weight elicits a lower relative load, a larger body mass still requires more energy to move. Stature may have conflicting results when bodyweight tasks such as stair climbing are

compared to a task involving external weight such as an equipment carry. In a task such as the victim drag, a larger body mass is very likely advantageous and research has shown that larger, heavier firefighters conduct victim drags with a different, more economical technique than their smaller counterparts (108). Height, body mass and fat free mass were negatively correlated to the delta time for the equipment carry task in the LC condition. As total body mass increases, the relative load placed on the firefighter by their gear is reduced, especially if that body mass is in the form of fat-free mass. Furthermore, in the current study, body fat percentage was positively correlated to the delta score for the victim drag in the SCBA condition, while plank time was negatively correlated to the delta score of the victim drag and hose drag in the LC condition. Abdominal or core strength/endurance has previously been shown in the literature to impact firefighter ability test performance in PPE (69).

Measure of anaerobic power, Wingate fatigue index and VJ power, were related to the decrement in performance on the equipment carry in the LC condition. This corresponds with other literature demonstrating correlations between anaerobic power and occupational task performance (69, 84, 90). Related to this, Sheaff et al. (2010) suggests that a large aerobic capacity may allow a subject to complete such tasks with less anaerobic contribution, finding that absolute VO_{2max} is an important predictor for candidate physical ability test (CPAT) performance, in line with findings of the current study (90). Rhea et al. (2004) also demonstrated that anaerobic endurance was related to overall performance and individual task performance in firefighters (84). It is important to note that their study allowed a minimum 10-minute break between tasks as opposed to a continuous SFGT employed in the current study. While many studies focus on

cardiovascular fitness and lower body measures, Rhea et al. (2004) also demonstrated

that upper body strength and endurance is important for performance as well (84). In the

current study, handgrip strength was related to the decrement in performance of several

tasks in the load carriage condition. Lastly, the fitness tests that were conducted by the

academy correlated well with several task decrements. Similarly, Rhea et al. (2004)

combined fitness scores of firefighters to create an overall score and reported that it was

related to occupational performance (84).

Related to health and performance, resting diastolic blood pressure was correlated

to overall percent difference due to the respirator as well as to the stair climb, equipment

carry, ladder raise and search tasks. In addition, it was correlated to the overall delta time

and forcible entry task time in the SCBA condition (Table 8). Nelson et al. (2009) found

that exercise with the SCBA increases intrathoracic pressure and also results in a

decreased end diastolic cavity area and stroke area (72). The authors suggest this is likely

due to reductions in venous return and preload which are further exacerbated when

combined with heat stress and dehydration (72). Sheaff et al. (2010) found that diastolic

blood pressure at the end of a stair mill task was correlated to overall performance on the

candidate physical ability test in firefighters with load carriage but not breathing through

the SCBA (90). This is a concerning find for the SCBA condition since data has shown

that 44-49% of fatalities in the line of duty for firefighters are related to sudden

cardiovascular or cerebrovascular events and that the average blood pressure for the

recruits in this study was pre-hypertensive (131.7 ± 5.3 / 83.6 ± 7.1 mmHg) (9, 100).

As the current study used academy recruits as opposed to incumbents, it is

pertinent to compare their fitness characteristics to incumbent firefighters previously

described in the literature. Inherently, the recruits were younger (28.6 ± 4.3 yr) compared to the subjects in Michaelides et al. (2011) (33 ± 7 yr) and Rhea et al. (2004) (34.5 yr ± 6.1). The current subjects had lower body fat percentages ($22.9 \pm 6.1\%$) compared to the subjects used in Michaelides et al. (2011) who were $23.1 \pm 5.58\%$, but higher than Rhea et al. (2004) who were $16.6 \% \pm 3.9$ (69, 84). The current recruits also had similar hand grip strength 62.3 ± 7.2 kg (right), 59.5 ± 5.5 kg (left) compared to Rhea et al. (2004) subjects who had 58.8 ± 11.2 kg as well as 60.93 ± 8.62 kg (right), 57.82 ± 8.42 kg (left) (84). Dennison et al. (2012) completed a similar SFGT using incumbent firefighters and found overall and split times very similar to those in the current study (23). All of the previously mentioned studies used professional incumbent fire fighters.

There are several limitations to the present study including subject variability, differences in environmental conditions, and use of academy fitness data. The LC condition was designed to remove the effects of the positive pressure of the respirator but maintain the effects of load carriage. Therefore, the mask, helmet and tank were worn but the regulator was disconnected from the face mask in the LC condition. The hood was also removed in the LC condition to prevent the face shield from fogging and obstructing visibility. Some of the recruits stated that the LC condition felt more difficult than the SCBA condition. Since the face shield was still partially covering their face it may have resulted in a feeling of dyspnea and slowed down air turnover. In addition, thoracic loading alone has been shown to decrease exercise tolerance by restricting chest wall movement and therefore ventilation (76, 78, 80) . While the LC condition was aimed at evaluating the effect of the load carriage and microclimate of the PPE, the SCBA cylinders were still full of air and strapped to the subjects' back. Tidal volume has been

shown to decrease in both traditional load carriage as well as chest strapping which simulates the chest constriction without the actual load (76). In addition, the SCBA trial could not isolate the decrement caused specifically by the respirator alone. There were differences in ambient conditions between the SFGT trials. Although performed in a randomized order, the SFGT was performed partially outside to enhance the external validity of the findings. The ambient temperatures varied throughout the summer testing period and although testing was performed at the same time of day, differences in ambient temperature and humidity between testing days may have had a confounding effect; however, we felt this provided a more realistic assessment of occupational physical ability. Although the heat index for the LC trial was slightly higher than that of the PT condition, the PT condition was cooler than the LC and SCBA conditions but was more humid than the LC and SCBA conditions (Table 3). Regardless, there was no correlation between the SFGT decrement and the heat index difference between PT versus LC conditions. In addition, the recruits training activities varied throughout the 8-week testing period and may have impacted performance. Lastly, there are some limitations in the fitness data collected from the academy. The 1.5 mile run was performed outside and not on a level track which may have impacted estimated VO_{2max} calculation. Academy fitness testing was performed in one session and there were minimum standards to pass as well as maximum standards for points for each task which may have promoted a pacing effect in some subjects and resulted in not performing a maximal number of repetitions past the desired threshold.

CHAPTER V

SUMMARY AND CONCLUSION

In conclusion, this study quantified the decrement in firefighter occupational physical ability caused by LC and LC plus the SCBA in firefighter recruits. While necessary, firefighting PPE produces tremendous performance decrements as the LC condition elicited a 38% decrement in performance, the respirator produced an additional 4.6% decrement and the total PPE elicited a 44.5% decrement. This study also demonstrated that performance in physical training attire is not an accurate depiction of occupational physical ability in PPE. Furthermore, absolute aerobic capacity, lower body power, anaerobic power and capacity, abdominal muscular endurance, and upper body strength were correlated to the decrement in performance caused by the PPE. Thus, it is important to train firefighters for these fitness outcomes, in order to minimize the decrement in occupational performance elicited by load carriage. This study also demonstrated that absolute measures of aerobic capacity such as absolute VO_{2max} and 1.5 mi run time were correlated with more tasks than relative aerobic capacity reiterating that there may be a minimum cardiorespiratory standard for occupational readiness, regardless of body mass. In summary, PPE increases the intensity of performing fire ground tasks. To enhance occupational performance, it is imperative that firefighters optimize specific physical fitness attributes to reduce the relative stress produced by the PPE.

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