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Maxwell Steele Norris, Student

Dr. Mark G. Abel, Major Professor

Dr. Melinda J. Ickes, Director of Graduate Studies

PREDICTORS OF WORK ECONOMY IN STRUCTURAL FIREFIGHTERS

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Education
at the University of Kentucky

By
Maxwell Steele Norris
Lexington, Kentucky
Director: Dr. Mark G. Abel, Associate Professor of Kinesiology
Lexington, Kentucky
2020

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ABSTRACT OF THESIS

PREDICTORS OF WORK ECONOMY IN STRUCTURAL FIREFIGHTERS

The purpose of this study was to investigate a novel work economy metric to quantify firefighter physical ability and identify physical fitness and anthropometric correlates of work economy. Physical fitness and anthropometric measurements were taken on 19 incumbent structural firefighters (Age: 35.0±7.1 yr, Body mass: 87.5±13.1 kg). Firefighters performed a timed maximal effort simulated fireground test (SFGT) in personal protective equipment. SFGT air depletion was represented by change in cylinder pressure. Work economy was quantified as: (1/(SFGT completion time x air depletion))x10^4. Bivariate and multiple linear regression analyses were used to identify anthropometric and physical fitness predictors of work economy. Work economy was significantly correlated to age (r=-0.67), relative body fat (r=-0.47), fat mass (r=-0.51), years of occupational experience (r=-0.64), maximum jump height (r=0.73), inverted row repetitions (r=0.60), relative bench press (r=0.54) and squat strength (r=0.63), treadmill time to exhaustion (r=0.71), relative ventilatory threshold (r=0.57), and relative VO_{2peak} (r=0.57). Treadmill time to exhaustion and relative lower body strength accounted for the greatest variance in work economy (R^2=0.72, RMSE=0.07). A diverse set of mass dependent fitness attributes were related to work economy. However relative lower body strength and aerobic endurance were the strongest predictors of work economy.

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04/30/2020

Date

PREDICTORS OF WORK ECONOMY IN STRUCTURAL FIREFIGHTERS

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CHAPTER I. INTRODUCTION

Firefighting often requires the completion of rigorous occupational tasks (Davis et al. 1982; Sothmann et al., 2004; Williams-Bell et al., 2009) in a time critical manner to save lives and limit property damage from structure fires. Performing occupational tasks is challenging due to the physical nature of the tasks (e.g., carrying heavy equipment, advancing charged hoselines, rescuing victims) and load carriage requirement associated with the requisite personal protective equipment (PPE; i.e., self-contained breathing apparatus (SCBA), turnout pants & coat, helmet, boots, hood, gloves) (Marcel-Millet et al., 2018). The physiological compromising effect of the PPE is further exacerbated by the positive pressure system of the SCBA which has been found to decrease firefighters' aerobic capacity by 13.1% (Eves et al., 2005). The time critical element of firefighting is also accentuated by the limited air supply provided by the SCBA. The SCBA can provide compressed oxygenated air for an estimated 30-60 minutes while in a rested condition, however this volume of air will support only a fraction of that time during periods of increased metabolic demand. Thus, firefighters possessing more economical air use per unit of work can work longer before requiring a new air cylinder and potentially enhance firefighters' safety.

Firefighter physical ability is typically assessed for research and occupational standard purposes via work capacity assessments using timed competition of simulated fireground tests (SFGT). Research utilizing SFGTs have indicated that numerous physical fitness attributes are associated with work capacity. These studies have reported that work capacity is related to body composition (fat-free mass, fat mass and relative body fat), aerobic and anaerobic capacity, and upper and lower body muscular strength and endurance (Davis et al., 1982; Michaelides et al., 2011; Rhea et al., 2004; Sheaf et al., 2010, Williams-Bell et al., 2009). Thus, it is paramount that firefighters possess optimal levels of physical fitness to adequately perform occupational tasks under load carriage. Although this research is very informative, from a physiological economy perspective, it seems critical to also account for air utilization to more accurately quantify firefighter physical ability and associated fitness attributes.

A recent investigation conducted by Windisch and colleagues (2017) accounted for work rate and associated physiological cost during the completion of simulated airport firefighting tasks. This study utilized a standardized aggregate calculation composed of time of occupational task completion, mean task heart rate, and cylinder air depletion (Windisch et al., 2017). The study found that peak aerobic capacity, time spent during the SFGT below ventilatory threshold, and breathing frequency were related to the novel work metric (Windisch et al., 2017). Although this study is informative, it was focused on airport occupational tasks and thus the SFGT did not include several typical rigorous tasks performed at a conventional structural fireground. In addition, an alternative mathematical approach to evaluate the economical completion of occupational tasks is to assess firefighters' work rate relative to air depletion. This derivation of structural firefighter work economy may provide a more appropriate assessment of structural firefighters' occupational physical ability. Furthermore, developing a more appropriate occupational metric provides an opportunity to identify fitness outcomes and physical characteristics that are associated with optimal occupational performance. This information is significant as work economy may be used as a screening assessment for occupational readiness and the relevant fitness and anthropometric correlates may be targeted through a tactical strength and conditioning program. Therefore, the primary purpose of this study was to develop a novel work economy metric to quantify structural firefighters' occupational physical ability. The secondary purpose of this study was to identify fitness and anthropometric correlates of structural firefighters' work economy. We hypothesized that higher aerobic and anaerobic capacities and favorable body composition profiles would be associated with higher work economy.

CHAPTER II. REVIEW OF LITERATURE

2.1 Economy vs. Efficiency

Economy has been defined as the oxygen consumption or energy expenditure relative to a given work rate or absolute exercise intensity (Coyle et al., 1992; Hunter et al., 2005; Rønnestad et al., 2013; Saunders et al., 2004). Efficiency refers to the ratio of work (typically "useful" work) produced to the energy expended (Coyle et al., 1992; Saunders et al., 2004). As defined by the Oxford English dictionary, efficiency is the "ratio of useful work performed to the total energy expended or heat taken in…" ("Efficiency," 2019). Economy and efficiency are often used interchangeably and although they have similarities, they indeed have different meanings. In the context of exercise and human kinematics, it seems logical that economy would refer to the energy cost of the exercises, movements or actions performed. Work economy may also act as a surrogate of efficiency. Economy signifies the energetic cost of a given work rate or absolute exercise intensity, regardless of how much "useful" work has been produced. Efficiency, on the other hand, signifies how much useful work can be done per unit of energy expended. Although related, it's clear that economy and efficiency have different meanings. Having defined work economy, it is important to understand how work economy can be defined in the context of a specific exercise or physical activity.

2.1.1 Work Economy and Exercise

Work is defined as force multiplied by displacement. Referring to the Oxford English dictionary, work is the “operation of force in producing movement or other physical change, esp. as a measurable quantity…” (“Work,” 2019). Work economy could prove to be a useful means of quantifying an individual’s performance or physical ability. Keeping in mind the previous definitions of work and economy, work economy could be defined as the energy cost to perform a given amount of work, representing the body’s ability to perform said work efficiently. Efficiency would not be a practical metric to quantify performance and physical ability as it must consider the “useful” amount of work produced. In addition, work economy considers an individual’s efficiency for a given work rate or exercise intensity. The equation for work is as follows:

$$W = F \times D \times \cos(\theta)$$

where W is the amount of work being done, F is the vector force, D is the magnitude of displacement and θ is the angle between the vector of force and the vector of displacement. Although the equation for work appears simple, measuring work can be complicated and prone to error if measuring complex tasks, such as an athlete running a series of agility drills or a soldier running through an obstacle course. Adding to this complexity would be the need to define “useful” work and ensuring the method of measuring work can differentiate useful from non-useful work. Using efficiency as a metric would require the direct measurement of the amount of work being performed. For example, if a researcher wanted to compare the efficiency of two groups of firefighters (one incumbent structural firefighter and the other newly graduated cadets) by having them run through an obstacle course, work would have to be calculated for every task for each participant and researchers would need to quantify the useful work performed. This can be daunting when attempting to record the θ for each exercise/task performed by every participant during the obstacle course. With work being difficult to measure for complex tasks, attempting to measure efficiency for exercise can be impractical and potentially require costly equipment. Work economy would not only represent the energy cost of the work being performed without the need to directly measure work but would also act as a surrogate of efficiency as it considers energy management and the biomechanical efficiency of the body during exercise. Work economy can be seen throughout literature, providing examples of how it has been utilized and defined.

Work economy has typically been utilized throughout physiological literature to quantify running economy (RE) (Barnes et al., 2015; Lundby et al., 2006; Marcora et al., 2007; Saunders et al., 2004). RE is commonly defined as the energy cost to run at a given velocity, where oxygen consumption (VO_2) represents the energy cost. In addition, Lundby et al. (2016) assessed exercise economy for cycle ergometry, where economy was defined as the energy cost to pedal at a given workload. Although the purpose of their study was to investigate changes in mechanical efficiency, exercise economy was utilized to evaluate the energy cost of the exercise, not the ratio of usable work performed per unit of energy expended. Work economy can easily be defined in general terms, but as previously shown, this definition can change based on the context of its usage. For cycle ergometry in the Lundby et al. (2016) study, workload was measured (in Watts), whereas velocity was measured as a surrogate of work when work economy was examined for running. VO_2 has been used as the measure for energy cost of a given action for both RE and exercise economy. However, the surrogate of work changes based on the activity being investigated. With the inability, or impractically, to measure work directly, work economy can be tailored to each activity or task being performed. This would be done by using a measurement representing the physical work performed during the activity of interest (running velocity, workload produced, time to complete a task, etc.) and relate it to some measurement of energy expenditure (e.g., VO_2). Essentially, work economy can be created by identifying physical or physiological components that are essential for that task and relating it to a measurement of energy expenditure. Losnegard et al. (2014), for example, used velocity for their measurement of exercise economy considering an athlete's speed is critical to performance during skiing and running. The ability to tailor work economy to a specific task, activity, exercise, etc. makes it a versatile tool to quantity the energic costs of many activities or tasks that lack a defined metric of work economy or make it difficult to directly measure work.

2.2 Firefighter Work Economy

2.2.1 Physiological Demands of Firefighting

Work economy for a specific activity or task can be determined using a representative measure of the physical work performed during the task or activity and relating that representative measure to the energetic cost of the task. The constituents of work economy may become difficult to determine for occupations where individuals perform tasks utilizing diverse movements patterns and physiological demands (i.e. aerobic and anaerobic requirements). To create a work economy metric for firefighting, the physical and physiological parameters vital to firefighting performance must be established in order to create a work economy metric founded on physiological and physical fitness parameters relevant to firefighting. Firefighting requires the ability to perform physically demanding tasks (Davis et al. 1982; Rhea et al., 2011; Williams-Bell et al., 2009) in an efficient manner. The time critical element in firefighting stems from the need for fast action in emergency situations, accentuated by the limited amount of oxygen provided by the self-contained breathing apparatus (SCBA). When firefighters arrive at the fireground, they have limited time to prevent the spread of the fire, save endangered lives and minimize further property damage. In addition to this, the SCBA can provide oxygenated air for an estimated 30-45 minutes in a rested condition, depending on the cylinder's capacity. Intuitively, the less air a firefighter consumes, the longer they can remain active before requiring a new cylinder. Moreover, full firefighting gear (personal protective clothing, SCBA, full-face mask and breathing regulator) contributes significantly to the physiological demands of firefighting (Marcel-Millet et al., 2018). Thus, it is paramount that firefighters possess optimal levels of physical fitness to adequately perform occupational tasks in an economical manner. However, it is important to determine which physiological and physical fitness outcomes are essential for firefighting performance.

Davis et al. (1982) sought to identify predictors of performance during a simulated fireground test (SFGT) by evaluating several physical performance measures. This study would facilitate the creation of a physical performance profile for firefighting. Variables/predictors were categorized as either 1) physical performance measures or 2) criterion measures of occupational physical ability. One-hundred structural firefighters participated in this study. Anthropometric measures were recorded for each firefighter (height weight, and BMI measures). Neuromuscular measures were taken by recording a firefighter's grip strength, sit-ups completed in 2 minutes, standing long jump distance, hamstring flexibility and push-ups and pull-ups to exhaustion. Resting blood pressure, pulse pressure and heart rate were taken as resting physiological measures. A 5-minute step test was conducted to measure physiological parameters for submaximal exercise testing and a Balke treadmill protocol for maximal exercise testing: blood pressure VO_2, heart rate, ventilation and ventilation equivalence. One-hundred career firefighters were randomly selected from the Washington D.C., Universe of Professional Fire Fighters database. The firefighters then completed a SFGT (consisting of five tasks commonly performed in the field) wearing their SCBA and full protective gear. The five tasks were performed continuously without rest. Completion times were recorded for individual tasks in the simulated fireground test as well as an overall completion score. ECG recordings were taken continuously during the test. Two factors accounted for the most variability of heart rate and completion time for each firefighter: physical work capacity and resistance to fatigue. Physical work capacity referred to the ability of the firefighter's aerobic capacity to meet the aerobic demands of the five tasks. Physical work capacity was influenced most by grip strength, sit-up count, maximal heart rate, age and submaximal oxygen pulse. Resistance to fatigue was referred to as the firefighter's ability to meet the energetic demands of performing all five tasks of the SFGT continuously. Resistance to fatigue was most influenced by lean body weight, maximal heart rate, age, percent body fat and final treadmill grade (obtained during the Balke treadmill protocol). As mentioned, work economy must be founded in physiological and fitness parameters/outcomes that affect firefighter performance during a SFGT. This study assisted with identifying these parameters, which facilitated the development of work economy for firefighting. Similar studies were conducted using a SFGT to simulate firefighting conditions to determine what physiological and physical fitness outcomes are important for firefighting.

Williford et al. (1999) investigated the relationship between various physical fitness parameters and tasks performed during a simulated fireground test. Ninety-one male firefighters were randomly selected for this study. The height, weight, body fat, blood pressure, resting heart rate, number of push-ups, sit-ups, pull-ups, sit and reach, grip strength and 1.5-mile run times were recorded for each firefighter. The subjects completed a simulated fireground test, called a simulated physical performance assessment (PPA). The PPA consisted of 5 tasks determined to be essential for firefighting suppression. Subjects wore standard protective firefighting gear (helmet, gloves, boots, fire-retardant coat and pants) and a SCBA. The following constituent tasks of the PPA were conducted continuously in sequential order: stair climb, hoisting, forcible entry, hose advance and victim rescue (mannequin drag). The firefighters were introduced to the PPA and given the opportunity to practice and familiarize themselves with the course for six weeks. From the study, Williford et al. determined that there were significant correlations between the PPA and total grip strength, fat-free mass, height, 1.5-mile run time, pull-ups, push-ups, weight, sit-ups and percent body fat. When the researchers performed a multiple regression analysis, the best combination of predictors for the PPA were the 1.5-mile run time, fat-free mass and maximal pull-ups completed. Williford et al. (1999) put more emphasis on investigating physical fitness outcomes, opposed to focusing on physiological parameters. The work done here provided more insight into how the work economy variable should be defined in order to justify its use and rationalize how it can function to quantify firefighter performance.

Michaelides et al. (2011) sought to identify the relationship between various physical fitness parameters and a firefighter's performance on a SFGT. Sixty-seven firefighters completed the study. The study was broken into two phases: the ability test/simulated fireground test and a physical fitness assessment 2-weeks later. The ability test was composed of 6 tasks that mimicked common tasks/activities performed in the field: stair climbing, rolled hose lift and move, forcible entry, hose pull and hydrant hook-up, rescue mannequin drag and a charged hose advance. These tasks were performed continuously without rest periods. Participants wore full protective gear with a total weight of 22.68 kg. There was no reported use of a SCBA. Completion times for each task were recorded along with an overall completion time. For the physical fitness assessment, researchers recorded the following fitness parameters: body composition, flexibility, muscular strength and endurance and anaerobic power. The study identified the following as correlates of occupational physical ability: abdominal strength, relative power (step test and vertical jump), upper body muscular endurance (push-up and sit-up reps) and strength (1RM bench press). Performances considered "poor" were largely associated with high resting heart rate, high body mass index, increasing age, high body fat, and a large waist size. Similar to the study by Davis et al. (1982), this study determined which physical fitness parameters were most influential on performance during a SFGT. A relatively similar study was conducted by Holmer et al. (2007) where they examined the metabolic and respiratory demands of performing a SFGT. Holmer et al. revealed the high energetic demands of firefighting, particularly for tasks involving climbing or carrying heavy objects (e.g., victim rescue). The investigation reported a significant, positive correlation between SFGT completion time and mean VO_2 during the SFGT. In addition, the SFGT elicited high minute ventilations of 100 L/min and near maximal heart rates throughout the SFGT. This study by Holmer et al. investigated primarily physiological responses to firefighting. A study be Sheaf et al. (2010) further investigated the physiological demands of firefighting, along with various physical fitness outcomes.

Sheaff et al. (2010) sought to investigate the importance of physiological characteristics on performance during the Candidate Physical Ability Test (CPAT). The CPAT is designed for applicants pursuing employment in the fire service as it uses a 22.7 kg weighted vest in place of personal protective equipment. No respirator is used during the CPAT. Specifically, the researchers wanted to determine which physiological characteristics accounted for the variance in CPAT performance. Although similar to a SFGT, the primary difference between the CPAT and the SFGTs in previous studies was the replacement of the SCBA and personal protective equipment with a weighted vest, which simulates the external load carriage of the SCBA and personal protective equipment. Both serve to mimic the tasks and demands imposed during firefighting. Thirty-nine volunteer and incumbent firefighters were recruited for the study. The following physiological characteristics were assessed: upper and lower body strength, muscular endurance, lower body muscle power, body composition, aerobic capacity, anaerobic capacity and heart rate (HR). Strength was measured by performing 1 repetition maximum tests on a leg extension, chest press and leg press machines. Lower body power, however, was determined through a modified leg-extension protocol. Chest and leg press machines were utilized to determine muscular endurance by performing repetitions to failure. Anaerobic characteristics were measured by performing a Wingate protocol on a cycle ergometer. Cardiovascular parameters were measured by performing a maximal GXT on a stair climbing machine. Subjects then completed the CPAT, which consisted of 8 tasks specific to firefighting (stair climbing, hose drag, equipment carry, ladder raise and extension, forcible entry, bear crawl, victim drag and ceiling breach and pull) performed continuously, with each task separated by a 25.9 m walk. The study concluded that mean power from the Wingate, relative peak power during the Wingate as well as relative and absolute VO_{2max} were significantly higher in subject's who successfully completed the CPAT than those who failed. Mean power during the Wingate, fatigue index during the Wingate, absolute VO_{2max}, upper body strength (chest press RM), grip strength and heart rate response during the stair climbing were significantly associated with CPAT performance time. The best predictors of CPAT performance time were absolute VO_{2max} and anaerobic fatigue resistance measured during the Wingate. The conclusions of this study further emphasize the physical and physiological characteristics that most impact firefighter performance during a SFGT, or a CPAT in the context of this study. As with previously mentioned studies, this study contributes to the understanding of what fitness and physiological parameters have the greatest effect on firefighter performance, providing additional insight into the physical and physiological demands of firefighting.

Williams-Bell et al. (2009) assessed the physiological demands of the CPAT. Fifty-seven healthy, physically active males and females volunteered for the study. It has been noted that these subjects were not firefighters. Subjects were given 2-weeks to familiarize themselves with the tasks performed in the CPAT. VO_{2max}, ventilation and gas exchange (VO_2, carbon dioxide, VCO_2 and RER) were recorded during a maximum treadmill GXT and the CPAT. In addition, Wingate anaerobic tests were conducted to measure peak power. Maximal 1RM strength tests and muscular endurance tests were conducted for both the upper and lower body. Subjects completed the CPAT wearing a 22.68 kg weighted vest and a Cosmed K4b portable metabolic system to collect and analyze expired air samples. To pass the CPAT, subjects had to finish the course within 10 minutes and 20 seconds. The CPAT consisted of the following tasks performed continuously in sequential order: stair climb, hose drag, equipment carry, ladder raise and extension, forcible entry, search (bear crawl), rescue (mannequin drag) and ceiling breach and pull. The researchers reported that 65% of the variance in CPAT completion time was predicted by maximal aerobic power, absolute and relative VO_{2max} in combination with handgrip strength and body mass. However, the SEE was high (1 minute and 15 seconds) making it unlikely that one physiological parameter could successfully predict

CPAT completion times. This study was very similar to the Sheaf et al. (2010) and Holmer et al. (2007) studies in that they provided the same insight into what fitness and physiological parameters have the greatest impact on firefighter performance when completing a SFGT. Considering the importance of time on firefighter SFGT performance, it would prove beneficial to understand what physiological parameters significantly influence SFGT completion time and the amount of time required to deplete the SCBA of air. Knowing these parameters, predictions can be made about SFGT completion and the duration a firefighter can work for a given amount of air in their SCBA.

Wu et al. (2001) sought to establish a methodology to determine the maximal acceptable work duration (MAWD). Wu et al. used thirty (fifteen male sand fifteen females) untrained subjects. During preliminary testing, each subjects' age, weight, body mass, resting heart rate, resting oxygen consumption (VO_{2rest}), average respiratory quotient (R) and the average ventilation per liter of oxygen consumed (V_E/VO_2) were measured. The subjects then performed a maximum GXT on an electronically braked cycle ergometer to obtain maximum heart rate (HR_{max}), maximum oxygen consumption (VO_{2max}) and maximum work rate (MWR). Wu et al. stated "when VO_{2max} was approached, the corresponding work rate was defined as the maximum work rate…" MAWD was defined as "the maximal period of time in which an individual can sustain with the average heart rate at work no greater than 150 beats/min and the peak heart rate not greater than 180 beats/min…" To determine MAWD, subjects performed two cycling tests on separate days. One ride was carried out at 60% MWR and another at 70%

MWR. Subjects rode until volitional exhaustion. Wu et al. determined that MAWD was inversely correlated to relative VO_2 (RVO_2) and relative heart rate (VHR). Wu et al. defined RVO_2 as “the elevation of oxygen uptake from the resting level as a percentage of the difference between maximum and resting oxygen consumption.” RHR was defined as “the elevation of heart rate from the resting levels as a percentage of the difference between maximum and resting heart rate. 80% of the variation in MAWD was explained by RVO_2 and RHR when used in their exponential decrease regression model used to predict MAWD. Although not directly related to firefighting, Wu et al. identified two physiological parameters that influenced MAWD, factors previously shown to affect firefighter performance on a SFGT. The harder a firefighter works, the more air they will potentially consume to meet the increasing metabolic demands, in turn increasing the rate at which they consume air from their SCBA (self-contained breathing apparatus). By knowing parameters that account for the largest variations in MAWD, these parameters can be related to firefighting in order to predict how long firefighters can work before relative workload significantly increases. This and the previously discussed studies reveal air depletion as a potential means of quantifying energy expenditure during a SFGT. Considering the physiological and physical fitness parameters that influence firefighter performance, it becomes easier to establish what parameters will define work economy for firefighting. In addition to determining what parameters will comprise work economy for firefighting, the structure of the work economy metric needs to be established.

Although not directly investigating at work economy, Windisch et al. (2017) sought to create a similar metric to quantify the physical demands of a simulated fireground test.

The aim of this study was to establish a relationship between occupational performance and endurance and strength measures. Windisch et al. quantified performance using a "time-strain-air depletion model (TSA)…" Forty-one male incumbent airport firefighters volunteered for this study. Anthropometric measurements were taken on each firefighter. A maximal treadmill GXT was performed to determine VO_{2peak}, maximal heart rate, minute ventilation (VE) and gas exchange (VO_2, carbon dioxide output (VCO_2) and respiratory exchange ratio (RER)). With these data, ventilatory threshold 1 (VT1) and respiratory compensation point (RCP) were determined. Each firefighters' balance, flexibility, muscular strength and endurance outcomes were measured. After these measurements were recorded, the firefighters completed a simulated fireground test twice, with all tasks being completed continuously with no rest periods. The first trial (i.e. Respiratory Protection Exercise Standard: $REPE_{standard}$) was performed with full personal protection gear that would be worn in the field. The second trial (i.e. Respiratory Protection Exercise Standard with Spirometry – $REPE_{Spirometry}$) was identical to the first, $REPE_{standard}$, but the facial mask of the self-contained berating apparatus (SCBA) was replaced with a mobile spirometry mask to measure VO_2, VCO_2, VE, RER, VE/VO_2, and VE/VCO_2. The TSA model was defined as the sum of the completion time of the simulated fireground test, heart rate and the air depleted during the simulated fireground test. A z-score transformation was done to the values from the TSA variables to standardize the contribution of each variable to the overall TSA value. Windisch et al. determined that VO_{2peak}, breathing frequency and how much time each firefighter exercised below their ventilatory threshold had the most significant influence on firefighter performance. This study provides insight into the proper structuring of the proposed WE variable. Many articles in this literature review sought to identify which physiological parameters and physical fitness outcomes were indeed the most important for firefighter performance. SFGT completion time and air depletion from the SCBA are clearly important variables that dictate firefighter performance.

Table 2.1. Summary of the reviewed literature investigating what physical and physiological variables affect firefighter physical ability

Study	# of Subject	Tasks Performed Continuously?	Incumbent Firefighters?	SCBA?	Correlates of SFGT Performance
Davis et al., 1982	100	Yes	Yes	Yes	Grip strength, sit-up reps, jump height, maximal heart rate, age, submaximal oxygen pulse, fat free mass, maximal, percent fat, final treadmill GXT grade
Holmer et al., 2007	15	Yes	Yes	Yes	Body mass, age, heart rate, VO_{2max}
Michaelides et al., 2011	67	Yes	Yes	No	Abdominal strength, relative power, 1RM bench press, push-up reps, sit-up reps, resting heart rate, body mass index, age, fat mass, waist size
Rhea et al., 2011	20	No	Yes	Yes	Bench press strength, hand grip strength, bent over row endurance, bench press endurance, shoulder press endurance, 400-m sprint
Sheaf et al., 2010	33	Yes	Mix of Incumbent and Volunteer Firefighters	No	Absolute VO_{2max}, chest press 1RM, Wingate measurements (mean power, relative mean power, total work, relative total work, fatigue index), heart rate at the end of a stair mill task, diastolic blood pressure at the end of a stair mill task, grip strength
Williams-Bell et al., 2009	53	Yes	No	Portable Metabolic System	Maximal aerobic power, absolute and relative VO_{2max}, body mass, hand grip strength
Williford et al., 1999	91	Yes	Yes	Yes	Grip strength, fat free mass, height, 1.5 mile run time, pull-up reps, push-up reps, body mass, sit-up reps, percent body fat
Wndisch et al., 2017	41	Yes	Yes	Yes	VO_{2peak}, push-up reps, time spent exercising below ventilatory threshold, mean breathing frequency

1RM: 1 Repetition maximum; VO_{2max}: maximum oxygen consumption; VO_{2peak}: peak oxygen consumption

2.3 Defining Work Economy for Firefighters

Based on the review of physical and physiological demands of firefighting, it would seem logical to define firefighting work economy using SFGT completion time and air depleted during the SFGT. Referring to the general definition of work economy established at the beginning of this review, SFGT completion time would act as the surrogate of work. Air depletion from the SCBA would act as a practical replacement of measuring VO_2, representing the energetic cost of "working" during the time required to complete the SFGT. Using the study by Windisch et al. as a framework, and assuming work economy increases with better SFGT performance, firefighter work economy would equal the product of SFGT completion time and the air depleted from the SCBA during the SFGT (the difference between pre- and post-SFGT PSI readings on the SCBA air cylinder). However, to ensure work economy increases as performance on a SFGT increases, the inverse of this product must be taken. Thus, work economy would be as follows:

$$\text{Work Economy} = \frac{1}{\text{SFGT Completion Time x Air Depletion}}$$

More precise measurements of work may be utilized. However, given the complex nature of the SFGT (numerous tasks occurring in different planes of motion), a measure other than SFGT completion time would need to be specific to the SFGT and not hinder the participants completion of SFGT tasks. VO_2 could be directly measured during an SFGT using a mobile spirometry mask. This device, however, is expensive, requires training on the device's usage as well as operation of associated software to determine VO_2. In addition, the breathing apparatus has been shown to affect firefighter performance during an SFGT, and the use of a spirometry mask may alter the performance outcomes compared to the use of the traditional SCBA breathing apparatus (Marcel-Millet et al., 2018). Using SFGT completion time and air depletion would require no additional costs or require special training, making this assessment of firefighter WE extremely practical to use.

Work economy, in general, can be defined as the energetic cost to perform a designated amount of work. When defining work economy in terms of exercise or a given task, the physiological parameters and physical fitness outcomes essential for the performance of said exercise or task must be determined. Regarding firefighting, completion time of tasks and air depleted from the SCBA's air cylinder are two essential components that dictate firefighter performance. Using a SFGT to test a firefighter's overall performance during a fire emergency, SFGT completion time and air depletion can be used to define work economy for firefighting. Firefighter work economy would thus be defined as the inverse of the product of SFGT completion time and air depleted for the SCBA's air cylinder (inverse only taken so that an increased work economy value indicated increased performance on a SFGT). These components of firefighter work economy should not only be used due to their necessity for firefighter SFGT performance, but also due to the practicality of measuring these parameters without the need of additional expensive equipment.

CHAPTER III. METHODOLOGY

3.1 Experimental Approach to the Problem

This study utilized a cross-sectional design to assess work economy in incumbent structural firefighters. In addition, physical fitness, anthropometric, and demographic predictors of work economy were identified.

3.2 Subjects

A convenience sample of 22 male incumbent structural firefighters from the United States were recruited to participate in this study. Of the 22 participants, three were excluded from the study due to a failure to complete all data collection tasks. Firefighters were also excluded from the study if they had any musculoskeletal injuries that precluded them from completing the testing procedures. Each firefighter completed an annual physical examination and was cleared for duty. Written informed consent was obtained from each subject prior to participation in the study. The consent form and study design were approved by the University's Institutional Review Board. The physical characteristics of the sample are displayed in Table 3.1.

Table 3.1. Demographic and physical characteristics of 19 male incumbent structural firefighters that participated in the study.

				95% CI	
	Mean ± SD			Lower	Upper
Age (yr)	35.0	±	7.1	31.5	38.4
Height (cm)	179.4	±	5.5	176.7	182.0
Body mass (kg)	87.5	±	13.1	81.2	93.8
Body fat (%)	18.8	±	6.7	15.6	22.0
Fat-free mass (kg)	70.5	±	8.0	66.7	74.4
Fat mass (kg)	17.0	±	7.7	13.3	20.7
Body mass index ($kg \cdot m^{-2}$)	26.8	±	3.2	25.3	28.4
Experience (yr)	10.8	±	7.5	7.2	14.4

3.3 Procedures

3.3.1 Anthropometric Assessments

Each participant completed three testing sessions and one SFGT familiarization session (Table 3.2). Anthropometric measurements were performed in the first testing session. Specifically, standing height was measured without shoes using a portable stadiometer (to the nearest 0.1 cm; Model 213, SECA, USA). Body mass was measured without shoes in minimal clothing (to the nearest 0.1 kg) with an electronic scale (HBF-516B Body Composition Monitor and Scale, OMRON Healthcare, USA). Body composition was measured via full body bioelectric impedance analysis (HBF-516B Body Composition Monitor and Scale, OMRON Healthcare, USA).

3.3.2 Fitness Assessments

A battery of physical fitness assessments were completed in testing sessions one and two. Participants completed a familiarization trial of the SFGT in the third session and the actual SFGT trial in the fourth session. Muscular strength, aerobic capacity, ventilatory thresholds, local muscular endurance and lower body power were evaluated. There was a minimum of two and a maximum of seven days of rest between sessions.. In addition, participants were instructed to not partake in any exercise at least 24 hours prior to each testing session.

Table 3.2. Testing schedule and outcome measures of the protocol.

Test Session	Measurement/Test
Session 1	Anthropometric measurements VO_{2peak} and ventilatory threshold • Maximal treadmill graded exercise test
Session 2	Muscular strength tests • Estimated 1RM bench press and back squat test Lower body power test • Vertical jump Local muscular endurance tests • Push-ups • Inverted rows
Session 3	Simulated Fireground Test – Familiarization trial
Session 4	Simulated Fireground Test – Official trial

1RM: 1 repetition maximum.

3.3.3 Muscular Strength

A multiple repetition maximum test was used to estimate each participant's one repetition maximum (1RM) for the bench press and back squat exercises. Relative 1RM bench and squat strength was calculated by dividing estimated 1RM by the participant's body mass. The test procedures followed the National Strength and Conditioning Association's guidelines for maximal strength testing with several modifications (Haff & Triplett, 2016). Participants performed two warm-up sets with a light resistance. In the first warm-up set, participants performed 5-10 repetitions with a load approximating 50% of their estimated 1RM, followed by one minute of recovery. In the second set the participant performed 3-5 repetitions using a submaximal load approximating 80% of their estimated 1RM, followed by one minute of recovery. After the two warm-up sets, participants performed a set with a load that allowed them to perform a maximum of 10 repetitions. If the participant performed more than 10 repetitions, the load was adjusted until the participant performed no more than 10 repetitions. A maximum of five attempts was allowed, with two minutes of recovery between each attempt. The Brzycki Prediction Equation was used to estimate 1RM from the max estimation set (Brzycki et al., 1993; Nascimento et al. 2006; Reynolds et al. 2006). The Brzycki equation has been found to demonstrate adequate validity ($r = 0.99$). The Brzycki equation is as follows:

$$1RM = 100 \times \text{load (kg)} / (102.78 - 2.78 \times \text{repetitions})$$

Strength was expressed in absolute units and relative to body mass and relative to PPE mass plus absolute fat mass.

3.3.4 Local Muscular Endurance and Lower Body Power

Push-ups and inverted rows were utilized to measure local muscular endurance. The push-up protocol followed the National Strength and Conditioning Association’s procedures (Haff & Triplett, 2016). The test-retest reliability for this test has been reported as adequately reliable ($r=0.93$) (Johnson & Nelson, 1986). A maximal number of push-ups were performed in two minutes, allowing for rest only in the extended arm position. The push-up test began with participants assuming the standard push-up position with hands shoulder-width apart, elbows extended and body in a plank position. The low position was determined when the chest made contact with the recorder's fist held vertically against the ground.

For the inverted row test, participants performed inverted rows for two minutes, with a maximum of 80 repetitions. Participants began the test by hanging from a barbell placed in a power rack. The barbell was adjusted so that each participant started in a standardized position. The starting position had participants grasp the bar at shoulder-width using a pronated grip. Participants then extended their legs, firmly planting their feet onto a fixed object and adjusting their torso so that it made an approximate 45° angle with the floor and the barbell perpendicular to the participant's sternum. The head and spine were maintained in a neutral position. A 5-inch prop was placed at the bottom of the barbell. The participant pulled themselves upwards until their chest touched the 5-inch prop, before returning to the starting position to complete the repetition.

Lower body power was assessed via a vertical jump test. Three trials of the vertical jump were performed in accordance with the National Strength and Conditioning Association's procedures using a Vertec device (Vertec Vertical Jump Trainer, Sports Imports, USA). The test-retest reliability of the vertical jump test was adequate (ICC = .99). The highest distance of the three trials was used in the data analysis. The Vertec device was setup with the stack of movable vanes adjusted to be within the participant's standing reach height. The set of vanes were adjusted so that the participant would not jump higher or lower than the stack of vanes. To begin, the participants were instructed to perform a countermovement by flexing the knees and hips, swinging the arms backwards. Participants jumped immediately following the countermovement, reaching upwards using their dominant hand. At the peak of their jump, participants tapped the highest vane possible. Vertical jump height was calculated as the difference between the jump and standing heights.

3.3.5 VO_{2peak} and Ventilatory Thresholds

A maximal treadmill graded exercise test (GXT) was used to measure peak aerobic capacity (VO_{2peak}) and ventilatory threshold (VT1) (Caiozzo et al., 1982). A metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT, USA) collected and analyzed samples of expired air during the GXT. Using the data collected from the metabolic cart, VT1 was determined as the inflection point of VE and VO_2 (Caiozzo et al., 1982). VO_{2peak} was calculated by averaging VO_2 values during the last four 15-second intervals during that last minute of the GXT. The GXT was performed in three-minute stages with the first stage starting at a speed of 5.5 $km \cdot hr^{-1}$ with a 1% incline. During the second stage treadmill speed increased to 7.5 $km \cdot hr^{-1}$ and 3% grade. Each subsequent stage was completed at 7.5 $km \cdot hr^{-1}$ with the grade increasing by 2% per stage. At stage six, the speed increased to 9 $km \cdot hr^{-1}$ and 10% incline. Every subsequent stage increased the speed by 2 $km \cdot hr^{-1}$ with no further change in grade until volitional exhaustion.

3.3.6 Occupational Physical Ability Test

Participants completed a timed standardized simulated fireground test (SFGT) to assess occupational physical ability. The test-retest reliability of the SFGT was ICC = 0.79. The SFGT consisted of nine tasks frequently performed by structural firefighters at a fire emergency scene. The time required to complete these tasks was recorded along with heart rate (HR). Heart rate was measured with a heart rate monitor (Polar H10, Polar, Finland). Mean relative heart rate was calculated by dividing the mean SFGT heart rate by the participant's estimated heart rate maximum ($HR_{max} = 220 - age$) and multiplying by 100. In addition, air depletion from the SCBA was reported as the reduction in cylinder's pressure (PSI) from the beginning of the SFGT to completion of the SFGT. Pre- and post-SFGT PSI levels were recorded using the air cylinder's PSI gauge by research personnel. Relative cylinder depletion was then calculated by dividing the pre- versus post-SFGT cylinder pressure difference by the cylinder's pre-SFGT pressure ($4500\ lb \cdot in^{-2}$). Participants wore full personal protective equipment (PPE; i.e., coat, pants, boots, gloves, and face mask) and breathed through a SCBA with a 45 min cylinder (3M Scott Air-Pak Pro SCBA, 3M Scott Fire & Safety, USA). The combined mass of the PPE was 23.7 kg.

The tasks that comprised the SFGT were performed continuously and in sequential order. Upon an auditory signal, participants began the SFGT by advancing a 27.2 kg dry hose line (composed of (3) 9.07 kg segments) 42.7 m. Next, participants advanced a charged hose line 22.6 m. Then, participants crawled 6.4 meters through a confined space simulation. Next, participants performed a simulated roof walk.

Participants started by ascending a 3.1 m distance along a 4.3-meter roof ladder while carrying a 10.4 kg load simulating a chainsaw. Participants then descended the same distance down the same ladder to complete the task. The roof ladder simulated a slanted rooftop. Next, participants performed a simulated forcible entry task by striking a steel I-beam with a 4.54 kg sledgehammer moving the beam a distance of 1.52 m. Then, participants performed a ladder carry task by removing a 4.27 m roof ladder (17.23 kg) from mounted hooks and carried the ladder around a diamond shaped course for a total distance of 16.5 m before returning the ladder to the mounted hooks. Next, participants performed a stair climb task by ascending and descending one flight of stairs three times while carrying an 18.1 kg hose bundle. Participants then performed a ceiling breach task by performing ten full extension raises with a 20.4 kg barbell. Lastly, participants performed a victim rescue by dragging an 82 kg mannequin 7.9 m until the participant crossed a designated finish line. All tasks were organized so that the completion point of one task marked the starting point for the next task, eliminating the need to travel between tasks.

3.4 Statistical Analysis

Work economy was calculated as the inverse of the total time required to complete the SFGT (min) multiplied by the pre- and post-SFGT difference in cylinder air pressure, multiplied by 10,000. The inverse of these variables was taken so that greater work economy would reflect favorable occupational performance (i.e., shorter SFGT completion time and/or less air depletion).

Basic statistics (mean ± standard deviation) were used to describe the anthropometric, physical fitness, and SFGT outcome variables. Intraclass correlation coefficients (ICC) were utilized to assess the test-retest reliability of select outcome variables. Bivariate correlations (Pearson product moment correlation) were used to identify significant correlates of SFGT work economy. Furthermore, multiple linear regression analysis (Enter Method) was used to assess the percentage of variance accounted for in work economy by the predictor variables. Root mean square error was used as a measure of error associated with the multiple linear regression analysis. The level of significance was set at $p < .05$ for all analyses. All statistical analyses were conducted using the software SPSS (IBM Corp. Released 2019. IBM SPSS for Windows, Version 26.0. Armonk, NY).

CHAPTER IV. RESULTS

Table 4.1 describes the physical fitness outcomes in the study's sample. Among the 19 participants who completed the study, the following notable physical fitness outcomes were observed: vertical jump height (58.4 ± 11.5 cm), relative 1RM bench (1.2 ± 0.2 $\mathrm{kg \cdot kg\ BM^{-1}}$ (body mass)), relative 1RM squat (1.4 ± 0.4 $\mathrm{kg \cdot kg\ BM^{-1}}$), inverted row reps (25.4 ± 7.1), treadmill time to exhaustion (14.4 ± 3.5 min), mean heart rate reserve at 118.6 ± 12.0 $\mathrm{b \cdot min^{-1}}$, relative $\mathrm{VO_{2peak}}$ (44.8 ± 6.8 $\mathrm{ml \cdot kg^{-1} \cdot min^{-1}}$) and relative VT (2.5 ± 0.3 $\mathrm{L \cdot min^{-1}}$). Table 4.2 displays descriptive statistics of the results of the SFGT. The mean work economy value was 0.60 ± 0.14 $((\mathrm{lb \cdot in^{-2} \cdot min^{-1}})^{-1}) \times 10^4$. The mean SFGT completion time was 7.73 ± 1.4 min. Air cylinder pressure difference (after the SFGT) and relative cylinder depletion were 2279 ± 274 $\mathrm{lb \cdot in^{-2}}$ and 50.6 ± 6.1%, respectively. Mean absolute SFGT heart and mean relative heart rate were 169.9 ± 8.5 $\mathrm{b \cdot min^{-1}}$ and 91.9 ± 4.5%, respectively.

Table 4.1. Physical fitness outcomes in 19 male incumbent structural firefighters.

					95% CI	
	N	Mean	±	SD	Lower	Upper
Vertical jump (cm)	19	58.4	±	11.5	52.9	64.0
Jump power (J)	19	5474	±	669	5152	57978
1RM bench press (kg)	18	103	±	24.9	90.7	115.4
Relative 1RM Bench (kg·kg BM^{-1})	18	1.2	±	0.2	1.1	1.3
1RM Squat (kg)	19	122.8	±	39.2	103.9	141.8
Relative 1RM Squat (kg·kg BM^{-1})	19	1.4	±	0.4	1.2	1.6
Push-up reps	19	36.4	±	8.0	32.5	40.3
Inverted row reps	19	25.4	±	7.1	22.0	28.9
Resting heart rate (b·min^{-1})	18	66.8	±	7.8	63.0	70.7
Heart rate reserve (b·min^{-1})	18	118.6	±	12.0	112.6	124.5
Treadmill time to exhaustion (min)	19	14.4	±	3.5	12.9	16.2
Peak VO$_2$ (L·min^{-1})	19	3.9	±	0.4	3.6	4.1
Relative Peak VO$_2$ (ml·kg^{-1}·min^{-1})	19	44.8	±	6.8	41.5	48.1
Relative VT (ml·kg^{-1}·min^{-1})	19	29.3	±	4.9	26.9	31.7
VT (L·min^{-1})	19	2.5	±	0.3	2.4	2.7

BM: body mass; 1RM: 1 repetition maximum; VT: ventilatory threshold

Table 4.2. Work economy and simulated fireground test (SFGT) outcomes in 19 male incumbent structural firefighters.

	Mean ± SD	95% CI Lower	95% CI Upper	Minimum	Maximum
Work economy $((lb \cdot in^{-2} \cdot min^{-1})^{-1})$ x10^4	0.60 ± 0.14	0.53	0.66	0.33	0.82
SFGT completion time (min)	7.73 ± 1.4	7.1	8.4	6.0	10.7
Absolute cylinder pressure difference $(lb \cdot in^{-2})$	2279 ± 274	2146.9	2411	1900	2800
Relative cylinder depletion (%)	50.6 ± 6.1	47.7	53.6	42.2	62.2
Mean heart rate $(b \cdot min^{-1})$	169.9 ± 8.5	165.8	174	155	190
Mean relative heart rate (% HR_{max})	91.9 ± 4.5	89.7	94	83.6	100

SFGT: simulated fireground test; Cylinder pressure difference $(lb \cdot in^{-2})$ = $SFGT_{pre}$ cylinder pressure –$SFGT_{post}$ cylinder pressure; $\%HR_{max}$: Percent of age-predicted maximum heart rate.

Table 4.3 displays the correlation matrix between work economy and anthropometric outcomes. Work economy was significantly correlated with age (r = -0.67), years of firefighting experience (r = -0.64), relative body fat (r = -0.47) and fat mass (r = -0.51). Table 4.4 displays the correlation matrix between work economy and physical fitness outcomes. Work economy was significantly correlated with mean absolute heart rate during the SFGT (r = 0.49), vertical jump height (r = 0.73), heart rate reserve (r = 0.51), relative 1RM bench press (r = 0.54), relative 1RM squat (r = 0.63), inverted row repetitions (r = 0.60), time to exhaustion during a maximal treadmill GXT (r = 0.71), relative ventilatory threshold (r = 0.57) and relative VO_{2peak} (r = 0.55).

Table 4.3. Correlation matrix displaying the relationship between WE and anthropometric measurements in 19 male structural firefighters.

	Work economy $((\mathrm{lb}\cdot\mathrm{in}^{-2}\cdot\mathrm{min}^{-1})^{-1})$ x10^4	Height (cm)	Weight (kg)	Experience (yr)	Age (yr)	Body fat (%)	Fat free mass (kg)	Body mass index $(\mathrm{kg}\cdot\mathrm{m}^{-2})$	Fat mass (kg)
Work economy $((\mathrm{lb}\cdot\mathrm{in}^{-2}\cdot\mathrm{min}^{-1})^{-1})$ x10^4	1								
Height (cm)	-0.29	1							
Weight (kg)	-0.39	.62**	1						
Experience (yr)	-0.65**	0.15	0.28	1					
Age (yr)	-0.67**	0.38	.58**	.82**	1				
Body fat (%)	-.47*	0.33	.64**	.63**	.66**	1			
Fat free mass (kg)	-0.16	.60**	.84**	-0.09	0.27	0.13	1		
Body mass index $(\mathrm{kg}\cdot\mathrm{m}^{-2})$	-0.42	0.33	.91**	0.43	.62**	.82**	.60**	1	
Fat mass (kg)	-.51*	0.43	.83**	.57*	.70**	.95**	0.40	.93**	1

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

Table 4.4. Correlation matrix displaying the relationship between work economy and physical fitness outcomes in 19 male incumbent structural firefighters.

	Work economy $((\mathrm{lb}\cdot\mathrm{in}^{-2}\cdot\mathrm{min}^{-1})^{-1})$ x10^4	Mean HR ($\mathrm{b}\cdot\mathrm{min}^{-1}$)	Heart rate reserve ($\mathrm{b}\cdot\mathrm{min}^{-1}$)	Vertical jump (cm)	1RM Bench ($\mathrm{kg}\cdot\mathrm{kg}$ BM^{-1})	1RM Squat ($\mathrm{kg}\cdot\mathrm{kg}$ BM^{-1})	Inverted Rows Reps	Treadmill Time to Exhaustion (min)	Relative Peak VO_2 ($\mathrm{ml}\cdot\mathrm{kg}^{-1}\cdot\mathrm{min}^{-1}$)	Relative VT ($\mathrm{ml}\cdot\mathrm{kg}^{-1}\cdot\mathrm{min}^{-1}$)
Work economy $((\mathrm{lb}\cdot\mathrm{in}^{-2}\cdot\mathrm{min}^{-1})^{-1})$ x10^4	1.00									
Mean heart rate ($\mathrm{b}\cdot\mathrm{min}^{-1}$)	0.49*	1.00								
Heart rate reserve ($\mathrm{b}\cdot\mathrm{min}^{-1}$)	0.51*	0.37	1.00							
Vertical jump (cm)	0.73**	0.42	.50*	1.00						
Relative 1RM Bench ($\mathrm{kg}\cdot\mathrm{kg}$ BM^{-1})	0.54*	0.05	.60*	0.50*	1.00					
Relative 1RM Squat ($\mathrm{kg}\cdot\mathrm{kg}$ BM^{-1})	0.63**	0.26	.71**	0.57*	0.82**	1.00				
Inverted Rows Reps	0.60**	0.30	.75**	0.66**	0.60**	0.60**	1.00			
Treadmill Time to Exhaustion (min)	0.71**	0.39	0.47	0.58**	0.11	0.19	0.49*	1.00		
Relative Peak VO_2 ($\mathrm{ml}\cdot\mathrm{kg}^{-1}\cdot\mathrm{min}^{-1}$)	0.55*	0.34	0.46	0.46*	0.09	0.13	0.44	0.93**	1.00	
Relative VT ($\mathrm{ml}\cdot\mathrm{kg}^{-1}\cdot\mathrm{min}^{-1}$)	0.57*	0.35	0.44	0.52*	0.24	0.17	0.38	0.88**	0.93**	1.00

* Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

BM: body mass; 1RM: 1 repetition maximum; VT: ventilatory threshold.

Note: All additional, non-significant correlation coefficients can be found in appendix 4.

Treadmill time to exhaustion and relative lower body strength (squat 1RM relative to body mass) were deemed the most ideal variables to create a regression equation that predicts work economy (adjusted R^2=0.72; RMSE=0.07). The resulting regression equation is as follows:

$$\text{Work economy} = -0.026 + 0.025\ (\text{GXT time to exhaustion (min)}) + 0.185\ (\text{relative 1RM squat (kg)})$$

This regression model accounted for the most variance among work economy and had the lowest levels of multicollinearity among the variables that comprised the regression model. Figure 4.1 exhibits a linear relationship between work economy and relative lower body strength. Figure 4.2 exhibits a linear relationship between work economy and treadmill time to exhaustion. Figures 4.1 and 4.2 support the findings of the multiple linear regression analysis.

Table 4.5. Multiple linear regression model predicting work economy with physical fitness, anthropometric and demographic outcomes in 19 male, incumbent structural firefighters.

Constant	-0.026
Time to Exhaustion	0.025*
Relative 1RM Squat	0.185*
R-squared	0.75
Adjusted R-squared	0.72
Root Mean Square Error	0.074

*p < 0.001; significance of model coefficients. Variable inflation factor (VIF) was 1.03 for both terms.

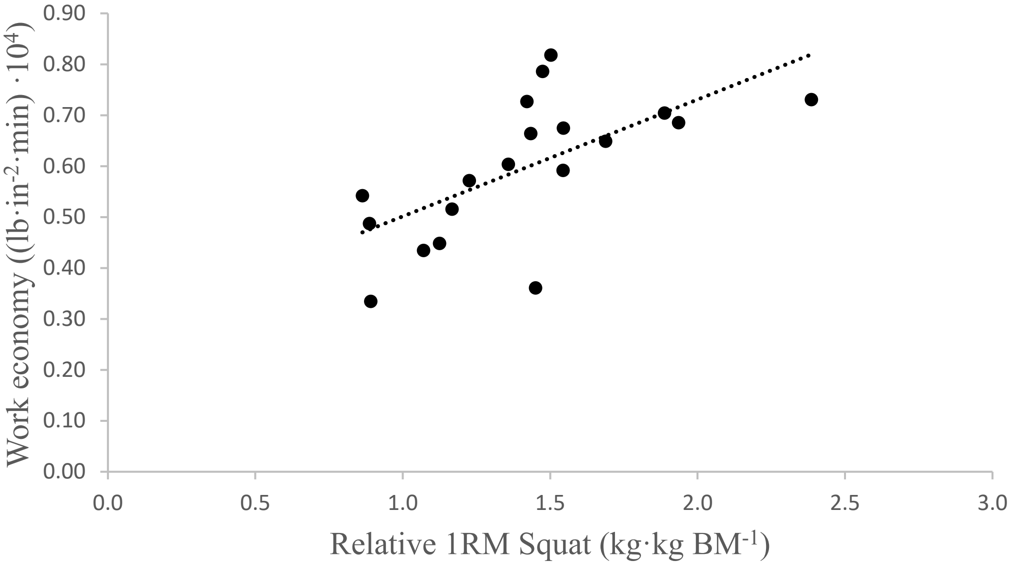

Figure 4.1. Relationship between work economy and relative lower body strength in 19 male incumbent structural firefighters.

1RM: 1 repetition maximum; BM: body mass.

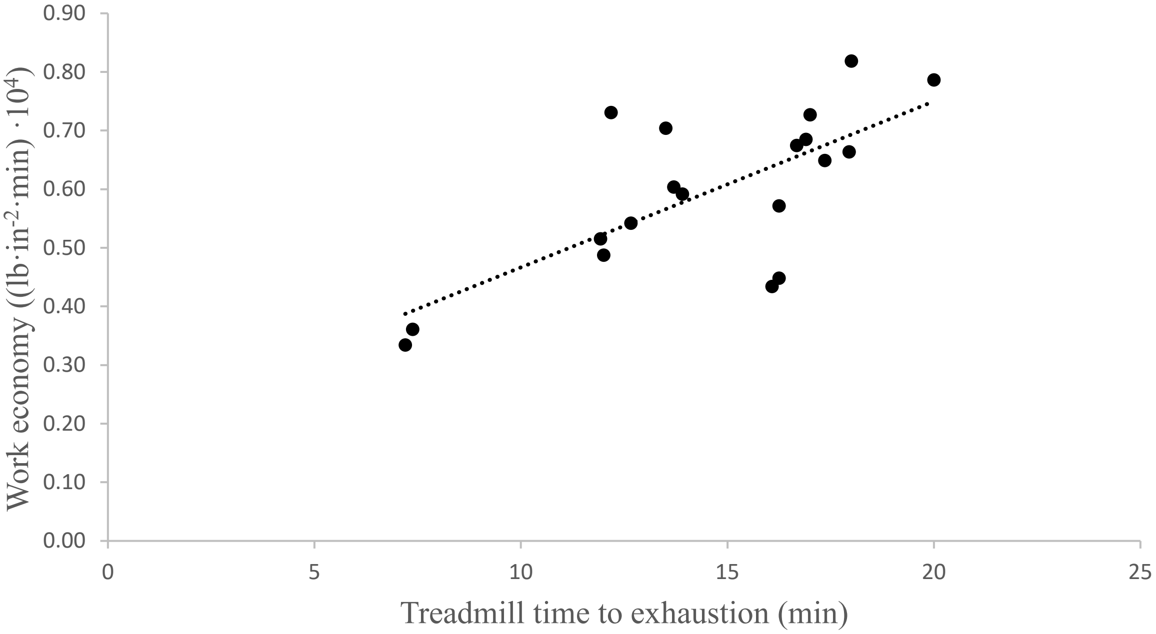

Figure 4.2. Relationship between work economy and treadmill time to exhaustion in 19 male incumbent structural firefighters.

CHAPTER V. DISCUSSION

The purpose of this study was to identify a work economy metric to quantify firefighter physical ability, as well as identify physical fitness, anthropometric, and demographic correlates of firefighter work economy. The primary findings of the present study indicated that relative lower body strength and treadmill time to exhaustion were the strongest predictors of firefighter work economy, accounting for 71.7% of the variance in work economy, as indicated by the multiple linear regression analysis. In addition, age, body composition, and a variety of body mass dependent physical fitness variables were also associated with work economy. Previous literature has examined this topic from various perspectives. For instance, Windisch and colleagues (2017) conducted a similar study among 41 airport firefighters, but quantified firefighter performance based on the standardized aggregate score of SFGT completion time, mean SFGT heart rate, and SFGT air depletion from the SCBA (i.e., time, strain, air: TSA); thus accounting for work rate and physiological strain. Given this variation of an occupational outcome variable, Windisch and coworkers (2017) found that VO_{2peak}, breathing frequency and time spent below individual ventilatory thresholds during the SFGT accounted for 70.1% of the variance in the TSA metric. Thus, both studies found that aerobic fitness outcomes were related to metrics of work rate relative to physiological demand. Windisch et al.'s (2017) identification of breathing frequency and time spent below ventilatory thresholds further indicates that aerobic metabolism was related to completing the occupational tasks in an economical manner. Finally, it should be noted that the SFGT tasks and procedures utilized by Windisch et al. (2017) and the present study were fairly different. Specifically, despite similar volumes of air depletion (Windisch et al.: 54.1 ± 9.9% vs. present study: 50.6 ± 6.1%), the Windisch et al. (2017) SFGT took longer to complete (13.4 ± 2.2 min vs. 7.7 ± 1.4 min) and elicited a lower mean relative heart rate (79.2 ± 6.6% vs. 91.9 ± 4.5% HR_{max}). The firefighters in Windisch et al. (2017) were instructed to complete the tasks as fast as possible, but at a pace similar to an emergency scene, whereas the firefighters in the present study were instructed to complete the tasks as quickly as possible. In addition, while the SFGTs in both studies used similar tasks, the SFGT in the present study consisted of more tasks than the SFGT in the Windisch et al. study. Thus, it is likely that the SFGT used in the present study required greater physical demands as it represented tasks involved in structural firefighting versus airport firefighting operations and the tasks were completed as fast as possible in the present study. Despite these methodological differences, aerobic fitness appears to be a critical element of work economy.

Other investigations have identified correlates of firefighter physical ability based solely on the time to complete a SFGT (i.e., work capacity assessment). For instance, regarding demographics, similar to the present study, Davis et al. (1982) and Williford et al. (1999) reported age as a correlate of timed SFGT performance. Similarly, Michaelides et al. (2011) reported that age was a correlate of poor SFGT performance. Age is inherently related to decreased physical capabilities and physical fitness outcomes (e.g., muscular strength, muscular endurance, cardiovascular endurance, etc.) as a result of deteriorating skeletal muscle and cardiorespiratory system function (Frontera et al., 2000; Miljkovic et al., 2015; Sharma et al., 2006). For instance, a cross-sectional firefighter research study by Baur et al. (2012) indicated that aerobic capacity decreases .21 $ml \cdot kg^{-1} \cdot min^{-1}$ (0.06 METs) per year. Similarly. Fleg et al. (2005) reported a similar decline in aerobic capacity (.29 $ml \cdot kg^{-1} \cdot min^{-1}$ per year) with age in a civilian population. Similarly, in the present study, years of occupational experience was inversely associated with work economy. This relationship may simply reflect the fact that experience was also positively correlated with age ($r = .82$, $p < .01$), or it may potentially reflect firefighters' true training experience and use of breathing techniques in attempt to decrease sympathetic modulation and potentially decrease compressed air consumption. Unfortunately, there was no way of knowing whether firefighters utilized such techniques in the present study. Future research should assess the effect of occupational breathing techniques on work economy.

Regarding anthropometrics, absolute and relative fat mass were significantly correlated to work economy (Table 4.3). Several studies have also identified anthropometric correlates, but with timed SFGT performance. For instance, Davis et al. (1982) identified two factors that dictated SFGT task completion time and mean heart rate during the SFGT: physical work capacity and resistance to fatigue. Using multiple linear regression analysis, Davis et al. (1982) identified body fat percent and fat-free mass among the predictors of the resistance to fatigue factor. Relative body fat was also reported as a predictor of physical work capacity, although it was not reported in the multiple linear regression analysis. Michaelides et al. (2011) reported BMI, body fat percent and waist circumference as significant correlates of physical ability test completion time. In addition, relative body fat was significantly correlated with the completion time of all tasks in the ability test. The ability test and SFGT used in the present study are similar. However, unlike a traditional SFGT, participants in the ability test wore a weighted vest to simulate the external load carriage of the SCBA and personal protective equipment. Williford et al. (1999) reported that relative body fat and/or fat mass were correlated to SFGT performance. These findings were supported in the present study. It seems intuitive that greater relative and/or absolute amounts of fat mass would deleteriously impact work economy, as body fat increases the internal load carriage demand. Interestingly, Davis et al. (1982) and Williford et al. (1999) reported fat-free mass and relative body fat as significant correlates of SFGT completion time. Moreover, fat-free mass was part of the multiple linear regression models that accounted for the most variance in SFGT performance in the studies by Davis et al. (1982) and Williford et al. (1999). Furthermore, Kleinberg and coworkers (2016) demonstrated that quadriceps muscle size (relative to body mass) and quality was significantly related to stair climbing performance in firefighters. Although the present study did not confirm the relationship between body composition outcomes with the novel work economy outcome, the relationship seems logical as greater absolute fat-free mass would decrease the relative external load carriage demand (assuming the fat-free mass exhibits oxidative metabolism efficiency) and thus enhance work economy. Future research is warranted to study this topic utilizing a larger sample size and criterion measures of body composition assessment.

Numerous studies have identified physical fitness correlates of timed SFGT performance. For instance, several studies have noted that absolute (Sheaff et al., 2010; Williams-Bell et al., 2009) and relative aerobic capacity (Williams-Bell et al., 2009) were correlated to the completion time from the candidate physical ability test (CPAT). These findings partially support the present study in that relative, but not absolute VO_{2peak} was correlated to SFGT performance. These findings are intriguing as it may speak to the difference in work capacity versus work economy. That is, work capacity (i.e., timed SFGT performance) was assessed by Williams-Bell et al. (2009) where absolute aerobic capacity was related to work rate, however, when air utilization (i.e., work economy) was factored into occupational performance in the present study only relative aerobic capacity was found to be correlated to occupational performance. Thus, aerobic capacity relative to body mass may be a more important predictor of work economy and efficiency of air utilization.

The present study identified a significant correlation between relative ventilatory threshold and work economy (Table 4.4). This finding supports the contribution of anaerobic metabolism to economical occupational performance. Intuitively, possessing a higher anaerobic threshold allows for a greater reliance on aerobic metabolism and thus increased economy due to reduced ventilation rates (Brooks et al., 1985; Davis et al., 1979; Ghosh et al., 2004). Several investigations have found various anaerobic outcomes to be associated with timed SFGT performance. For instance, Sheaff et al. (2010) reported that mean power and fatigue index during a Wingate Anaerobic Test were correlated to CPAT completion time. Furthermore, 400 m run time (Rhea et al., 2004) and 60 s step test (Michaelides et al., 2011) performance have been correlated with SFGT performance.

The present study included several occupational tasks that required muscular power (e.g., hose line advance, forcible entry & victim rescue). Interestingly, we found that relative lower body power (i.e., vertical jump height) was positively correlated with work economy, whereas absolute lower body power was not correlated to work economy (Table 2.6). Davis et al. (1982) also reported that vertical jump height was a correlate of timed SFGT performance. These findings suggest that power output, relative to body mass is related to economical work rate, whereas absolute power is not. Sheaf et al. (2010) also reported mean power and relative mean power (measurements from Wingate testing) were among the significant correlates of SFGT completion time. Although not assessed in the present study, one might expect absolute lower body power to be related to absolute work rate as has been demonstrated by Michaelides et al. (2011), however, when work rate is expressed relative to air consumption, relative lower body power appears to be a more appropriate expression of power output.

Regarding muscular strength, the present study found that relative, but not absolute bench press and squat strength was positively correlated with work economy (Table 4.4). Similar to the findings of relative power output, the present study indicated that economical work rate is associated with upper and lower body strength relative to body mass. Interestingly, the literature has indicated that 1RM bench press (Michaelides et al., 2011; Rhea et al., 2004) and grip strength (Davis et al., 1982; Rhea et al., 2004; Williams-Bell et al., 2009) are correlated to timed SFGT performance. Although there are likely requisite amounts of absolute strength required to perform absolute occupational demands, economical occupational performance tended to be superior in those po ssessing greater strength-to-body mass ratios. Again, this result may be different if focusing simply on occupational work rate, however, when factoring in economy, relative strength appears to be a more appropriate expression of strength. Unfortunately, we are not aware of any existing literature that has investigated the relationship between relative strength and SFGT performance.

The present study noted a significant correlation between the muscular endurance assessment of inverted row repetitions and work economy (Table 4.4). This finding seems intuitive given that several of the occupational tasks require some degree of upper back muscular endurance completed with isometric and/or dynamic muscular contractions (e.g., forcible entry, equipment carry, ladder climb, victim rescue). In addition, muscular endurance is associated with oxidative metabolism within the working muscles (Ventura-Clapier et al., 2007; Befroy et al., 2008) which parlays this assessment with work economy. Similarly, muscular endurance has been found to be correlated to SFGT performance and firefighter physical ability (Michaelides et al. (2011): push-ups, sit-ups; Rhea et al., 2004: row, bench press, shoulder press, bicep curl, squat; Williford et al., 1999: pull-ups, push-ups, sit-ups). In addition, despite a nonsignificant trend of moderate magnitude (r = .37), push-up repetitions were not significantly correlated to work economy. Although this may be simply a factor of being under-powered it is possible that the SFGT tasks did not require a substantial contribution of muscle endurance for upper body horizontal pressing movements.

The present study noted that mean absolute heart rate was positively correlated with work economy. Although this may seem counterintuitive, it is important to consider that the SFGT was performed at a maximal absolute intensity, thus eliciting high heart rate values regardless of fitness level. Furthermore, mean absolute SFGT heart rate was trending towards a significant, inverse correlation with age ($r = -.418$, $p = .075$) in the present study. Thus, the relationship between SFGT heart rate and work economy was likely driven by age, as younger firefighters tended to have a higher work economy and mean heart rate.

5.1. Limitations

There are several limitations to the present study. First, a relatively small sample size was utilized, which may have limited the statistical power to identify additional variables that may explain a greater variance in firefighter work economy. Second, air depletion per se, was not directly measured. Instead, the concept of air depletion was represented using the change in cylinder pressure as indicated on the firefighters' SCBA. Despite this limitation, the use of pressure as a primary outcome is applicable as firefighters monitor air usage based on cylinder pressure levels and thus this assessment applies to air utilization. Third, firefighters completed the SFGT at a maximal level of exertion. Typically, on the fireground, firefighters will operate at a submaximal intensity that will allow for the safe and effective completion of occupational tasks. Thus, the SFGT intensity utilized by firefighters in this study may or may not reflect each firefighter's optimal work economy. Literature on running economy indicates that there is an inverted "U" function reflecting the relationship between runners' economy versus work rate (Barners et al., 2015; Losnegard et al., 2014). Thus, it is possible that optimal work economy is elicited at a lower, submaximal work rate. Finally, work rate was quantified as the timed completion of SFGT tasks. Although it would be more accurate, it would be extremely challenging to accurately quantify the aggregate amount of work (i.e., force x displacement) completed through various simulated occupational tasks due to the variability in dynamics and frictional resistance associated with each task. Additional biomechanical research is warranted to quantify resultant workloads from each occupational task.

5.2. Conclusion

In conclusion, a novel work economy metric was utilized in this study to quantify firefighter occupational physical ability. Firefighters' aerobic fitness and relative lower body strength were among the strongest predictors of work economy. These findings are logical from a physiological perspective and supported by research in other athletic populations. Based on these findings work economy appears to be a viable measure of firefighter occupational physical ability. However, further research is necessary to assess the validity and reliability of this novel metric.

5.3. Practical Applications

There are numerous practical applications associated with the concept of firefighter work economy. First, the development of this metric provides a more accurate assessment of occupational physical ability of firefighter recruits and incumbents. Unlike performing a SFGT at a maximal pace, which reflects maximal work capacity, this metric assesses the efficiency of work performed per physiological cost. In a profession where work time and volume are limited based on the efficient utilization of compressed air, it seems logical to account for air utilization in this model. Although this metric shows promise for use in the fire service it important to note that there are no existing federal and national association standards for work economy. Additional research on this topic is necessary for its prospective use to guide hiring practices and consideration to establish municipality-specific work economy or associated fitness standards for firefighter recruits and incumbents. In addition, treadmill time to exhaustion and relative lower body strength were the strongest predictors of firefighter work economy. This information is helpful for fire department administrators, firefighters, training officers, and tactical strength and conditioning practitioners to target the modifiable fitness attributes through appropriate exercise prescription to enhance work economy. The following example demonstrates the utility of this metric. Applying the multiple linear regression equation and assuming an equivalent work rate, it can be estimated that a 10% improvement in relative lower body squat strength and 10% improvement in treadmill time to exhaustion will reduce air depletion (i.e. pressure change) by 14.1% (635 $\mathrm{lb \cdot in^2}$) during the SFGT. Thus, achievable improvements in physical fitness can enhance firefighters' safety and allow for greater work volume per cylinder.

APPENDICIES

APPENIDIX 1. DEMOGRAPHIC TABLE

Participant #	Age (yr)	Height (cm)	Weight (kg)	Body fat (%)	Fat mass (kg)	Fat free Mass (kg)	Body mass index ($kg \cdot m^{-2}$)	Resting heart rate ($b \cdot min^{-1}$)	Experience (yr)
2	42	185	100.9	19.3	19.47	81.43	28.3	78	18
3	37	178.5	77	16.3	12.55	64.45	23.8	75	18
4	41	176	64.09	21.4	13.72	50.37	24	64	22
5	43	181.5	95.18	24.3	23.13	72.05	29.2	66	13
6	41	182.7	107	25.2	26.96	80.04	31.9	N/A	8
7	29	181.5	95.72	21.3	20.39	75.33	29.3	66	5
8	31	175	81.9	20	16.38	65.52	26.6	65	10
9	33	185.5	90.81	13.4	12.17	78.64	25.6	77	2
10	25	175	75.27	22.2	16.71	58.56	24.4	61	7
11	41	184	109.4	24.5	26.80	82.60	32.2	77	19
12	47	177	101.3	32.2	32.62	68.68	32	59	23
13	39	188	100.8	23.2	23.39	77.41	27.7	79	11
16	33	181.5	82.18	13.9	11.42	70.76	24.9	60	7
17	24	176.4	78.81	11.5	9.06	69.75	24.9	66	3
18	25	173	76.63	14.1	10.80	65.83	25.6	58	5
19	43	180.5	95.63	24.3	23.24	72.39	29.4	65	23
20	28	179.5	84	16.9	14.20	69.80	25.7	73	1.16
21	31	183.5	73.63	7.6	5.60	68.03	21.4	60	6.41
22	31	164	72.54	5.6	4.06	68.48	23.2	54	4

APPENDIX 2. FITENESS OUTCOME TABLE

Participant #	Vertical jump (cm)	Jump power (J)	Relative 1RM bench (kg·kg BM^{-1})	1RM bench press (kg)	Relative 1RM squat (kg·kg BM^{-1})	1RM squat (kg)	Push-up reps	Inverted row reps
2	60.96	6216.04	0.8	83.9	0.9	87.1	30	17
3	62.23	5210.46	1.1	87.1	1.5	115.6	34	27
4	46.99	4153.57	1.0	64.9	1.1	72.1	27	26
5	49.53	5172.53	1.1	104.3	1.2	111.1	30	23
6	62.23	6569.46	1.7	177.3	2.4	255.3	30	30
7	60.96	5981.39	1.1	100.7	1.4	136.1	32	27
8	53.34	4892.81	1.2	94.3	1.5	126.5	40	24
9	76.20	6684.03	1.3	122.4	1.5	140.1	40	29
10	59.69	4977.91	1.0	74.4	1.4	107.9	32	25
11	36.83	5136.40	N/A	N/A	0.9	97.5	18	15
12	41.91	5077.83	1.1	111.6	1.5	146.9	34	18
13	48.26	5440.62	0.9	88.9	1.1	107.9	35	14
16	52.07	4828.40	1.4	112.0	1.4	111.6	43	35
17	66.04	5523.72	1.4	112.0	1.9	148.8	37	25
18	81.28	6350.04	1.3	97.5	1.9	148.3	45	40
19	52.07	5437.69	1.0	94.3	0.9	84.8	43	16
20	68.58	5913.02	1.5	126.1	1.5	123.8	44	27
21	58.42	4826.53	1.1	84.4	1.2	90.2	52	34
22	72.39	5621.06	1.6	118.4	1.6	122.4	45	31

BM: body mass; 1RM: 1 repetition maximum.

APPENDIX 2.1. FITNESS OUTCOME TABLE (CONTINUED)

Participant #	Relative peak VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	VO_{2peak} ($L \cdot min^{-1}$)	Treadmill time to exhaustion (min)	Relative VT ($ml \cdot kg^{-1} \cdot min^{-1}$)	VT ($L \cdot min^{-1}$)
2	41.91	4.23	12.66	26.76	2.7
3	47.44	3.65	18	30.78	2.37
4	55.44	3.55	16.25	33.08	2.12
5	39.47	3.76	11.93	27.21	2.59
6	39.98	4.28	12.18	25.23	2.7
7	49.17	4.71	17	29.15	2.79
8	47.00	3.85	16.68	30.40	2.49
9	41.48	3.77	13.91	27.75	2.52
10	51.43	3.87	17.95	33.21	2.5
11	34.05	3.72	7.2	22.85	2.5
12	31.43	3.18	7.38	20.34	2.06
13	46.15	4.65	16.08	29.76	3
16	40.86	3.36	13.7	25.19	2.07
17	44.40	3.50	13.51	30.96	2.44
18	47.79	3.66	16.9	30.80	2.36
19	36.62	3.50	12	24.05	2.3
20	55.93	4.70	20	41.67	3.5
21	49.19	3.6	16.25	32.05	2.36
22	51.72	3.75	17.36	35.84	2.6

VT: ventilatory threshold: VO_{2peak}: peak oxygen consumption.

APPENDIX 3. SFGT OUTCOME TABLE

Participant	Work economy ((lb·in^{-2}·min^{-1})$^{-1}$) x10^{4}	Absolute Cylinder pressure difference (lb·in^{-2})	Relative cylinder depletion (%)	SFGT trial completion time (min)	SFGT trial completion time (min)	Mean heart rate (b·min^{-1})	Relative Mean Heart Rate (%)
2	0.54	2500	55.6	8.66	7.38	170	95.5
3	0.82	2000	44.4	7.05	6.11	181	98.9
4	0.45	2300	51.1	14.25	9.7	171	95.5
5	0.52	2500	55.6	8.06	7.76	177	100.0
6	0.73	2300	51.1	7.01	5.95	163	91.1
7	0.73	2000	44.4	6.95	6.88	166	86.9
8	0.67	2000	44.4	6.93	7.41	174	92.1
9	0.59	2500	55.6	7.13	6.76	175	93.6
10	0.66	1900	42.2	13.58	7.93	190	97.4
11	0.33	2800	62.2	10.46	10.68	159	88.8
12	0.36	2600	57.8	12.66	10.65	166	96.0
13	0.43	2700	60.0	N/A	8.53	155	85.6
16	0.60	2200	48.9	8.38	7.53	168	89.8
17	0.70	2000	44.4	7.58	7.1	174	88.8
18	0.69	2100	46.7	7.98	6.95	175	89.7
19	0.49	2500	55.6	8.46	8.21	162	91.5
20	0.79	2000	44.4	7.28	6.36	170	88.5
21	0.57	2100	46.7	8.55	8.33	158	83.6
22	0.65	2300	51.1	9.15	6.7	174	

SFGT: simulated fireground test.

APPENDIX 4. CORRELATION MATRIX OF WORK ECONOMY AND FITNESS OUTCOMES

	Work economy ((lb·in^{-2}·min^{-1})$^{-1}$) x10^{4}	Mean HR (b·min^{-1})	Mean relative heart rate (% HR$_{max}$)	Resting HR (b·min^{-1})	Heart rate reserve (b·min^{-1})	Vertical jump (cm)	Jump Power (J)	1RM Bench Press (kg)	1RM Bench (kg·kg BM^{-1})	1RM Squat (kg)	1RM Squat (kg·kg BM^{-1})	Push-Ups Reps	Inverted Rows Reps	Treadmill Time to Exhaustion (min)	Peak VO$_2$ (L·min^{-1})	Relative Peak VO$_2$ (ml·kg^{-1}·min^{-1})	VT (L·min^{-1})	Relative VT (ml·kg^{-1}·min^{-1})
Work economy ((lb·in^{-2}·min^{-1})$^{-1}$) x10^{4}	1.00																	
Mean heart rate (b·min^{-1})	0.49*	1.00																
Mean relative heart rate (% HR$_{max}$)	-0.02	0.69**	1.00															
Resting heart rate (b·min^{-1})	-0.10	-0.21	0.00	1.00														
Heart rate reserve (b·min^{-1})	0.51*	0.37	-0.23	-.82**	1.00													
Vertical jump (cm)	0.73**	0.42	-0.09	-0.13	.501*	1.00												
Jump power (J)	0.37	-0.02	-0.14	0.32	-0.05	.67**	1.00											
1RM bench press (kg)	0.32	-0.20	-0.16	-0.03	0.14	0.30	0.60**	1.00										
Relative 1RM Bench (kg·kg BM^{-1})	0.54*	0.05	-0.23	-0.39	.60*	.50*	0.36	0.82**	1.00									
1RM Squat (kg)	0.42	-0.01	-0.79	-0.18	0.39	0.34	0.59**	0.87**	0.69**	1.00								
Relative 1RM Squat (kg·kg BM^{-1})	0.63**	0.26	-0.06	-0.45	.71**	.57*	0.45	0.74**	0.82**	0.89**	1.00							
Push-Ups Reps	0.37	-0.01	-0.39	-0.45	.57*	.54*	0.11	0.06	0.33	-0.02	0.22	1.00						
Inverted Rows Reps	0.60**	0.30	-0.16	-0.55*	.75**	.66**	0.17	0.24	0.60**	0.31	0.60**	0.56*	1.00					
Treadmill Time to Exhaustion (min)	0.71**	0.39	-0.13	-0.11	0.47	.58**	0.02	-0.27	0.11	-0.11	0.19	0.48*	0.49*	1.00				
Peak VO$_2$ (L·min^{-1})	0.32	-0.20	-0.34	0.50*	-0.19	0.19	0.46*	0.19	0.00	0.19	0.02	-0.12	-0.15	0.42	1.00			
Relative Peak VO$_2$ (ml·kg^{-1}·min^{-1})	0.55*	0.34	-0.14	-0.15	0.46	.46*	-0.12	-0.32	0.09	-0.19	0.13	0.31	0.44	0.93**	0.39	1.00		
VT (L·min^{-1})	0.35	-0.11	-0.30	0.49*	-0.16	0.28	0.47*	0.29	0.17	0.16	0.06	0.02	-0.15	0.41	0.89**	0.37	1.00	
Relative VT (ml·kg^{-1}·min^{-1})	0.57*	0.35	-0.15	-0.09	0.44	.52*	-0.02	-0.15	0.24	-0.15	0.17	0.40	0.38	0.88**	0.39	0.93**	0.54*	1.00

* Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

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