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Original Research

The relationship between firefighters' physical performance characteristics and simulated firefighting demands

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Abstract. Prior research indicates firefighting to be a demanding and hazardous profession that places tremendous amounts of stress on the body, both physically and mentally. Likewise, degraded fitness levels can affect the firefighter's (FF) ability to execute rescue tasks efficiently and places the imperiled and FF at risk for injury or death. The current study examined the relationship between physical fitness tests (PFT) and Simulated Fire Ground Test (SFGT) performance among active FF. Twenty (n=20) male career FF (age 37.8±8.4 years, height 182.1±7.0 cm, body mass 95.6±8.9 kg) were assessed for PFT and the SFGT. The PFT assessments included: maximum grip strength (GS), 3-minute step test, vertical jump (VJ), 1-RM back squat (BS), and 1-RM bench press (BP). The SFGT was composed of: stair climb with hose bundle (SC), 30m charged hose advance (CHA), and 30m dummy drag (DD). The SFGT demands were completed in full PPE (personal protective equipment) gear and pack. SFGT scores were then compared to the PFT scores with Pearson correlation coefficients (r). Grip strength demonstrated a negative moderate ($r=-0.49$: $p<0.05$) relationship with the time to complete the CHA, a high negative relationship with the SC times ($r=-0.61$: $p<0.05$), a high negative relationship with the DD times ($r=-0.70$: $p<0.05$), and a high negative relationship the total time to complete all tasks ($r=-0.64$: $p<0.05$). Heart rate response, measured as $\%HR_{max}$ following the step test demonstrated a positive moderate relationship with the time to complete the SC ($r=0.51$: $p<0.05$), CHA ($r=0.52$: $p<0.05$), and the total time to complete all tasks ($r=0.50$: $p<0.05$); and a positive low ($r=0.38$: $p<0.05$) relationship with the time to complete the DD. The BP 1-RM demonstrated a negative high relationship with the time to complete the SC ($r=-0.79$: $p<0.05$) and CHA ($r=-0.79$: $p<0.05$); and a negative very high relationship with the time to complete the DD ($r=-0.80$: $p<0.05$) and the total time to complete all tasks ($r=-0.82$: $p<0.05$). The SQ 1-RM demonstrated a negative moderate ($r=-0.52$: $p<0.05$) relationship with the time to complete the CHA; and a negative high relationship with the time to complete the SC ($r=-0.70$: $p<0.05$), DD ($r=-0.68$: $p<0.05$), and the total time to complete all tasks ($r=-0.70$: $p<0.05$) ($p<0.05$). The VJ scores demonstrated a negative moderate ($r=-0.49$: $p<0.05$) relationship with the time to complete the CHA; and a negative high relationship with the time to complete the SC ($r=-0.67$: $p<0.05$), DD ($r=-0.60$: $p<0.05$), and the total time to complete all tasks ($r=-0.66$: $p<0.05$). Peak power relative to body mass demonstrated a negative moderate relationship with the time to complete the SC ($r=-0.55$: $p<0.05$), DD ($r=-0.42$: $p<0.05$), and the total time to complete all tasks ($r=-0.52$: $p<0.05$); and a negative low non-significant relationship with the time to complete the CHA ($r=-0.30$: $p>0.05$). Age did not demonstrate a significant relationship with performance on any of the SGFT assessments ($p>0.05$). Within the parameters of this study, FF's exhibited a moderate to very high relationship between PFT and the execution of simulated firefighting demands.

Keywords. Firefighter, firefighting demands, physical fitness.

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Introduction

Firefighting is a demanding and hazardous profession that places tremendous amounts of stress on the body, both physically and mentally (Pawlak et al., 2015). Being a firefighter (FF) requires high levels of physical fitness in order to meet the demands of the job (Pawlak et al., 2015). The lack of a physical training program for FFs is linked to higher rates of job-related injuries (Sheaff et al., 2010). Therefore, training programs that are appropriately designed to meet the demands of the tactical environment play a vital role in the survival and success of career FFs.

Even though research shows high levels of physical fitness is required to meet the demands of firefighting, many FFs neglect to maintain the required levels of fitness (Poston et al., 2011). Degraded fitness levels can affect their ability to execute rescue tasks efficiently and put not only the victim at risk but also themselves at risk for injury or death (Kales et al., 1999). While there may be long periods of sedentary activity at times, FFs are required to be ready to respond instantly to a call that can lead to hostile and dangerous environments that require maximal physical effort.

Maintaining high fitness levels are imperative for FFs and the safety of the public, therefore, regular physical fitness should be emphasized in fire departments across the nation. The National Fire Protection Association (NFP) recognizes the importance of FF health and physical exercise training and how it is necessary for the job. The NFP suggests that fire departments, nationwide, should participate in exercise programs while on-shift to increase the probability of FFs participating in fitness training programs on a regular basis (NFPA, 2007). Programs designed for tactical athletes should include exercises to reduce the risk for injury, enhance strength, endurance, and functional agility that transfers to job specific demands such as lifting, carrying, dragging, hauling heavy equipment, pulling fire hose, performing forcible entries, victim rescues, and search and rescue maneuvers (Kendrickson et al., 2010; Poston et al., 2011).

Firefighting includes a variety of tasks that place high demands on the body by significantly activating the cardiovascular, metabolic, and hormonal systems (Rhea et al., 2004). Physical fitness plays a key role in improving FF performance by increasing efficiency and safety in overall task performance (Durand et al., 2011). The ability of a FF to generate high explosive power, strength, endurance, and high-quality aerobic fitness is an important factor in FF performance (Rhea et al., 2004). Injuries and mistakes occur when FFs become fatigued both mentally and physically. Therefore, FFs should follow a well-designed and organized physical fitness training program on a regular basis (Barr et al., 2010).

The National Fire Protection Association states that the leading cause of injury to FFs is physical strain and overexertion. Even the fittest FFs experience dangerous physical strain while on the fireground. Cardiorespiratory fitness is a critical factor that enables FFs to carry out on-duty tasks more efficiently and contributes to enhanced performance (Perroni et al., 2013). Research shows firefighting tasks to cause significant physiological stress that can produce heart rates that exceed 95% age-predicted maximum heart rate (Von Heimburg et al., 2006). Fire ground tasks place high demands on the aerobic and anaerobic energy systems and requires an aerobic capacity of at least 39.9 to 45 ml/kg-1/min-1 or approximately 12 METs (Glenhill & Jamnik, 1992; Lusa et al, 1993). Research shows this as the minimum requirement for the safety of the FFs to perform their duty in protecting and serving the citizens. Improving cardiovascular capacity through physical exercise can train the body to work harder at lower heart rates and be able to recover faster during fire-ground tasks (El-Kader & Mahoun, 2010; Hendrickson et al., 2010).

Physical activity that requires larger muscles require more oxygen therefore the oxygen needs increase during those activities. Most, if not all, of fire specific tasks require full body movement which includes large muscle groups. Myers and colleagues state that "Exercise capacity is a more powerful predictor of mortality rates among men than any other established risk factor for cardiovascular disease" (Myers et al., 2002). Statistics show FFs with a below-average work capacity are 2.5 times more likely to suffer sudden cardiac events (Rosenstock & Olsen, 2007). Cardiovascular disease (CVD) contributes to 45% of the deaths that occur within U.S. FFs while on-duty (Kales et al., 2007). Inadequate levels of fitness cause FFs to be more prone to metabolic syndrome and obesity which are associated with an unfavorable CVD risk (Soteriades et al., 2005). Current studies indicate obesity to be a concern in the fire service with 80% of FFs being overweight or obese, which increase the odds of a CVD duty-related death by 3-fold (Poston et al., 2011). Peate et al. (2002) found that inactive FFs have a 90% increased risk of heart attack (myocardial infarction) than FFs who are aerobically fit.

Designing an exercise training program for tactical athletes should be created from a needs analysis which provides information including physiological and biomechanical demands of the job, as well as common work related injuries (Abel et al., 2015). A physiological analysis would identify the primary energy systems utilized during occupational tasks. Tasks such as dragging a charged hose to a burning structure would utilize the phosphate system, rescuing a victim would utilize the glycolytic system, and performing ongoing tactics to put out a burning structure would utilize the oxidative system (Abel et al., 2015). A biomechanical analysis would identify primary movement patterns that are vital to the occupational tasks of FFs including the primary planes of motion, types of muscular contractions, and the joints involved during movements. Exercises should mimic specific movement patterns utilized during fire ground and rescue tasks (Abel et al., 2015). An injury analysis would identify the common sites prone to injury while performing rescue tasks (Abel et al., 2015). According to the United States Department of Homeland Security and Federal Emergency Management Association, approximately 80,000 injuries occur annually among FFs, which leads to lost employment hours and high costs in treatment. Injuries most commonly reported are due to direct trauma, being struck by an object, load carriage, patient rescue and transport, falling, overexertion, and fire operations (Karter, 2013).

Poor muscular strength, neuromuscular control, and deficits in mobility are major contributors to musculoskeletal injuries (Myer et al., 2005). Karter (2013) reports 34% of injuries, classified as moderate-to-severe, suffered on the job are categorized as a sprain or strain to the shoulders, lower extremities, and lumbar spine. Injuries most often occur due to faulty movement patterns that happen because of poor neuromuscular control and muscle imbalances/weaknesses (Peate et al., 2007). Peate et al. (2007) also found that implementing a program that focused on strength, flexibility, and mobility of the muscles that surround the pelvis, spine, and trunk to decrease injuries by 42% and time lost due to injury by 62%. The functional strength gained by the aforementioned type of program may improve the FFs' ability to safely maneuver in awkward body positions that can be associated with the hazards of the occupation.

Designing a functional strength and conditioning program for FFs includes the following variables; exercise selection, order, frequency, volume, intensity, and session parameters (Abel et al., 2015). Exercises should be specific and transferable to job demands. The programs should include exercises that are functional and include total body movements that require the activation of large muscle groups (Abel et al., 2015). Training both bilateral and unilateral movements is highly recommended for this population (Abel et al., 2015). Ability for FFs to appropriately and efficiently absorb, transfer, and move load is a crucial component in avoiding injuries (McGill et al., 2009). Peate et al. (2007) state a program that incorporates exercises that mimic firefighting tasks, enhance mobility, strength, and neuromuscular control seem to be suitable in maintaining readiness and reducing injury risk (Peate et al., 2007; Peate et al., 2002).

Functional strength should be directly related to a FF's ability to lift, carry, drag, push, and pull any type of load. A simulated firefighting tasks and demands test battery (SFGT) includes: stair climb carrying a high-rise pack, charged hose advance, and a dummy drag. The SFGT has been deemed as a reliable and valid assessment of FF preparedness (Gledhill & Jamnik, 1992). However, the relationship between the SFGT and commonly used physical characteristic assessments is unknown. As such, the purpose of this study is to determine the relationship between the SFGT and commonly used physical fitness tests (PFTs).

Methods

Participants

A convenient sample of 20 male career FFs between the ages of 24-55 years old volunteered to participate in this study. Participants were in good health and free of any neuromuscular, orthopedic, or neurological conditions that might restrict physical activity. They were recruited via an email sent out to the entire fire department, calling for volunteers.

Prior to any assessment, permission from the University Institutional Review Board was obtained. Each participant provided a written informed consent prior to engaging in the study. It was made clear that participation in the study was voluntary and that one could withdraw from the study at any time for any reason without penalty.

Instruments and Apparatus

A Baseline Hydraulic Hand Dynamometer with a 90.9kg capacity was used to assess grip strength (range 0-90 kg; accuracy 0.1 kg) following the American College of Sports Medicine protocol (American College of Sports Medicine, 2018). A Just Jump Mat was used to assess vertical jump (VJ) (Probiotics Inc-Standard Version, Huntsville, AL). Equipment used for testing 1-RM (one repetition maximum) Bench and Back Squat included Hammer Strength power racks, benches and barbells.

Equipment used for the SFGT includes: 4.44 cms (1¾ inch) diameter fire hose bundle weighing 18.1 kg, four story training tower (72 steps), two links of 4.44 cms (1¾ inch) diameter fire hose, training dummy "Rescue Randy" (84kg), full PPE gear that included turnouts, helmet, hood, gloves, boots, and pack. An ACCUSPLIT Pro Survivor-A601X hand held stopwatch was used as the timing device. Height and weight were verbally self-reported by each participant.

Procedures

The study was administered on two (2) separate days with one (1) hour increments blocked for testing, and participants chose which hour to attend based on preference and availability. There was one session on March 16 beginning at 7:30am and ended at 11:00am and one session on March 23 beginning at 7:30am and ended at 11:00am. Participants completed all PFT tests and the SFGT on the same day except the 1-RM Bench press (BP) and 1-RM Back Squat (BS). Participants completed 1RM BP and 1 RM BS on one (1) separate day one week prior to the PFT and SGFT testing day to help limit the possibility of fatigue influencing the SFGT performances.

When participants arrived at the testing site for the PFT and SFGT, they were gathered as a group and began the session by first lying supine on the floor for two minutes. At the start of the second minute, participants were instructed to take a 1-minute pulse at the carotid artery. Resting heart rate was recorded. Participants then performed a dynamic warm-up. The dynamic warm-up consisted of eight different movements including the following: inch-worm to upward/downward dog rotations, single leg hip hinge, walking forward lunge with an overhead reach, leg swings, walking knee hugs, dynamic quad pull, bodyweight squats, and side to side lunges. Each movement was performed for 5 repetitions. This same warm up was conducted at the initiation of the test session for the 1 RM BS and 1 RM BP. Participants first completed each PFT in shorts, t-shirt, and workout shoes prior to putting on full PPE gear and completing the SFGT. Each movement was demonstrated for the participants before they were given time to ask clarifying questions.

Physical Fitness Performance Tests

Anaerobic Power-Vertical Jump Assessment. The VJ is an assessment of lower body power where participants jump off two feet as high as possible and land in the same spot. This assessment was completed using the Just Jump Mat (Probiotics Inc-Standard Version, Huntsville, AL.). The participants stood on the contact mat and used a countermovement to jump up as high as possible and then land on two feet on the mat. Three attempts were allowed with the best attempt recorded. Participants took approximately 30 seconds between jump attempts. This test has been shown to be a valid and reliable measure for lower-body power (Rodriguez-Rosell et al., 2016; Buckthorpe et al., 2012). The power output was calculated using the following formula (Harman et al., 1991):

Peak Power (W) = [61.9 x (jump height [cm]) + 36 x (body mass [kg] + 1,822]

Aerobic Fitness- YMCA 3-Minute Step Test. Participants stood facing a 30.5 cm step. When the clock started, the participants stepped up onto the step to the beat of a metronome set at 96 beats per minute for 3 consecutive minutes. The stepping rhythm was up, up, down, down. At the end of 3 minutes the participant immediately sat down on the step and a radial pulse was taken for one full minute. Recovery heart rate was recorded and reported as a percentage of maximal heart rate (%HR_{max}). Studies show the 3-Minute step test to be a valid and reliable test (Bennett et al., 2016).

Figure 1. Firefighter in full PPE gear

Upper Body Muscular Strength- Grip Strength and 1-Repetition Maximum Bench Press. Participants stood with the dynamometer in one hand parallel to the side of the body and elbow flexed at 90 degrees. The participant then squeezed the handle as hard as possible while breathing. Grip strength was recorded in kilograms. This procedure was repeated with the other hand. Each side was repeated for three trials each, alternating between hands. The highest reading from each hand was recorded and then added together to get a measure of grip strength. It has been demonstrated that GS does not vary throughout the day (Young et. al, 1989). This hand grip strength test protocol has been shown to be a valid test (Wadsworth et al., 1992; Peolsson et al., 2001).

The 1 RM bench test was also used to assess upper body strength. The participants gripped the barbell with a closed, pronated grip wider than shoulder width apart while laying supine on a bench with five points of contact (head, back, buttocks, right foot, and left foot). The participant lowered the barbell down to the chest and back up to the starting position with elbows fully extended in one fluid motion. The participants performed a 3-5 repetition maximum with submaximal weight. A 1 RM was then estimated based off a 1 RM Load Chart (Baechle, 2016). The 1 RM test protocol used in the current study was consistent with the National Strength and Conditioning Association guidelines (Miller, 2012). Studies have shown the 1 RM bench press to be a valid test of muscular strength (Baker, 2001; Baker & Newton, 2006).

Lower Body Strength-1 RM Back Squat. Lower body Muscular Strength was assessed using 1 RM bilateral back squat. The participants gripped the barbell with a closed, pronated grip wider than shoulder width apart and resting the barbell behind the head and above the posterior deltoids. Feet position was slightly wider than hip width and toes were turned slightly outward. Participants squatted down until thighs reached parallel to the ground and then ascended back up in one fluid motion. For safety purposes the participants performed a 3-5 repetition maximum with submaximal weight. A 1 RM was then estimated based off a 1RM Load Chart (Baechle, 2016). The 1 RM test protocol used in the current study was consistent with the National Strength and Conditioning Association guidelines (Miller, 2012). High test-retest reliability has been shown using this protocol to assess the 1 RM BS (McBride et al., 2002; Sanborn et al., 2000).

Simulated Fire Ground Performance Test

The SFGT assessed FF specific task performance. This test included the following 3 tasks: stair climb carrying a high-rise pack (SC), charged hose advance (CHA), and a dummy drag (DD). These tasks were previously judged by fire department administrators and previous research which considered these reliable and valid tests for FFs (Gledhill & Jamnik, 1992). Time to complete each task was recorded individually. Participants wore full firefighting gear consisting of PPE including helmet, hood, pants, coat, gloves, boots and air pack (22.7kg). The test included a SC high-rise pack (rolled 6.35cm fire hose bundle 18.1kg), CHA from a fire hydrant, and a 30 meter 'Rescue Randy' (84kg) DD performed sequentially. The tasks are described below. Firefighters were instructed to complete the following tasks sequentially, at a work rate they would operate at a real fire scene.

Task 1- SC with high-rise pack. The FFs first lifted a high-rise pack consisting of two links of fire hose (18.1kg) from ground level and placed it over one shoulder. They then climb up six flights of stairs to the top floor of the fire training tower (72 total steps at 20cm/step) and then down six flights to ground level. After the FF picked up the high-rise pack and placed it over the shoulder, the time started when the FF took their first step up the stairs and stopped when both feet returned to ground level. Time was recorded using a stopwatch.

Task 2- CHA. The second task included CHA. Two 15.3m links of 4.44 cms (1¾ inch) fire hose were hooked up to an open fire hydrant with the nozzle end coiled up on the pavement. Firefighters were instructed to bend over and pick up the nozzle end (6.1 kg) and drag the charged hose to the designated end point 30 m away. After the FF picked up the charged hose and placed the nozzle end over the shoulder, the time started when the FF took their first move to advance the hose forward and stopped when both feet crossed the 30m mark. Time was recorded using a stopwatch.

Task 3- Victim Rescue Randy DD. The third task included dragging an 84 kg ‘Rescue Randy’ dummy for 30 m. The dummy was lying supine on the ground outside the fire tower. The FFs were required to approach the dummy from behind, lifting the head and shoulders off the ground and grabbing it under the arms around the torso and drag it backwards until the feet of the dummy fully crossed the 30 m mark. After the FF lifted the head and shoulders of the dummy off the ground, the time started when the FF took their first step backwards and stopped when both feet of the dummy crossed the 30m mark. Time was recorded using a stopwatch.

Due to previous firefighting experience, all participants were familiar with the movements and standards required for the SFGT. All data were recorded by hand and later transferred to an electronic database.

Design and Analysis

The PFT variables assessed in this study included: GS (kgs), HR (%HR_{max}), VJ (cm), peak power relative to bodyweight (W/kg), upper body and lower body relative strength (absolute strength kgs/body mass), and age (years). The SFGT variables assessed in this study included the time (seconds) to complete each of the following tasks: SC, CHA, and the DD. The association between the PFT variables and the SFGT variables were conducted with Pearson correlation coefficients (r). Significance for the study was set *p*<0.05. All statistical analyses were completed in MS Excel Office 365. The data analysis spread sheet was peer reviewed for accuracy as suggested by AlTarawneh & Thorne (2017).

Results

Twenty male participants completed the study without incident and the demographics are presented in Table 1. The average age, height, body mass, and BMI were: 37.8±8.4 years, 182.1±7.0 cm, 95.6±8.9 kg, and 28.9±3.1 kg/m^2 respectively. The participants had approximately one year of resistance training experience and were familiar with the BP and SQ exercises.

Grip strength demonstrated a negative moderate (r=-0.49: p<0.05) relationship with the time to complete the CHA, a high negative relationship with the SC times (r=-0.61: p<0.05), a high negative relationship with the DD times (r=-0.7: p<0.05), and a high negative relationship the total time to complete all tasks (r=-0.64: p<0.05) (see Tables 4,5,6,7).

Heart rate response, measured as %HR_{max}, on the step test demonstrated a positive moderate relationship with the time to complete the SC (r=0.51: p<0.05), CHA (r=0.52: p<0.05), and the total time to complete all tasks (r=0.50: p<0.05); and a positive low (r=0.38: p<0.05) relationship with the time to complete the DD (see Tables 4,5,6,7).

Table 1
Participant Descriptive Information (Mean ± SD).

	Age (years)	Height (cm)	Mass (kg)	BMI (kg/m2)
Male (n=20)	37.8 ± 8.4	182.1 ± 7.0	95.6 ± 8.9	28.9 ± 3.1

cm: centimeters, kg: kilograms, m: meters

The BP 1-RM demonstrated a negative high relationship with the time to complete the SC (r=-0.79: p<0.05) and CHA (r=-0.79: p<0.05); and a negative very high relationship with the time to complete the DD (r=-0.80: p<0.05) and the total time to complete all tasks (r=-0.82: p<0.05) (see Tables 4,5,6,7).

The SQ 1-RM demonstrated a negative moderate (r=-0.52: p<0.05) relationship with the time to complete the CHA; and a negative high relationship with the time to complete the SC ($r=-0.70$: $p<0.05$), DD ($r=-0.68$: $p<0.05$), and the total time to complete all tasks ($r=-0.70$: $p<0.05$) ($p<0.05$) (see Tables 4,5,6,7).

The VJ scores demonstrated a negative moderate ($r=-0.49$: $p<0.05$) relationship with the time to complete the CHA; and a negative high relationship with the time to complete the SC ($r=-0.67$: $p<0.05$), DD ($r=-0.60$: $p<0.05$), and the total time to complete all tasks ($r=-0.66$: $p<0.05$) (see Tables 4,5,6,7).

Peak power relative to body mass demonstrated a negative moderate relationship with the time to complete the SC ($r=-0.55$: $p<0.05$), DD ($r=-0.42$: $p<0.05$), and the total time to complete all tasks ($r=-0.52$: $p<0.05$); and a negative low non-significant relationship with the time to complete the CHA ($r=-0.30$: $p>0.05$) (see Tables 4,5,6,7).

Age did not demonstrate a significant relationship with performance on any of the SGFT assessments ($p>0.05$) (see Tables 4,5,6,7).

Table 2
Physical Fitness Scores (Mean ± SD).

	Grip Strength (kg)	3-Min Step Test HR (%HR_{max})	Vertical Jump (cm)	1 RM BP/BM (kg/BM)	1 RM BS/BM (kg/BM)	Peak Power Relative to BM (W/kg)
Male (n=20)	95.6 ± 13.3	50.0 ± 10.0	56.9 ± 10.2	1.2 ± 0.3	1.5 ± 0.4	92.7 ± 10.4

BM: body mass (kg), W: watts, cm: centimeters, kg: kilograms, HR: heart rate, BP: bench press, BS: back squat, 1 RM: one repetition maximum.

Table 3
SFGT Performance Scores (Mean ± SD).

	Stair Climb (sec)	Charged Hose Advance (sec)	Dummy Drag (sec)	Total Time (sec)
Male (n=20)	73.5 ± 16.7	7.7 ± 2.1	15.6 ± 4.9	96.7 ± 23.0

Sec: seconds

Table 4
Summary of correlations to stair climb.

Variables	PCC	Interpretation of Correlation	Significant? p<0.05
Age	0.27	NA	No
Step Test	0.51	Moderate	Yes
Grip Strength	-0.61	High	Yes
1 RM BP/BM (kg/BM)	-0.79	High	Yes
1 RM BS/BM (kg/BM)	-0.70	High	Yes
Vertical Jump	-0.67	High	Yes
Peak Power Relative to BM	-0.55	Moderate	Yes

BM=body mass (kg), BP-bench press, BS-back squat, 1 RM-one repetition maximum.

Table 5

Summary of correlations to charged hose advance.

Variables	PCC	Interpretation of Correlation	Significant? p<0.05
Age	0.19	NA	No
Step Test	0.52	Moderate	Yes
Grip Strength	-0.49	Moderate	Yes
1 RM BP/BM (kg/BM)	-0.79	High	Yes
1 RM BS/BM (kg/BM)	-0.52	Moderate	Yes
Vertical Jump	-0.49	Moderate	Yes
Peak Power Relative to BM	-0.30	Low	Yes

BM: body mass (kg), BP: bench press, BS: back squat, 1 RM: one repetition maximum.

Table 6

Summary of correlations to dummy drag.

Variables	PCC	Interpretation of Correlation	Significant? p<0.05
Age	0.14	NA	No
Step Test	0.38	Low	Yes
Grip Strength	-0.70	High	Yes
1 RM BP/BM (kg/BM)	-0.80	Very High	Yes
1 RM BS/BM (kg/BM)	-0.68	High	Yes
Vertical Jump	-0.60	High	Yes
Peak Power Relative to BM	-0.42	Moderate	Yes

BM: body mass (kg), BP: bench press, BS: back squat, 1 RM: one repetition maximum.

Table 7

Summary of correlations to total time.

Variables	PCC	Interpretation of Correlation	Significant? p<0.05
Age	0.25	NA	No
Step Test	0.50	Moderate	Yes
Grip Strength	-0.64	High	Yes
1 RM BP/BM (kg/BM)	-0.82	Very High	Yes
1 RM BS/BM (kg/BM)	-0.70	High	Yes
Vertical Jump	-0.66	High	Yes
Peak Power Relative to BM	-0.52	Moderate	Yes

BM: body mass (kg), BP: bench press, BS: back squat, 1 RM: one repetition maximum.

Discussion

The purpose of this study was to determine the relationship between physical fitness characteristics and the performance of simulated firefighting tasks and demands of a FF. The physical fitness characteristics included in this study were: GS and 1RM BP to determine relative upper body strength, 1RM BS to determine lower body relative strength, VJ, and 3-minute step test. The SGFT included the SC, CHA, and DD. It was hypothesized that the PFT scores would have a meaningful association with the time to complete the SGFT and the time to complete each individual SGFT fire performance task.

The study results demonstrated most of the PFT to be significant and meaningfully associated with SGFT performance. The ST correlation with the DD and the peak power/BM correlation to the CHA demonstrated low associations ($r<0.39$). There was not a significant correlation between age and SFGT performance. Overall, the data supports the hypothesis of PFT having a significant association with SFGT performance and emphasizes the existence of a meaningful relationship between PFT and SFGT.

In order to mimic a real-life scenario, participants performed the SGFT tasks at a realistic pace that would be seen on duty at an emergency scene. There is significant research from multiple studies stating muscular strength and endurance to be closely associated with FF performance due to the amount of lifting, carrying, pulling, and dragging that occurs on the job (Durand et al., 2011; El-Kader & Mahoun, 2010; Gledhill & Jamnik, 1992; Hendrickson et al., 2010; Michaelides et al., 2011; Pawlak et al., 2015; Rhea et al., 2004; Williford et al., 1999).

A study by Michaelides et al. (2011) found that high performance on multiple physical fitness assessments including upper body strength and muscular endurance, abdominal strength, and anaerobic power were related to high performance on simulated fire ground tasks. The current study also found similar relationships between physical fitness including upper and lower body relative strength and anaerobic power with higher performance on simulated fire tasks. Williford et al. (1999) and Rhea et al. (2004) reported significant correlations between fire task performance and physical fitness assessments. The current study demonstrated moderately strong to very strong correlations between PFT and fire task performance similar to the aforementioned studies (Rhea et al., 2004; Williford et al., 1999).

Grip strength is often perceived as a potential limiting factor for overall FF performance. While on duty, many of the tasks expected of FFs include gripping and carrying heavy equipment such as firehose and/or rescue equipment. Gledhill & Jamnik (1992) identified that FFs are exposed to various weighted tasks/implements when on duty. Weighted tasks/implements identified included ladders, 25 to 61 kg; Jaws of Life, 33 kg; Hurst portable pump, 57kg; sand pails used for car accidents, 36kg; and charged hose lines, 51 to 69 kg (Gledhill & Jamnik, 1992). It would appear that grip strength and the ability to handle firehose and/or rescue equipment would be a strong asset to a FF. The current study demonstrated that grip strength was meaningfully and significantly associated with SFGT performance with correlations ranging from moderate to high ($p<0.05$).

It has been shown that there are high rates of cardiovascular disease and sudden cardiac events leading to death within the fire service community. Research by Durand et al. (2011) demonstrated that heart rate response and recovery to be a primary indicator of early mortality rates in FFs. The ability for a FF`s heart to recovery from a strenuous bout of exertion is one of the key factors in determining early mortality rates among FFs worldwide (Durand et al., 2011). The current study demonstrated heart rate recorded immediately following the 3-minute step test to be significantly associated with SFGT performance. Participants who had higher heart rates (%HR_{max}) after the step test also required longer times to complete the SC, CHA, and DD. Therefore, is appears that cardiovascular fitness is an important indicator of task efficiency while on duty.

During periods of alarm response, FFs are more prone to experience CVD events due to the unpredictable bouts of strenuous activity and periods of higher emotional stress (Baur et al., 2012). Kales et al. (2007) found that deaths from CVD among FFs were linked to alarm response (13.4%), returning from alarm (17.4%), fire suppression (32.1%), non-fire emergency calls (9.4%), physical training (12.5%), and performing nonemergency duties (15.4%). The odds of death from CVD were 12.1 to 136 times higher during fire suppression, 2.2 to 10.5 times higher during alarm calls, and 2.9 to 6.6 times higher during physical training (Kales et al., 2007). Increased stress levels (physical, mental, emotional) can lead to an increased risk for CVD (Kales et al., 2007). Stressful situations and chronic overexertion cause the body to shift into a sympathetic state that induces cardiovascular activation, which can trigger acute heart disease events if the heart is unable to recover and the body is unable to shift back to a parasympathetic state (Durand et al., 2011). The ability to quickly switch from a sympathetic state (stressful/fight or flight) to a parasympathetic state (recovery/rest and digest) can result in better recovery and overall health in FFs (Durand et al., 2011). Therefore, cardiovascular fitness is a critical component to FF health and safety.

How does this all translate to firefighting? For instance, a FF arrives at a fire scene and needs to perform a forcible entry and pull a hose line up a flight of stairs to the second story to put out the fire and then rescue any victims that are on the second story. During this time, they are already in full gear with Self-contained breathing apparatus (SCBA) air supply which is known to increase oxygen demands due to the restricted breathing that occurs when the mask is on causing a 15% reduction in efficiency (El-Kader & Mahmoud, 2010). In this scenario there is limited supply of oxygen to start with, the FF is approaching their $VO2_{max}$ and HR_{max} due to the physical demands, and they are reaching the maximum amount of effort they can give, and they haven't come close to completing the rescue mission. The FF must also be able to continue to perform job demands that require muscular strength and endurance to maneuver throughout the scene and carry and/or drag any victims out of danger. All this needs to be done efficiently to ensure the safety of both the FF and the victim. Given the physical demands required in order to carry out firefighting tasks in conjunction with the dangerous task environment, the authors of the current study view the FF as a tactical athlete.

The most obvious limitation of the current study is the small sample size. Due to the limited number of participants, there was a variety of height, weight, age, and fitness level. The participants were local area career FFs (which could be considered a strength of the current study). Along with sample size, gender is also a limitation. There is a low number of female FFs in the fire departments involved in the study, as such, this study was conducted with only male FFs. Future research should include both genders.

To provide a broader understanding of the physiological needs for success in the firefighting profession, further research should expand on the extent of physical fitness and its correlation to efficient firefighting performance. Future research might also help determine what other factors may affect the ability of a FF to complete firefighting tasks efficiently and successfully. There are a multitude of factors beyond physical fitness, not limited to, but including nutrition, sleep deprivation, mental health, and recovery that all play a role in overall FF performance. Future research should include a longitudinal study that factors in all these aspects to see how such factors might contribute to a FF's health, job performance, and career longevity.

Within the parameters of this study, the FF's exhibited a moderate to very high relationship between PFT and the execution of simulated firefighting demands. This study is significant as it may be applicable to first responders nationwide who perform similar work-related task. Because of the high physical and cardiovascular demands of firefighting, it is necessary for FFs to have a high level of physical fitness to safely and efficiently perform duties of the profession. There is also significant research on the benefits of physical fitness training for FF health and safety, which leads to a growing support for structured physical fitness training programs being implemented into fire departments across the nation (El-Kader & Mahoun, 2010; Hendrickson et al., 2010; Michaelides et al., 2011; Pawlak et al., 2015).

Being fit for duty is the most basic requirement for both career and volunteer FFs. At the end of the day, a FF's lifestyle choices and exercise routine directly affect the lives of the citizens, other fellow FFs, and their family members. If FFs do not possess the appropriate levels of physical fitness, will they be able to perform their job, or will they fall short?

Conflict of Interest Declaration

No funding was received for this research. The authors have no conflict of interest related to this research. This research has not been previously published.

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