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The Impact of Gloves and Simulated Occupational Tasks on Handgrip Strength in Structural Firefighters

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THE IMPACT OF GLOVES AND SIMULATED OCCUPATIONAL TASKS ON HANDGRIP STRENGTH IN STRUCTURAL FIREFIGHTERS

by

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(Under the Direction of Stephen J. Rossi)

ABSTRACT

Adequate handgrip strength (HGS) is important to safely and effectively perform fireground tasks. However, there is limited research describing the deleterious impact of glove use and fatigue from occupational tasks on HGS. Therefore, the aims of this investigation were to quantify the impact of glove use and occupational tasks on HGS, to explore the relationship between HGS versus the glove and task-induced decrement in HGS, and to evaluate the relationship between HGS and decrement in HGS versus occupational performance. Fourteen (Males: n=13) career structural firefighters performed a maximal isometric HGS assessment with and without gloves before and immediately following completion of a simulated fireground test (SFGT). A general linear model with written contrasts was used to identify significant differences in HGS between conditions. Pearson Product Moment Correlations were used to describe bivariate relationships. Significance was set at $p<0.05$. There were significant main effects indicating that gloves, performing occupational tasks, and their combined effects decreased HGS ($p<0.001$ for all). There were strong inverse relationships between baseline (barehanded) HGS versus the decrement in HGS from donning gloves (r=-0.82, p<0.001) and from performing occupational tasks with gloves (r=-0.61, p=0.021). Baseline HGS and the decrement in HGS due to wearing gloves and performing occupational tasks were not correlated to the timed completion of occupational tasks ($p\geq0.27$). These findings suggest that the use of regulation fire gloves and the presence of fatigue reduces maximal handgrip force production capabilities. Practitioners are encouraged to utilize training strategies to optimize HGS among structural firefighters.

INDEX WORDS: Gloves, Tactical, Fitness, Handgrip strength, Occupational readiness

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CHAPTER 1

INTRODUCTION

Firefighting involves performing strenuous occupational tasks in hazardous environments. Adequate handgrip strength is important to safely and effectively perform firefighting tasks (Lindberg, Oksa, & Malm, 2014; Williford et al., 1997). Many of these tasks involve the use of hand and power tools (e.g., pike poles, chainsaws, sledgehammers). Holding a tool with appropriate grip force is a complex motor task (Domalain et al., 2008). An insufficient amount of applied force can result in the tool slipping, posing a safety hazard to the firefighter, bystanders, and the environment. Furthermore, excessive muscle fatigue may disrupt firefighters' attention and subject them to an increased risk of injury or death (Games et al., 2020; Sonne et al., 2015). In addition, previous investigations have reported that maximal handgrip strength is positively correlated with overall strength (Bohannon, 2008) and firefighters' work efficiency (Lindberg, Oksa, & Malm, 2014; Williford et al., 1997).

Several occupational factors may be associated with impaired handgrip strength including the use of standard issued gloves and muscular fatigue from occupational tasks. For instance, Bishu and Klute (1995) demonstrated that extravehicular activity (EVA) gloves significantly reduced handgrip strength (-50%, $p < 0.01$). Bishu and Klute (1995) also noted that donning gloves increases grip span and results in an earlier contact between fingers indicating that handgrips with versus without gloves are biomechanically different. In addition, Dianat and colleagues (2012) reported that wearing cotton, nylon, and nitrile-coated cotton gloves decreased handgrip strength compared to barehanded grip strength and that longer glove use further reduced hand performance capability. Furthermore, Cochran and colleagues (1986) observed significant decrements in total grip force capabilities when donning multiple glove types (leather and cotton, steel mesh, leather, nylon and steel, and cotton) compared to barehanded. This research indicates that glove use and extended performance of occupational tasks may impart independent and collective effects on handgrip strength and occupational performance in other populations. However, additional occupationally specific research is necessary to quantify these effects among firefighters.

It is important to gain an understanding of the factors that may negatively affect handgrip strength, and ultimately occupational performance, to identify and implement appropriate countermeasures, which may include exercise interventions, glove material, and design, and enhanced ergonomic tool design. To date, no published investigations have examined the effect of regulation fire gloves or occupational tasks on handgrip strength in structural firefighters. Therefore, the primary purpose of this investigation was to quantify the impact of glove use and performance of occupational tasks on handgrip strength. It was hypothesized that absolute isometric handgrip strength would decrease while donning gloves and following completion of a simulated fireground test (SFGT). The secondary purpose was to determine if glove- and task-induced decrements in handgrip strength were associated with baseline handgrip strength and the timed completion of occupational tasks. Timed completion of the breach and pull task was selected as a measure of occupational performance because it requires adequate handgrip strength to perform and is considered one of the most physically demanding tasks associated with firefighting (Poplin et al., 2016). It was hypothesized that the glove- and task-induced decrements in handgrip strength would be inversely associated with baseline handgrip strength and inversely associated with the timed completion of a breach and pull task and a set of SFGT tasks.

CHAPTER 2

METHODS

Experimental Approach to the Problem

The primary purpose of this study was to determine the independent and collective effect of glove use and performance of occupational tasks on subsequent handgrip strength. Therefore, the primary purpose used a within-subjects design to descriptively compare handgrip strength levels with and without firefighter gloves before and after completion of occupational tasks. The independent variables for this purpose included the glove condition (with vs. without gloves) and occupational task condition (pre vs. post SFGT condition). The dependent variable was handgrip strength.

The secondary purpose of this study was to explore the relationship between baseline handgrip strength versus glove and task-induced decrements in handgrip strength. Thus, this purpose utilized a cross-sectional design to evaluate the relationship between baseline handgrip strength versus the glove- and task-induced decrement in handgrip strength versus baseline handgrip strength. For these analyses, the predictor variable was baseline handgrip strength and the dependent variable was the glove- and task-induced decrement in handgrip strength. In addition, we sought to determine if any glove and task-induced decrements in handgrip strength were correlated to the timed completion of occupational tasks. In this case, the predictor variables were the glove- or task-induced decrement in handgrip strength and the dependent variables were the timed completion of the breach and pull task and the timed completion of a set of SFGT tasks.

Subjects

Fourteen (Males: 13, Female: 1) career structural firefighters (Experience: 8.0 ± 5.2 yr; Age: 35.5 ± 7.2 yr; Body mass index: 27.9 ± 3.2 $kg{\cdot}m^{-2}$) from one metropolitan fire department in the southeastern United States volunteered to participate in this study. All study procedures were approved by the

University's Institutional Review Board (Protocol #67300). Subjects provided written informed consent before participation in the study. Inclusion criteria included 18-60 years of age, a full-time employee of the participating fire department, and medical duty clearance by a physician. Exclusion criteria included any respiratory or musculoskeletal condition that would impair occupational physical ability. Subjects completed a Physical Activity Readiness Questionnaire (2021 PAR-Q+) and a health history questionnaire.

Anthropometrics

Standing height was taken with a portable stadiometer (Seca 213, Seca, Chino, CA; to the nearest 1.0 cm). Body mass was measured without shoes, in standard issued departmental uniform, and in full personal protective equipment (PPE; to the nearest 0.1 kg) with a portable digital scale (Medline Digital Step-On Scale, Northfield, IL). Hip circumference was measured (to the nearest 0.1 cm) at the greatest protrusion of the buttocks with a plastic tape measure (Baseline Gulick, Quick Medical, Warwick, RI), whereas waist circumference was measured at the narrowest part of the torso between the umbilicus and xiphoid process (Dumke, 2018). Each circumference measurement was taken in triplicate to ensure internal validity. The closest two values within 1.0 cm were averaged for analysis. The waist-to-hip ratio was calculated by dividing the waist circumference by hip circumference. Body composition was assessed with a dual-frequency (5 and 50 kHz) tetrapolar bioelectrical impedance analyzer (BIA; BodyStat 1500MDD, BodyStat Ltd., Isle of Man, UK). The device reported body fat percentage, fat mass (kg), lean mass percentage, and lean mass (kg) using the manufacturer's proprietary prediction equation. This BIA device has excellent reliability ($r > 0.90$, $p < 0.05$) and validity ($r = 0.83$, $p < 0.05$). Subjects were asked to arrive in a euhydrated state and abstain from vigorous exercise for 24 hours prior to testing.

Muscular Power

Muscular power was assessed to account for the potential confounding effects regarding the relationship between the glove- and/or task-induced decrements in handgrip strength and timed completion of occupational tasks. The standing long jump was used as an assessment of lower-body power (Mann et al., 2021). The jump distance was measured as the shortest distance from the toe before take-off to the back of the rearmost heel upon landing. The highest value of three attempts was used for analyses. Lower body power was calculated using the following prediction equation: Power (W) = [(32.49 x jump length (cm)) + (39.69 x body weight (kg))] - 7,608 (Mann et al., 2021).

Aerobic Capacity

Aerobic capacity was assessed to account for the potential confounding effects regarding the relationship between the glove- and/or task-induced decrements in handgrip strength and timed completion of occupational tasks. Aerobic capacity was measured via the 30-15 Intermittent Fitness Test (Buchheit, 2010) using a 28 m course (Figure 1). Each stage of the test consisted of 30 s of running and 15 s of active recovery. The 30-15 Intermittent Fitness Test has excellent test-retest reliability for maximal velocity (ICC = 0.80-0.99; CV =1.5-6.0%; Grgic, 2021). Stage running velocities were indicated by an audio recording (Buchheit, 2010). The first stage began at 8 $km \cdot h^{-1}$ and increased by 0.5 $km \cdot h^{-1}$ for each stage thereafter. The test was terminated if the subject did not successfully reach the 3 m safe zone at the subsequent tone three consecutive times or upon volitional fatigue. The velocity of the final completed stage was used in the statistical analysis.

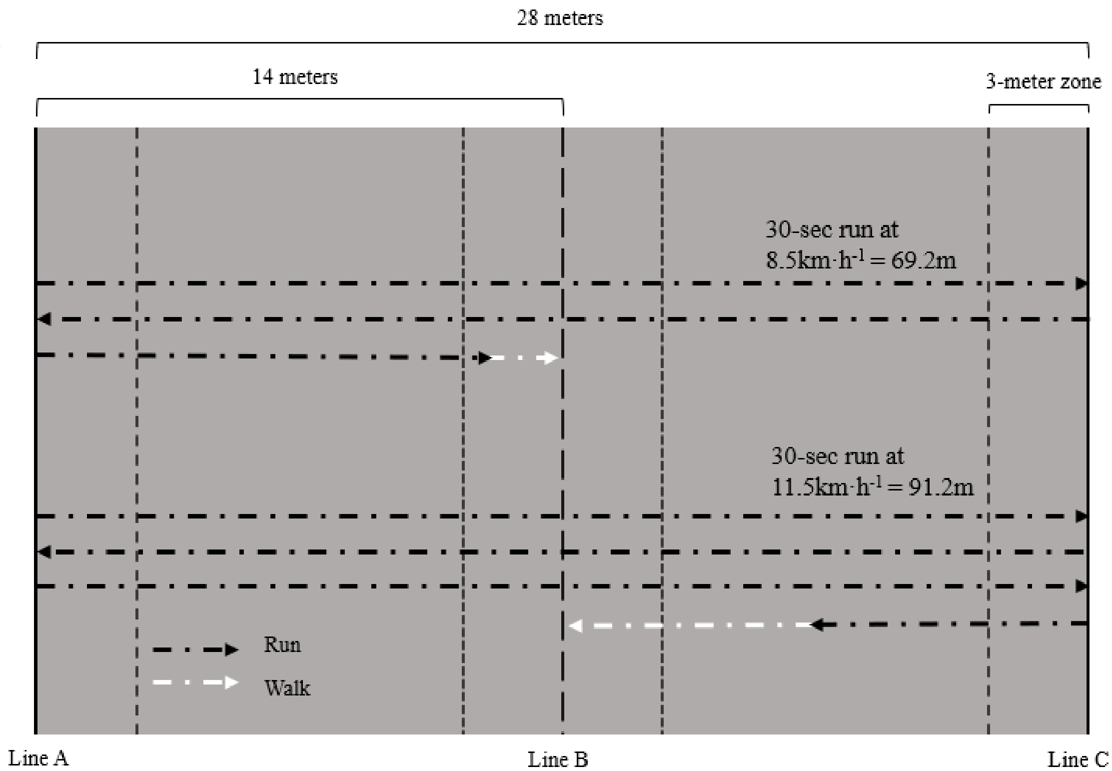

Figure 1. An example of two stages of the 28-meter 30-15 Intermittent Fitness Test (Larsen and Buchheit, 2019).

Blood Lactate

Blood lactate was taken to reflect the anaerobic demand of performing the SFGT and has demonstrated strong test-retest reliability (r = 0.99, $p < 0.05$; Hart et al., 2013). Blood lactate was taken with a portable lactate analyzer (Lactate Plus, Nova Biomedical, Waltham, MA) prior to and five minutes following completion of the SFGT. Low (1.0-1.6 $mmol \cdot dL^{-1}$) and high (4.0-5.4 $mmol \cdot dL^{-1}$) control solutions were used to check the accuracy of the device. Universal precautions were used to obtain the sample. Specifically, a finger stick was administered to obtain a blood sample. The first drop of blood was discarded. The second drop of blood was applied to the assay strip.

Handgrip Strength

Isometric handgrip strength was assessed with a hand dynamometer (Jamar Hydraulic Hand Dynamometer 5030J1, Newport, United Kingdom; to the nearest 1.0 kg). Measurements taken with this device have good-to-excellent test-retest reliability ($r > 0.80$, $p < 0.05$; Mathiowetz et al., 1984) and concurrent validity ($r = 0.99$, $p < 0.05$; Mathiowetz et al., 2001).

This study utilized a standard handgrip strength assessment protocol approved by The American College of Sports Medicine (Dumke, 2018). Specifically, subjects stood during the assessment to enhance the external validity within an occupational setting. The subject was instructed to stand with the shoulder adducted, elbow unsupported and flexed to 90°, and wrist in a neutral grip position (De et al., 2011). The adjustable handle was set to fit the subjects' hands such that the second phalanx was approximately at a right angle (Beam and Adams, 2014). The device's clip was secured to the lower post. Subjects were instructed to squeeze the dynamometer with maximal effort for three seconds before releasing tension. The peak-hold needle determined peak force and that value was recorded. Two trials were taken from each hand for each condition to assess test-retest reliability, alternating hands between measurements. Data from the present study indicated that the handgrip strength trials resulted in excellent test-retest reliability ($r \geq 0.93$, $p < 0.01$) for each of the four conditions.

To begin, the first condition examined handgrip strength without gloves before the SFGT. Next, subjects donned regulation firefighting gloves (FireCraft Phoenix, FC-P5000, Columbus, OH) and repeated the handgrip strength assessment. Subjects then performed a set of simulated occupational tasks. Immediately following completion of the last task (breach and pull task), subjects completed the third handgrip strength condition while wearing gloves. Finally, subjects removed the gloves and performed a barehanded grip strength test following the occupational tasks. The highest value from each hand for each condition was used for analyses.

Simulated Fireground Test

Subjects performed a simulated fireground test (SFGT) mimicking occupational tasks (Figure 2) which is similar to that conducted by numerous fire departments. The tasks and dimensions were derived from a department-specific job task survey and analysis. All subjects performed two familiarization trials of the SFGT at a fixed pace (as part of another study) prior to performing the official trial at a self-selected occupationally relevant pace. "Occupationally relevant" refers to a comfortable and familiar pace that is likely to mimic effort during an emergency response. Subjects wore full personal protective equipment (PPE) (i.e., NFPA 1971: standard helmet, gloves, boots, turnout coat, and pants) and utilized a self-contained breathing apparatus (SCBA; Scott Inc., Monroe, NC, USA; PPE mass: 23.8 ± 1.3 kg). The SFGT was composed of eight occupational tasks and began as the subjects ascended three levels of two 9-stair flights separated by a landing (total of 54 stairs) while carrying a hose packaged as a high-rise pack (Mass: 9.1 kg). The subjects touched the wall on the fourth level, placed the high-rise pack on the landing, and descended to the ground floor. Next, subjects walked 8.2 m to the next task and advanced a $1^{3/4}$ inch charged hoseline in a straight line for 30.5 m. Then, subjects walked 3.4 m and carried a K12 saw and chainsaw (Mass: 27.2 kg) 30.5 m in a straight line, around a cone, and returned to the starting position (Total distance: 61 m). Next, subjects walked 37.4 m and raised a 7.3 m aluminum extension ladder from the ground to the side of a structure using a hand-over-hand technique touching each rung and lowered the ladder to the ground in a similar manner. Then, subjects walked 17.3 m to complete a simulated forcible entry task by striking a pneumatic device with a sledgehammer (Mass: 4.5 kg) until the completion tone was audible. Then, subjects walked 53.5 m and performed a right-hand search by crawling 49.1 m on hands and knees in a square pattern. After the search, subjects walked 15.1 m to and dragged a mannequin (Mass: 75 kg) 7.6 m, around a cone, and returned to the starting position (total distance: 16.8 m). Lastly, subjects walked 8.5 m and performed a breach-and-pull task with a threaded pike pole inside an equipment frame. The breach-and-pull is a task that simulates checking for fire extension in a ceiling structure and requires sufficient handgrip, as well as upper and lower body strength to complete. This task consisted of three rounds of three breaches (i.e., completely opening the 27.2 kg ceiling simulator) and five pulls (hooking and pulling the adjacent 36.3 kg ceiling simulator). After the final pull, the test administrator signaled the completion of the task and SFGT.

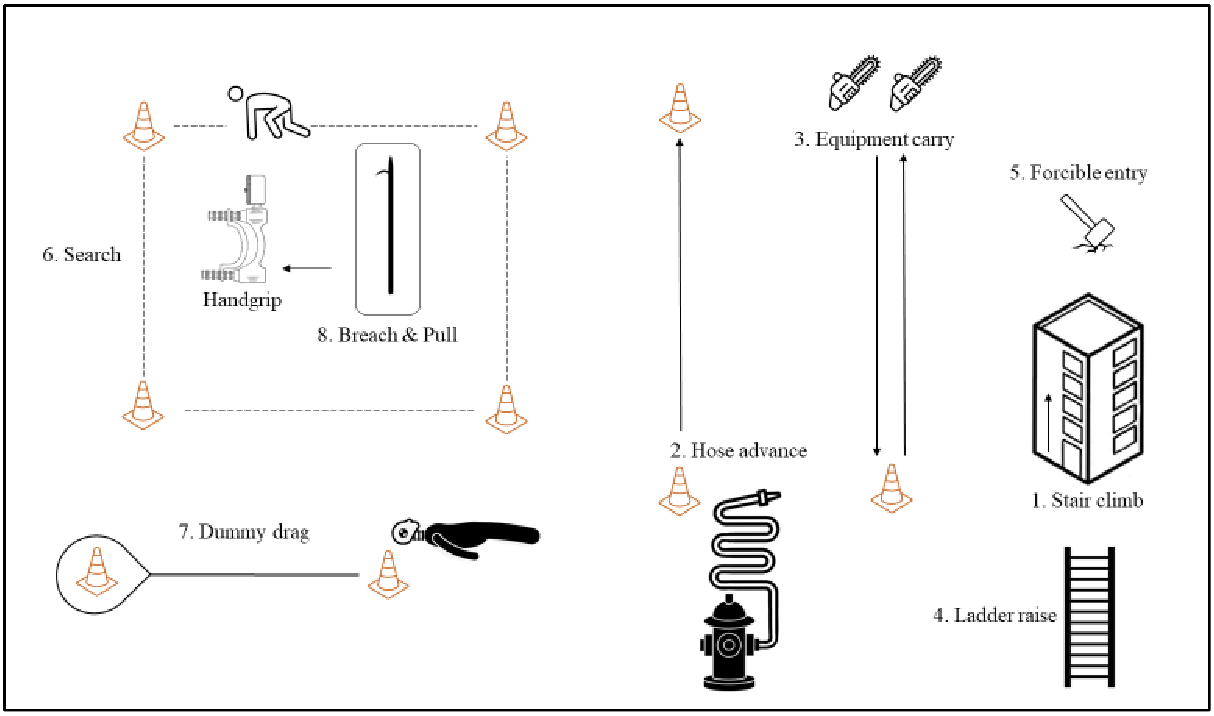

Figure 2. Schematic of the simulated fireground tasks in sequential order.

Assessments of perceived exertion, dyspnea, and thermal strain were taken before the SFGT and immediately following the final handgrip assessments post-SFGT. Dyspnea was measured with the 0-10 category-ratio scale (Borg, 1982; 0 = Nothing at all; 10 = Shortness of breath so severe you need to stop) (Appendix A). The 0-10 Borg RPE scale has been used in previous research to assess firefighters' rating of perceived exertion (Dennison et al., (2012). Before and following completion of the SFGT, subjects reported their rating perceived exertion using a 10-point category-ratio scale (0 = Nothing at all; 10 = Very, very hard) (Appendix B). Immediately before testing, ambient temperature, humidity, and heat index were reported. Before and following completion of the SFGT, subjects reported perceived thermal strain on a seven-point Likert type scale ranging from -3 (cold) to +3 (hot) (Gagge, 1967; Appendix C).

Statistical Analysis

Descriptive statistics were used to represent the distributions' central tendency (mean) and dispersion (standard deviation). The normality of variable distributions was evaluated using Fischer's coefficient of Skewness and calculated as skewness divided by the standard error of skewness. Coefficients outside of the absolute value of 1.96 were deemed to be significantly skewed. General Linear Model and written contrast statements were used to evaluate the effect of gloves and occupational tasks on maximal isometric handgrip strength. Specifically, the handgrip strength assessment conditions included: pre-SFGT without gloves ($preSFGT_{no\ glove}$) and with gloves ($preSFGT_{glove}$) and post-SFGT with gloves ($postSFGT_{glove}$) and without gloves ($postSFGT_{no\ glove}$) conditions. The difference between $preSFGT_{no\ glove}$ and $preSFGT_{glove}$ described the effect of gloves on handgrip strength. The difference between $preSFGT_{no\ glove}$ and $postSFGT_{no\ glove}$ described the effect of muscular fatigue resulting from occupational tasks (without the confounding effect of wearing gloves). The difference between $preSFGT_{no\ glove}$ and $postSFGT_{glove}$ described the combined effect of the glove and occupational tasks on handgrip strength. The difference between $preSFGT_{glove}$ and $postSFGT_{glove}$ described the effect of fatigue from occupational tasks while wearing gloves. The difference between $preSFGT_{glove}$ and $postSFGT_{no\ glove}$ examined combined main effects and therefore was not used for analyses.

Pearson Product Moment Correlations were used to describe the bivariate relationships between baseline handgrip strength and glove- and task-induced decrements in handgrip strength. Pearson correlations were also used to describe relationships between baseline handgrip strength and glove- and task-induced decrements in relative handgrip strength versus timed completion of the breach and pull task and the timed completion of all SFGT tasks. Relative handgrip strength for each condition was calculated as: ((experimental condition - baseline) / baseline condition) x 100. Additionally, paired *t*-tests were used to assess differences between pre-and-post-SFGT physiological (i.e., blood lactate concentration) and perceptive responses (i.e., RPE, dyspnea, thermal strain). The level of significance was established *a*-

priori and set at $p < 0.05$ for all analyses. Data were analyzed using IBM® SPSS® Statistics 27 (IBM Corp., Chicago, IL).

CHAPTER 3

RESULTS

The demographic and performance characteristics of the sample are displayed in Tables 1 and 2, respectively. To provide context, the subjects' baseline (barehanded) dominant handgrip and non-dominant strength were combined then stratified by sex and age and compared to normative data (Dumke, 2018). Thus, 21% (n = 3) of subjects were classified as having "Poor" grip strength, 21% (n = 3) as "Good", 36% (n = 5) as "Very good", and 21% (n = 3) as "Excellent". There was no effect of hand dominance (F (1,107) = 0.37, p = 0.54, $p\eta^2$ = 0.003) indicating that decrements in handgrip strength were similar between dominant and non-dominant hands for each condition and therefore dominant hand data were used in the remaining analyses. The body composition outcomes (i.e., body mass, body fat percentage, fat mass, lean mass percentage, lean mass, body mass index, waist-to-hip ratio) were not significantly correlated to baseline handgrip strength or decrements in handgrip strength between conditions ($r \leq 0.37$, $p \geq 0.076$), thus scaling strength outcomes relative to anthropometric characteristics was not warranted.

Table 1. Demographic and anthropometric characteristics of 14 structural firefighters.

Variable	(Mean ± *SD*)			95% Confidence Intervals	
				Lower	Upper
Age (yr)	35.5	±	7.2	31.5	38.9
Years of service (yr)	8.0	±	5.2	5.5	10.8
Height (cm)	178.1	±	6.2	175.1	181.2
Body mass (kg)	87.3	±	12.7	81.0	93.5
Body mass index ($kg \cdot m^{-2}$)	27.9	±	3.2	26.3	29.4
PPE (kg)	24.4	±	1.2	23.8	25.0
PPE (%bm)	28.5	±	4.2	26.3	30.7
Body fat (%)	20.8	±	5.9	17.3	29.3
Body fat (kg)	19.0	±	6.9	14.8	22.0

Lean mass (%)	79.2	±	5.9	76.7	82.7
Lean mass (kg)	70.4	±	8.1	66.1	74.0
Dry Lean mass (kg)	20.6	±	2.6	19.2	21.9
Total body water (%)	56.0	±	4.5	54.0	58.5
Total body water (L)	49.8	±	5.7	46.6	52.3
Waist-to-hip ratio	0.9	±	0.1	0.8	0.9
Impedance (Ω)	440.4	±	40.0	423.7	463.4
Resistance at 50Hz (Ω)	436.5	±	40.7	420.1	459.3
Reactance at 50Hz (Ω)	58.7	±	6.3	56.9	62.2

PPE(%bm): (Personal protective equipment / Body mass) x 100, the percentage of subjects' body mass that was carried during the performance of the simulated fireground test.

Table 2. Performance characteristics of 14 structural firefighters.

				95% Confidence Intervals	
Variable	(Mean ± *SD*)			Upper	Lower
30-15$_{IFT}$ (km·h^{-1})	15.6	±	1.8	14.8	16.8
Long jump distance (cm)	196.4	±	25.0	184.3	208.8
Lower body power (W)	2320.7	±	807.7	416.1	487.1
Breach and pull task time (s)	55.4	±	14.3	48.9	62.9
Total SFGT time (s)	449.8	±	68.4	416.1	487.1

30-15$_{IFT}$: Running velocity of the last successfully completed stage in 30-15 Intermittent Fitness Test; SFGT: Simulated fireground test.

Table 3. Dominant handgrip strength by condition (N = 14).

Condition	Handgrip Strength (kg) (Mean ± *SD*)		
preSFGT$_{no\ glove}$	48 .0	±	13.0
preSFGT$_{glove}$	32.0	±	9.2
postSFGT$_{glove}$	18.0	±	9.3

$postSFGT_{no\ glove}$	26.0	±	11.9

$preSFGT_{glove}$: gloved handgrip condition prior to the simulated fireground test;
$postSFGT_{glove}$: gloved handgrip condition following the simulated fireground test;
$postSFGT_{no\ glove}$: barehanded handgrip strength measurement condition following the simulated fireground test.

Handgrip strength values are provided in Table 3. A descriptive comparison of the effect of glove use and occupational tasks is provided in Table 4. There was an overall main effect of condition (F (3,104) = 35.62, $p < 0.001$, $p\eta^2 = 0.50$) indicating that gloves, occupational tasks, and the combined effect of gloves plus occupational tasks decreased handgrip strength ($p < 0.001$ for all). There was a main effect for glove use ($\beta = 15.43$, (F (1,107) = 28.04, $p < 0.001$)) indicating that glove use decreased handgrip strength in non-fatigued state ($preSFGT_{no\ glove}$ vs. $preSFGT_{glove}$). There was a main effect of occupational tasks when testing with gloves ($\beta = 13.50$, (F (1,107) = 21.47, $p < 0.001$)) indicating that handgrip strength decreased after performing occupational tasks while wearing gloves ($preSFGT_{glove}$ vs. $postSFGT_{glove}$). Likewise, there was a main effect of occupational tasks when testing without gloves ($\beta = 21.57$, (F (1,107) = 54.82, $p < 0.001$)) indicating that handgrip strength decreased after performing occupational tasks and testing without gloves ($preSFGT_{no\ glove}$ vs. $postSFGT_{no\ glove}$). There was a collective main effect of glove use and occupational tasks ($\beta = 28.93$, (F (1,107) = 98.56, $p < 0.001$)) indicating that handgrip strength decreased from the pre-SFGT barehanded condition to the post-SFGT glove condition ($preSFGT_{no\ glove}$ vs. $postSFGT_{glove}$).

Table 4. Absolute (Abs) and relative changes in dominant handgrip strength and correlations to baseline handgrip strength (N = 14).

Condition	Abs Δ (kg)			%Δ			Correlation Abs to Baseline	
	(Mean ± *SD*)			(Mean ± *SD*)			*r*	*p*
$preSFGT_{no\ glove}$	48 .0	±	13.0		-		-	-
$preSFGT_{glove}$ - $preSFGT_{no\ glove}$	-16.0	±	5.2	*-33.4	±	5.6	-0.82	≤ 0.001
$postSFGT_{glove}$ - $preSFGT_{no\ glove}$	-30.0	±	12.4	*-61.6	±	17.4	-0.73	0.003

postSFGT$_{no\ glove}$ - preSFGT$_{no\ glove}$	-22.0	±	13.7	*-44.9	±	23.5	-0.61	0.021
postSFGT$_{glove}$ - preSFGT$_{glove}$	-14.0	±	9.2	*-42.5	±	25.5	-0.52	0.055

Abs Δ: Absolute change between conditions;
%Δ: ((experimental condition - baseline) / baseline condition) x 100; SFGT: simulated fireground test;

preSFGT$_{no\ glove}$: barehanded handgrip condition prior to the simulated fireground test ;
preSFGT$_{glove}$: gloved handgrip condition prior to the simulated fireground test ;
postSFGT$_{glove}$: gloved handgrip condition following the simulated fireground test ;
postSFGT$_{no\ glove}$: barehanded handgrip strength measurement condition following the simulated fireground test.

Baseline handgrip strength and the glove- and task-induced decrement in handgrip strength were not correlated to breach and pull task time or total SFGT time (Table 5). Compared to preSFGT, postSFGT blood lactate (t (12) = -13.03, p < 0.001, d = -3.61), RPE (t (13) = -10.22, p < 0.001, d = -2.73), thermal strain (t (13) = -7.79, p < 0.001, d = -2.08), and dyspnea (t (13) = -6.70, p < 0.001, d = -1.79) levels were greater (Table 6).

Table 5. Correlations between baseline handgrip strength and glove- and task-induced handgrip strength decrements versus timed completion of the breach and pull task (s) and simulated fireground test (s) (N = 14).

Condition	Breach & Pull Task		SFGT	
	r	*p-value*	*r*	*p-value*
preSFGT$_{no\ glove}$	-0.32	0.26	0.06	0.84
preSFGT$_{glove}$ - preSFGT$_{no\ glove}$	0.12	0.68	0.11	0.70
postSFGT$_{glove}$ - preSFGT$_{no\ glove}$	0.20	0.49	-0.01	0.97
postSFGT$_{no\ glove}$ - preSFGT$_{no\ glove}$	0.32	0.27	-0.01	0.97
postSFGT$_{glove}$ - preSFGT$_{glove}$	0.21	0.47	-0.12	0.97

SGFT: simulated fireground test; Δ: change.
preSFGT$_{no\ glove}$: barehanded handgrip condition prior to beginning the SFGT.
preSFGT$_{glove}$: gloved handgrip condition prior to beginning the SFGT.
postSFGT$_{glove}$: gloved handgrip condition following the SFGT completion.
postSFGT$_{no\ glove}$: barehanded handgrip strength measurement condition following the SFGT completion.

Table 6. Physiological and perceptual outcomes before and after completion of a simulated fire ground test (SFGT) in 14 structural firefighters.

Variable	Baseline					Posttest				
				95% Confidence Intervals					95% Confidence Intervals	
	(Mean ± *SD*)			Lower	Upper	(Mean ± *SD*)			Lower	Upper
Blood lactate ($mmol \cdot dL^{-1}$; n=13)	1.3	±	0.6	1.0	1.6	*11.7	±	3.2	10.2	13.3
Thermal strain	0.2	±	0.7	-0.2	0.5	*1.7	±	0.9	1.2	2.2
RPE	0.2	±	0.6	0.0	0.5	*6.1	±	2.1	4.9	7.2
Dyspnea	0.1	±	0.3	0.0	0.4	*4.7	±	0.0	3.3	6.0

RPE: Rating of perceived exertion.
*Significant difference from baseline ($p < 0.05$).

CHAPTER 4

DISCUSSION

Handgrip strength plays a critical role in performing occupational tasks safely and effectively (Lindberg, Oksa, & Malm, 2014; Sonne et al., 2015; Williford et al., 1997). Therefore, the primary aims of the present study were: (Aim #1) to quantify the independent and collective impact of glove use and performance of occupational tasks on handgrip strength, (Aim #2) to explore the relationship between baseline handgrip strength versus glove and task-induced decrements in handgrip strength, (Aim #3) to explore the relationship between glove and task-induced decrements in handgrip strength versus occupational performance. Regarding Aim #1, the findings from the present study indicate that decrements in handgrip strength occur when donning regulation firefighting gloves (Table 4). These findings are supported by Bishu and colleagues (1987) who indicated that donning gloves reduced mean grip force by 11% when compared to a barehanded condition ($p < 0.001$). The researchers concluded that strength decrements from gloves were due to lack of tactile feedback when wearing gloves, improper fit, and/or individual and task differences (Bishu et al., 1987). As expected, the 11% decrement from the leather, suede, and cotton gloves was not as substantial as the 33% decrement from regulation fire gloves observed in the present investigation. This discrepancy may be due to the greater thickness of three-layered firefighting gloves, which reduces range of motion compared to the leather, suede, or cotton gloves. Bishu and Klute (1995) conducted a similar study that evaluated the impact of extravehicular activity gloves (EVA or space gloves) on gripping and grasping tasks and concluded that these gloves produced a 50% reduction in grip strength, and compromised inter-digital movements, range of motion, and tactile sensitivity. The EVA gloves likely had a greater negative impact on handgrip force production than regulation fire gloves because Bishu and Klute (1995) manipulated the surrounding pressure differential. Furthermore, EVA gloves utilize a thicker design which limits the hand to a larger increase in grip span and inner grasp diameter than suede, cotton, leather, and firefighting gloves. Moreover, EVA gloves partially cover the forearm, which limits wrist motion more than the gloves examined by Bishu et al., (1987) and the present study. In addition, Bishu and Klute (1995) examined the impact of gloves on fine motor skills. The present study only evaluated the impact of gloves and tasks on maximal voluntary isometric contraction (MVIC) and did not assess fine motor performance. However, firefighters do perform numerous essential job tasks that require dexterity such as operating radios, connecting hose couplings, and utilizing a self-contained breathing apparatus (SCBA). Future research should consider assessing the impact of firefighter gloves on fine motor control.

The findings from Aim #1 also indicated that the performance of occupational tasks decreased handgrip strength suggesting that fatigue played a role in the diminished post-SFGT MVIC (Table 4). Literature suggests that the muscle contraction intensity and pattern influence the accumulation of fatigue. For instance, Sonne and coworkers (2015) demonstrated that performing a pyramid complex of submaximal isometric handgrip tasks (15 s contraction at 15, 30, & 45% of MVIC) for 2.5-3.8 min decreased MVIC by approximately 18%. The study indicated that fatigue accumulates with increasing intensity demands and dissipates with lower intensity demands (Sonne et al., 2015). In addition, Yung and colleagues (2012) reported that the pattern of muscle contraction influences the accumulation of fatigue. Specifically, individuals performing sustained isometric contractions at 15% MVC accumulated greater fatigue than performing variable intensity contractions that resulted in the same average force as the sustained condition. The authors suggested that spending some time at lower contraction intensities may have allowed for a spatial redistribution of muscle activity, whereas allowing for brief periods of muscle relaxation may provide reperfusion of blood flow to washout local vasodilators and provide energy substrates (Yung et al., 2012; Bystrom and Lilbom, 1990). Considering the nature of the firefighting tasks in the present study, it would appear that these tasks required a variety of muscular contraction intensities and patterns. For instance, carrying handsaws likely requires a sustained lower intensity contraction, whereas securing and dragging a victim, advancing a charged hose line, swinging a sledgehammer, and holding a pike pole during a breach and pull task requires sustained higher intensity contractions. In addition, some tasks utilize a contract-relax pattern such as raising and lowering a ladder against a structure using a hand-over-hand technique. Finally, some tasks allow for muscle relaxation, such as walking between tasks without carrying gear. Although it is difficult to compare the findings from the aforementioned laboratory-controlled studies to the present study, we may speculate that the greater magnitude of handgrip force decrement in the present study (relative difference: 42.5-44.9%, Table 4) was due to performing multiple tasks over a 7.5 min period that required sustained high-intensity contractions, including performing the breach and pull task (task duration: 55.4 s) immediately preceding the post-SFGT MVIC.

The present study measured handgrip strength immediately following completion of the SFGT and did not assess the recovery response. This information is important to provide perspective regarding recovery in handgrip capabilities. Related research has indicated that muscle function (i.e., twitch force) is depressed up to 24 hours post-exercise due to performance of sustained handgrip contraction performed for 2.5-3.8 min at 15% of MVC, however, the MVC force output was statistically similar to baseline (Yung et al., 2012). Regardless, future research should evaluate the recovery response to performing firefighting tasks and consider the implementation of potential restoration strategies.

Extending the aforementioned task-induced fatigue findings, we noted in Aim #2 that subjects with greater baseline handgrip strength tended to exhibit lesser independent and collective glove- and task-induced decrements in handgrip strength (Table 4). Thus, it appears that greater handgrip strength confers benefits regarding the deleterious impact of glove use and provides tolerance to task-induced fatigue. There are a host of factors related to the magnitude of handgrip strength, including muscle thickness and greater electromyography (EMG) activity, as well as employment in physical labor occupations, physical training status, and preferred leisure activities (Cronin et al., 2017; Josty and colleagues, 1997; Trinidad-Fernandez et al., 2020). Accordingly, firefighter schedules typically require lengthy shifts (i.e., 24- and 48-hour) and relatively frequent intense physical labor (Smith, 2011). The current investigation supports the contention that physical labor occupations may enhance grip strength, as 78% of firefighters in the present study displayed “Good” to “Excellent” handgrip strength as compared to normative data from the general population (Dumke, 2018). In addition, the fact that firefighters possessing greater grip strength tended to overcome the restrictive nature of gloves and experienced less fatigue accumulation from performing occupational tasks highlights the need for training interventions to optimize grip strength.

Regarding Aim #3, the time to complete the breach and pull task and total SFGT were not associated with baseline or glove- and task-induced decrements in handgrip strength. In contrast, previous research has demonstrated that maximal isometric handgrip strength was inversely related to the timed completion of a job-related performance test in firefighters (r = -0.71, p < 0.05, Rhea et al., 2004; r = -0.54, p < 0.01, Williford et al., 1997). Specifically, Rhea et al. (2004) examined the timed completion of individual fireground tasks, allowing for full inter-task recovery. This methodology may have produced the discrepant findings as 4 of the 5 occupational tasks took, on average, 38 s or less (Combined task time: 162 s), suggesting a greater reliance on muscular strength. Whereas, the total SFGT time took, on average, 7.5 min in the present study, potentially suggesting a greater reliance on aerobic endurance and muscular endurance versus muscular strength. Interestingly, Rhea et al. (2004) also assessed grip strength endurance and accordingly, did not identify significant relationships with individual or overall timed task completion. Thus, it is possible that the work: rest format of a fireground assessment may influence the relationship with handgrip strength and endurance.

The breach-and-pull task, which simulates structure ventilation and checking for fire extension, has been described as one of the most physically demanding tasks on a fireground (Smith, 2011). It is important to note that many firefighting tasks are completed with varying techniques. For example, the breach and pull task can be performed by grasping the pike pole and utilizing the back and arms to push and pull. However, the motion is more often performed by a firefighter cupping their hands underneath the pike pole and using their legs to drive the pole vertically against the overhead ceiling structure. Given the nature of the later technique, lower body power coupled with handgrip strength may be more influential toward breach and pull task performance than handgrip strength alone. In addition, the breach-and-pull task was completed at the end of a series of occupational tasks and therefore the observed decrement in handgrip strength was produced by all SFGT tasks and not independent of the other tasks, thus potentially making it difficult to identify a potential relationship between total strength decrement and independent breach and pull completion time.

Limitations

There are several limitations in the present study. The present study used a standardized handgrip assessment order pre-and post- SFGT. This was purposeful to ensure that the post-SFGT glove assessment was conducted immediately after completion of the simulated fireground tasks. In addition, the present study used a threaded pike pole for the breach and pull task that may have provided an ergonomic advantage enhancing the ability to hold the pike pole and thus allowing firefighters with lesser grip strength to still complete the task in a timely manner and ultimately affect the potential relationship between grip strength and task completion time. It is difficult to speculate how utilization of a smooth-handled pike pole may have impacted breach and pull performance. Additionally, firefighters were instructed to perform the SFGT at an “occupationally relevant pace”. However, some firefighters may have been competitive and completed the SFGT at near maximal levels of effort which may have impacted the correlation analysis. This investigation, however, disregards the potential order effect of gloved versus barehanded grip strength pre-and post- SFGT. However, pretest data demonstrate the large effect the gloves imposed on grip strength. It is possible that the post-SFGT no glove grip strength condition recovered more due to the additional recovery time from measuring handgrip strength in the gloved condition first.

CHAPTER 5

PRACTICAL APPLICATION

Firefighting differs from traditional occupations given the reoccurring presence of emergency situations. It is well known that firefighting is physically and psychologically stressful (Dennison et al., 2012). The ability to manipulate tools while enduring the associated stress is essential for completing firefighting tasks. Baseline handgrip strength has been shown to correlate with firefighter occupational performance in previous investigations (Lindberg, Oksa, & Malm, 2014; Williford et al., 1997). Practitioners are encouraged to monitor handgrip force production capabilities given the present finding that fatigue magnitude is influenced by baseline strength values. Departments may elect to assess firefighters' handgrip strength at the start of a shift and/or after responding to an emergency. Over time, results from these assessments may provide valuable insight into an individual's fatigue response, recovery status, as well as relative risk for an upper limb injury while performing occupational tasks (Sonne et al., 2015).

Additionally, tactical strength and conditioning practitioners are encouraged to utilize training strategies and targeted resistance training programs to optimize handgrip strength among structural firefighters. Derived from the comprehensive findings from Feix et al. (2016), it is evident that occupational tasks associated with firefighting often require small-diameter power palm grasps, large-diameter power palm grasps, and medium wraps. Specific training strategies may encompass maximal force production efforts (e.g., pinching or grasping relatively heavily weighted plates), endurance-focused grip training (e.g., hanging from a pull-up bar for an intended duration), and varying grip types for standard exercises when appropriate (e.g., grasping the wide underside of a kettlebell instead of the narrow handle).

CHAPTER 6

CONCLUSION

Sufficient handgrip capabilities are necessary to safely and effectively perform fireground tasks (Rhea et al., 2004). The findings from this study indicate that wearing gloves and performing occupational tasks reduces handgrip force production capabilities (Fleming et al., 1997; Bishu and Klute, 1995) and greater handgrip strength tends to attenuate the independent and collective glove- and task-induced decrements in handgrip strength. Overall, practitioners are encouraged to monitor handgrip force production capability and utilize handgrip strengthening strategies to enhance firefighter safety and occupational readiness.

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APPENDIX A

REVIEW OF LITERATURE

The primary purpose of this study was to determine the independent and collective effect of glove use and performance of occupational tasks on subsequent handgrip strength. The secondary purpose of this study was to explore the relationship between baseline handgrip strength versus glove and task-induced decrements in handgrip strength. In addition, we sought to determine if any glove and task-induced decrements in handgrip strength were correlated to the timed completion of occupational tasks. To date, there are no published investigations are examining the effect of regulation fire gloves or occupational tasks on handgrip strength in structural firefighters. Therefore, this literature review will cover relevant literature regarding the fundamentals of handgrip ability, central and peripheral fatigue mechanism and their effects on handgrip force production capability, the role of handgrip strength in occupational tasks, and the importance of sufficient handgrip capabilities to safely perform firefighting tasks.

Handgrip Overview

The hand is a complex multipurpose tool, comprised of more than fifteen joints, which results in more than 20 degrees of freedom (Feix et al., 2016). Optimal handgrip function depends on the integrity of the structures from wrist to fingers. Grasping or gripping requires synchrony between multiple muscles of the hand (e.g., wrist extensors and finger flexors during grip tasks). The primary muscles involved in grip are flexor carpi radialis, flexor carpi ulnaris, flexor digitorum superficialis, extensor carpi radialis, extensor carpi ulnaris, and extensor digitorum communis (Ambike et al., 2014).

Feix et al. (2016) define a grasp as every static hand posture in which an object can be held securely in one hand regardless of hand orientation. Each grasp can be classified into a dichotomy of precision or power. The power grip describes a rigid relationship between the object and the hand, which means that all movements of the object have to be created by the arm. Conversely, precision handling refers to the hand's ability to perform movements without having to move the arm. Additional grip classifications include whether or not the object is in constant relation to the hand or static grasp, while intermediate (or link grasp) has similar power and precision proportions. There are kinematic implications and limitations associated with different grips (Feix et al. 2016).

Many variables must be considered when measuring grip strength, such as upper extremity and body position, proper choice of instrument, number and duration of trials, subject age, sex, and impairment state of the individual being tested. Beam and Adams (2014) describe the rationale, methods, procedures, and purpose of testing isometric (static) handgrip strength. Beam and Adams (2014) begin by stating that handgrip strength (HGS) is vital for tasks of daily living. Interestingly, they offered the insight that strength can fluctuate daily by 5-9% in men and 2-12% in women. Additionally, Beam and Adams (2014) suggested that hand dominance impacts HGS, with the dominant hand being 8-14% stronger on average.

Regarding test reliability, intraclass correlation coefficients (ICC) revealed that there are no differences in assessment reliability between single-trial maximal force production, the mean of two trials, or the mean of three trials paired with the highest maximal force of three trials (Beam & Adams, 2014). Furthermore, inter-rater reliability is optimal when following the same procedures and using a Jamar hydraulic hand dynamometer for assessment ($r = 0.97$). The authors state that the accuracy of testing isometric HGS is valid because it is positively correlated with muscle mass ($r = 0.60$), positively correlates with the total strength of 22 other muscles ($r = 0.69$), and is specific for testing isometric muscle actions (Beam & Adams, 2014).

Balogun et al. (1991) investigated the effects of testing posture and elbow position on isometric handgrip strength in 61 subjects (Males: 35, Females: 26). Four randomized experimental conditions were used: (1) sitting with the elbow in 90-degree flexion, (2) sitting with the elbow in full extension, (3) standing with the elbow in 90-degree flexion, and (4) standing with the elbow in full extension. A two-factor repeated-measures ANOVA determined significance between grip strength conditions and when factored by sex. Post hoc analyses determined males to have greater HGS than females in all testing positions ($p < 0.01$). Second, the researchers found that all participants had greater HGS values when standing versus sitting regardless of elbow position ($p < 0.05$). Balogun and colleagues. (1991)

emphasized the need for universally accepted standard testing procedures for assessing isometric handgrip strength.

Similarly, De et al. (2011) examined variations in isometric HGS concerning changes in posture and joint angles in 380 healthy Bengali adults (Males: 156, Females: 224; aged 20 – 60 yr). HGS was tested with a Lafayette handgrip dynamometer. HGS was measured across three postures (sitting, standing, and laying down) and different arm postures. When seated, HGS was also measured with the elbow at 90-degrees of flexion while supported and non-supported. The 180-degree condition was described as the arm hanging normally beside the body with the elbow angle at approximately 180-degrees. Readings were measured in triplicate on each hand and the maximum value was used for analyses. The results added to the consensus of male subjects may have greater HGS than female subjects ($p < 0.001$). De et al. (2011) concluded that standing grip strength was higher (1.3-5.9%) than all other tested postures ($p < 0.05$). The researchers concluded that there was no significant difference in HGS values between the 90-degree and 180-degree joint angles. Additionally, the variance between the elbow joint angles was minimal (0.9-3.4%).

Previous investigations have examined handgrip force production capabilities between different postures, mainly sitting versus standing (Åstrand and Rodahl, 1977); Ibarra-Mejia et al., 2012), and concluded that standing elicited greater force production capability in part from greater central nervous system activity. The reduced central nervous system activity observed while seated position may be explained by the physiological relaxation combined with lesser muscle recruitment from the lower extremities, (Ibarra-Meija et al., 2012). Clark and colleagues (1991) offered another perspective that discrepancies were resultant of mechanical and systemic factors. Clarke et al. (1991) reported that decreases in handgrip force generation capabilities may result from the tension in the cervical cord and dura while the flexion is occurring at the hips.

Mechanisms of Fatigue

Fatigue is commonly described as a multi-factorial, task-dependent, decrease in muscle function or force production capability. Carroll et al. (2017) define *peripheral fatigue* as the reduction in voluntary force production resulting from actions distal to the neuromuscular junction (i.e., the muscle fibers and the neuromuscular junction). Moreover, Carroll et al. (2017) define *central fatigue* as the reduced capacity for the central nervous system to activate skeletal muscles resulting from actions within the central nervous system (i.e., central drive to motoneurons).

Peripheral and central fatigue are similar in that symptoms typically continue after the demand for force has ended, but contrast by cause and time until recovery. For example, continuous low-intensity exercise and rapid decline of force production for approximately two minutes following high-intensity exercise are associated with central fatigue (Kennedy et al., 2012); Carroll et al.,2017). Factors of peripheral fatigue, excitation-contraction coupling, and reperfusion of muscles last for approximately three to five minutes following the cessation of intense exercise. Because of these factors, complete recovery may not be present for hours (Caroll et al., 2017). The mechanisms of fatigue and duration of recovery following exercise-induced fatigue are greatly impacted by the nature of the exercise.

Given this information, it is reasonable to expect the isometric handgrip strength assessment to result in peripheral fatigue and the simulated fireground test to result in central and peripheral fatigue.

Literature suggests that the muscle contraction intensity and pattern influence the accumulation of fatigue. For instance, Sonne and coworkers (2015) demonstrated that performing a pyramid complex of submaximal isometric handgrip tasks (15 s contraction at 15, 30, & 45% of maximal voluntary isometric contraction: MVIC) for 2.5-3.8 min decreased MVIC by approximately 18%. The study indicated that fatigue accumulates with increasing intensity demands and dissipates with lower intensity demands (Sonne et al. 2015). In addition, Yung and colleagues (2012) reported that the pattern of muscle contraction influences the accumulation of fatigue. Specifically, individuals performing sustained isometric contractions at 15% MVC accumulated greater fatigue than performing variable intensity contractions that resulted in the same average force as the sustained condition. The authors suggested that spending some time at lower contraction intensities may have allowed for a spatial redistribution of muscle activity, whereas allowing for brief periods of muscle relaxation may provide reperfusion of blood flow to washout local vasodilators and provide energy substrates (Yung et al. 2012; Byström and Lilbom, 1990). Considering the nature of the firefighting tasks in the present study, it would appear that these tasks required a variety of muscular contractions intensities and patterns. For instance, carrying handsaws likely requires a lower intensity sustained contraction, whereas securing and dragging a victim, advancing a charged hose line, swinging a sledgehammer, and holding a pike pole during a breach and pull task requires higher intensity sustained contractions. In addition, some tasks utilize a contract-relax pattern such as raising and lowering a ladder against a structure using a hand-over-hand technique to touch each ladder rung. Finally, some tasks allow for muscle relaxation, such as walking between tasks without carrying gear.

Handgrip and Occupational Performance

Bishu et al. (1987) explained the general use and need of gloves in occupational tasks but suggests that performance may be compromised as a result of glove use. The authors suggest that several factors may contribute to strength decrements, mainly (1) lack of tactile feedback when wearing gloves, (2) improper fit, and (3) individual and task differences. Researchers tested the grip and grasp abilities of 15 healthy subjects (aged 20-46 years; 5 subjects per glove size: small, medium, and large) while barehanded and donning three types of gloves. The gloves “Deerskin style 1090 glove” (suede), “Smooth Thorobred leather glove” (leather), and “Flannel Clute cut glove” (cotton) were measured and factored by tenacity, snugness, suppleness, and material thickness. Donning gloves reduced mean grip force by 10.9% and grasp force by 8.3% when compared to the barehanded condition ($p < 0.001$). All measured factors of the gloves were inversely associated with the gripping task ($r \geq -0.42$, $p < 0.001$) and grasp task ($r \geq -0.41$, $p < 0.001$). Ultimately, the investigation concludes that strength decrements from gloves result from more than one of the four glove structure descriptors. Bishu et al., (1987) concluded that the decrements from wearing gloves may be explained by discomfort from an increase in grip span and inner grasp diameter.

In a later study, Bishu and Klute (1995) investigated the impact of extravehicular activity (EVA) gloves on hand capabilities under different micro atmospheric pressures in 6 subjects (Males: 3, Females: 3). Independent variables were gender (2), glove type (2), pressure differential (5), and glove configurations (3). Subjects performed multiple tests to assess the glove effect on occupational performance. To measure occupational performance, subjects performed two strength assessments including grip and pulp pinch strength, two dexterity assessments consisting of a rope tying test and nuts and bolts test, and one tactility measure of a two-point discrimination assessment. This study added to the consensus that on average, female subjects have lesser grip strength, approximately 60-70% of male subjects. Interestingly, donning gloves resulted in an average of 50% grip strength reduction and 10% pinch strength reduction. The gloved time to completion of the nut and bolt assembly task was 5-6 times slower than barehanded. The effect was similar for the knot-tying time. The authors conclude that gloves reduce inter-digital movements, range of motion, and tactile sensitivity.

Similarly, Dianat et al. (2012) conducted a study on the effects of three industrial gloves (cotton, nylon, and nitrile gloves) on hand performance capabilities while using pliers during simulated assembly line tasks for two hours. The results suggest that the length of time worn does not impact muscle activity, wrist posture, touch sensitivity, handgrip strength, or forearm torque strength. They found that wearing gloves had a significant effect on handgrip strength ($p \leq 0.001$) and task time was also significant for handgrip strength ($p \leq 0.05$). The researchers conclude that the use of gloves and their potential implications should be evaluated during the performance of relevant occupational tasks.

Handgrip strength and Firefighting

Firefighting differs from traditional occupations concerning the presence of an emergency. There is limited research evaluating the effect of handgrip strength and firefighters' occupational performance. Williams-Bell et al. (2009) examined CPAT completion times among healthy, physically active adults (n =57) to simulate the physiological demands of firefighting recruits. A backward stepwise regression resulted in models accounting for greater than 67% of the variance being absolute VO_{2max} alone or relative VO_{2max} plus body mass and handgrip strength (Williams-Bell et al. 2009). The study reported large errors of estimation but agrees that handgrip strength is important to occupational tasks associated with firefighting.

Similarly, Lindberg et al. (2014) investigated relationships between physical assessments and the performance of firefighting tasks. Participants included a mix of full-time, and part-time male firefighters as well as civilian men and women. One task included *cutting*, where subjects used a modified 16.1 kg concrete saw back and forth across a two-meter-sided square on the floor at a rate of 40 moves per minute until exhaustion or a maximum of 15 minutes in duration. The strongest correlations with time were trunk extension (r_s = 0.72, $p < 0.01$) and maximal handgrip strength (r_s=0.67, $p < 0.01$). The researchers concluded that work capacity was strongly correlated ($r_s \geq 0.7$) with maximal handgrip strength, bench press, chin-ups, dips, upright barbell row, standing broad jump, and barbell shoulder press.

Dennison et al. (2012) examined the effect of training status and fatigue on the occupational performance of twelve male career firefighters who were deemed physically trained. Participants underwent a battery of anthropometric and performance assessments and performed a researcher-designed, seven-part, timed simulated fireground test (SFGT) in full personal protective equipment while breathing through a self-contained breathing apparatus. The trained firefighters completed the SFGT, performed a circuit-style exercise session, rested for 10 minutes, then completed the SFGT again to simulate a fatigued response to a fire scene. Performance on the SFGT was determined via time to completion and mean relative heart rate. Additionally, the results were compared to the non-fatigued (baseline) SFGT values untrained group consisting of thirty-seven male career firefighters from the same department. The researchers concluded that exercise-induced fatigue contributed to a 9.6% time increase for the SFGT. Collectively, the trained and fatigued group displayed a 70% more efficient SFGT than the unfatigued untrained group. The authors concluded that this work highlights the importance of implementing and continuing consistent efforts that increase physical fitness parameters in firefighters.

It is well known that firefighting is a dangerous occupation (Smith, 2011). Annually, about 80,000 firefighters are injured while on duty with 40% of those injuries occurring on the scene of a fire (Smith, 2011). With this in mind, Poplin et al. (2016) developed a comprehensive fitness measure to predict injury risk by examining 799 fire service employees over a five-year period. The authors described occupationally relevant fitness for firefighters to encompass high aerobic fitness, anaerobic capacity, muscular strength, and muscular endurance (Poplin et al., 2016; Smith, 2011). Poplin et al. (2016) examined aerobic capacity with a submaximal treadmill protocol, resting heart rate, maximal isometric handgrip strength via hand dynamometer, push-ups and sit-ups to a metronome until failure, flexibility via sit-and-reach distance, and percent body fat via bioelectrical impedance analyzer. Each subject earned an equally weighted fitness score per year. Over the five-year period, each subject was seen for at least one physical examination, with the group average being 3.5 visits per employee. Poplin et al. (2016) utilized a Cox proportional hazard model with repeated measures to identify the associations between tiered fitness scores and injury probability. They found that firefighters with decreased comprehensive fitness scores were associated with a higher risk of an injury compared to their more fit counterparts regardless of age. The work by Poplin et al. (2016) highlights the importance of efforts toward monitoring and improving physical fitness in firefighters.

Conclusion

This investigation agrees with the current academic consensus that handgrip is complex (Domalain et al. 2008), gloves and fatigue affect handgrip force production capability (Bishu and Klute, 1995), and sufficient handgrip capabilities are necessary to safely perform firefighting tasks (Williams-Bell et al., 2009). Currently, there is no published literature measuring the decrement in handgrip force production capabilities following the performance of simulated firefighting tasks while wearing regulation firefighting gloves. This study is unique in that it will explore the link between multiple outcomes and the use of regulation fire gloves while performing firefighting tasks. Given the general overview of fatigue mechanisms, it is reasonable to expect the occupational tasks to manifest in central and peripheral fatigue that may result in observable decrements in handgrip strength. The results may provide practitioners with insight into the impact of fatigue and gloves on firefighters' occupational performance.

Additionally, this research may lead to further investigations regarding variables that may impact tactical operator readiness, the impact of personal protective equipment on performing occupational tasks, and relevant strength and conditioning training strategies.

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APPENDIX B

IRB APPROVAL

GEORGIA SOUTHERN UNIVERSITY
RESEARCH INTEGRITY

Institutional Review Board (IRB)
Veazey Hall 3000
PO Box 8005 • STATESBORO, GA 30460
Phone: 912-478-5465
Fax: 912-478-0719
IRB@GeorgiaSouthern.edu

To:	Lanham, Sarah Melton, Bridget
CC:	Langford, Emily University of Kentucky
From:	Eleanor Haynes, Director, Research Integrity
Date:	August 17, 2021
Expiration Date:	April, 27, 2022 ***This date is based on the approval period granted by the primary institution.***
Subject:	Status of Application for Reciprocal Agreement Approval to Utilize Human Subjects in Research

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As authorized in the Federal Policy for the Protection of Human Subjects, I am pleased to notify you that the Institutional Review Board of Georgia Southern University has elected to rely on the approval of University of Kentucky Institutional Review Board for approval of your proposed research project titled "Air Consumption Efficiency in Structural Firefighters," associated with the following identification numbers:

Georgia Southern University ID: H21447
University of Kentucky (Primary Institution) ID: 67300

This approval is contingent on the following:

- **This approval will become invalid at any time the primary institution's approval is not in effect.**
- **Any alteration, amendment, adverse event or discontinuance of the primary IRB approval will be reported to the GS IRB immediately and no research will be conducted on this approval during any time in which the Primary IRB approval is invalid.**
- **The review performed by the primary institution/organizations designated IRB meets the human subjects protection requirements of the GS OHRP-approved FWA.**
- **The IRB at the primary institution/organization will follow written procedures for reporting its findings and actions to appropriate officials at GS including minutes of meetings that address any process relating to actions required in continuing review of the project.**
- **The primary institution remains responsible for ensuring compliance with the IRB's determinations and with the Terms of its OHRP-approved FWA.**

You are required to notify the GS IRB when this project is complete or closed. A termination form is available on the IRB website.

APPENDIX C: PERCEIVED DYSPNEA SCALE

Rate of Perceived Dyspnea

(Breathing)

0	Nothing at all
0.5	Very, very slight shortness of breath
1	Very mild shortness of breath
2	Mild shortness of breath
3	Moderate Shortness of breath or breathing difficulty
4	Somewhat severe
5	Strong or hard breathing
6	-
7	Severe shortness of breath or very hard breathing
8	-
9	Extremely severe
10	Shortness of breath so severe you need to stop

APPENDIX D: RATE PERCEIVED EXERTION SCALE

0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)

APPENDIX E: PERCEIVED THERMAL STRAIN SCALE (Gagge, 1967).