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Original Research

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

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ABSTRACT

International Journal of Exercise Science 16(4): 1087-1102, 2023. Adequate handgrip strength (HGS) is important to safely 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 (Male: n = 13) career structural firefighters (Age: 35.5 ± 7.2 yr) performed a maximal isometric HGS assessment with and without gloves before and immediately following completion of a simulated fireground test (SFGT). General linear model with written contrast was used to identify significant differences in HGS between conditions. Pearson Correlations were used to describe bivariate relationships between the decrements in HGS and occupational task times. 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 ($p \geq 0.27$). These findings suggest that the use of regulation fire gloves and work-induced fatigue reduces HGS and these decrements are related to HGS. Practitioners are encouraged to utilize training strategies to optimize HGS among structural firefighters.

KEY WORDS: Tactical operator, fitness, occupational readiness, personal protective equipment, physical performance

INTRODUCTION

Firefighting involves performing strenuous occupational tasks in hazardous environments. Adequate handgrip strength is important to safely and effectively perform firefighting tasks (20, 32). 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 (12), and 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 (15, 30). In addition, previous investigations have reported that greater handgrip strength was favorable for the performance of cutting tasks (r_s = 0.67, $p < 0.01$) and fire suppression and rescue tasks (r = -0.54, $p < 0.01$) (20, 32), thus, indicating that handgrip strength is important to safely and effectively perform occupational tasks.

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 (3) demonstrated that extravehicular activity (EVA) gloves significantly reduced handgrip strength (-50%) and noted that donning gloves increases grip span and results in earlier contact between fingers indicating that gloves alter grip function. In addition, Dianat and colleagues (11) 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 (7) observed significant decrements in total grip force capabilities when donning various glove types (leather & cotton, steel mesh, leather, nylon & steel, & cotton) compared to barehanded. Thus, glove use and extended performance of occupational tasks may impart independent and collective effects on handgrip strength and ultimately occupational performance and worker safety 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 research has 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 (Aim #1) and the performance of occupational tasks (Aim #2) on handgrip strength. It was hypothesized that absolute isometric handgrip strength would decrease while donning gloves and following the completion of simulated occupational tasks. The secondary purpose (Aim #3) was to determine if glove- and task-induced decrements in handgrip strength were associated with baseline handgrip strength and the timed completion of a breach and pull task (described in Methods section) and a set of occupational tasks. 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 occupational tasks.

METHODS

Participants

Fourteen (Males: 13, Female: 1) career structural firefighters from one metropolitan fire department in the southeastern United States volunteered to participate in this study. The sex distribution within this study sample was similar to the demographic profile within the U.S. Fire Service (i.e., 5% of career firefighters are female) (25). Participants' demographic and physical characteristics are provided in Table 1. All study procedures were approved by the University's Institutional Review Board (Protocol Redacted). Participants 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 active-duty status. Exclusion criteria included any respiratory or musculoskeletal condition that would impair occupational physical ability. Participants completed a Physical Activity Readiness Questionnaire (2021 PAR-Q+) and a health history questionnaire. Research and manuscript activities were conducted in accordance with IJES ethical policies and guidelines (24). The authors report no undue influence or conflict of interest in the design or execution of this study.

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

Variable	(Mean ± *SD*)			95% Confidence Intervals Lower	95% Confidence Intervals Upper
Age (yr)	35.5	±	7.2	31.5	38.9
Firefighting experience (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	23.3
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
Waist-to-hip ratio	0.88	±	0.06	0.85	0.90
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.

Protocol

Standing height was taken to the nearest 1.0 cm with a portable stadiometer (Seca 213, Seca, Chino, CA). Body mass was measured to the nearest 0.1 kg without shoes, in standard issued departmental uniform, and in full personal protective equipment (PPE) 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 (13). 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 ($r = 0.83$, $p < 0.05$) (23, 25). Participants were asked to arrive in a euhydrated state and abstain from vigorous exercise for 24 hours prior to testing.

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 (21). The jump distance was measured as the shortest distance from the initial position 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 mass (kg))] - 7,608 (21).

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 (5) using a 28 m course. 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%) (17). Stage running velocities were indicated by an audio recording (5). 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.

Blood lactate was measured to reflect the anaerobic demand of performing the SFGT. Blood lactate was taken prior to and five minutes following completion of the SFGT with a portable lactate analyzer (Lactate Plus, Nova Biomedical, Waltham, MA) that has demonstrated strong test-retest reliability ($r = 0.99$, $p < 0.05$) (18). 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.

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 ($r > 0.80$, $p < 0.05$) and concurrent validity ($r = 0.99$, $p < 0.05$) (22). This study utilized a standard handgrip strength assessment protocol approved by The American College of Sports Medicine (13). Specifically, participants stood during the assessment to enhance the external validity within an occupational setting. Each subject was instructed to stand with the shoulder adducted, elbow unsupported and flexed to 90°, and wrist in a neutral grip position (9). The adjustable handle was set to fit the participants' hands such that the second phalanx was approximately at a right angle (1). The device's clip was secured to the lower post. Participants were instructed to squeeze the dynamometer with maximal effort for three seconds before releasing tension. The peak-hold needle determined the 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, participants donned regulation firefighting gloves (FireCraft Phoenix, FC-P5000, Columbus, OH) and repeated the handgrip strength assessment. Participants then performed a set of simulated occupational tasks. Immediately following the completion of the last task (breach and pull task), participants completed the third handgrip strength condition while wearing gloves. Finally, participants removed the gloves and performed a barehanded grip strength test following the occupational tasks. This order was purposeful to ensure that the post-SFGT glove assessment was conducted immediately after the simulated fireground tasks were completed.

Furthermore, pilot data were collected in a separate sample of structural firefighters (N=11) in an unfatigued state and results indicated no barehanded versus glove order effect on handgrip strength ($p \geq 0.19$), thus negating the need to randomize the pre-SFGT order of handgrip strength conditions which enhanced testing efficiency. The highest value from each hand for each condition, a total of 4 values, was used for analyses.

Participants performed a SFGT mimicking occupational tasks (Figure 1). The tasks and respective dimensions were derived from a department-specific job task survey and analysis. Furthermore, this survey indicated that the mean categorical level of criticality reported to being able to perform these tasks successfully on an actual fireground was "critical" to "very critical". All participants 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. Participants wore full personal protective equipment (PPE; i.e., NFPA 1971: standard helmet, gloves, boots, turnout coat, and pants) and breathed through 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 participants ascended three levels of two 9-stair flights (total of 54 stairs) separated by a landing while carrying a hose packaged as a high-rise pack (Mass: 9.1 kg). The participants touched the wall on the fourth level, placed the high-rise pack on the landing, and descended to the ground floor. Next, participants 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, participants 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, participants 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, participants 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, participants 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, participants walked 15.1 m to and dragged a mannequin (Mass: approximately 75 kg) 7.6 m, around a cone, and returned to the starting position (total distance: 16.8 m). Lastly, participants 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) using a pike pole. Timed completion of the breach and pull task was selected as an independent 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 (26). After the final pull, the test administrator signaled the completion of the task and SFGT.

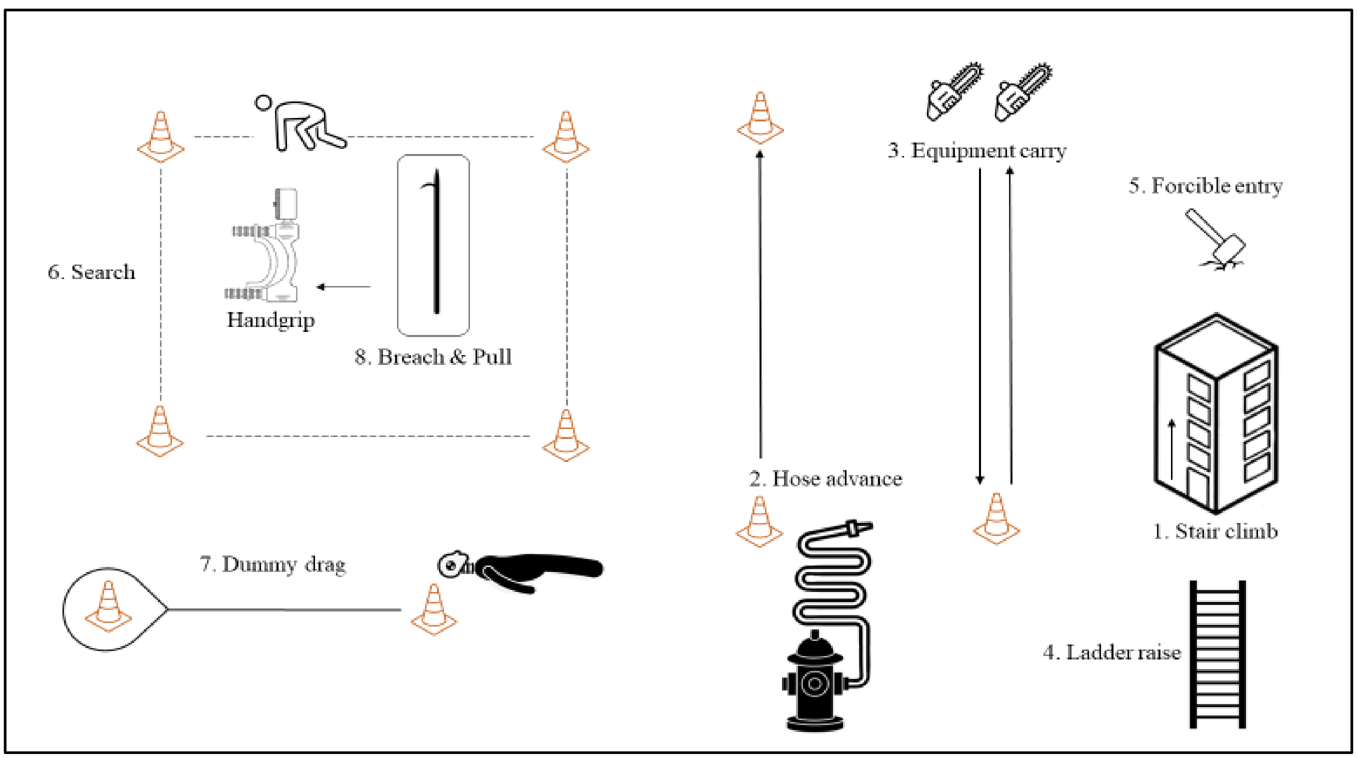

Figure 1. Schematic of the simulated fireground tasks presented in sequential order.

Assessments of dyspnea, perceived exertion, and thermal strain were taken before the SFGT and immediately following the final handgrip assessments post-SFGT. Dyspnea was measured with a 0-10 category-ratio scale (4) (0 = Nothing at all; 10 = Shortness of breath so severe you need to stop). Perceived exertion was assessed using a 10-point category-ratio scale (0 = Nothing at all; 10 = Very, very hard) which has been used in previous research to assess firefighters' rating of perceived exertion (10). Participants reported perceived thermal strain on a seven-point Likert-type scale ranging from -3 (cold) to +3 (hot) (16). The ambient temperature, humidity, and heat index were recorded immediately before each trial.

Statistical Analysis

Descriptive statistics were used to represent the distributions' central tendency (mean with 95% confidence intervals) 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. To provide context regarding this sample's handgrip strength, the participants' baseline (barehanded) dominant handgrip and non-dominant strength were combined and then stratified by sex and age and compared to normative data (13). 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 ($postSFGT_{no\ glove}$). 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. Effect sizes were assessed using partial eta squared (η_p^2; 0.01: small effect, 0.06: medium effect, 0.14: large effect) for the overall ANOVA model and Cohen's *d* (0.2: small effect, 0.5: medium effect, and 0.8: large effect) and partial eta squared (η_p^2; 0.1: small effect, 0.25: medium effect, and 0.4: large effect) for t-tests and analysis of variance models, respectively. Post-hoc analysis of statistical power was reported for the overall ANOVA model.

Pearson Product Moment Correlations were used to describe the bivariate relationships between baseline handgrip strength versus 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 condition) / baseline condition) x 100. Additionally, paired sample *t*-tests were used to assess differences between pre- and post-SFGT physiological (i.e., blood lactate concentration) and perceptual 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).

RESULTS

The demographic characteristics and performance outcomes of the sample are displayed in Tables 1 and 2, respectively. The distribution of the sample's baseline handgrip strength included: 21% (n = 3) of participants were classified as having "Poor" grip strength, 21% (n = 3) as "Good", 36% (n = 5) as "Very good", and 21% (n = 3) as "Excellent" (13). There was no effect of hand dominance (F (1,107) = 0.37, p = 0.54, η_p^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 2. Occupational and physical fitness outcomes of 14 structural firefighters.

Variable	(Mean ± *SD*)			95% Confidence Intervals Upper	95% Confidence Intervals Lower
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
$30\text{-}15_{IFT}$ (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

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

Handgrip strength values are provided in Figure 2. A descriptive comparison of the effect of glove use and occupational tasks is provided in Table 3. There was an overall main effect of condition (F (3,104) = 35.62, p < 0.001, η_p^2 = 0.50, Power = 0.73) 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 (β = 15.43, (F (1,107) = 28.04, p < 0.001)) indicating that glove use decreased handgrip strength in the non-fatigued state ($preSFGT_{no\ glove}$ vs. $preSFGT_{glove}$). There was a main effect of occupational tasks when testing with gloves (β = 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 (β = 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 (β = 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. $postSFGT_{glove}$).

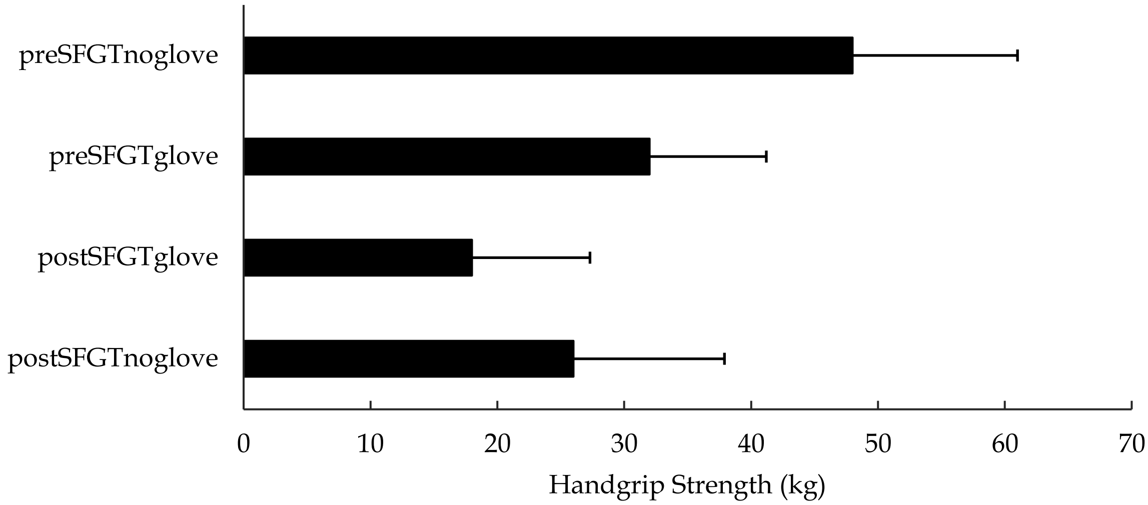

Figure 2: Dominant hand grip strength by condition in 14 structural firefighters.
SFGT: simulated fireground test;
preSFGT$_{no\ glove}$: barehanded handgrip condition prior to the SFGT;
preSFGT$_{glove}$: gloved handgrip condition prior to the SFGT;
postSFGT$_{glove}$: gloved handgrip condition following the SFGT;
postSFGT$_{no\ glove}$: barehanded handgrip strength measurement condition following the SFGT.

Table 3. Absolute (Abs) and relative changes in dominant hand grip strength and correlations to baseline handgrip strength in 14 structural firefighters.

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;
*Significant difference from baseline ($p < 0.05$);
preSFGT$_{no\ glove}$: barehanded handgrip condition prior to the SFGT;
preSFGT$_{glove}$: gloved handgrip condition prior to the SFGT;
postSFGT$_{glove}$: gloved handgrip condition following the SFGT;
postSFGT$_{no\ glove}$: barehanded handgrip strength measurement condition following the SFGT.

Lower body power and final velocity of the 30-15 IFT were not significant mediators of baseline handgrip strength and glove- and task-decrements versus occupational task times, therefore these variables were not utilized in the correlation analysis. Regardless, 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 4). Physiological and perceptual outcomes before and after the simulated fireground test (SFGT) are presented in Table 5.

Table 4. Correlations between baseline handgrip strength (kg) and glove- and task-induced handgrip strength decrements (kg) 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*
$\text{preSFGT}_{\text{no glove}}$	-0.32	0.26	0.06	0.84
$\text{preSFGT}_{\text{glove}}$ - $\text{preSFGT}_{\text{no glove}}$	0.12	0.68	0.11	0.70
$\text{postSFGT}_{\text{glove}}$ - $\text{preSFGT}_{\text{no glove}}$	0.20	0.49	-0.01	0.97
$\text{postSFGT}_{\text{no glove}}$ - $\text{preSFGT}_{\text{no glove}}$	0.32	0.27	-0.01	0.97
$\text{postSFGT}_{\text{glove}}$ - $\text{preSFGT}_{\text{glove}}$	0.21	0.47	-0.12	0.97

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

Table 5. Physiological and perceptual outcomes before and after completion of a simulated fireground test (SFGT) in 14 structural firefighters.

Variable	Pre-SFGT					Post-SFGT					
				95% Confidence Intervals					95% Confidence Intervals		
	(Mean ± *SD*)			Lower	Upper	(Mean ± *SD*)			Lower	Upper	*d*
Blood lactate (mmol ·dL^{-1}; n = 13)	1.3	±	0.6	1.0	1.6	*11.7	±	3.2	10.2	13.3	-3.6
Thermal strain	0.2	±	0.7	-0.2	0.5	*1.7	±	0.9	1.2	2.2	-2.1
RPE	0.2	±	0.6	0.0	0.5	*6.1	±	2.1	4.9	7.2	-2.7
Dyspnea	0.1	±	0.3	0.0	0.4	*4.7	±	0.0	3.3	6.0	-1.8

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

DISCUSSION

Handgrip strength plays a critical role in performing occupational tasks safely and effectively (20, 30, 32). 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 and 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 3). These findings are supported by Bishu and colleagues (2) who indicated that donning gloves reduced mean grip force by 11% when compared to a barehanded condition ($p < 0.001$). The researchers concluded that glove-induced strength decrements were due to lack of tactile feedback when wearing gloves, improper fit, and/or individual and task differences (2). 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 (3) 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. In addition, Bishu and Klute (3) 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 3). Literature suggests that the muscle contraction intensity and pattern influence the accumulation of fatigue. For instance, Sonne and coworkers (30) 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 (30). In addition, Yung and colleagues (33) reported that the pattern of muscle contraction influences the accumulation of fatigue. Specifically, individuals performing sustained isometric contractions at 15% MVIC accumulated greater fatigue than performing variable intensity contractions that resulted in the same average force as the sustained condition (33). 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 3) 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.

Extending the aforementioned task-induced fatigue findings, it was noted in Aim #2 that participants with greater baseline handgrip strength tended to exhibit lesser independent and collective glove- and task-induced decrements in handgrip strength (Table 3). 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 neuromuscular activity, as well as employment in physical labor occupations, physical training status, and preferred leisure activities (8, 19, 31). Accordingly, firefighter schedules typically require lengthy shifts (i.e., 24- and 48-hour) and relatively frequent intense physical labor (29). 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 (13). 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 ($r = -0.71$, $p < 0.05$; $r = -0.54$, $p < 0.01$) (26, 32). Specifically, Rhea et al. (27) 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 that these tasks required a greater reliance on muscular strength. Whereas, in the present study the total SFGT time took, on average, 7.5 min, potentially suggesting a greater reliance on aerobic endurance and muscular endurance versus muscular strength. Interestingly, Rhea et al. (27) 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. Taken collectively, this information may indicate that both muscular strength and endurance are important to perform fireground tasks.

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 (29). 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.

The present study's findings have numerous practical applications. For instance, firefighting is physically and psychologically stressful (10, 27). The ability to manipulate tools while enduring the associated stress is essential for completing fireground tasks. Baseline handgrip strength has been shown to correlate with firefighter occupational performance (20, 27, 31). Therefore, practitioners are encouraged to regularly assess handgrip force production capabilities throughout firefighters' career span given that strength levels are associated with the fatigue response during occupational tasks. 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 (6, 30). In addition, our sample was composed of a large range of handgrip strength capabilities which is representative of the general population. Therefore, these findings highlight the importance of assessing handgrip strength among applicants and/or recruits to determine their baseline strength status, thus providing an opportunity to address deficiencies prior to incumbent status.

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. (14), it is evident that occupational tasks associated with firefighting often require small-diameter palm grasps, large-diameter palm grasps, and medium wraps, therefore training with these grips may result in handgrip strength adaptations that carry greater occupational relevance. Specific training strategies may encompass maximal force production efforts (e.g., pinching or grasping relatively heavily weighted plates), endurance-focused grip training (e.g., small-diameter palm grasp: hanging from a pull-up bar for an extended duration), and varying grip types for standard exercises when appropriate (e.g., large-diameter palm grasp: grasping the wide underside of a kettlebell instead of the narrow handle; medium palm wrap: utilizing a thicker training bar). In addition to increasing HGS and endurance, firefighters may utilize restoration techniques while in a fatigued state such as, passive stretching for handgrip flexors and extensors and performing tasks that do not require handgrip demands.

There are several limitations in the present study. In the current study, the sample was a small (N=14) convenience sample and the post hoc power was 73.43%. In practice, it is generally desirable to have at least 80% power to detect the effect. 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 the 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 did not account for the potential order effect of gloved versus barehanded grip strength post-SFGT. Thus, performing the $postSFGT_{glove}$ trial first may have allowed for some recovery prior to performing the $postSFGT_{no\ glove}$ trial and attenuated the decrement in barehanded grip strength. Regardless, the researchers felt it was more informative to gain an immediate assessment of postSFGT strength in the occupationally relevant glove condition given the external validity and generalizability of this outcome. Finally, the present study measured handgrip strength immediately following the completion of the SFGT and did not assess the recovery response. This information is important to provide perspective regarding recovery in handgrip capabilities and requires additional research.

Sufficient handgrip capabilities are important to safely and effectively perform fireground tasks. The findings from this study indicate that wearing gloves and performing occupational tasks reduces handgrip force production capabilities 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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REFERENCES

1. Beam WC, Adams GM. Exercise physiology laboratory manual. 7th ed. New York, NY: McGraw-Hill; 2014.

2. Bishu RR, Batra S, Cochran DJ, Riley MW. Glove effect on strength: An investigation of glove attributes. Proc Hum Factors Ergon Soc Annu Meet 31(8): 901–905, 1987.

3. Bishu RR, Klute G. The effects of extravehicular activity (EVA) gloves on human performance. Int J Ind Ergon 16(3): 165–174, 1995.

4. Borg GAV. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14(5): 377–381, 1982.

5. Buchheit M. The 30-15 intermittent fitness test: 10-year review. Myorobie J 1: 1–19, 2010.

6. Byström SE, Kilbom A. Physiological response in the forearm during and after isometric intermittent handgrip. Eur J Appl Occup Physiol 60(6): 457–466, 1990.

7. Cochran DJ, Albin TJ, Bishu RR, Riley MW. An analysis of grasp force degradation with commercially available gloves. Proc Hum Factors Ergon Soc Annu Meet 30(8): 852–855, 1986.

8. Cronin J, Lawton T, Harris N, Kilding A, McMaster DT. A brief review of handgrip strength and sport performance. J Strength Cond Res 31(11): 3187–3217, 2017.

9. De S, Sengupta P, Maity P, Pal A, Dhara PC. Effect of body posture on handgrip strength in adult Bengalee population. J Exerc Sci Physiother 7(2): 79, 2011.

10. Dennison KJ, Mullineaux DR, Yates JW, Abel MG. The effect of fatigue and training status on firefighter performance. J Strength Cond Res 26(4): 1101-1109, 2012.

11. Dianat I, Haslegrave CM, Stedmon AW. Using pliers in assembly work: Short and long task duration effects of gloves on hand performance capabilities and subjective assessments of discomfort and ease of tool manipulation. Appl Ergon 43(2): 413–423, 2012.

12. Domalain M, Vigouroux L, Danion F, Sevrez V, Berton E. Effect of object width on precision grip force and finger posture. Ergonomics 51(9): 1441-1453, 2008.

13. Dumke CL. Health-related physical fitness testing and interpretation. ACSM's guidelines for exercise testing and prescription. 10th ed. Riebe D, Ehrman JK, Liguori G, Magal M, eds. Philadelphia, PA: Wolters Kluwer Health; 2018.

14. Feix T, Romero J, Schmiedmayer HB, Dollar AM, Kragic D. The grasp taxonomy of human grasp types. IEEE Trans Hum Mach Syst 46(1): 66–77, 2016.

15. Games KE, Winkelmann ZK, McGinnis KD, McAdam JS, Pascoe DD, Sefton JM. Functional performance of firefighters after exposure to environmental conditions and exercise. J Athl Train 55(1): 71-79, 2020.

16. Gagge AP, Stolwijk JA, Hardy JD. Comfort and thermal sensations and associated physiological responses at various ambient temperatures. Environ Res 1(1): 1–20, 1967.

17. Grgic J, Lazinica B, Pedisic Z. Test-retest reliability of the 30–15 intermittent fitness test: A systematic review. J Sport Health Sci 10(4): 413–418, 2021.

18. Hart S, Drevets K, Alford M, Salacinski A, Hunt BE. A method-comparison study regarding the validity and reliability of the lactate plus analyzer. BMJ Open 3(2): 1-7, 2013.

19. Josty IC, Tyler MP, Shewell PC, Roberts AH. Grip and pinch strength variations in different types of workers. J Hand Surg 22(2): 266–269, 1997.

20. Lindberg AS, Oksa J, Malm C. Laboratory or field tests for evaluating firefighters' work capacity? PLoS One 9(3): e91215, 2014.

21. Mann JB, Bird M, Signorile JF, Brechue WF, Mayhew JL. Prediction of anaerobic power from standing long jump in NCAA Division IA football players. J Strength Cond Res 35(6): 1542–1546, 2021.

22. Mathiowetz V, Weber K, Volland G, Kashman N. Reliability and validity of grip and pinch strength evaluations. J Hand Surg Am 9(2): 222-226, 1984.

23. Maughan RJ. An evaluation of a bioelectrical impedance analyser for the estimation of body fat content. Br J Sports Med 27(1): 63-66, 1993.

24. Navalta JW, Stone WK, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

25. Noor N, Pao C, Dragomir-Davis M, Tran J, Arbona C. PTSD symptoms and suicidal ideation in US female firefighters. Occup Med 69(8): 577–585, 2019.

26. Poplin GS, Roe DJ, Burgess JL, Peate WF, Harris RB. Fire fit: Assessing comprehensive fitness and injury in the fire service. Int Arch Occup Environ Health 89(2): 251-259, 2016.

27. Rhea MR, Alvar BA, Gray R. Physical Fitness and job performance of firefighters. J Strength Cond Res 18(2): 348–352, 2004.

28. Shanholtzer BA, Patterson SM. Use of bioelectrical impedance in hydration status assessment: Reliability of a new tool in psychophysiology research. J Psychophysiol 49(3): 217-226, 2003.

29. Smith DL. Firefighter fitness. Curr Sports Med Rep 10(3): 167–172, 2011.

30. Sonne MW, Hodder JN, Wells R, Potvin JR. Force time-history affects fatigue accumulation during repetitive handgrip tasks. J Electromyogr Kinesiol 25(1): 130–135, 2015.

31. Trinidad-Fernández M, González-Molina F, Moya-Esteban A, Roldán-Jiménez C, González-Sánchez M, Cuesta-Vargas AI. Muscle activity and architecture as a predictor of hand-grip strength. Physiol 41(7): 075008, 2020.

32. Williford H, Duey W, Olson M, Howard R, Wang N. Relationship between firefighting suppression tasks and physical fitness. Ergonomics 42(9): 1179–1186, 1999.

33. Yung M, Mathiassen SE, Wells RP. Variation of force amplitude and its effects on local fatigue. Eur J Appl Occup Physiol 112(11): 3865–3879, 2012.