



The influence of age on the recovery from worksite resistance exercise in career firefighters[☆]

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ABSTRACT

Resistance exercise is an important strategy to reduce injuries and improve performance in the fire service. However, given the large age range of firefighters, it is important to determine if age influences their recovery following an acute bout of resistance exercise.

Purpose: To examine the changes in indirect markers of muscle damage in young and older firefighters following a feasible worksite resistance exercise routine.

Methods: Nineteen young (25.5 ± 3.4 years) and 19 older male career firefighters (50.3 ± 3.5 years) completed pre-testing, an acute bout of resistance exercise, and post-testing at 24, 48, and 72 h post-exercise at their fire station. Prior to all testing, firefighters completed a work-related fatigue (WRF) questionnaire to account for potential unanticipated differences in previous shift workloads. Testing included perceived muscle soreness, ultrasonography to quantify muscle size and echo intensity (EI) of the vastus lateralis (VL) and biceps brachii (BB), countermovement jump (CMJ) height and velocity, upper body (UB) peak force (PF), lower body (LB) PF and rapid force, and electromyographic (EMG) amplitude of the VL. The resistance training session included 3 sets of 8–10 repetitions of a deadlift, shoulder press, lunge, and upright row exercise at 80% 1-RM. All recovery variables were analyzed using a linear mixed model, controlling for WRF.

Results: There was no interaction (age \times time) for any of the variables and a similar training volume were completed between groups ($P \geq 0.171$). Muscle soreness, CMJ height and velocity, UB PF, LB rapid force and EMG amplitude at later time intervals (100–200 ms), and VL and BB muscle size were altered from baseline ($P \leq 0.044$) for 48, 24, 48, 72, and 72 h post-exercise, respectively. Young firefighters exhibited greater CMJ height and velocity, LB PF, LB rapid force (200 ms), and lower VL EI values than the older firefighters ($P \leq 0.047$).

Conclusions: Age did not influence the recovery from an acute bout of worksite resistance exercise in firefighters. However, UB muscle strength, CMJ performance, and LB rapid force production were reduced 24–72 h post-exercise. Appropriately scheduled and chronic on-duty resistance training may mitigate these decrements.

1. Introduction

Firefighters provide critical emergency services to communities

across the country, despite experiencing one of the highest rates of occupational injuries (Houser et al., 2004). The National Fire Protection Association reported that there were 60,825 injuries among firefighters

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in 2019 (Campbell and Evarts, 2020). The primary non-fatal injuries that are commonly reported include strains and sprains (Campbell and Evarts, 2020; Poplin et al., 2011) to the extremities and back (Poplin et al., 2011) and are often attributed to acute overexertion and slips, trips, and falls (Campbell and Evarts, 2020). These injuries result in above average worker's compensation claims (Walton et al., 2003), extended worker absence rates (Centers for Disease Control and Prevention, 2017; Leffer and Grizzell, 2010), and are the leading cause of early retirement in firefighters (Szubert and Sobala, 2001).

Exercise has consistently been listed as the primary approach to reducing injuries in the fire service (Storer et al., 2014; Smith, 2011). However, more than 75% of firefighters fail to achieve the minimum physical activity recommendations from the American College of Sports Medicine (Durand et al., 2011). The workplace (e.g. fire station) may provide an optimal setting to improve the exercise habits of firefighters. For example, worksite exercise programs may offer unique advantages to the firefighter that include convenience (i.e. less travel, ease of access to equipment), lower associated-costs, and improved camaraderie among co-workers who train together (Andersen et al., 2015). Previous studies have shown that worksite exercise can improve working physical capacity, musculoskeletal (MSK) pain, and reduce the incidence of injury in a number of occupations (Leffer and Grizzell, 2010; Pedersen et al., 2013). It is also well documented that resistance training improves muscle strength, power, and endurance (Aagaard et al., 2002; Staron et al., 1994; Thompson et al., 2015), which are critical to the safe execution of essential firefighter tasks (Henderson et al., 2007; Rhea et al., 2004; Hilyer et al., 1999). These data may demonstrate that worksite resistance exercise can be an important tool to reduce injuries and improve performance in the fire service.

Nearly all United States firefighters assigned to frontline duty are between the ages of 20–59 years (Haynes and Stein, 2017). Given the large age range of firefighters, it is important to determine if age influences their recovery from a worksite resistance exercise routine. It is possible an altered recovery response in older firefighters may have unintended consequences that include increases in injury risk and impaired subsequent job performance when performed on-shift. For example, previous studies have indicated that older or middle-aged adults have a prolonged exercise recovery time when compared to younger adults (Fernandes et al., 2019; Chapman et al., 2008; Dedrick and Clarkson, 1990; Ploutz-Snyder et al., 2001). However, others have reported prolonged recovery times in younger adults (Arroyo et al., 2017; Lavender and Nosaka, 2006) or similar recovery times between young and older or middle-aged adults (Nikolaidis, 2017; Gordon et al., 2017; Lavender and Nosaka, 2008). These studies suggest that future research is needed to examine the influence of age on the recovery following worksite resistance training to inform future worksite exercise prescription among firefighters. Therefore, the purpose of this study was to examine the influence of age on the recovery from a feasible (e.g., brief, requires minimal equipment, can be performed in a group setting) worksite resistance exercise routine in career firefighters. Further, we employed a comprehensive assessment of neuromuscular function (at the fire station) including maximal and rapid strength, electromyography, vertical jump performance, ultrasound derived measures of muscle size and quality, and muscle soreness used by previous studies (Chapman et al., 2008; Dedrick and Clarkson, 1990; Gordon et al., 2017; Damas et al., 2016; Byrne and Eston, 2002; Nosaka and Clarkson, 1996) to examine the recovery from exercise-induced muscle damage (EIMD) traditionally limited to laboratory settings.

2. Methods

2.1. Participants

Forty-one (20 young and 21 older) active-duty male career firefighters (demographic data are displayed in Table 1) volunteered for this study and were recruited by age (young: 18–30 years; older: 45–60

Table 1

Mean \pm standard deviation (SD) values for demographics in younger and older firefighters.

	Young firefighters	Older firefighters
Age (years)	25.45 \pm 3.27	50.57 \pm 3.79*
Stature (cm)	181.00 \pm 6.40	176.49 \pm 6.65*
Body mass (kg)	92.58 \pm 18.26	93.30 \pm 12.87
BMI (kg/m ²)	28.01 \pm 5.51	30.66 \pm 4.64

BMI body mass index.

Note: Young: n = 20, older: n = 21.

* $P < 0.05$, significant age group difference.

years). Three participants withdrew from the study due to experiencing low back discomfort (2 older firefighters) or a lack of follow-up contact (1 younger firefighter) following familiarization testing. Thus, 38 participants completed all testing visits (19 young and 19 older firefighters). The firefighters were solicited from local departments. All participants provided written and dated informed consent (IRB# 18-0025) to participate in the research study. Additionally, the participants agreed to abstain from vigorous exercise (48 h) or any exercise (24 h) prior to all testing visits as well as abstain from any recovery strategies (i.e., massage, ice baths, ibuprofen, etc.) for the duration of the study. Participants abstained from caffeine, tobacco, and alcohol (8 h) prior to all testing visits. None of the participants reported any neuromuscular, cardiovascular, or metabolic disease (i.e., diabetes), had a current or recent (within the past three months) musculoskeletal injury of the upper- or lower-body and/or lower back that would not allow them to complete the testing, were involved in an active workers' compensation or personal injury case, or currently performed more than three sessions per week of resistance training over the last three months. The average reported hours of resistance training per week for all participants was 2.00 \pm 2.15 h/week.

2.2. Experimental design

The participants completed five days of testing at local fire stations that included a familiarization (visit one), pre-testing and an acute resistance exercise bout (visit two), and post-testing at 24, 48, and 72 h following the bout of resistance exercise (visits 3–5). All visits were completed in the morning around the same time of day (\pm 2 h).

2.3. Familiarization (visit one)

Each firefighter reported for visit one immediately after a shift, at least four days (mean \pm SD: 7.5 \pm 3.2 days) prior to visit two to ensure all familiarization assessments did not influence subsequent testing. All participants read and signed an informed consent document stating the experimental protocol with the potential risks and benefits associated with participation in the study, as well as a health history questionnaire. Participants first had their stature measured to the nearest 0.1 cm and body mass measured to the nearest 0.01 kg using a calibrated clinical scale (Seca 769, Hamburg, Germany). Participants were then familiarized with the ultrasonography imaging, countermovement vertical jump (CMJ) assessment, isometric strength assessments, and resistance training exercises. To prescribe the appropriate loads for the resistance exercise bout, each firefighter performed a multi-repetition maximum assessment for each exercise (deadlift, shoulder press, lunge, and upright row) similar to the procedures described by the National Strength and Conditioning Association (Coburn and Malek, 2012). Participants were initially instructed how to complete each exercise safely using proper form. The deadlift was completed using a kettlebell handle (KettleClamp, In The Box RX, LLC) and a commercially available plate-loaded dumbbell (ODH-20, Ader Sporting Goods, Dallas, TX, USA). The shoulder press and lunges were completed using adjustable dumbbells (PowerBlock Inc., Owatonna, MN, USA) and the upright row was

completed using a single adjustable dumbbell with a kettlebell handle (PowerBlock Inc., Owatonna, MN, USA). They performed a weighted warm-up for each exercise, with progressively heavier loads, for sets of 8–10 and 4–6 repetitions with 1 min of rest between sets. After completing the warm-up sets, participants were given 2 min of rest. An estimated weight that the participant could lift for six repetitions was then selected for the participant to perform one set of as many repetitions as possible to failure. Using the weight and number of repetitions the participant completed, the participant's one repetition maximum (1RM) was estimated using the following modified equation (Mayhew et al., 1992):

$$1RM = \frac{\text{Repetition Weight}}{0.522 + 0.419e^{(-0.055 \times \text{RTF})}}$$

The repetition weight is the load (kg) used for each exercise and RTF is the number of repetitions completed to failure. This calculation was used to estimate the 1RM for each exercise.

2.4. Testing (visits 2–5)

Visit two (PRE) occurred following a participant's shift. Post-testing visits 3–5 occurred 24 (P24), 48 (P48), and 72 (P72) h after visit two as participants were coming on- or off-shift. All testing included a comprehensive neuromuscular assessment commonly used to examine recovery from exercise (Damas et al., 2016). Each testing visit included 1) a questionnaire to assess the participant's current level of work-related fatigue (WRF), 2) a visual analog scale (VAS) to determine subjective perceived muscle soreness, 3) ultrasonography to determine the size and echogenicity of the vastus lateralis (VL) and biceps brachii (BB), 4) a CMJ test to measure jump height and average velocity, 5) an upper-body (UB) maximum isometric strength assessment, and 6) a lower-body (LB) maximum and rapid isometric strength assessment using a calibrated custom isometric dynamometer with pre-amplified electromyographic (EMG) electrodes placed over the VL to examine muscle activation.

2.5. Recovery assessments

2.5.1. Fatigue scale

To account for the unanticipated changes in work schedules, variability in occupational demands, and/or volume of calls that firefighters may experience on shift, a WRF questionnaire (Bláfoss et al., 2018) was used to determine WRF prior to testing during visits 2–5. The questionnaire asked participants: 'How tired are you right now as a result of your previous workday in: 1) your body in general; 2) your back; 3) your neck/shoulders; 4) your arms/wrists; and 5) your lower limbs?'. Participants were instructed to circle one answer for each of the five questions. The answer options included: 1) not tired; 2) a little tired; 3) somewhat tired; 4) very tired; or 5) completely exhausted. As described previously (Bláfoss et al., 2018), an average WRF score from all five questions was calculated for each participant on each visit and used in the analyses.

2.5.2. Visual analog scale

A separate VAS was used to determine the participant's perceived muscle soreness for their lower- and upper-body (LB VAS and UB VAS, respectively) during visits 2–5. The scale ranged from 0 (no discomfort at all) to 100 (worst imaginable pain) and asked the participants to rate their muscle soreness by placing a vertical mark on the line given.

2.5.3. Ultrasonography

A B-mode ultrasound (Logiq-e, General Electric Company, Milwaukee, WI, USA) with a multi-frequency linear-array probe (12L-RS; 5–13 MHz; 38.4 mm FOV, General Electric Company, Milwaukee, WI, USA) was used to determine muscle size (cross-sectional area; CSA) and muscle quality (echo-intensity; EI) of the VL and muscle thickness (MT)

and EI of the BB. All imaging was performed on the right limbs and the settings for all scans were held constant at: gain (56 dB), depth (6 cm), frequency (10.0 MHz). Muscle size and EI of the VL were determined from a transverse panoramic scan of the thigh, as described previously (Rosenberg et al., 2014). Prior to the VL imaging, the participants were positioned supine with the right leg relaxed and supported at 50 degrees of flexion, which was verified using a goniometer (Model G300, Whitehall Manufacturing, City of Industry, CA, USA). A piece of foam padding was strapped to the participant's leg in line with the transverse plane at mid-thigh (approximately halfway between the greater trochanter and lateral femoral epicondyle) so that the probe slid along the skin surface in a straight line perpendicular to the longitudinal axis of the thigh. The probe was moved from the medial to lateral portion of the muscle at a consistent speed using non-allergenic ultrasound gel (Aquasonic 100, Parker Laboratories Inc., Fairfield, NJ, USA) to improve acoustic coupling. Muscle thickness of the BB was determined from a transverse scan at approximately 66% of the distance from the acromion of the scapula to the fossa cubiti, as described previously (Jenkins et al., 2015). During the scan, participants were positioned with their arm extended, abducted, relaxed, and supported on a table. All ultrasound scans were completed by the same researcher.

All ultrasound imaging analyses were performed by the same investigator using ImageJ software (National Institute of Health, MD, USA, Version 1.37). The straight-line function was used to convert each image from pixels to centimeters. To determine CSA, the same technician used the polygon function to trace the outline of the VL for each participant's scan along the fascia border as close as possible to capture only the muscle. This traced region was then analyzed within ImageJ to determine CSA (cm²). The same ImageJ software was also used to determine muscle thickness of the BB using the straight-line function to measure the distance (cm) from the deep to superficial border of the BB at the mid-point of the muscle. The rectangle function was used to measure the largest possible internal area of the BB, without including any surrounding fascia, which was then used for the analysis of EI. Echo-intensity was determined for the VL and BB with a standard mean gray scale analysis, ranging from 0 to 255 units (black = 0, white = 255). Subcutaneous fat thickness (SFT) was measured by using the straight-line function to measure the depth of the subcutaneous fat layer from the average of the mid-point, medial, and lateral borders of the muscle for the VL (Young et al., 2015) and from the mid-point of the BB (Jenkins et al., 2015). Given SFT was not significantly different between groups or changed over time (see Section 3.4), EI values were not corrected for SFT.

2.5.4. Countermovement vertical jump

For the CMJ, participants were positioned with feet shoulder-width apart and were instructed to jump vertically, as high as possible, and return to the same position with both feet landing at the same time. A jump mat (Just Jump or Run, Probotics, Inc., Huntsville, AL, USA) was placed beneath the participant's feet and was used to measure jump height. A linear transducer (Tendo Weightlifting Analyzer, Tendo Sports Machines, Trencin, Slovak Republic) was used to measure average velocity (m/s) in accordance with the manufacturers' guidelines (Tendo Weightlifting Analyzer, Microcomputer User's Manual, Trencin, Slovak Republic). The unit cord was attached to the posterior aspect of a belt placed just below the participant's umbilicus with the linear transducer on the floor behind them, as previously described (Ryan et al., 2014). Participants completed 3–4 total jumps separated by 30 s of rest and the greatest jump height (and associated velocity) of all three jumps was used for analysis.

2.5.5. Isometric strength

Upper-body peak force (PF) was determined from an upper-body strength assessment (Fig. 1A) that was performed as an isometric upright row utilizing a calibrated load cell (TSD121C, Hand Dynamometer, Biopac Systems Inc., Goleta, CA, USA). The load cell was attached to a



Fig. 1. Examples of (A) the upper-body isometric upright row and (B) the lower-body isometric leg extension strength assessments as well as the four resistance training exercises including the (C) deadlift, (D) shoulder press, (E) lunges, and (F) upright row.

flat metal platform (on which the participants stood on) and an adjustable chain which connected to a metal bar. Participants grasped the bar with a pronated grip, hands in line with their shoulders, shoulders abducted, and elbows flexed. The chain was adjusted to one chain link below the level of the umbilicus and this chain length was kept consistent for each participant. Following three submaximal warm-up contractions (50%–75% of perceived maximum effort), participants performed three isometric maximal voluntary contractions (MVCs) with a two-minute recovery period in between each muscle contraction. Participants were initially instructed to pull the bar sub-maximally to remove the slack in the chain immediately prior to the start of the MVC, as determined with visual feedback of force production. Once the baseline force was completely steady, participants were given strong verbal encouragement to pull as hard and as fast as possible during each contraction for 3–4 s. If the participant utilized a countermovement or did not explosively produce force during the MVC (visual inspection of the force-time curve), an additional MVC was performed. An additional UB MVC was performed at PRE ($n = 10$), P24 ($n = 6$), P48 ($n = 1$), and P72 ($n = 4$).

Lower body peak and rapid force variables were examined with a custom-built, calibrated, isometric dynamometer during an isometric MVC as described previously (Fig. 1B) (Giuliani et al., 2020). Participants were seated in the dynamometer chair with their right knee fixed

at 60-degrees below full extension, as verified with a goniometer. The load cell (Model 41, Honeywell Inc., Columbus, OH, USA) was positioned approximately two centimeters above the lateral malleolus. A strap was placed across the participant's waist and their left leg to prevent extraneous movements during leg extension. They were also instructed to place their arms across their chest during testing. All of the chair adjustments were recorded and replicated for each testing session. Following three submaximal warm-up contractions (50% - 75% of perceived maximum effort), participants performed three MVCs with a two-minute recovery period in between contractions. Participants were instructed to kick their right leg out as hard and as fast as possible against a stationary padded lever arm for 3–4 s to produce maximal force. If the participants did not remain relaxed (i.e., performed a countermovement) before the MVC or did not explosively produce force during the MVC (visual inspection of the force-time curve), an additional MVC was performed. An additional LB MVC was performed at PRE ($n = 1$), P24 ($n = 2$), and P48 ($n = 1$).

All MVCs were visually inspected for any countermovement and pretension as described by Gerstner et al. (2017a). There was a noticeable countermovement or pretension for 11 MVCs (PRE: $n = 2$; P24: $n = 2$; P48: $n = 3$; P72: $n = 4$). The mean \pm standard deviation (SD) of the baseline slope (200 ms prior to contraction onset) for these excluded MVCs were $-14.44 \pm 11.41 \text{ N}\cdot\text{s}^{-1}$. The baseline slopes for all remaining

values were $-0.72 \pm 2.88 \text{ N}\cdot\text{s}^{-1}$. The MVC with the highest peak force value was used for all subsequent analyses.

2.5.6. Surface electromyography

A bipolar, pre-amplified, surface electromyographic (EMG) electrode (TSD150B, Biopac Systems Inc., Goleta, CA, USA; gain = 350 and interelectrode distance of 20 mm) was placed on the VL in accordance with recommendations from the Surface EMG for the Non-Invasive Assessment of Muscles (SENIAM) project (Hermens et al., 2000). Specifically, the electrode was placed two-thirds the distance from the anterior superior iliac spine to the superior aspect of the lateral patella on the right leg. Additionally, a reference electrode was placed on the tibial tuberosity. Prior to placing the EMG and reference electrodes, the skin was shaved, lightly abraded, and cleansed with rubbing alcohol.

2.6. Signal processing

The force and EMG signals were sampled at 2 kHz with a Biopac data acquisition system (MP150WSW, Biopac Systems Inc., Goleta, CA, USA) and stored on a personal computer (ThinkPad T420; Lenovo, Morrisville, NC). Custom-written software (LabView 17; National Instruments, Austin, TX) was used to process all of the signals offline. The LB force signals were corrected for baseline passive tension and the UB and LB force signals were filtered using a fourth order, zero phase shift low pass Butterworth filter with a 150 Hz cutoff frequency (Thompson, 2019). The EMG signals were filtered using a fourth order, zero phase shift bandpass filter (10–500 Hz).

Force and EMG onsets were manually determined by the same investigator using previously established guidelines (Gerstner et al., 2017a). The last trough/peak before signal deflection from baseline was manually selected as the force or EMG signal onset. Isometric PF was determined as the highest 500 ms epoch during the 3- to 4-s MVC for UB and LB PF. Absolute rapid force variables for the LB were calculated from the force-time curve at 50 (F_{50}), 100 (F_{100}), 150 (F_{150}), and 200 ms (F_{200}) from onset. Normalized rapid force variables were calculated at the same time points as a percentage of PF. The EMG signal was simultaneously analyzed during the same time epoch as used to determine PF, as the root mean squared amplitude. The EMG amplitude calculated during the PF epoch (EMG_{MVC}) during each post-testing visit was then normalized to the pre-testing values. In addition, similar to previous work (Gerstner et al., 2017a), EMG amplitude variables were quantified at 0–100 (EMG_{0-100}) and 100–200 ms ($EMG_{100-200}$) following contraction onset, to represent early and late muscle activation time-points, and were subsequently normalized to the root mean squared amplitude obtained during PF on each respective day.

2.7. Resistance exercise (visit two)

The resistance exercise bout occurred on the same day as pre-testing, following all pre-testing data collection. Participants first completed a brief warm-up set using 40% of their predicted 1RM, which was also used to reinforce proper lifting form. Each firefighter then performed three sets of the deadlift, shoulder press, lunge, and upright row exercises (Fig. 1C–F) at 80% of their predicted 1RM until muscular failure. These exercises were selected because they are multi-joint movements that engage major muscle groups and can be performed with minimal equipment. The exercises were performed in a circuit style using an adjustable dumbbell set (same as testing) and there was 1 min of rest between exercises and 2 min of rest between sets. If participants completed more or less than 8–10 repetitions the loads were increased or decreased by 10% for the subsequent set. An experienced member of the research team was present at all times to ensure safe execution of the lifts. Total training volume (load \times repetitions) was calculated for each participant to assess any potential training volume differences between groups.

2.7.1. Rating of perceived exertion

The participant's rating of perceived exertion (RPE) was assessed with the OMNI resistance training RPE scale (Robertson et al., 2003). The participants' RPE was recorded at the completion of the warm-up and after each of the three exercise sets.

2.8. Statistical analysis

Descriptive data were summarized using mean \pm standard deviation (SD). An independent *t*-test was employed to examine baseline group differences in age, stature, body mass, BMI, and total training volume. A linear mixed model, with fixed effects for group and time, was employed to examine the change in RPE during the training session and changes in reported WRF over time for both groups.

Due to the significant interaction for WRF (see Section 3.2 below), a linear mixed model, with fixed effects for group (young v. older) and time (PRE v. P24 v. P48 v. P72), while covarying for WRF, was employed to examine the mean and longitudinal changes in UB maximal PF. The interaction was tested first; if non-significant, a reduced model was used without the interaction. Contrasts were then used to test for differences between time and/or group and only if overall contrasts were significant, pairwise comparisons were completed. The same methods were used to examine self-reported soreness for UB and LB VAS, CMJ height and velocity, CSA and EI of the VL, MT and EI of the BB, SFT of the VL and BB, absolute and normalized (% of PF) rapid force production of the lower body at F_{50} , F_{100} , F_{150} , and F_{200} , and EMG amplitude (EMG_{0-100} , $EMG_{100-200}$, EMG_{MVC}). The subjects were chosen as the random effect within the linear mixed model because of the expected between-subjects variation and this was significant for all analyses ($P < 0.001$). Outliers were defined as values being at least three times greater than the interquartile range and were removed from analyses. All analyses were performed with SAS (Version 9.4, SAS Institute Inc., Cary, NC, USA) with an alpha level set a priori at $P \leq 0.05$.

3. Results

3.1. Demographics

All demographic data are presented in Table 1. There was a significant difference in age ($P < 0.001$) and stature ($P = 0.033$), with young firefighters being taller than older firefighters, but there were no significant differences for body mass ($P = 0.885$), or BMI ($P = 0.104$) between the young and the older firefighters.

3.2. Fatigue scale

The raw means for all dependent variables are presented in Table 2. For WRF, there was a significant group \times time interaction ($P = 0.002$, Fig. 2A). The older firefighters reported greater and less ($P \leq 0.041$) WRF at PRE and P48, respectively, when compared to the young firefighters. There were no differences in WRF between groups at P24 ($P = 0.121$) or P72 ($P > 0.999$). For the young, WRF at P24 and P48 was greater than both PRE and P72 ($P < 0.001$). For the older firefighters, WRF at P72 was less than PRE and P24 ($P \leq 0.008$), and P48 was less than P24 ($P = 0.033$). Thus, for all the following variables, we included the time-varying WRF value as a covariate.

3.3. Visual analog scale

There were no significant group \times time interactions ($P \geq 0.251$) or main effects for group ($P \geq 0.268$) for UB or LB VAS. However, there were main effects for time ($P < 0.001$, Fig. 2B). When collapsed across groups, UB and LB VAS values increased from PRE to P24 and P48 ($P < 0.001$), but not at P72 ($P \geq 0.142$). Upper- and lower-body VAS values at P24 and P48 were also greater than P72 values ($P \leq 0.025$).

Table 2
Unadjusted pre- and post-exercise raw means (mean ± standard deviation) for all dependent variables.

	Age group	PRE	P24	P48	P72
WRF (AU)	Y	1.52 ± 0.41	2.31 ± 0.74	2.06 ± 0.57	1.52 ± 0.37
	O	1.94 ± 0.69	2.01 ± 0.68	1.67 ± 0.56	1.52 ± 0.52
UB VAS (AU)	Y	10.37 ± 10.93	33.63 ± 20.75	30.47 ± 18.64	11.68 ± 10.71
	O	14.42 ± 18.05	24.40 ± 19.53	16.32 ± 14.33	12.84 ± 16.22
LB VAS (AU)	Y	10.22 ± 10.46	40.95 ± 26.06	34.63 ± 22.54	12.68 ± 13.18
	O	16.26 ± 18.33	33.53 ± 22.32	25.63 ± 24.27	9.79 ± 13.28
CMJ height (cm)	Y	43.51 ± 6.15	42.21 ± 6.30	43.36 ± 6.22	42.88 ± 6.02
	O	34.75 ± 6.35	32.74 ± 6.96	34.37 ± 5.97	34.09 ± 6.53
CMJ velocity (m/s)	Y	1.30 ± 0.13	1.26 ± 0.19	1.29 ± 0.17	1.31 ± 0.16
	O	1.17 ± 0.18	1.13 ± 0.20	1.18 ± 0.18	1.19 ± 0.18
VL SFAT (cm)	Y	1.08 ± 0.39	1.08 ± 0.41	1.06 ± 0.41	1.09 ± 0.39
	O	0.99 ± 0.29	0.96 ± 0.30	0.99 ± 0.36	0.98 ± 0.34
VL CSA (cm ²)	Y	32.12 ± 7.22	32.20 ± 7.20	32.54 ± 7.62	32.28 ± 7.08
	O	28.68 ± 4.62	30.19 ± 5.85	29.79 ± 4.80	30.50 ± 5.91
VL EI (AU)	Y	57.35 ± 4.20	56.80 ± 5.23	57.77 ± 4.87	56.80 ± 4.76
	O	61.81 ± 7.72	62.52 ± 6.96	62.40 ± 6.92	62.01 ± 6.06
BB SFAT (cm)	Y	0.24 ± 0.15	0.23 ± 0.15	0.23 ± 0.15	0.23 ± 0.14
	O	0.29 ± 0.15	0.28 ± 0.14	0.34 ± 0.35	0.27 ± 0.13
BB MT (cm)	Y	2.83 ± 0.45	2.91 ± 0.43	2.92 ± 0.44	2.88 ± 0.43
	O	2.75 ± 0.42	2.77 ± 0.40	2.84 ± 0.38	2.79 ± 0.42
BB EI (AU)	Y	73.60 ± 5.98	72.18 ± 7.41	71.13 ± 9.19	72.09 ± 8.07
	O	74.81 ± 7.77	72.90 ± 5.71	74.53 ± 6.31	78.54 ± 6.72
UB PF (N)	Y	879.23 ± 100.38	841.55 ± 103.89	848.52 ± 96.03	848.70 ± 114.34
	O	812.46 ± 107.91	785.77 ± 122.83	801.40 ± 123.33	814.28 ± 123.71
LB PF (N)	Y	745.51 ± 221.67	706.27 ± 181.10	697.82 ± 172.54	741.42 ± 214.51
	O	589.71 ± 115.33	564.75 ± 138.23	582.28 ± 146.38	554.90 ± 147.27
F ₅₀ (N)	Y	46.44 ± 21.89	39.83 ± 24.97	36.80 ± 16.11	41.75 ± 28.02
	O	41.39 ± 15.58	40.69 ± 22.07	39.76 ± 17.11	36.65 ± 20.02
F ₁₀₀ (N)	Y	250.09 ± 93.86	205.74 ± 96.91	188.65 ± 77.85	205.19 ± 96.80
	O	212.06 ± 79.83	185.59 ± 73.64	200.97 ± 72.13	166.85 ± 82.96
F ₁₅₀ (N)	Y	384.00 ± 119.58	332.39 ± 111.11	318.65 ± 94.02	334.58 ± 123.24
	O	321.95 ± 99.69	286.31 ± 80.19	304.98 ± 93.70	267.43 ± 105.79
F ₂₀₀ (N)	Y	471.90 ± 142.41	409.63 ± 115.16	394.74 ± 109.37	424.75 ± 144.84
	O	382.73 ± 106.09	348.07 ± 89.52	357.50 ± 100.97	329.29 ± 120.05
Normalized F ₅₀ (%)	Y	7.18 ± 4.09	5.77 ± 3.51	5.68 ± 3.10	5.58 ± 3.33
	O	7.89 ± 3.79	7.23 ± 3.53	7.69 ± 4.29	6.34 ± 2.40

Table 2 (continued)

	Age group	PRE	P24	P48	P72
Normalized F ₁₀₀ (%)	Y	34.54 ± 11.75	29.44 ± 12.30	27.74 ± 10.33	27.13 ± 11.19
	O	36.40 ± 12.29	33.13 ± 11.31	34.25 ± 11.21	28.60 ± 8.84
Normalized F ₁₅₀ (%)	Y	52.41 ± 11.64	47.75 ± 13.21	46.18 ± 7.79	43.81 ± 11.95
	O	55.16 ± 13.93	51.38 ± 12.06	51.78 ± 12.08	46.50 ± 9.50
Normalized F ₂₀₀ (%)	Y	63.89 ± 11.26	58.83 ± 12.22	57.47 ± 11.94	55.74 ± 13.26
	O	63.71 ± 11.74	62.41 ± 12.37	62.58 ± 6.94	57.56 ± 9.59
EMG ₀₋₁₀₀ (%)	Y	121.02 ± 80.90	91.60 ± 33.92	91.03 ± 49.98	83.22 ± 29.57
	O	103.61 ± 33.18	97.57 ± 51.77	99.40 ± 34.12	81.68 ± 54.00
EMG ₁₀₀₋₂₀₀ (%)	Y	106.28 ± 38.77	100.87 ± 39.84	86.74 ± 41.99	85.01 ± 23.60
	O	101.69 ± 32.31	90.39 ± 26.95	84.14 ± 27.36	84.58 ± 34.07
EMG _{MVC} (%)	Y	100.00 ± 0.00	94.07 ± 19.91	104.59 ± 35.32	117.35 ± 58.01
	O	100.00 ± 0.00	105.23 ± 11.66	114.14 ± 28.23	99.85 ± 26.59

PRE pre-testing, P24 24-h post-testing, P48 48-h post-testing, P72 72-h post-testing, Y young, O older, WRF work-related fatigue, UB upper-body, LB lower-body, VAS visual analog scale, CMJ countermovement jump, VL vastus lateralis, SFAT subcutaneous fat thickness, CSA cross sectional area, EI echointensity, BB biceps brachii, MT muscle thickness, PF peak force, F₅₀₋₂₀₀ lower-body force at specific time point (ms), EMG₀₋₁₀₀ electromyography amplitude at 0–100 ms, EMG₁₀₀₋₂₀₀ electromyography amplitude at 100–200 ms, EMG_{MVC} electromyography amplitude during MVC, AU arbitrary units.
 Note: (n = 18) WRF: Y-P24; LB VAS: Y-PRE; CMJH: O-P24; VL CSA: O-PRE & P48; BB EI: O-P48; F₅₀: Y-P48; F₁₀₀, F₁₅₀, F₂₀₀, EMG₀₋₁₀₀, EMG₁₀₀₋₂₀₀, EMG_{MVC}: Y-PRE & P48, O-PRE.
 Note: (n = 17) F₅₀: Y-PRE & P72, O-PRE, P24 & P72; F₁₀₀, F₁₅₀, F₂₀₀, EMG₀₋₁₀₀, EMG₁₀₀₋₂₀₀, EMG_{MVC}: Y-P72, O-P24, P48, P72.
 Note: (n = 16) F₅₀: O-P48.
 Note: (n = 19 per group) VL SFT & BB SFT: PRE-P72.

3.4. Ultrasonography

There were no significant group × time interactions ($P \geq 0.490$) or main effects for group ($P \geq 0.228$) or time ($P \geq 0.421$) for SFT for the VL and BB. There were no significant group × time interactions ($P \geq 0.277$) or main effects for group ($P \geq 0.313$) for VL CSA or BB MT. However, there were main effects for time ($P \leq 0.006$, Fig. 2D). When collapsed across groups, VL CSA and BB MT increased from PRE to P24, P48, and P72 ($P \leq 0.041$). There were no significant group × time interactions ($P \geq 0.171$) or main effects for time ($P \geq 0.169$) for VL EI or BB EI. However, there was a main effect for group for VL EI ($P = 0.006$, Fig. 3A), while BB EI approached significance ($P = 0.069$, Fig. 3A) with the older firefighters having greater EI values when compared to the young firefighters.

3.5. Countermovement vertical jump

There were no significant group × time interactions ($P \geq 0.910$) for CMJ height or velocity. However, there were main effects for time ($P \leq 0.022$, Fig. 2C) and main effects for group ($P \leq 0.020$, Fig. 3B). When collapsed across groups, CMJ height and velocity decreased from PRE to P24 ($P \leq 0.007$), but not at P48 or P72 ($P \geq 0.092$). Countermovement jump height then increased from P24 to P48 ($P = 0.019$) and CMJ velocity increased from P24 to P48 and P72 ($P \leq 0.003$). When collapsed across time, CMJ height and velocity were greater in the young compared to the older firefighters.

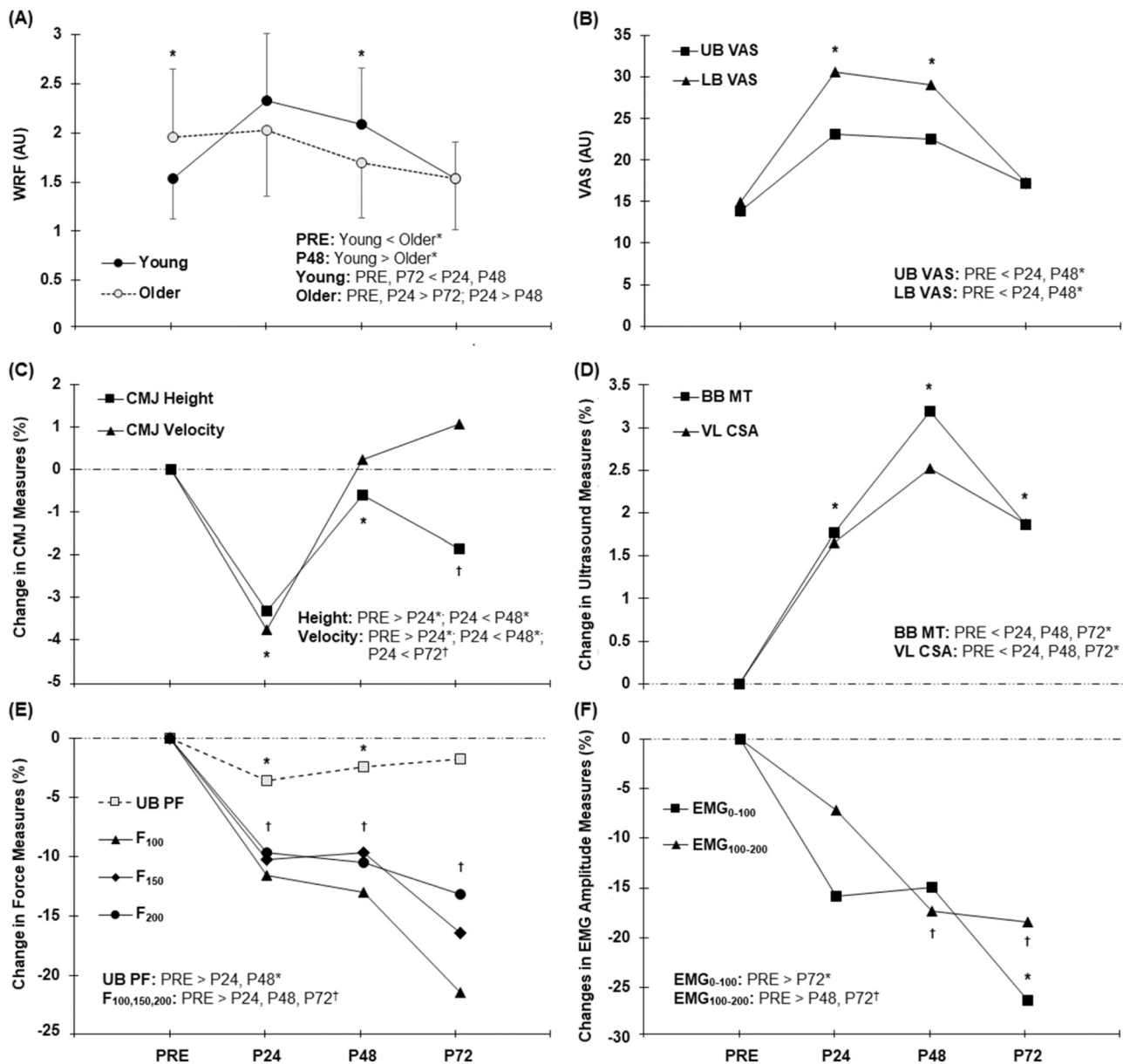


Fig. 2. The changes in (A) the raw (mean \pm SD) values for work-related fatigue (WRF), adjusted marginal mean changes in (B) upper-body soreness (UB VAS) and lower-body soreness (LB VAS), the percent change in (C) countermovement jump (CMJ) height and velocity, (D) biceps brachii muscle thickness (BB MT) and vastus lateralis cross-sectional area (VL CSA), (E) upper-body peak force (UB PF), lower-body force at 100 ms (F_{100}), 150 ms (F_{150}), and 200 ms (F_{200}), (F) EMG amplitude at 0–100 ms (EMG_{0-100}) and EMG amplitude at 100–200 ms ($EMG_{100-200}$) over the testing period. For (A) WRF (*) indicates significant group differences ($P < 0.05$), while for B–F (*, †) indicates significant difference ($P < 0.05$) between the time points denoted on each graph separately.

3.6. Isometric strength

There was no significant group \times time interactions ($P \geq 0.185$) for UB or LB PF, main effect for group ($P = 0.138$) for UB PF or time ($P = 0.279$) for LB PF. However, there was a main effect for time ($P = 0.027$, Fig. 2E) for UB PF. When collapsed across groups, UB PF decreased from PRE to P24 and P48 ($P \leq 0.035$), but not at P72 ($P = 0.132$). Further, there was a main effect for group ($P = 0.004$, Fig. 3C) with young firefighters having greater LB PF when compared to the older firefighters.

There were no significant group \times time interactions ($P \geq 0.579$) for all absolute and normalized rapid strength at all time points (F_{50} , F_{100} , F_{150} , or F_{200}). There were also no main effects for group ($P \geq 0.135$) for F_{50} , F_{100} , F_{150} , and all normalized rapid strength variables, however, there was a main effect for group ($P = 0.047$) for F_{200} . When collapsed

across time, F_{200} was greater for the young when compared to older firefighters (Fig. 3C). There was no main effect for time ($P = 0.212$) for absolute and normalized F_{50} , however, there were main effects for time ($P \leq 0.012$, Fig. 2E) for absolute and normalized F_{100} , F_{150} , and F_{200} . When collapsed across groups, absolute F_{100} , F_{150} , and F_{200} decreased from PRE to P24, P48, and P72 ($P \leq 0.044$). Normalized values responded similarly, with F_{100} , F_{150} , and F_{200} being greater at PRE when compared to P72 ($P < 0.001$), and F_{100} and F_{150} greater at P24 when compared to P72 ($P \leq 0.049$).

3.7. Surface electromyography

There was no significant group \times time interaction ($P = 0.216$), main effect for group ($P = 0.637$), or main effect for time ($P = 0.230$) for EMG_{MVC} .

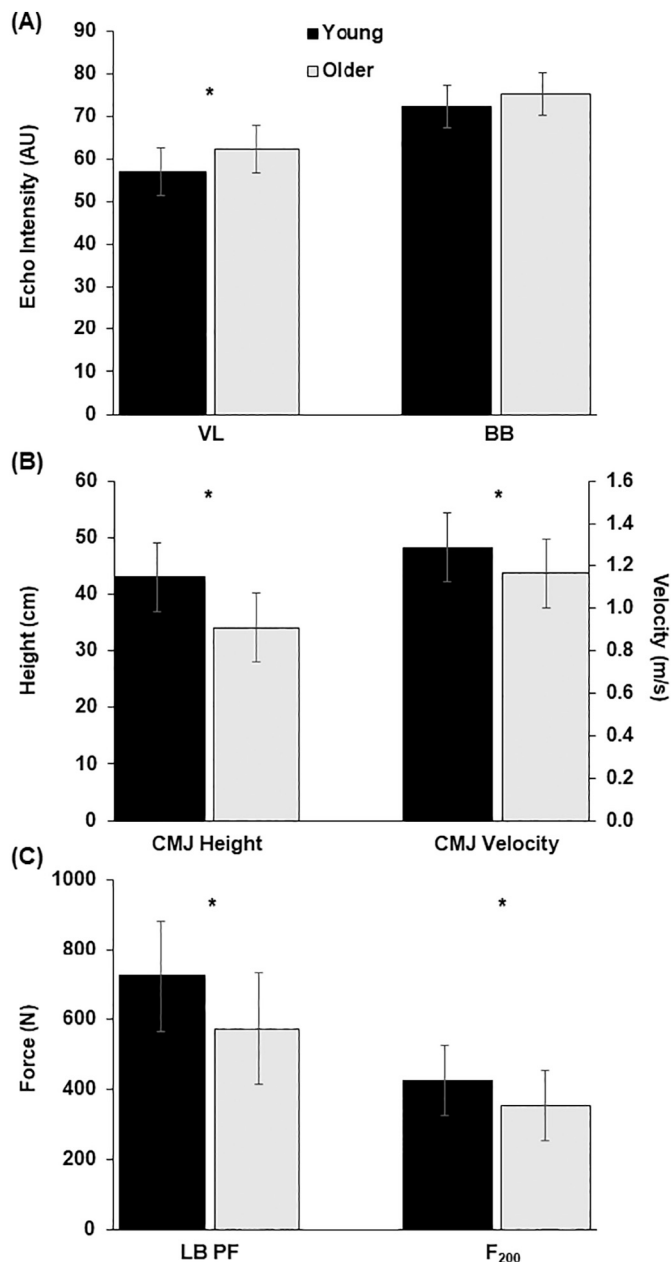


Fig. 3. Adjusted marginal mean changes (mean \pm SD) in (A) echo-intensity of the vastus lateralis (VL EI) and biceps brachii (BB EI), (B) countermovement jump (CMJ) height and velocity, (C) lower-body peak force (LB PF) and lower-body force at 200 ms (F_{200}) between the groups. (*) significant difference ($P < 0.05$) between the groups.

There was no significant group \times time interaction ($P = 0.590$) or main effect for group ($P = 0.895$) for EMG_{0-100} . However, there was a main effect for time ($P = 0.021$, Fig. 2F). When collapsed across groups, EMG_{0-100} decreased from PRE to P72 ($P = 0.002$). In addition, P24 and P48 time points were lower than PRE and approached significance ($P \leq 0.075$).

There was no significant group \times time interaction ($P = 0.812$) or main effect for group ($P = 0.638$) for $EMG_{100-200}$. However, there was a main effect for time ($P = 0.014$, Fig. 2F). When collapsed across groups, $EMG_{100-200}$ decreased from PRE to P48 and P72 ($P \leq 0.008$), but not P24 ($P = 0.282$).

3.8. Resistance training

There was no significant difference ($P = 0.256$) between young and older firefighters in total training volume during the resistance training session (4371.58 ± 908.10 kg and 4000.57 ± 1067.37 kg, respectively).

3.8.1. Rating of perceived exertion

There was no significant group \times time interaction ($P = 0.937$) or main effect for group ($P = 0.214$) for RPE. However, there was a main effect for time ($P < 0.001$). When collapsed across groups, RPE increased across all time point comparisons ($P < 0.001$) from warm-up (3.00 ± 1.12), Set 1 (6.47 ± 1.39), Set 2 (7.76 ± 1.17), and Set 3 (9.05 ± 0.97).

4. Discussion

The current study examined the influence of age on the recovery from a worksite resistance exercise routine in career firefighters. The primary findings of the present study indicated that when accounting for WRF differences between groups, the young and older firefighters demonstrated a similar recovery following an acute bout of worksite resistance exercise. The total training volume during the training session and the increased perceived exertion across sets was similar between groups. Further, the resistance training bout resulted in exercise-induced alterations from baseline in muscle soreness, CMJ performance, UB PF, LB rapid force and EMG amplitude at later time intervals (100–200 ms), and VL and BB muscle size lasting 48, 24, 48, 72, and 72 h, respectively (Fig. 2). However, there was no significant change in LB PF, rapid strength at early time intervals (F_{50}), or EI. These results add to the work of previous authors (Fernandes et al., 2019; Chapman et al., 2008; Dedrick and Clarkson, 1990; Ploutz-Snyder et al., 2001; Arroyo et al., 2017; Lavender and Nosaka, 2006; Nikolaidis, 2017; Gordon et al., 2017; Lavender and Nosaka, 2008) who have examined the influence of age on the recovery from resistance training and isokinetic exercise.

4.1. Recovery responses between young and older firefighters

Previous studies (Fernandes et al., 2019; Chapman et al., 2008; Dedrick and Clarkson, 1990; Ploutz-Snyder et al., 2001; Arroyo et al., 2017; Lavender and Nosaka, 2006; Nikolaidis, 2017; Gordon et al., 2017; Lavender and Nosaka, 2008) investigating the influence of age on post-exercise recovery responses and EIMD have used a variety of modalities (e.g., traditional resistance training, isokinetic exercise including concentric/eccentric and eccentric-only muscle actions), age groups (e.g., young vs older (≥ 65 years); young vs middle-aged), and muscle groups (e.g., leg extensors, forearm flexors) in both men and women. The current study utilized a full-body resistance training routine that could be feasibly employed at a fire station with minimal equipment to enhance external validity. The results of these previous studies have indicated similar recovery times between young and older or middle-aged adults (Nikolaidis, 2017; Gordon et al., 2017; Lavender and Nosaka, 2008), prolonged recovery times in older or middle-aged adults (Fernandes et al., 2019; Chapman et al., 2008; Dedrick and Clarkson, 1990; Ploutz-Snyder et al., 2001), or prolonged recovery times in younger adults (Arroyo et al., 2017; Lavender and Nosaka, 2006) when examining changes in isometric and/or isokinetic maximal muscle strength, which has been considered the best indicator of EIMD (Damas et al., 2016). When specifically looking at studies that have enrolled participants in similar age groups to our study, our findings are similar to those reported by Gordon et al. (2017) and Lavender and Nosaka (2008). These authors (Gordon et al., 2017; Lavender and Nosaka, 2008) reported similar changes in muscle strength following repeated concentric and eccentric isokinetic contractions ($60^\circ \cdot s^{-1}$) of the leg extensors in young (21.8 ± 2.2 years) and middle-aged (47.0 ± 4.4 years) men (Gordon et al., 2017), and eccentric-only contractions (40% of isometric strength) of the forearm flexors in young (19.4 ± 0.4 years) and middle-aged men (48.0 ± 2.1 years) (Lavender and Nosaka, 2008).

However, [Fernandes et al. \(2019\)](#) reported that middle-aged resistance trained men (39.9 ± 6.2 years) experienced greater post-exercise decreases in isometric PF and squat peak power when compared to their younger trained counterparts (22.3 ± 1.7 years) at 24 and 72 h after performing 10×10 squats at 60% 1RM. Further, [Arroyo et al. \(2017\)](#) reported that muscle strength recovered faster in middle-aged men when compared to young men using an identical protocol described by [Gordon et al. \(2017\)](#). It is also interesting to note that among these studies ([Fernandes et al., 2019](#); [Arroyo et al., 2017](#); [Gordon et al., 2017](#)) and our work (see [Fig. 2B](#)) that examined post-exercise perceived muscle soreness, soreness increased and peaked around 24–48 h post-exercise, which were similar between groups despite the range of recovery responses in muscle strength. It is possible that the similar recovery response between the young and older firefighters in our study may be due to: 1) the minimal training volume (only 4 exercises split across the upper and lower body) performed in the current study when compared to previous work that investigated higher resistance training volumes using the same musculature ([Fernandes et al., 2019](#)) and/or 2) similar training volumes and perceived exertion between groups which may suggest that the mechanical strain on the muscle may be similar ([Lavender and Nosaka, 2008](#)).

4.2. Time course of exercise-induced muscle damage

The results of our current study indicated CMJ performance (see [Fig. 2C](#)) and UB isometric PF (see [Fig. 2E](#)) were reduced 24 and 48 h post-exercise, respectively. However, LB isometric PF did not significantly change from baseline. These findings are similar to previous studies who have reported reductions in vertical jump performance and muscle strength following resistance training or isokinetic exercise ([Ploutz-Snyder et al., 2001](#); [Arroyo et al., 2017](#); [Nikolaidis, 2017](#); [Lavender and Nosaka, 2008](#); [Byrne and Eston, 2002](#); [Jamurtas et al., 2005](#)). The prolonged recovery for UB strength when compared to CMJ performance and LB strength is supported by previous authors ([Jamurtas et al., 2005](#)) who have demonstrated that the recovery of muscle function is slower in the arms versus the leg extensors following eccentric exercise of the same relative intensity. It is possible that firefighters are less frequently exposed to heavy eccentric loading in their arms than the leg extensors. Further, although [Gordon et al. \(2017\)](#) reported no changes in muscle strength post-exercise similar to our study, a number of other previous studies ([Dedrick and Clarkson, 1990](#); [Ploutz-Snyder et al., 2001](#); [Arroyo et al., 2017](#); [Nikolaidis, 2017](#); [Lavender and Nosaka, 2008](#); [Byrne and Eston, 2002](#); [Jamurtas et al., 2005](#)) have reported reductions in muscle strength post-exercise. The lack of changes in LB PF was supported by the lack of changes in EMG_{MVC} as previous work has suggested muscle activation influences changes in muscle strength following EIMD ([Farup et al., 2016](#); [Vila-Chã et al., 2012](#)). As noted in a recent review ([Peake et al., 2016](#)), the lack of changes in leg extension PF may be due to the use of multi-joint exercises (versus isolated single-joint exercises), and lower training volume and subsequently fewer eccentric muscle actions during the acute resistance training bout.

Unlike LB PF, LB absolute and normalized rapid strength later time variables (F_{100} , F_{150} , and F_{200}), but not early time variables (F_{50}), remained depressed at 72 h post-exercise ([Fig. 2E](#)). These findings are similar to previous studies that have reported greater decreases in rapid strength at later time intervals (100–200 ms) than MVC and early time intervals ([Farup et al., 2016](#); [Vila-Chã et al., 2012](#)). These authors ([Farup et al., 2016](#); [Vila-Chã et al., 2012](#)) have suggested that these EIMD impairments are linked to the damage and remodeling processes of the contractile and cytoskeletal proteins and/or altered muscle activation. For example, [Vila-Chã et al. \(2012\)](#) noted the concurrent suppression of rapid force and EMG amplitude may be due to a reduction in maximal motor unit discharge rates and/or incidence of discharge doublets near the onset of contraction. These findings also have important functional implications as previous work by [Mota et al. \(2018\)](#) has demonstrated that rapid force production at 100 ms significantly impacts occupational

performance during a simulated fireground task (i.e., walking on uneven surfaces, overhead obstacle avoidance).

In the present study, VL CSA and BB MT increased and remained significantly greater than baseline up to 72 h post-exercise despite no changes in EI. Similar findings were reported by [Chapman et al. \(2008\)](#) who found that young (25 ± 6 years) and older (64 ± 4 years) men experienced similar increases in muscle thickness and arm circumference, but no change in EI following 30 maximal eccentric muscle actions of the forearm flexors at $210^\circ \cdot s^{-1}$. These findings indicated that EIMD resulted in swelling of the exercised muscle which often peaks and continues to develop as soreness is reduced ([Nosaka and Clarkson, 1996](#); [Peake et al., 2016](#)) and is due to an accumulation of fluid causing edema from inflammatory swelling and/or protein synthesis ([Nosaka and Clarkson, 1996](#)). However, contrasting results have been reported by previous authors ([Radaelli et al., 2012](#)) who have demonstrated simultaneous increases in muscle size and EI following an acute bout of resistance exercise. Further, previous work using an animal model has suggested that although increases in EI are seen after muscle damage, they are unlikely influenced by the infiltration of inflammatory cells and may be more linked to the inflammatory edema response ([Fujikake et al., 2009](#)). It is possible that increases in EI values are more noticeable following exercise protocols that elicit greater muscle damage and subsequently greater swelling. For example, [Chen et al. \(2011\)](#) demonstrated that EI values were only increased when additional traditional measures of EIMD (i.e. strength, plasma creatine kinase, muscle soreness, arm circumference) also exhibited a greater change post-exercise. Thus, it is possible that the minimal training volume and limited eccentric muscle actions of the current resistance training bout may have not elicited significant muscle damage and subsequent muscle swelling to alter EI. However, future studies are needed to test this hypothesis.

4.3. Differences between young and older firefighters

The results of the present study indicated the young firefighters had greater LB PF (23.3%) and absolute F_{200} (17.8%) when compared to the older firefighters, although no significant group differences existed for the earlier time intervals ($F_{50} - F_{150}$) or all normalized rapid force values. These findings are similar to [Gerstner et al. \(2017a\)](#) who demonstrated that maximal strength and absolute later rapid strength variables, but not earlier absolute rapid strength variables, are reduced in older men. However, the present study indicated no significant group differences in UB isometric strength. Previous research in firefighters ([Findley et al., 1995](#)) and other physically demanding occupations (i.e. waste collectors) ([Schibye et al., 2001](#)) have reported no differences in UB strength between young and older workers. It is possible there may be a training effect among occupations that utilize their upper body more during daily job-related tasks when compared to age-matched white-collar controls ([Schibye et al., 2001](#)). Further, young firefighters exhibited greater CMJ height (23.1%) and velocity (10.1%) than older firefighters, which was supported by [Perroni et al. \(2015\)](#) who reported a 13% difference in CMJ height between young (<30 years) and older (>45 years) firefighters.

No age-related differences existed between groups for VL CSA or BB MT. However, older firefighters exhibited higher EI values of the VL and non-significantly higher EI values of the BB ($P = 0.069$). This finding is supported by [Gerstner et al. \(2017a\)](#) who found no age-related differences in medial gastrocnemius CSA, although the older men exhibited higher EI values. These results may suggest that although muscle size is maintained in the older firefighters, they may have an altered muscle tissue composition due to a greater infiltration of non-contractile tissue (i.e. fat and fibrous tissues) ([Gerstner et al., 2017a](#)). Further, given the lack of age-related differences in muscle activation, alterations in EI may contribute to the age-related reduction in LB strength and CMJ performance. Previous work ([Gerstner et al., 2017b](#)) has supported this and demonstrated that EI was related to the relative change in plantarflexion

maximal strength and power from slow to fast velocities in both young and older men.

4.4. Practical applications and limitations

The National Fire Protection Association has advocated for fire administrators to allocate time for their firefighters to participate in exercise while on-duty. Although the results from this study demonstrated young and older firefighters experience a similar recovery following an acute bout of resistance exercise, key neuromuscular variables including UB maximal strength, LB rapid strength, and CMJ performance remained reduced 24–72 h post-exercise. Given these variables have previously been shown to impact performance during simulated firefighter tasks (Henderson et al., 2007; Rhea et al., 2004; Hilyer et al., 1999) and are risk factors for slip, trip, and fall injuries (Mota et al., 2018), the implementation and timing of on-duty resistance training should be carefully considered. It is also important to note that the repeated bout effect (McHugh, 2003) suggests that a single bout of exercise will protect against muscle damage when exposed to a subsequent similar bout of exercise. Thus, for firefighters engaging in novel resistance exercise or that are untrained, it may be advisable to schedule their initial on-duty resistance exercise bout just before the completion of the firefighters shift cycle prior to their extended off-days (e.g., final 24-hour shift prior to their 4 consecutive off-duty days during a Kelly shift schedule). Further, chronically resistance trained men have been reported to experience less muscle damage than untrained men (Newton et al., 2008; Vincent and Vincent, 1997). Collectively these findings may suggest that the numerous benefits (e.g. improved health, reduced risk of injury, enhanced performance) (Pedersen et al., 2013; Thompson et al., 2015; Kraemer et al., 2002) of chronically performing resistance training are critically important to firefighters and the short-term EIMD reduction in performance can be mitigated with consistent and appropriately timed on-duty resistance exercise. It is also important to discuss our limitations. Although the majority of the fire service is predominantly men (92%) (Evarts and Stein, 2019), these findings may not be applicable to women with contrasting findings reported (Hicks et al., 2016; Sewright et al., 2008) when examining sex differences in response to EIMD. Lastly, we examined the right limb versus the dominant limb for all our lower body maximal and rapid force assessments. Given the exercise training (deadlifts and lunges) impacted both legs similarly and leg dominance has been shown to not impact the magnitude of EMID (Hody et al., 2013), we believe testing the dominant leg would have yielded similar results.

5. Conclusion

In summary, the primary findings of the current investigation indicated that age did not influence the recovery following an acute bout of a brief, on-site, free-weight resistance exercise routine in career firefighters. These findings may suggest that the recovery from a worksite resistance training program (similar to that used in the current study) would be similar across the broad age range in the fire service. However, firefighters experienced the majority of performance and symptomatic decrements between 24- and 72 h post-exercise. Fire administrators should be cognizant of this when implementing on-duty resistance training.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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