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Blood Pressure Surge with Alarm Is Reduced after Exercise and Diet Intervention in Firefighters

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Background Cardiac-related incidents are a public health concern for tactical occupations, and cardiovascular disease rates are higher in these populations compared with civilians. Research is needed to examine blood pressure (BP) responses in firefighters. The pager alert is one occupational hazard, and it is unknown if lifestyle change can reduce the systolic surge response.

Purpose To measure BP surge with alarm in firefighters to determine whether the magnitude is lower after a 6-week tactical exercise and Mediterranean-diet intervention.

Methods SBP and DBP and BP surge levels, circulating markers, vascular health, and fitness were analyzed. BP surge with alarm was captured during a 12-hour workshift. Exercise and diet were self-reported. Diet was tracked with diet scores based on number of servings.

Results Twenty five firefighters (43.4 ± 13.9 years) participated. We found changes in the magnitude of BP surge with alarm (SBP surge from16.7 ± 12.9 to 10.5 ± 11.7 mmHg, $P < 0.05$; DBP surge from 8.2 ± 10.8 to 4.9 ± 5.6 mmHg, $P > 0.05$) after intervention. We confirm that clinical (127.6 ± 9.1 to 120 ± 8.2 mmHg) and central (122.7 ± 11.3 to 118.2 ± 10.7 mmHg) SBP levels improve with exercise and diet. We report for the first time in firefighters that oxidative stress markers superoxide dismutase (9.1 ± 1.5 to 11.2 ± 2.2 U/ml) and nitric oxide (40.4 ± 7 to 48.9 ± 16.9 μmol/l) levels improve with an exercise and diet intervention.

Conclusion These findings have implications toward the benefit that short-term lifestyle changes make toward reducing the alarm stress response in first responders. *Blood Press Monit* 28: 134–143 Copyright © 2023 The Author(s). Published by Wolters Kluwer Health, Inc.

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Introduction

Cardiac-related incidents are a critical public health concern for tactical occupations like firefighting and military positions. In fact, cardiovascular disease (CVD) rates are higher in these populations compared to civilians. In firefighters, over 50% of line-of-duty deaths are cardiac-related, and it is estimated that 39% of firefighters have elevated blood pressure (BP), and 50% do not know their BP [1]. CVD is an overwhelming public health issue with the lack of BP control as a strong risk factor, and secondary prevention through lifestyle change is an effective way to reduce CVD risk. Yet, the efficacy of interventions in tactical populations to induce overt improvements in BP remains to be determined. The occupational dangers and pressure-filled situations that firefighters face put them at greater risk than the general population. Recently it was reported that firefighters may prefer to follow a Mediterranean diet [2] which was then shown to improve BP levels in fire academy recruits [3].

Firefighting is an occupation characterized by high stress, an immediate call to action through an alarm response, and constant exposure to hazardous risks. There is a need to develop functional interventions that can be effective at lowering BP in firefighters. In our recent review, we describe a gap in the literature on interventions examining BP responses in firefighters [4]. Interestingly, the National Fire Protection Association (NFPA) publishes a standard on health and fitness but does not require fire companies to have fitness testing with data suggesting that <30% of fire stations in the USA actually do have a wellness or fitness program as part of their standard operating procedures [5].

The pager alert is one occupational hazard for firefighters. The alarm sound causes an instant sympathetic system response causing an immediate spike in BP and heart rate (HR), and theories suggest this contributes to the line-of-duty death incidence in firefighters [4]. Ambulatory BP (ABP) monitoring is clinically recommended by guidelines for the diagnosis of hypertension. Recently we used

ABP and reported that the BP surge responses to alarms are higher when firefighters respond to medical calls than to fire calls [6]. We have found that this BP surge can be extreme, with 17.1 mmHg increases in SBP and 10.3 mmHg increases in DBP measured in response to a one-pager alert [6]. Another type of BP surge is morning BP surge which occurs in some adults and can be related to cardiovascular events such as myocardial infarction, stroke, and death [7]. While they are both BP surges, it could be assumed that the BP surge firefighters experience when the fire alarm sounds could be similar physiologically to morning BP surge and therefore could also present risk.

Finally, there is a paucity in the literature examining the vascular health of firefighters, with only a few studies measuring inflammation [8,9], vessel stiffness [10,11], structure [12], and function [13]. The relationship between circulating markers of vascular health and BP has been studied in civilians, with studies showing a direct relationship between high-sensitivity C-reactive protein (CRP) and BP levels [14], between superoxide dismutase (SOD) and BP [15,16], and between nitric oxide and BP [17]. It seems there is no study that reports on vascular health relationships using these biomarkers with the immediate BP surge with alarm in firefighters.

Therefore, the purpose of this study was to measure pre and postintervention BP surge response to alarm, and CVD risk factors, in municipal firefighters to determine whether the magnitude of BP surge with alarm is lower after a 6-week tactical exercise and Mediterranean diet intervention. We hypothesized that the BP surge with alarm would be lower after intervention and that CVD risk factors would be related to the magnitude of the BP surge with alarm measured.

Methods

This was a prospective cohort pre-post diet and exercise intervention which involved a 6-week Mediterranean diet and a tactical circuit training program. Overall, 44 firefighters met the inclusion criteria and were enrolled. Criteria for inclusion were no more than one BP medication and no more than one cholesterol medication; no prior cardiovascular incidents, diagnosed heart disease or diabetes; nonsmoker, and no physical limitation that would preclude an exercise program. All firefighters completed pretesting, underwent the 6-week intervention, and post-testing within 24–48 h of the last training bout. The pre and post-data collection included three visits each: a clinical fasted testing appointment, an ABP monitoring, and a fitness test. All post-testing was conducted at the same time of day as pretesting, and each posttest session was administered in the same manner. All participants gave written informed consent, filled out a general health history form, and completed a validated 21-question depression, anxiety, and stress scale (DASS-21) [18]. All firefighters also provided a 3-day diet report at enrollment. The dietary data gave us a baseline measure of their dietary pattern, and nutrient analysis was completed using the ESHA Research Food Processor nutritional analysis software and database (ESHA Research, Salem, Oregon). The study protocol was approved by Institutional Review Board, and all procedures were in accordance with the ethical standards of the Helsinki Declaration.

Clinical testing

For the clinical fasted testing, firefighters reported to the laboratory following an overnight fast. The visit took place in a quiet, temperature-controlled room. They were asked to refrain from exercise for 24 h prior, as well as food, drink, medication, and caffeine for at least 10 h prior to the test. We asked them to empty their pockets and remove their pagers and other accessories prior to the measurements. Height and weight were measured using a stadiometer and digital floor scale (Adam Equipment Inc., Oxford, Connecticut, USA) without shoes. BMI was calculated and recorded. Body fat percentage was estimated by whole-body bioelectrical impedance analysis in accordance with the manufacturer's instructions (ImpediMed DF50, San Diego, California, USA).

Brachial BP measurements were obtained in accordance with clinical guidelines by laboratory personnel during each testing session using an aneroid sphygmomanometer (Medline Industries, Mundelein, Illinois, USA) [19]. Brachial BP measurements were performed in triplicate with the average BP over the three visits reported as the clinical SBP and clinical DBP.

Serum glucose levels and lipid levels, including total cholesterol (TC), LDL-cholesterol, HDL-cholesterol, and triglycerides were measured using the Alere Cholestech LDX lipid profile system (San Diego, California, USA). Alere Cholestech lipid profile values correlate with venous plasma measured in clinical diagnostic laboratories ($r > 0.95$).

Vascular measurements were collected after 15 min of supine rest as previously reported [20]. Arterial stiffness was determined noninvasively by carotid-femoral pulse wave velocity (PWV) assessment with the commercially available SphygmoCor XCEL system (SphygmoCor XCEL, AtCor Medical, Sydney Australia). BP was measured first, and then peripheral pulse waveforms were captured in the carotid artery using a hand-held tonometer probe (Millar/AtCor Medical pressure tonometer, Houston, Texas, USA) and in the femoral artery using volumetric displacement within a cuff placed around the thigh. Data from pulse waveforms were assessed by the software's internal quality control index (operator index > 80%). The average of three measures is reported. Carotid-femoral PWV is reliable and provides multiple biomarker measurements: central aortic SBP and DBP, augmentation index adjusted to HR of 75 beats per min (AIx@75), and subendocardial viability ratio (SEVR) [21]. Central BP is argued to be more relevant than brachial BP for determining CVD risk and thus has gained prognostic significance recently [22]. AIx@75 is a measure of arterial stiffness which is an independent marker of premature CVD [23]. SEVR is an estimate of myocardial oxygenation related to cardiac workload and could be an indicator of coronary blood flow [24]. In our laboratory, we have calculated the intraclass correlation coefficient (ICC) for PWV measurements at >0.962.

Flow-mediated dilation (FMD) is an index of nitric oxide-mediated endothelial-dependent function, which assesses blood vessel vasodilatory function [25]. The same operator (D.L.F.) completed all FMD studies. HR was continuously monitored using a three-lead ECG, and BP measurements were taken in the left arm to confirm a steady state. A 5 × 84-cm automatic cuff (E-20 rapid cuff inflator; D.E. Hokanson, Bellevue, Washington, USA) was placed around the right forearm distal to the olecranon process following established FMD guidelines [26]. Image collection, transducer placement, and detailed methods were completed as previously described [27]. FMD videos were recorded using the GE Logiq E ultrasound system (Model BT12, GE Medical Systems, Chicago, Illinois, USA) and downloaded to a separate computer using Movavi Video Editor (Movavi, St Louis, Missouri, USA). Arterial diameters and blood flow velocity levels were analyzed using the edge detection software Brachial Analyzer for Research (Medical Imaging Applications, Coralville, Iowa, USA). The highest 10-s interval throughout the 2-min collection period represented the true peak hyperemic diameter. FMD reported is the percent increase in diameter from baseline at preinflation. The ICC for baseline diameter and peak diameter are 0.94 and 0.94, respectively. Intra-observer reliability for the image analysis using the analysis software has been established at 99.2%.

Carotid artery intima-media thickness (IMT) is an index of plaque buildup, atherosclerotic potential, and vascular remodeling [28]. Images were obtained, and measurements were made using the GE Logiq E ultrasound system with automated calculation software (Auto-IMT Software Option, GE Medical Systems, Chicago, Illinois, USA). In our laboratory, we have calculated the ICC for IMT measurements at >0.90 with interobserver variability <0.04 mm and intra-observer variability <0.02 mm. To the best of our knowledge, this is only the second study to report these vascular markers in firefighters in response to exercise training [29].

Ambulatory blood pressure monitoring

Noninvasive portable ABP monitors (SpaceLabs, Model 90127, Redmond, Washington, USA) were worn by each firefighter for a 12-h work period. BP measures were obtained at 30-min intervals during the daytime period (6:00 a.m.–10:00 p.m.), and 60-min intervals at night (10:00 p.m.–6:00 a.m.) if worn during that timeframe. Firefighters were all instructed to wear the monitor for at least 12 h. When an emergency call came in and their pager went off, they were instructed to push the monitor's button to force an automatic BP reading to capture the immediate BP surge with alarm. Additionally, each participant was asked to keep a log while wearing the ABP monitor. They were given a data sheet where they provided information on the time of day for each reading, what they were doing, how they were feeling, and what type of emergency call or work activity they were performing. Overall SBP, DBP, mean arterial BP, and HR during the 12-h work shifts were averaged and are reported for pre and postintervention. As a measure of relative BP variability, the coefficient of variation was calculated for all the SBP and DBP values. Finally, the magnitude of the BP surge with alarm was calculated based on forced BP measurements collected by firefighters when the alarm sounded.

Fitness testing

All firefighters reported to the facility on a separate day for fitness testing, which included the submaximal Gerkin-protocol treadmill test and other assessment tests outlined in the NFPA 1583 Standard on Health-Related Fitness Programs [5]. The work of firefighting involves exertion, balance, lifting, climbing, dragging, pulling objects, and crawling. The occupational requirements pose demands on all aspects of health and fitness, so a variety of fitness tests were completed, including an assessment of power, muscular endurance, muscular strength, balance, and functional strength through a dummy drag.

First, after 5 min of seated rest, brachial BP was measured. The Gerkin treadmill protocol begins with a warm-up period of 3 min at a speed of 3.0 mph and 0% grade. The workload raises incrementally each minute by either an increase in speed (0.5 mph) or an increase in incline (2%). HR was measured continuously throughout the test, and the termination criteria were 85% of maximal HR [208 – (0.7 × age) × 0.85]. Estimated peak oxygen consumption (VO_{2peak}) was calculated using the Gerkin formula: VO_{2peak} = 56.981 + (1.242 × TT) – (0.805 × BMI), where TT is test time.

Following the treadmill test, the firefighters completed a battery of other fitness tests as described [29]. First, they finished a 2-min stair climb test where the number of steps climbed was recorded. The stair climb test has been reported as a quality measure of overall fitness in firefighters and is a task performed during the candidate physical ability test (CPAT) [30]. The next fitness test completed was a 12-step sprint which was used to indirectly evaluate power. Faster stair sprinting is suggestive of higher speed generation and more explosive power, which are both physical attributes necessary for any military-like occupation [31]. Muscular endurance was tested using a prone plank test and a stationary wall sit. The WFI-prone static plank test has been used to test firefighter fitness [32]. Balance was measured with single-leg stand time. For the rescue drag test, the firefighters were instructed to grab and drag a 65.9 kg Rescue Randy Training Manikin (Simulaids, Inc., Leicestershire, UK) as far as possible in 30 s. The distance was recorded in meters. These mannequins were developed for lifelike simulations involving rescue, extrication, and confined space and have been used by the military, fire, police, and emergency personnel worldwide, and a rescue drag test is one of the specific tasks included in the CPAT [30].

Exercise intervention

Student trainers worked with participants for the first two exercise sessions to teach proper technique. After that, the intervention was self-reported weekly. The circuit program was completed three times per week and included six stations of exercises which were completed three times per workout. The stations included 40-lb carry for 100 ft; 3-min stair climb; 45-s plank pose; 20-lb carry with a fast walk for 100 ft; right and left single leg stands for as long as balance was maintained; and 15-lb carry up and down 30 stairs. Firefighters were recommended to complete the circuit at the firehouse using a hose line, fireground tools, or extrication tools. If they chose to complete the workout at home, they were recommended to select items of the appropriate weight or use dumbbells or weight plates for each station. Overall adherence to the program was calculated based on the number of workouts completed in the 6-week period.

Mediterranean diet intervention

All firefighters were taught how to follow a modified Mediterranean diet during an hour-long training session. This session taught about food groups important to the Mediterranean dietary pattern, specified which foods fall into each group, and outlined the number of servings that should be consumed for each food group. They were provided with a study diet manual which included detailed instructions on serving sizes and portion control, sample tracking sheets, sample recipes, and extensive lists of foods that would fall into each food group. In addition, we gave each firefighter a reusable canvas grocery bag containing a set of colorful diet serving-size cups, some plastic food storage containers, and a package of serving-size portion-control bags. Throughout the duration of the study, the firefighters had access to our clinical study website. At the log-in page, they could self-report serving counts for each food group, record workouts, and reach study personnel with any questions. To further encourage diet adherence throughout the intervention, participants received diet tips through weekly coaching sessions with research members. Each participant was assigned an independent ‘health coach’ who was a member of the research team. This coach worked one-on-one with the study participant to increase adherence, track progress, and answer any diet-related questions. Regular weekly communication helped educate the firefighters and kept adherence high. We recently reported that using this model of constant interaction through phone or virtual calls is feasible and leads to positive health and fitness improvements [33].

Our Mediterranean Diet Score System (MDSS) method gives greater importance to foods that should be consumed in every meal, more frequently, and less importance (lower point value) to those that should be consumed weekly or limited altogether, and recently we validated this scoring system [34]. The structure of the Mediterranean diet and the diet scoring method was based on a modification of diet scores used by Panagiotakos *et al*. and Monteagudo *et al* [35,36]. Our MDSS recommends: ≥4 servings of vegetables per day, ≥3 servings of fruit per day, 2–3 servings of low/nonfat dairy per day, minimize regular dairy intake, ≥4 servings of fish per week, <3 servings of poultry per week, minimize intake of red meat, ≥3 more servings of beans per week, ≥5 servings of nuts and healthy oils per week, <4 servings of sweets and processed foods per week, and 6–7 servings of grains/potatoes per day (Table 4). Scores were calculated based on the number of servings per food group each week and adherence was calculated based on the total score in relation to total possible points over the 6-week period. The MDSS has a maximal possible 17 points where a higher score denotes greater adherence, as reported, and validated recently [34]. For the intervention, all firefighters received the same diet and exercise training program and nutrition-related resources.

Cardiac reactive protein, superoxide dismutase, and nitric oxide measurements

Blood samples were drawn into serum separator tubes on the morning of the clinical fasted study visit at pre and postintervention time points. Samples were centrifuged at 3000 g for 20 min at 4 °C, and the isolated serum was frozen at −80 °C until the time of assay. For indirect measurement of nitric oxide, frozen samples were thawed and then ultrafiltered through a 10 000 MWCO Amicon Ultra filter (MilliporeSigma Merck KGaA, Darmstadt, Germany) by micro-centrifuge (14 000 g, 30 min, 4 °C). Levels of nitric oxide end-products were measured using a modified Griess assay [37]. CRP levels were measured by ELISA assay kit (Invitrogen, ThermoFisher, Life Technologies Corporation, Carlsbad, California, USA). Samples were diluted 1 : 3000 prior to assay, and the sensitivity of the assay is reported at <10 pg/ml CRP. To assess total SOD activity, serum samples were diluted 1 : 5 in sample buffer and measured by assay kit (Cayman Chemical, Ann Arbor, Michigan, USA) [38]. Inter-assay and intra-assay coefficients of variation were 7.6 and 10.6% for nitric oxide assay, 2.01 and 1.56% for CRP, and 5.9 and 12.4% for SOD assay.

Statistical analysis

Statistical analyses were performed using SPSS 28.0.1 (SPSS Inc., Chicago, Illinois, USA) The corresponding author had full access to the data in the study and was responsible for the integrity of the data set and data analysis. The distribution of outcome variables was assessed using the Shapiro–Wilk test of normality. For the report of ABP measurements, all ABP readings over the 12-h work shift were averaged to give a single SBP and DBP measure. The values of SBP and DBP readings were analyzed separately. Differences between pre and postintervention values were compared using the paired sample *t*-test. A one-way analysis of variance was performed to confirm the intervention effect. The effect size for analysis was examined using Cohen's *d*. Relationships between BP measures and CVD risk factors or dietary data were examined with correlations (Pearson, two-tailed), and these were confirmed by regression. The results are expressed as mean values ± SD, and significance was set at $P < 0.05$.

Results

Forty-four firefighters started the intervention, nine firefighters dropped out within the first 2 weeks of the study, and three firefighters did not complete the full exercise and diet intervention. Thus, we had 32 firefighters complete the entire study, but seven were missing vascular data, blood draws, or BP measurements, so they have not been included. Therefore, we present data on 25 firefighters (22 M, 3 F). This is a similar sex ratio (12% female) to the overall firefighter population which has been reported by the NFPA (10% female) [39]. Our population averaged 19.6 (±13.6) years of experience as municipal firefighters.

Our firefighters were overweight, hypertensive, and inactive upon enrollment. The firefighters did not have as high a call volume as some busy city departments, they reported running 6.3 (±3.9) calls per day and attending 4.1 (±2.1) trainings per month. They reported exercising 2.3 (±1.8) times per week for a total of 96.5 min, which falls below the activity guidelines recommendation of 150 min per week. Pre and postintervention clinical characteristics are presented in Table 1. The exercise and diet intervention improved perceived health from 6.6 to 8.3 ($P = 0.00$, $d = 1.37$), which was scored on a subjective scale from 1 to 10. The intervention also improved weight (92.9–89.9 kg, $P = 0.00$, $d = 1.28$), body fat (31.2–28.7%, $P = 0.02$, $d = 0.83$), TC levels (190.3–181.7 mg/dl, $P = 0.04$, $d = 0.38$), triglyceride levels (111.9–97.6 mg/dl, $P = 0.01$, $d = 0.51$), and BMI (31.0–30.0 kg/m^2, $P = 0.00$, $d = 1.17$). The only vascular health measure that changed in 6 weeks was FMD percentage (8.2–10.1%, $P = 0.001$, $d = 1.70$). With correlation analysis, we found that the change in FMD percentage was inversely related to red meat ($r = -0.77$, $P = 0.04$) and regular dairy ($r = -0.84$, $P = 0.02$) consumption. Also, the change in PWV had a direct relationship with diet adherence ($r = 0.5$, $P = 0.02$) and oil/nut consumption ($r = 0.5$, $P = 0.03$). These relationships support the beneficial effects of following a Mediterranean dietary pattern. Table 1 also reports results from the DASS-21. The intervention led to some improvements, with moderate effect decreases seen in subjective depression (2.76–1.45 score out of 7, $P = 0.01$, $d = 0.49$), anxiety (2.48–1.54 score out of 7, $P = 0.03$, $d = 0.42$), and overall DASS-21 score (10.28–6.95 score, $P = 0.02$, $d = 0.47$).

Figure 1 displays the SBP and DBP surge with alarm data. For the analysis, we included the maximal SBP and DBP surge with alarm captured for each 12-h shift for each firefighter as this represented the highest occupational stress point. The figure displays the magnitude of SBP surge with alarm at pre and postintervention. At preintervention, the captured SBP surge with alarm was 16.7 ± 12.9 mmHg (124.2–140.9 mm Hg increase with alarm) and the DBP surge with alarm was 8.2 ± 10.8 mmHg (75.7–83.9 mm Hg increase with alarm). These were both at a lower magnitude during postintervention: SBP surge with alarm measured at 10.5 ± 11.7 mmHg (122.2–133.0 mm

Table 1 Pre and postintervention characteristics

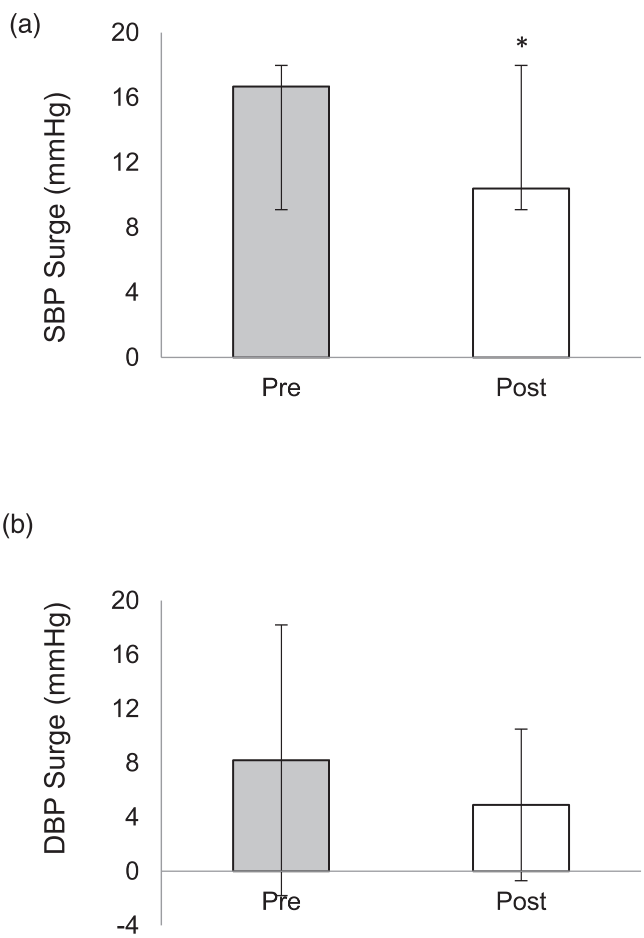
	Pre	Post	Change
Demographic characteristics			
Age (years)	43.4 (13.9)	–	–
Number of Years as firefighter	19.6 (13.6)	–	–
Height (cm)	174.9 (8.0)	–	–
Weight (kg)	92.9 (14.6)	89.9 (14.4)[a]	−3.02
BMI (kg m^{-2})	31.0 (4.5)	30.0 (4.6)[a]	−0.97
Body fat (%)	31.2 (6.4)	28.7 (6.3)[a]	−2.40
Health rating (1–10)	6.6 (0.8)	8.3 (0.7)[a]	–
Family history (yes/no)	15/10	–	–
Medication status (yes/no)	12/13	–	–
Clinical laboratory values			
TC (mg dl^{-1})	190.3 (11.0)	181.7 (38.5)[a]	−8.67
Triglycerides (mg dl^{-1})	111.9 (56.1)	97.6 (46.3)[a]	−14.33
HDL-cholesterol (mg dl^{-1})	47.3 (20.2)	44.1 (16.9)	−3.33
LDL- cholesterol (mg dl^{-1})	120.9 (33.1)	121.8 (32.1)	−1.80
Glucose (mg dl^{-1})	95.4 (11.0)	92.7 (7.5)	−2.71
Vascular measures			
FMD (%)	8.2 (2.8)	10.1 (2.8)[a]	1.87
FMD norm	0.72 (0.1)	0.79 (0.1)	0.07
IMT (mm)	0.51 (0.1)	0.48 (0.1)	−0.02
AIx at 75	16.7 (11.3)	16.9 (13.6)	−0.82
SEVR (%)	156.7 (26.7)	160.2 (33.1)	3.45
PWV (m/s)	6.9 (1.9)	7.3 (1.8)	0.19
Depression, anxiety, and stress scale (DASS-21) score			
Depression (out of 7)	2.76 (5.0)	1.45 (3.2)[a]	−1.36
Anxiety (out of 7)	2.48 (2.7)	1.54 (1.8)[a]	−1.00
Stress (out of 7)	5.04 (5.7)	3.95 (4.9)	−1.24
DASS-21 total (out of 21)	10.28 (12.0)	6.95 (7.9)[a]	−3.60

Data are presented as mean (SD). Absolute change is reported.
Family history, reports family history of cardiovascular disease;
AIx at 75, augmentation index adjusted to 75 beats per minute; FMD, flow-mediated dilation; IMT, intima-media thickness; PWV, pulse wave velocity; SEVR, subendocardial viability ratio; TC, total cholesterol.
[a]Significant at $P < 0.05$ between groups.

Hg increase with alarm) and DBP surge with alarm was 4.9 ± 5.6 mmHg (75.8–80.9 mm Hg increase with alarm), but only the difference in magnitude of SBP surge with alarm was significant ($P = 0.005$, $d = 0.57$). The HR surge with alarm was also captured by each firefighter, and the magnitude of the HR surge decreased with intervention. We found a smaller increase in HR with alarm at postintervention measurements. HR surge was measured at 11.4 bpm (71.4–82.7 bpm increase with alarm) at preintervention monitoring and measured at 0.2 bpm (72.1–72.3 bpm increase with alarm) at postintervention ($P = 0.002$, $d = 0.69$).

Table 2 presents the pre and postintervention BP measurements. We found improvements in clinical SBP (127.6–120.2 mmHg, $P = 0.00$, $d = 0.95$), DBP (80.9–77.4 mmHg, $P = 0.00$, $d = 0.79$), central SBP (122.7–118.2 mmHg, $P = 0.02$, $d = 0.43$), and central DBP (83.9–80.6 mmHg, $P = 0.02$, $d = 0.44$) with the intervention. BP variability was defined using the coefficient of variation of all BP measurements collected during the 12-h monitoring session at both pre and postintervention. DBP variability was higher at both pre (13.24 vs 9.48%) and post (10.92 vs 8.64%) compared to SBP. With correlation analysis, the change in SBP was directly related to whole grain ($r = 0.43$, $P = 0.034$) and fish ($r = 0.43$, $P = 0.035$) consumption, and the change in DBP was related to fish ($r = 0.46$, $P = 0.024$). These relationships further support the beneficial effects of following a Mediterranean dietary pattern.

Fig. 1



Pre and postintervention blood pressure surge levels. Data shows (a) SBP surge and (b) DBP surge values in firefighters comparing pre (solid bars) to post (open bars). *$P < 0.05$ between groups.

Figure 2 reports the improvements seen in serum biomarker measurements. We found that SOD (9.1 ± 1.5 to 11.1 ± 2.8 U/ml, $P = 0.003$, $d = 0.76$) and nitric oxide (40.4 ± 17.9 to 48.9 ± 17.1 umol/l, $P = 0.00$, $d = 1.07$) levels increased with the intervention. Our population of firefighters was in the high relative risk category (above 3.0 mg/l) based on their average high sensitivity CRP. We found that CRP levels did not change with intervention (3.6 ± 0.6 to 3.3 ± 0.8 mg/l, $P = 0.07$). There were no relationships between serum biomarkers and any BP measures. With dietary intake though, found that change in SOD was directly related to fish ($r = 0.50$, $P = 0.049$) and oil/nut ($r = 0.65$, $P = 0.001$) consumption. Change in CRP levels was inversely related to fish consumption ($r = -0.53$, $P = 0.02$), and change in nitric oxide was directly related to vegetable consumption ($r = 0.52$, $P = 0.03$). These relationships are also evidence supporting the beneficial effects of following a Mediterranean dietary pattern.

Table 3 presents the pre and postintervention fitness measurements. As expected, the exercise intervention improved overall fitness in firefighters. We found improvements in estimated VO_{2peak} ($P = 0.02$, $d = 0.44$), balance ($P = 0.03$, $d = 0.41$), stair climb ($P = 0.03$, $d = 0.42$), plank ($P = 0.04$, $d = 0.38$), wall-sit time ($P = 0.01$, $d = 0.52$), and rescue dummy drag distance ($P = 0.00$, $d = 1.24$).

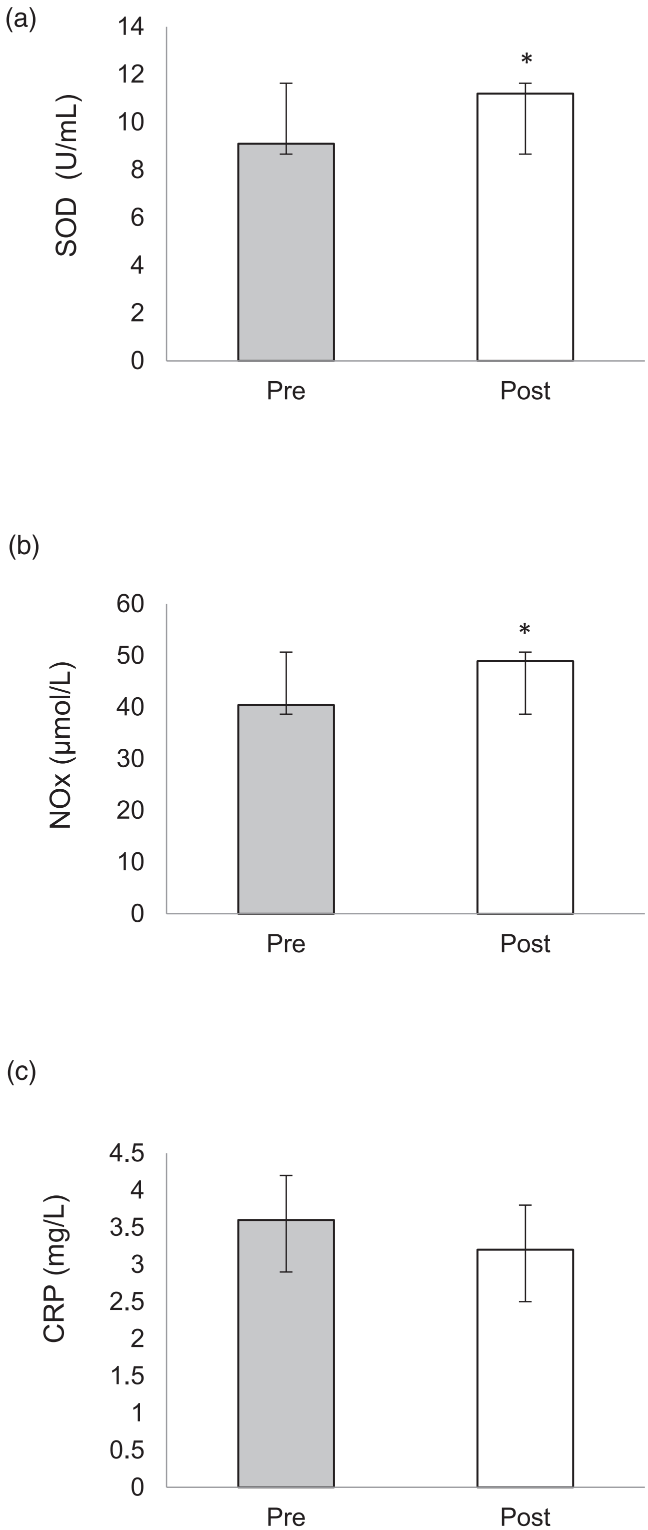
Table 4 reports the diet characteristics of the firefighters and the number of servings per food category recommended with the modified Mediterranean dietary

Table 2 **Blood pressure measurements**

	Pre	Post	Change
Clinical SBP (mmHg)	127.6 (9.1)	120.0 (8.2)[a]	−7.51
Clinical DBP (mmHg)	80.9 (5.6)	77.4 (6.3)[a]	−3.52
Central SBP (mmHg)	122.7 (11.3)	118.2 (10.7)[a]	−4.46
Central DBP (mmHg)	83.9 (6.9)	80.6 (9.4)[a]	−3.29
Ambulatory SBP (mmHg)	129.6 (13.3)	126.8 (10.7)	−2.71
Ambulatory DBP (mmHg)	79.6 (8.4)	78.0 (6.7)	−1.55
Ambulatory MAP (mmHg)	95.5 (9.7)	93.6 (7.3)	−1.86
Ambulatory HR (bpm)	76.6 (11.9)	74.2 (10.9)	−2.42
Ambulatory SBP coefficient of variation (%)	9.48	8.64	–
Ambulatory DBP coefficient of variation (%)	13.24	10.92	–

Data are presented as mean (SD).
HR, heart rate; MAP, mean arterial blood pressure.
[a]Significant at $P < 0.05$ between groups.

Fig. 2



Pre and postintervention serum biomarker measurements. Data shows (a) superoxide dismutase (SOD) levels, (b) nitric oxide (NOx) levels, and (c) cardiac reactive protein (CRP) levels in firefighters comparing pre (solid bars) to post (open bars). *$P < 0.05$ between groups.

intervention. Overall, firefighters in our study did not meet the average recommended number of servings of vegetables, fruits, whole grains, and low-fat dairy. Also, analysis of the preintervention 3-day diet logs confirmed previous reports that firefighters consume high sodium (2915.2 mg compared to the recommended 2300 mg), low calcium (498.4 mg compared to the recommended 1300 mg), low potassium (1666.0 mg compared to the recommended 4700 mg) and follow a high-fat diet with 11% of their daily calories as saturated fat compared to the recommended <10%.

Discussion

This is the first study to report these measures after an exercise and diet intervention in municipal firefighters. We measured BP surge levels to the 911 pager alarm and quantified the magnitude of BP surge with the alarm that occurs with the stress response. We then demonstrated that this surge level could improve and be lower after a short-term tactical circuit exercise training and Mediterranean diet intervention. We found that circulating SOD and nitric oxide levels are higher after an exercise and diet intervention which is novel as it's the first report of these measures in an at-risk population of firefighters pre and postintervention. We also confirm that clinical and central SBP levels are lower after exercise and diet intervention. We do not confirm improvements with ABP measurements from pre to postintervention, and this is most likely because the ABP monitor was only worn for a 12-h period during a work shift. Finally, confirming prior research, we found improvements in body composition, TC, FMD, depression, and anxiety. All told, this study has important implications for the benefits that preventive lifestyle factors can have on reducing the alarm stress response in first responders.

BP responses are multifactorial, and ABP is a valuable diagnostic tool for hypertension profiles which is useful for identifying cardiac risk. Prospective evidence supports the idea that morning BP surge is an independent risk factor for vascular dysfunction and CVD [7]. The BP surge with alarm in firefighters may be call-type

Table 3 **Fitness measurements**

	Pre	Post	Change
Adherence to program (%)	89.3 (13.1)	–	–
VO_{2peak} (mg kg^{-1} min^{-1})	34.7 (5.6)	37.2 (6.3)[a]	2.29
Balance (s)	146.6 (118.8)	216.3 (191.9)[a]	68.7
Plank pose (s)	96.5 (54.6)	115.9 (58.8)[a]	17.31
Wall sit (s)	94.5 (55.1)	133.8 (79.3)[a]	37.29
Stair climb (Number of steps)	301.1 (71.4)	326.7 (56.8)[a]	20.12
12-step sprint (s)	2.9 (0.7)	2.9 (0.5)	0.03
Dummy drag (m)	40.6 (16.2)	48.6 (17.8)[a]	7.51

Data are presented as mean (SD).

Balance, sum of right and left leg balance; VO_{2peak}, estimated peak oxygen consumption.

[a]Significant at $P < 0.05$ between groups.

Table 4 Mediterranean diet characteristics

Adherence to diet (%)	66.2 (1.6)	
Overall 6-week MDS	65.1 (14.5)	
Food groups	[a]per week	Target
Vegetables	19.4 (8.1)	≥28 servings/week
Fruits	15.7 (8.0)	≥21 servings/week
Whole grains	22.9 (12.5)	≥49 servings/week
Nuts and oils	8.0 (4.3)	≥5 servings/week
Fish	4.0 (2.4)	≥4 servings/week
Low-fat dairy	9.7 (5.4)	14–18 servings/week
Beans	3.4 (2.5)	≥3 servings/week
Poultry	3.8 (2.9)	≤3 servings/week
Red meat	2.2 (1.5)	≤2 servings/week
Regular dairy	4.0 (2.4)	≤6 servings/week

Data are presented as mean (SD).
MDS, Mediterranean diet score; Target, recommended per week for scoring.
[a]Per week, number of servings in food group consumed per week.

dependent and could be related to years of experience as a firefighter, to overt CVD risk factors, or to other causes. In relation to this, a prior study found that the HR surge responses to alarm can range from 2 to 48 beats per minute [40]. But the authors in that study did not measure BP responses. Recently we examined BP levels in an occupational setting and found that medical calls have higher BP surge responses compared to fire calls, to BP while riding on apparatus, or to the pre-alert sounds in the firehouse [6]. With the current study, we found that the SBP surge with alarm that firefighters experience may be lower after exercise and diet intervention which supports the benefit of exercise and wellness programming in the firehouse. Furthermore, firefighters have expressed satisfaction, and improved adherence, and agree that this type of intervention is feasible [33]. With very little intervention research existing on firefighters, more studies are needed to confirm these findings. If exercise and diet reduce the BP surge with alarm that firefighters experience, then wellness programs should become mainstream in the fire service as part of the primary prevention of CVD in firefighters.

To the best of our knowledge, this is the first study measuring serum levels of oxidative stress and inflammation markers in response to an exercise and diet intervention in firefighters. The firefighting occupation is related to the increased production of stress hormones which can lead to oxidative stress and inflammation. Gaughan *et al.* showed that an oxidative stress response occurs in response to the workload and to the respiratory exposure firefighters face [41]. We report improvements in SOD and nitric oxide but no changes in CRP levels. Oxidative stress plays a significant role in the pathogenesis of CVD and high BP, but we found no relationships between CVD risk factors and the measured BP surge with alarm. Nitric oxide acts as a vasodilator that helps regulate BP, making it an important antihypertensive agent [42]. Excessive production and or dysregulated production of nitric oxide can lead to increased CVD risk; however, SOD also functions to regulate nitric oxide production. Our results suggest an environment with improved endogenous antioxidant and vasodilatory capacity after exercise and diet intervention. Longer interventions need to be conducted to understand the full benefit that firefighters can experience.

We report that vascular function measures were overall the same or slightly better after the intervention. Our findings suggest that the FMD percentage improves, and it can be theorized that this improvement is likely due to the changes seen in vasoactive nitric oxide production. The improvement in endothelial function may be due to the exercise-mediated upregulation of endothelial nitric oxide synthase, a potent vasodilatory enzyme. Alternately, we found no change in vascular stiffness in the firefighters with the intervention which is similar to prior research that found no change in PWV measures in men wearing firefighter protective equipment after a heat-stress treadmill-based exercise protocol [11]. While this was a short-term intervention, longer interventions are needed in larger populations to confirm these findings and to examine if a magnitude response exists.

Importantly our study adds to the clinical nutrition research in tactical populations. We observed that changes in clinical SBP pre to postintervention were related to whole grain and fish consumption. Additionally, changes in clinical DBP were related to fish consumption. These results highlight the efficacy of a Mediterranean diet intervention for improving CVD risk factors, especially in a high-risk population such as firefighters. This data is in line with a meta-analysis and a recent systematic review that support the Mediterranean diet as beneficial for preventing and reducing the risk of CVD [43]. SOD levels were directly related to fish and oil/nut consumption, suggesting that the consumption of healthy fats is beneficial for reducing oxidative stress. A study by Vázquez *et al.* found that white fish consumption reduces DBP, similar to the results of our intervention [44]. An observational study from 2018 found that a Mediterranean diet with supplemented healthy oil/nut consumption was related to decreased CVD risk [45]. Interestingly, we also found that improvements in FMD were inversely related to red meat and regular dairy consumption confirming the link between red meat and the risk of CVD [46]. Whether dairy is beneficial or detrimental to CVD health remains controversial, however, our intervention and others suggest that is it mainly the saturated fats in high-fat dairy that elevate CVD [47]. Lastly, our results found that the change in nitric oxide abundance was directly related to vegetable consumption. A potential explanation is the increased antioxidant effect of vegetable consumption that contributed to greater nitric oxide production, but further investigation on this for a short-term intervention is needed. Overall, our findings indicate that a dietary shift toward the Mediterranean diet pattern reduces cardiovascular risk in firefighters in just 6 weeks, and the major contributions seem to be related to increased fish, healthy fat, and vegetable intake with reduced consumption of red meat and regular fat dairy.

Firefighters are exposed to traumatic incidents and events which place them at increased risk for mental health issues including stress, depression, and anxiety. Health promotion initiatives do not exist in many firehouses. Those stations that do have programs, focus more on the NFPA recommendations of fitness and wellness with a very limited focus on mental health outcomes [48]. We demonstrate that depression and anxiety levels are lower after a short-term exercise and diet intervention. These findings are supportive of the beneficial effects of wellness programming and may be used to promote psychosocial wellness programming in fire departments.

Our study had several limitations. First, there was no control group to compare improvements. Pilot studies in our lab determined that a realistic control group is not possible as the occupational risk and work involved with firefighting are unique. The sample includes municipal firefighters from a suburban area and is likely not representative of all firefighters. The call volume in suburban firehouses is lower than in busy city departments, so this may result in different BP surges with alarm or overall BP levels between the two types of municipal fire department employees. ABP monitoring is a reliable way to measure BP surge with alarm in tactical populations, yet the BP response could also be dependent on the amount of sleep. Sometimes during a shift, firefighters are more active and get less sleep, therefore future studies should examine the effects of sleep deprivation on the BP surge with alarm seen. Also, while we took measures to ensure proper fitness and dietary education, workout adherence and serving sizes reported for each patient were self-report and contributes to the interpretation of results. Additionally, overall adherence to the Mediterranean diet from some firefighters was less than 70%. We would expect to see stronger relationships between cardiovascular outcomes and diet if higher adherence was observed. We report relationships between CVD risk factors, nutrition components, and BP surge with alarm, but this is the first study to examine these measures. Mechanistic research is needed that examines other oxidative stress or inflammatory biomarkers. Finally, there is a need for more detailed cardiovascular testing which was beyond the scope of this study.

In conclusion, we are the first to demonstrate that the magnitude of BP surge with alarm could improve after tactical circuit exercise training and a Mediterranean diet. We show that the immediate stress that occurs when the 911 pager alarm sounds could be reduced to a lower risk level with a diet and exercise intervention. We also report lower clinical and central SBP levels, and higher SOD and nitric oxide levels, as improvements with the intervention. These seminal findings in a group of firefighters have important implications for the benefits that preventive lifestyle factors can have on reducing the alarm stress response in first responders.

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Conflicts of interest

There are no conflicts of interest.

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