Spor Hekimliği Dergisi, 56(3):98-105; 2021
Turkish Journal of Sports Medicine
Turk J Sports Med. DOI: 10.47447/tjsm.0492

Research Article / Araştırma Makalesi

The ambulatory blood pressure and heart rate variability responses following sudden vigorous physical exertion among firefighters with hypertension

Hipertansiyonlu itfaiyeciler arasında ani yüksek şiddetli fiziksel efor sonrası ambulatuvar kan basıncı ve kalp atım hızı değişkenliği yanıtları

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ABSTRACT

Objective: To examine postexercise hypotension (PEH) after a maximal cardiopulmonary stress test (GEST) as well as heart rate variability (HRV), a surrogate marker of sympathovagal balance, as it relates to PEH among career firefighters with hypertension.

Materials and Methods: Firefighters (n=5) who were middle-aged (40.6±6.2yr) and overweight (28.1±3.9kg.m^{-2}) men with high BP (Systolic 126.4±9.5mmHg/Diastolic 85.6±5.9mmHg) and normal resting HR (71.1±11.2bpm) randomly performed a GEST and non-exercise control (CONTROL) session followed by attachment to ambulatory BP (ABP) and HR monitors for 19hr. Systolic (ASBP) and diastolic (ADBP) ABP, and HRV low (LF) and high (HF) frequency were recorded at hourly intervals over awake (11hr), sleep (8hr), and 19hr. Repeated measure analysis of variance (ANOVA) tested if BP and HRV differed over time and between experimental conditions. Multivariate regression tested the relationship between HRV and BP responses.

Results: Compared to CONTROL, after the GEST ASBP significantly increased over awake (21.7±3.4mmHg, p=0.003) and 19hr (15.8±2.2mmHg, p=0.002), and exhibited a statistically trending increase over-sleep (7.9±2.9mmHg, p=0.055). Compared to CONTROL, after the GEST ADBP showed a statistically trending increase over awake (8.8±3.9 mmHg, p=0.091), sleep (8.2±4.3mmHg, p=0.134), and 19hr (8.6±3.5mmHg, p=0.072). Compared to CONTROL, after the GEST LF/HF significantly increased over awake (1.9±0.5, p=0.015), and displayed a statistically trending increase over 19hr (0.8±0.5 p=0.155). LF/HF statistically tended to explain up to 59.3% of the variance in the SBP response over 19hr (r:-0.77, p=0.068) and significantly explained 84.5% of the variance in the DBP response over awake (r:-0.92, p=0.014).

Conclusion: Sudden vigorous exertion evoked ***postexercise hypertension*** as opposed to PEH among firefighters with elevated BP. Reasons for these unexpected findings are not clear but may reside in a compensatory baroreflex response to sympathetic predominance as reflected by higher LF/HF due to either increased sympathetic or decreased parasympathetic modulation.

Keywords: *Blood pressure, exercise, heart rate, hypertension, postexercise hypotension*

ÖZ

Amaç: Bu çalışmanın amacı, hipertansiyonlu itfaiyeciler arasında maksimum kardiyopulmoner stres testi sonrasında olabilecek egzersiz sonrası hipotansiyon ve kalp atım değişkenliği cevaplarını incelemektir.

Gereç ve Yöntemler: çalışmaya orta yaşlı (40.6±6.2), aşırı kilolu (28.1±3.9kg.m^{-2}), yüksek kan basıncına (Sistolik: 126.4±9.5mmHg / Diastolik: 85.6±5.9mmHg) ve normal kalp atım sayısına (71.1±11.2bpm) sahip erkek itfaiyeciler (n=5) katıldı. İtfaiyeciler maksimum kardiyopulmoner stres testi ve herhangi bir egzersiz içermeyen kontrol süreçlerini randomize şekilde tamamladı. Katılımcılara kardiyopulmoner stres testi ve kontrol sonrası 19 saat süreyle ambulatuvar kan basınç ölçer ve kalp atım monitörü takıldı. Ambulatuvar sistolik ve diastolik kan basıncı ile kalp atım değişkenliği düşük (LF) ve yüksek (HF) frekansları uyanık (11saat), uyku (8saat) ve 19 saat sürelerince bir saat aralıklarla ölçüldü. Tekrarlanan ölçüm varyans ve çok değişkenli regresyon analizleri kullanılarak kan basıncı ve kalp atım değişkenliğinin 19 saat boyunca ve deneysel durumlar arasında değişip değişmediği test edildi.

Bulgular: Kontrol grubuyla karşılaştırıldığında, kardiyopulmoner stres testi sonrası ambulatuvar sistolik kan basıncı uyanık dönemde (21.7±3.4mmHg, p=0.003) ve 19 saat (15.8±2.2mmHg, p=0.002) süresince anlamlı artış gösterdi. İstatistiksel anlamlılığa ulaşılmamasına rağmen ambulatuvar sistolik kan basıncı uyku (7.9±2.9mmHg, p=0.055) saatlerinde artış eğilimi gösterdi. Yine istatistiksel anlamlılığa ulaşılmamasına rağmen kontrol grubuyla karşılaştırıldığında, kardiyopulmoner stres testi sonrası ambulatuvar diyastolik kan basıncı uyanık (8.8±3.9mmHg, p=0.091), uyku (8.2±4.3mmHg, p=0.134) ve 19 saat (8.6±3.5mmHg, p=0.072) sürelerinde artış eğilimi gösterdi. Kontrol grubuyla karşılaştırıldığında, kardiyopulmoner stres testi sonrası, LF/HF uyku (1.9±0.5, p=0.015) saatlerinde anlamlı artış gösterdi. İstatistiksel anlamlılığa ulaşılmamasına rağmen, LF/HF 19 saat (0.8±0.5 p=0.155) süresince artış eğilimi gösterdi. LF/HF değişkeni uyku saatlerinde ortaya çıkan diyastolik kan basınındaki değişimin %84.5'ini (r:-0.92, p=0.014) açıklarken, ista-

Received / Geliş: 22.09.2020 · **Accepted / Kabul:** 11.01.2021 · **Published / Yayın Tarihi:** 02.03.2021

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Cite this article as: Cilhoroz B, Zaleski A, Taylor B, Fernhall B, Chen M, Thompson P, Pescatello L. The ambulatory blood pressure and heart rate variability responses following sudden vigorous physical exertion among firefighters with hypertension. *Turk J Sports Med.* 2021;56(3):98-105; http://dx.doi.org/10.47447/tjsm.0492

tistiksel olarak anlamlı düzeye ulaşamasa da, 19 saat süresince orataya çıkan sistolik kan basıncındaki değişimin %59.3'ünü açıklama eğilimi gösterdi (r:-0.77, p=0.068).

Sonuç: İtfaiyecilikle ilişkilendirilen ani yüksek şiddetli efor, egzersiz sonrası hipotansiyon yerine hipertansiyon yanıta yol açtı. Bu beklenmedik bulguların nedenleri belirsiz olmasına karşın, barorefleks mekanizmasının baskın sempatik yanıta (yüksek LF/HF) karşı gösterebileceği negatif yanıtın nedenlerden biri olabileceği düşünülmüştür.

Anahtar Sözcükler: *Kan basıncı, egzersiz, kalp atımı, hipertansiyon, egzersiz sonrası hipotansiyon*

INTRODUCTION

The National Fire Protection Association (NFPA) estimates that approximately 1.2 million firefighters serve in the United States (U.S.), with near 350.000 or 30% being career firefighters (1). The leading cause of on-duty death among firefighters in the U.S. is sudden cardiac death (SCD), accounting for approximately 42% of on-duty fatalities (2). Considering firefighters play a vital role in life safety, property conservation, and incident stabilization, optimizing their health and safety is a significant public health issue (3). Reasons for the increased incidence of sudden cardiac death (SCD) among firefighters remain unclear but is thought to be due to the excessive physical demands of firefighting coupled with underlying subclinical cardiovascular disease (CVD) (4).

Hypertension is the most common, prevalent and modifiable risk factor for CVD in the general population (5). There is a disproportionate prevalence of hypertension among firefighters (30%) compared to the general population and other emergency responders including police (21%-23%) and emergency medical technicians (9%) (6). Furthermore, firefighter mortality is 12 times more likely among those that have hypertension posing a greater risk of mortality than the other major CVD risk factors of diabetes (10.2 times), smoking (8.6 times), and dyslipidemia (4.4 times) (7). Even in the absence of hypertension, firefighters are 64 times more likely to suffer from a heart attack when they are involved in physically demanding emergency tasks than at rest (7). Lifestyle strategies, such as regular aerobic exercise are effective in preventing, treating and controlling hypertension (8), and thereby, reducing the risk of CVD and related events. Regular exercise participation reduces systolic BP (SBP) 5-8 mmHg among individuals with hypertension (9) mitigating the risk of having an acute cardiac event by 20-30% (8–10).

Several recent lines of evidence suggest the BP reductions that result from long-term aerobic exercise training are related to the short-term BP reductions following an acute exercise session, termed postexercise hypotension (PEH), that persists for 24 hr after a bout of exercise (11–17). Although there is no consensus on the mechanisms of PEH, it has been reported that PEH occurs due to persistent reductions in systemic vascular resistance (SVR) without concomitant increases in cardiac output (CO) among individuals who are healthy other than their hypertension (18). Suppression of sympathetic nerve activity resulting from baroreflex resetting following exercise contributes to the reductions in SVR that is thought to produce PEH (19,20). These actions indicate that there is a role of autonomic nervous system activity in PEH that remains to be better elucidated (21–23). Surprisingly, PEH and associated autonomic nervous system responses as measured by frequency and time domains of heart rate variability (HRV) have not been examined under ambulatory conditions among career firefighters.

HRV is the beat-to-beat fluctuations in the time between sequential heartbeats. The time domain measures demonstrate the variance between sequential R-R intervals and are used to quantify the amount of variability during the recording (24). Frequency domain measures are calculated from the power or variance spectral density analysis of the R-R interval time series (24). This analysis provides information on how the power (i.e., variance of a rhythm) is distributed as a unit of frequency in the hertz (Hz) (24). The aim of this study is to investigate the relationship between PEH and domains of HRV following a bout of sudden vigorous physical exertion among career firefighters. We hypothesize firefighters would experience PEH after a GEST that would be partially explained by alterations in the domains of HRV.

MATERIAL and METHODS

Subjects. Subjects were required to stop taking any medications (e.g., oral steroids, aspirin, and herbal) that could possibly influence BP and HRV at least 4 wk prior to testing. Subjects with musculoskeletal impairments were not enrolled if these conditions restricted their ability to complete the GEST. The subjects' weight was monitored throughout study duration to ensure weight stability defined as gaining or losing <2.25 kg of baseline body weight by the National Weight Control Registry (25). All subjects completed an informed consent approved by the Institutional Review Boards of the Hartford Hospital and University of Connecticut (Protocol#: H14-183HH and Approval Date: 3/16/2015).

Experiments

Subjects completed the GEST and CONTROL at the same time of day separated by a minimum of 48 hr to avoid the confounding effects of acute exercise and diurnal variation on BP and HRV (26,27). The participants were instructed to consume a standard breakfast 2 to 3 hr before the experiments and refrain from caffeinated beverages for 6 hr before the experiments. At the beginning of GEST and CONT-

ROL, baseline HRV was recorded with a V800™ HR monitor for 5 min in supine position in the beginning of 25 min period, whereas baseline SBP and DBP were obtained every other minute with the automated monitor for 25 min at rest. During the 45-min postexercise recovery period following the GEST and CONTROL, the same 5 min of HRV measurement in supine position was performed in the first 5 min of 45 min period, whereas SBP and DBP were measured every 2 min for 45 min with the same automated monitor. The subjects left the laboratory wearing ABP and HR monitors after the experiments until the following morning and returned them to the research assistant. An average ABP and HR monitor attachment time was 8:30±0:28 am.

The Peak Cardiopulmonary Graded Exercise Stress Test

After baseline HRV and BP measurements were taken, the study physician or his assistant reviewed subjects' BP status, medical history, medications and family history. Later, a respiratory apparatus was placed on each subject (ParvoMedicsTrueOne® 2400 Metabolic Measurement System, ParvoMedics Inc., Sandy, UT) to measure peak oxygen consumption (VO_{2peak}) through breath-by-breath analysis of expired gases. Following a 2–5 min seated stabilization period, participants performed the GEST to exhaustion that consisted of a graded cardiopulmonary exercise test with the Balke protocol (28) on a treadmill. During the GEST, HR was recorded continuously with a 12-lead electrocardiograph (Marquette Case 8000, Jupiter, FL), and BP was obtained every 3 min by auscultation. The study physician was present during the GEST to monitor the subjects and reviewed the ECG for signs of ischemia after the test. Following the GEST, subjects were at rest for 45 min of post-exercise recovery. At the beginning of post-exercise recovery HRV was measured for 5 min in supine position and BP was measured in the seated position every other minute for 45 min. Then, subjects were attached to the automated ABP and HR monitors and left the laboratory with monitors until the next morning.

Non-Exercise Control

After baseline HRV and BP measurements were taken, subjects performed 30 min of seated rest during which HR was recorded continuously with a 12-lead electrocardiograph, and BP was obtained every 3 min by auscultation. CONTROL subjects were at rest for another 45 min with HRV measured for 5 min in supine position at the beginning and BP was measured every 2 min for 45 min in the seated position. Subjects then left the laboratory wearing the ABP and HR monitors until the next morning.

Blood Pressure. Resting BP was measured according to the American Heart Association (AHA) standards using an automated BpTRU™ monitor (BPM 200 BpTRU™ Medical Devices; Coquitlam, Canada) (29).

Subjects were then attached to an ABP monitor (Oscar2 automatic noninvasive ABP monitor, Suntech Medical Instruments Inc., Raleigh, NC) with a calibration check done by a mercury sphygmomanometer. The ABP monitor was programmed to record BP at regular intervals three times per waking hour and two times per sleeping hour. Subjects were asked to proceed with normal activities, not to exercise, and to keep their arm still and extended at their side when each ABP measurement was being taken. Study participants were given a standard journal to record activities performed during each measurement, any unusual physical or emotional events, and sleep and wake times. The next morning, they detached the monitor and physically returned it along with the journal that day to the study investigators at the local fire department or Hartford Hospital based upon their convenience. The research assistant examined the journal and ABP reports after each visit for any unusual physical or emotional events that may have impacted readings. We removed ABP readings of SBP >220 or <80 mmHg or DBP >130 or <40 mmHg according to the manufacturer's exclusion criteria. ABP reports were valid if we received at least 80% of the potential BP readings. The ABP data was averaged over hourly intervals for the awake, sleep, and 19 hr.

Heart Rate Variability. The HRV assessments were performed for 5 min in supine position before and after GEST and CONTROL in a quiet, low-light, and temperature-controlled room after a 5 min rest period using the Polar® V800™ HR monitor and Polar® H7 chest strap. The Polar® H7 chest strap was placed below the chest muscles with conductive gel and applied as described by the manufacturer. The Polar® V800™ HR monitor was removed after the completion of the resting HRV assessment. After the GEST and CONTROL prior to leaving the laboratory, subjects were fitted with the same Polar® V800™ HR monitor and Polar® H7 chest strap for the assessment of ambulatory HRV over 19 hr. The next morning, they detached the HRV monitor and physically returned it that day to the study investigators at a local fire department or Hartford Hospital based upon their convenience. The ambulatory HRV data was averaged over hourly intervals for the awake, sleep, and 19 hr.

Both the resting and ambulatory HRV recordings were made at a sampling frequency of 1,000 Hz. The Polar® H7 chest strap simultaneously transmitted the HR and R-R intervals to the Polar® V800™ HR monitor where the data were stored. Subsequently, R-R intervals were downloaded through the Polar Flow Software (Version 2.3; Polar Electro

Oy, Kempele, Finland) to a computer and exported in ASCII format. Kubios HRV Premium 3.1 (The Biomedical Signals Analysis and Medical Imaging Group, University of Kuopio, Finland) analyzed the selected segments to obtain the time and frequency domain measures.

The time domain measures included standard deviation of normal R-R intervals (SDNN), root mean square of successive differences in normal R-R intervals (RMSSD), and percentage of successive normal R-R intervals greater than 50 ms (pNN50%). Autoregressive model was used to quantify power spectrum density into absolute low frequency (LF ms^2: 0.04–0.15 Hz) and absolute high frequency (HF ms^2: 0.15–0.40 Hz) domains. In addition, normalized LF (LF nu), normalized HF (HF nu), and LF/HF ratio were calculated. Artifacts including ectopic beats, missing beats, arrhythmias and noise were corrected with interpolated values using the threshold-based correction method of the software package. Our recent paper (30) showed that threshold-based correction method is a better artifact correction method than the automatic correction method of the Kubios Premium when the Polar HR monitor is used for resting HRV measurement. The average percentage of corrected artifacts by the threshold-based correction method was 1.6%±0.8.

Body Composition

Body mass index (BMI) kg/m^2 was calculated from body weight and height obtained with a calibrated balance beam weight scale and stadiometer (Seca 700 Balance Beam Scale, California, USA). Waist circumference (WC) was measured with a non-flexible Gulick tape measure at the narrowest part of the torso (31).

Blood Sampling and Analysis

Subjects reported to Department of Preventive Cardiology at Hartford Hospital after a 10 hr overnight fasting to obtain a cardiometabolic profile and baseline biomarkers associated with cardiovascular disease on the GEST visit. Prior to and immediately after the GEST, a trained phlebotomist collected five tubes of venous blood (52 cc or 3.5 tablespoons) from the antecubital vein of each subject for the determination of fasting lipid-lipoproteins, glucose, insulin, and high sensitivity C-reactive protein (hs-CRP) (Quest Diagnostics, LLC). Serum samples were archived in a locked -81° freezer at Hartford Hospital. All samples were sent to Quest Diagnostics® to be analyzed in batch. Briefly, serum total cholesterol, triglycerides, high-density lipoprotein cholesterol (HDL-C) and low-density lipoprotein cholesterol (LDL-C) were determined by colorimetric enzymatic assays. Serum glucose and insulin were determined by enzymatic/spectrophotometric methods and radioimmunoassay, respectively. Serum hs-CRP was determined by immunoturbidimetry. Results were reported according to Clinical Laboratory Improvement Amendments (CLIA) standards.

Statistical Analysis

Descriptive statistics were calculated on all study variables and data were reported as mean ± SD. Repeated measures analysis of covariance (RMANCOVA) compared BP and HRV between GEST and CONTROL at hourly intervals under ambulatory conditions over 19hr. The ABP and HRV changes in response versus control were calculated as follows: [(GEST BP or HRV at each hourly interval - GEST BP or HRV baseline) - (CONTROL BP or HRV at each hourly interval - CONTROL BP or HRV baseline)]. Simple linear regression was used to test the relationship between the magnitude of the ABP change and HRV change from baseline over awake, sleep, and 19 hr after versus before the GEST versus CONTROL. All statistical analyses were made with the Statistical Package for Social Sciences Version 20.0 for Windows (SSS, Inc, Chicago, IL) with $p<0.05$ established as the level of statistical significance.

Table 1. Subject Descriptive Characteristics for the Total Sample and by Subject (Mean±SD)

Subject #	Age (yr)	Height (cm)	Weight (kg)	WC (cm)	BMI (kg/m^2)	HR (bpm)	SBP (mmHg)	DBP (mmHg)	Rate Pressure Product*	VO_{2max} ($ml \cdot kg/min^{-1}$)	TC (mg/dL)	LDL-C (mg/dL)	HDL-C (mg/dL)	TG (mg/dL)	Glucose (mg/dL)	Insulin (uIU/mL)	Fibrinogen (mg/dL)	CRP (mg/dL)	Medication Use
1	42	171	72	76	24.5	63	117	86	7.4	50.4	215	143	58	71	112	2.3	233	0.5	None
2	33	174	76	85	25.2	58	123	80	7.1	51.7	206	133	59	68	79	2.8	241	0.7	None
3	50	170	96	99	33.1	84	138	94	11.6	34.3	207	132	48	136	152	13	306	4.7	None
4	36	191	100	99	31.4	81	135	88	10.9	37.5	223	144	56	113	100	4.3	233	0.3	None
5	42	182	86	86	26.1	72	119	80	8.6	42.2	167	99	56	61	94	4.9	337	0.02	Chlorthalidone (25mg)
Mean±SD	40.6±6.5	177.6±8.8	86.0±12.2	89±9.9	28.1±3.9	71.6±11.2	126.4±9.5	85.6±5.9	9.1±2.0	43.2±7.7	203.6±21.6	130.2±18.3	55.4±4.3	89.8±32.9	107.4± 27.6	5.5±4.3	270.0±45.4	1.2±1.9	

BMI: Body Mass Index; CRP: C-Reactive Protein; DBP: Diastolic Blood Pressure; SBP: Systolic Blood Pressure; TC: Total Cholesterol; TG, Triglycerides; VO_{2max}: maximum oxygen consumption; WC: Weight Circumference. *Rate Pressure Product is calculated as (HR X SBP) 10^{-3}.

RESULTS

Subjects. Table 1 displays the individual and mean±SD descriptive characteristics of the subjects. Overall, the subjects (n=5) were middle-aged and overweight and had hypertension and dyslipidemia. Their fasting blood glucose, insulin and fibrinogen levels were normal, hs-CRP levels were desirable, and they had good cardiorespiratory fitness levels for men of their age (ref). One subject was taking antihypertensive medications for high BP.

Peak and Recovery Heart Rate, Blood Pressure, and Pulse Pressure. None of our subjects (n=5) exhibited a hypertensive response to the GEST as their SBP and DBP were <210 mmHg and 110 mmHg, respectively. The peak HR, SBP, DBP, RPP (rate pressure product) and PP (pulse pressure) values of the subjects returned to their baseline levels within an hour following the GEST prior to the attachment of the ABP monitor (Table 2).

Table 2. The Peak and 1 Hour Post Heart Rate, Blood Pressure, and Pulse Pressure Responses to the Graded Exercise Stress Test (Mean±SD)

Subject #	Peak HR (bpm)	Post HR (bpm)	Peak SBP (mmHg)	Post SBP (mmHg)	Peak DBP (mmHg)	Post DBP (mmHg)	Peak Rate Pressure Product	Post Rate pressure Product*	Peak PP (mmHg)	Post PP (mmHg)
1	173	81	192	117	88	67	33.2	9.5	104	50
2	184	83	204	123	70	79	37.5	10.2	134	53
3	171	114	208	138	74	83	35.6	15.7	134	45
4	181	92	182	135	80	77	32.9	12.4	102	54
5	187	112	146	119	78	112	27.3	13.3	68	41
Mean±SD	179.2±6.9	96.4±15.7	186.4±24.8	132.2±13.1	78.0±6.8	83.6±16.9	33.3±3.8	12.2±2.5	108.4±27.4	48.6±5.5

HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; PP: pulse pressure. *Rate Pressure Product is calculated as (HR X SBP) 10^{-3}.

Ambulatory Blood Pressure. After versus before the GEST versus CONTROL, systolic ABP (ASBP) (126.4±9.5 mmHg) significantly increased from baseline over awake an average of 21.7±3.4mmHg (p=0.003). ASBP also significantly increased over 19 hr an average of 15.8±2.2 mmHg (p=0.002). Moreover, ASBP exhibited a statistically trending increase over-sleep an average of 7.9±2.9mmHg (p=0.055) (Figure 1). After versus before the GEST versus CONTROL, diastolic ABP (ADBP) (85.6±5.9 mmHg) also showed a statistically trending increase from baseline over awake an average of 8.8±3.9 mmHg (p=0.091). Additionally, ADBP displayed a statistically trending increase over-sleep an average of 8.2±4.3mmHg (p=0.134). Finally, ADBP showed a statistically trending increase over 19 hr an average of 8.6±3.5mmHg (p=0.072) (Figure 2).

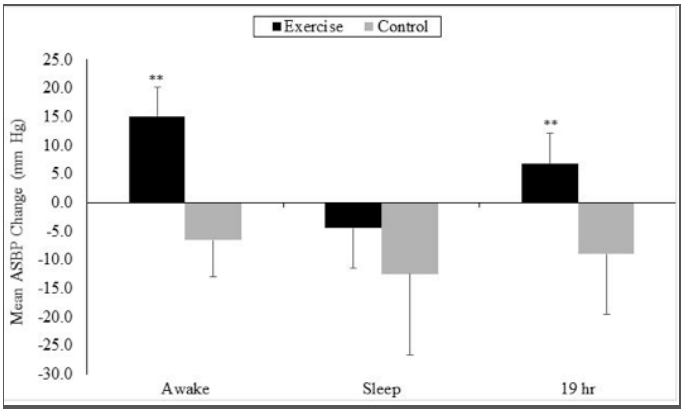

Figure 1. Mean systolic ambulatory blood pressure (ASBP) from baseline following the GEST versus CONTROL over the awake, sleep, and 19 hr. *p<0.05, **p<0.01, *** p<0.001 GEST vs CONTROL

Ambulatory Heart Rate Variability. After versus before the GEST versus CONTROL, the LF/HF ratio significantly increased from baseline over awake an average of 1.9±0.5 U (p=0.015). Furthermore, the LF/HF ratio exhibited a statistically trending increase over 19 hr an average of 0.8±0.5 U (p=0.155) (Figure 3). All other time and frequency HRV domains were not different from baseline over awake, sleep or 19 hr after versus before the GEST versus CONTROL (all p values >0.05) (Table 3).

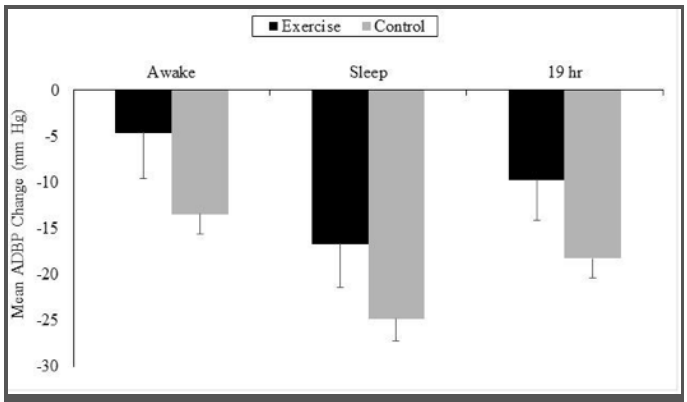

Figure 2. Mean diastolic ambulatory blood pressure (ADBP) change from baseline following the GEST versus CONTROL over the awake, sleep, and 19 hr. *p<0.05, **p<0.01, *** p<0.001 GEST vs CONTROL

Table 3. The Changes in HRV After Versus Before the GEST and CONTROL Over the Awake, Sleep, and 19hr (Mean + SEM)

Variable	Time	GEST	CONTROL	GEST vs CONTROL
SDNN	Baseline	35.4±11.8	52.9±17.3	-17.4±4.8
	Awake	-2.2±1.2	-3.1±1.4	0.9±2.0
	Sleep	4.1±3.5	4.1±2.2	-0.1±2.4
	19 hr	0.4±1.7	-0.1±1.4	0.4±1.5
RMSSD	Baseline	26.5±5.4	44.2±23.1	-17.6±5.7
	Awake	-5.1±1.2	-2.3±1.5	-2.8±2.6
	Sleep	10.4±2.4	5.3±2.8	5.1±2.2
	19 hr	1.4±2.2	0.9±1.7	0.5±1.9
pNN50%	Baseline	7.3±7.3	17.6±13.8	-10.2±3.2
	Awake	-1.9±0.6	-3.6±0.8	1.7±1.3
	Sleep	7.8± 1.6	3.9±1.8	3.8±1.4
	19 hr	2.1±1.3	-0.4±1.2	2.6±0.9
LF (ms^2)	Baseline	945.3±215.3	1999.8±626.6	-10.5±480.0
	Awake	-23.9±55.1	-33.1±99.0	9.2±137.7
	Sleep	498.7±333.5	511.0±212.1	-12.3±204.3
	19 hr	196.1±151.2	195.9±120.5	0.2±113.7
HF (ms^2)	Baseline	282.3±93.9	642.9±547.5	-360.5±165.2
	Awake	-60.9±17.2	-67.6±47.5	6.6±53.8
	Sleep	227.9±66.5	141.7±70.6	86.1±39.6
	19 hr	60.7±44.1	20.5±46.2	40.1±35.7
LF (nu)	Baseline	77.3±3.8	76.6±8.1	0.6±0.7
	Awake	6.5±2.0	3.5±3.0	3.0±1.7
	Sleep	-1.5±2.2	-0.5±1.6	-1.1±3.1
	19 hr	3.1±1.1	1.8±1.8	1.3±1.8
HF (nu)	Baseline	22.6±3.7	23.2±8.0	-0.6±0.7
	Awake	-6.5±2.0	-3.5±3.0	-3.0±1.7
	Sleep	1.4± 2.2	0.5±1.6	0.9±3.2
	19 hr	-3.2±1.1	-1.8±1.8	-1.3±1.8

Standard deviation of normal-to-normal RR intervals (SDNN), Root mean square of successive RR interval differences (RMSSD), Relative number of successive RR interval pairs that differ more than 50 msec (pNN50%), low frequency in absolute power (LF ms2), high frequency in absolute power (HF ms2), low frequency in normalized units (LF nu), low frequency in normalized units (HF nu). All ps>0.05.

Relationship between Ambulatory Blood Pressure and Heart Rate Variability. As the LF/HF ratio over 19 hr increased, ASBP exhibited a statistically trending decrease following the GEST versus CONTROL (r=-0.77; p=0.068). This accounts for 59.3% of the variability in the ASBP response over 19 hr. In addition, as the LF/HF ratio over 19 hr increased, ADBP significantly decreased over awake after versus before the GEST versus CONTROL (r=-0.92; p=0.014). This explains 84.5% of the variability in ADBP response over awake. No other HRV domains were correlated with the ASBP and ADBP responses over awake, sleep and 19 hr (all p values >0.05) (Table 3).

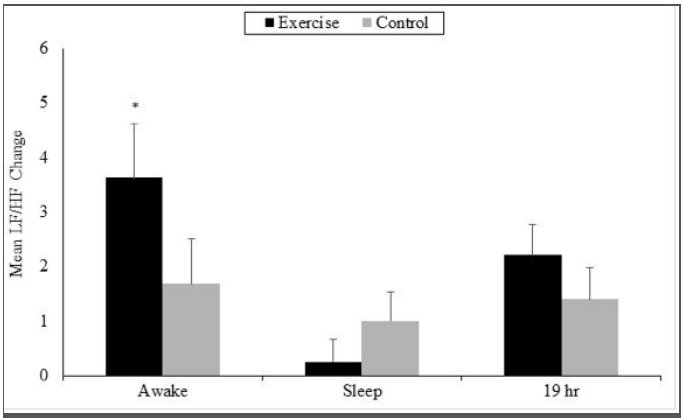

Figure 3. Mean ambulatory LF/HF change from baseline following the GEST versus CONTROL over awake, sleep, and 19 hr. *p<0.05, **p<0.01, *** p<0.001 GEST vs CONTROL

DISCUSSION

We examined the influence of a bout of maximal physical exertion on the ABP and HRV responses over 19 hr on non-workdays among a small sample of middle-aged male career firefighters with elevated BP. ASBP increased from baseline by 15.7 mmHg following the GEST compared to CONTROL. In addition, the LF/HF ratio tended to increase from baseline by 0.8 U explaining 59.3% of the variability in the ASBP response and 85.4% of the variability in ADBP response over awake.

Contrary to our hypothesis that the firefighters would exhibit PEH as our (17,18,32,33) and others' (13,14,16,20)laboratory groups have observed in similar populations of overweight men with hypertension and dyslipidemia, we found that the firefighters exhibited *postexercise hypertension* following an acute bout of sudden vigorous exertion. This unexpected finding suggests that firefighters may have an adverse BP response to sudden vigorous exertion that may contribute to the greater number of cardiac events observed among firefighters. Of note, none of our subjects exhibited a hypertensive response to the GEST despite of all having hypertension. The peak SBP and DBP responses of all the subjects to the GEST were < 210 mmHg and <110 mmHg, respectively (Table 2). Further, the SBP and DBP values returned to baseline values within an hour following the GEST. Therefore, we conclude that the potential differences in the peak BP response to the GEST did not impact the *postexercise hypertensive* response observed in our study.

Horn et al. (34) studied the BP response following 18 min of firefighting drills (e.g., stair climbing, simulated forcible entry, a simulated search, and simulated hose advance) consisting of nine 2-minute periods of alternating rest and work cycles among firefighters with elevated to Stage 1 hypertension according to the Joint National Committee Seven criteria (9). In contrast to our fin-

dings, these authors found SBP and DBP decreased by 9 mmHg and 3 mmHg, respectively, during 120 min of recovery after the firefighting drills. Reasons for the discrepancy between our findings and those of Horn et al. (34) are not clear but may be attributed to differences in our experimental designs that include the firefighters in our study being studied under ambulatory conditions on non-work days, different types of vigorous physical exertion that were attempts to simulate the extreme conditions of firefighting, and application of cooling rehabilitation prior to recovery in their study.

Autonomic modulation of heart is of notable role in the pathogenesis of arrhythmic death (36). In our study, we observed that the LF/HF ratio increased from baseline by 0.8 U over 19 hr, suggesting sympathetic predominance due to either increased sympathetic or decreased parasympathetic modulation of the heart. Similarly, Al-Zaiti et al. (36) investigated the clinical risk factors of SCD among firefighters with elevated BP that performed 20 min of physical exertion separated by 10 min breaks that included fire suppression and roof chopping activities. They found over 40% of firefighters had a SDNN <50 ms during 20 min of recovery following these firefighting tasks, again suggesting sympathetic predominance. Our findings and those of Al-Zaiti et al. (36) indicate that suboptimal vagal control may partially explain the *postexercise hypertensive* response and perhaps higher prevalence of cardiac events among firefighters. Additionally,we observed an inverse relationship between the LF/HF ratio and ABP response to the GEST compared to CONTROL among this small sample of firefighters, further supporting this premise.

The small sample size in our study limits the extrapolation of our findings to the general firefighter population. Nonetheless, they are provocative and warrant further investigation in a large, more diverse population of firefighters due to their potential to provide insight into reasons why firefighters incur a disproportionate number of cardiac events both on and off the job. Additionally, we are aware that the physical exertion (GEST) in our study may not have simulated actual cardiovascular strain associated with firefighting. Strengths of our study include the random assignment of the subjects to the experimental conditions and controlled administration of the procedures that accounted for the circadian rhythm of BP and HRV under ambulatory conditions.

CONCLUSION

Contrary to our hypothesis, we found in a small sample of firefighters exhibited *postexercise hypertension* as opposed to PEH following a bout of vigorous exertion compared to CONTROL over 19 hr. Further, our HRV results suggests predominant sympathetic influence on the heart resulting from parasympathetic withdrawal or higher sympathetic activity that also accounted for 59% to 84% of the ABP response to vigorous physical exertion. These findings provide potential pathophysiological explanations for the disproportionate cardiac events among firefighters both on and off the job during line-of-duty that merit confirmation among a larger, more diverse sample of firefighters.

Conflict of Interest / Çıkar Çatışması

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

Financial Disclosure / Finansal Destek

This study was supported by funding from the University of Connecticut Institute for Collaboration on Health Intervention and Policy, and the United States Department of Agriculture (SAES, HATCH Project No. CONS00954).

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