The Influence of Emergency Call Volume on Occupational Workload and Sleep Quality in Urban Firefighters

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Objective: The aim of the study is to determine the impact of emergency call volume on exertion, autonomic activity, and sleep among urban structural firefighters. **Methods:** Thirty-four firefighters wore a wrist-based monitor to track sleep and autonomic parameters and rated their level of perceived exertion (Borg Rating of Perceived Exertion) and subjective sleepiness after a 24-hour shift. Predictive variables included total run time and total run time after 11:59 PM. **Results:** Total run time and sleep duration accounted for Borg Rating of Perceived Exertion and subjective sleepiness, while total run time and total run time after 11:59 PM accounted for sleep durations on-duty. **Conclusions:** The current results suggest that emergency call volume is associated with indicators of exertion and sleep. As such, call volume tracking is an important consideration for departments to ensure personnel readiness and wellness and provide a method of tracking the occupational demands experienced by firefighters on-duty.

Keywords: autonomic nervous system, emergency responder, heart rate variability, shift work

Firefighting has been cited as one of the most hazardous job occupations in the United States because of its physical demand and its increased risk exposure.[1] However, the hazards of firefighters are not exclusive to the United States alone. In fact, both national and international reports have shown musculoskeletal (MSK) injuries encompass 65% of all nonfatal injuries in firefighting, resulting in approximately $430,000–$1,000,000 per fire department per year in total medical and compensation costs.[2,3] Despite a decline in reported fires over the past four decades, the fireground injury rate since 2000 has remained between 14.4–26.9 injuries per 1000 fires per year.[4]

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LEARNING OBJECTIVES

- Identify the effect of firefighter emergency call volume on exertion, autonomic activity, and sleep
- Compare the use of different subjective methods of assessing exertion, stress, and sleep
- Recognize the potential use of physiological monitoring as a method of assessing workload

Previous research has identified a potential link between high occupational stress with poor sleep quality, fewer hours slept, and increased day time dysfunction.[5] In particular, obese firefighters who do not get enough sleep are twice as likely to sustain an on-duty injury than those who have enough sleep.[6] Consequently, biological stress activation has been observed secondary to sleep deprivation.[7] The autonomic nervous system (ANS) indexes stress demands and responses via two of its branches, the sympathetic and parasympathetic nervous system, which work synergistically to predict and adjust physiological responses, including heart rate, blood pressure, respiration, and hormones to physical demands. Studies have shown that the ANS's ability to recover in active-duty firefighters is intensity specific.[8] It is possible, therefore, that higher levels of occupational stress exposure may influence both factors of sleep quality and regulation of the ANS.

Occupational stress exposure may partly be influenced by the nature of a firefighter's work shift. Alterations in autonomic function have previously been reported in shift work populations, including firefighters.[9] It has been suggested that changes in autonomic function may compromise workers to perform their daily job tasks in the short-term, along with their physical health outcomes long-term.[10,11] A 24-hour shift is a common practice seen in firefighting and its impact on autonomic function has been documented.[12–14] In fact, one review found a transition away from a parasympathetic dominant state after 24-hour shift work.[12] Measuring autonomic activity, therefore, becomes a critical assessment as any noted changes after a firefighter's work shift may be reflective of possible changes in occupational stress exposure.

Heart rate variability (HRV) is a reliable and noninvasive method of assessing ANS function that analyzes the variability of time between successive R waves, also referred to as NN distances or the inter-beat interval.[15] The distance between successive beats, or variability, have been suggested as the system's capacity to regulate and cope with a varying environment.[16] As such, observing the impact of a firefighter's exposure to job-related stressors may provide valuable insight into the individual system's capacity to mobilize and restore its resources in response to external or internal stimuli. For example, Lyytikäinen and colleagues[17] found that 48 hours is required to observe significant improvements in autonomic function after a 24-hour shift. However, the researchers did not capture daily on-duty activity. As a result, how on-duty exposures, such as a firefighter's emergency call volume, may have impacted autonomic function could not be determined. Moreover, how occupational stress exposure may impact other physiological processes, such as sleep, could not be inferred given the interactions and implications between ANS function and sleep hygiene.[5,18]

Sufficient sleep quality and sleep duration, typically 8 hours of continuous sleep, are essential for general health.[19,20] However, because of nature of emergency services and responding to emergency calls, firefighters may not be able to obtain optimal sleep (both sufficient duration and consolidated) as a result of shift work.[21] The effects of sleep deprivation on cognitive function have been well documented,[22–24] and its detrimental effects have also been particularly noted in tactical populations.[18,25–27] Poor sleep quality and sleep deprivation are common occurrences in firefighting due to job task demands. In addition, occupational stress and poor sleep quality have been found in firefighting, along with a significant relationship also identified between shift work and poor sleep quality.[5,28] In fact, occupational stress scores and MSK disorders are significantly higher in firefighters with poor sleep quality,[18] with a two-fold increased risk of injury when on duty.[5,6] For example, Grier and colleagues[26] found an inverse relationship between sleep duration and MSK injury. Moreover, individuals who slept less than 4 hours were 2.35 times more likely to experience a MSK injury compared to those who slept 8 hours or more.[26] Work-related stress has been identified as a significant indicator of insomnia symptoms, short sleep duration, sleep dissatisfaction, and sleepiness.[25] One plausible surrogate method of monitoring occupational demands on-duty (ie, occupational workload) is quantifying the number of emergency calls a firefighter responds to while on-duty. Call volume tracking may act as a potential option for monitoring occupational demand given its direct translatability to the fire service. For example, individuals who are routinely subjected to on-call work report difficulties in returning to sleep after responding to calls and report sleeping less than the minimum recommended amount.[29] One study capturing objective sleep measures via actigraphy found the average firefighter sleeps just under 5.5 hours while on-duty.[27] However, sleep duration in isolation is not a good predictor of sleep quality, but rather differences in sleep environment may also contribute to these findings.[27] As such, capturing subjective measures that assess a firefighter's perceived experience after a 24-hour shift may complement the objective measures currently in use. For example, the Karolinska Sleepiness Scale has been previously shown as a viable proxy for electroencephalographic activity and behavioral indicators of sleepiness.[30] Therefore, in addition to monitoring occupational demand and objective sleep measures, assessment of firefighter status using a subjective method, such as sleepiness, may complement objective measures observed on-duty. Furthermore, developing a viable method of monitoring firefighter workload is critical to evaluate how emergency calls impact factors contributing to on-duty demand and sleep.

Tactical populations, in particular firefighters, constantly face highly stressful, psychologically, and/or physiologically taxing situations. Previous research in sport suggests that periods of high psychological stress are significant contributors to athletic injury during the competitive collegiate football season.[31] Furthermore, chronic psychological stress has a significant impact on the rate of muscle recovery.[32] Traditional sport has extensively researched how day-to-day psychological and physical demands impact injury risk through the implementation of workload monitoring.[33–40] For example, large increases in acute workload have been associated with increased injury risk,[33] with intensity and duration of load proportionally increasing risk.[35] However, such a model has yet to be substantiated in an occupational setting, in particular firefighting. Given the adaptive actions occurring within the body may be brought upon by either an external or internal stimulus,[41] there has been an increased interest in understanding the contribution of psychological stress, physical stress, and their impact on health and function. Impairments in health and function may not solely be reflective of increased physical demand. Rather, physical and/or psychological stressors may impact an individual's overall well-being. As such, by identifying if emergency call volume is one viable surrogate for monitoring firefighter workload, future research may then continue to investigate its long-term utility for minimizing firefighter injury.

Physical injury is not solely a result of a physical debilitation. Rather, physical or psychological stressors may influence injury. Whether the same results are prevalent in a tactical population remains unclear. As such, there is a critical need to understanding how emergency call volume as an indicator of occupational stress exposure may influence factors contributing to stress and sleep in a firefighter population. Therefore, the purpose of the current study was to determine the impact of emergency call volume on exertion, autonomic activity, and sleep among urban structural firefighters. We hypothesized that if firefighters responded to higher emergency call volumes while on-duty, then they would report greater levels of perceived exertion and increased levels of subjective sleepiness, as well as poorer sleep and decreased resting HRV values when compared to firefighters who respond to lower call volumes.

METHODS

Participants

A convenience sample of 34 (male: 33; female: 1) firefighters participated in the study. Each participant that volunteered for the study was an active-duty member of a large urban fire department, with an average of 10.1 ± 6.7 years of emergency service (for participant characteristics, see Table 1). All participants were recruited from the same large urban fire department. Recruitment of interested participants was by word of mouth via the primary and co-investigators or by contacting the study investigators via approved research study flyers located at fire stations throughout the city. Participants were excluded from the study if they were under 18 years of age or were not full-time active-duty (career) firefighters. Participants were also excluded if they were on light-duty status within 6 months of the time of study enrollment. All participants were naïve to the hypothesis of the study and provided consent after reading the consent form outlining potential risks and study procedures. The consent form and procedures were approved by the University of Kentucky human subjects review committee.

Fire Department Demographic Profile

The fire department included in the current study is a large urban department located in the eastern United States. The department currently has 601 employees, all of which are full-time, career firefighters. The department's shift cycle consisted of 24 hours on-duty,

TABLE 1. Participant Demographic and Physical Characteristics

	Mean ± SD	95% CI Lower	95% CI Upper	Minimum	Maximum
Age (yr)	35.26 ± 5.67	33.35	37.17	23.00	51.00
Height (cm)	179.47 ± 8.19	176.72	182.22	160.02	193.04
Weight (kg)	92.27 ± 13.97	87.57	96.97	63.64	122.73
BMI (kg m^{-2})	28.53 ± 3.11	27.48	29.58	21.20	37.40
Years of service with local FD	7.92 ± 5.80	5.97	9.87	1.00	22.00
Total years of firefighter service	10.09 ± 6.74	7.82	12.36	1.00	24.00

BMI, body mass index; CI, confidence interval; FD, fire department.

followed by 48 hours off-duty. However, personnel may also work overtime shifts and/or swap shifts (ie, workback shift) depending on schedule assignments. The fire company offers a combined service providing both fire (ie, fire truck and ladder) and emergency medical services (ie, ambulance), a total of 24 firehouses servicing the city. As such, the department also provides patient transport with the provided emergency medical services (EMS). Annual call volume for fire-related emergencies is approximately 25,000 and for EMS is approximately 50,000.

Research Design

The current observational study enabled the measurement of occupational workload, HRV, perceived exertion, and sleep among firefighters over a six-month period. The study was conducted from April 2022 to October 2022. The current study adhered to the STROBE Guidelines (Supplemental Digital Content, http://links.lww.com/JOM/B575). Each participant received a wearable physiological monitor (WHOOP, Boston, MA) worn on the wrist that tracked HRV using an optical based light sensor to measure capsular flow.[42] In addition, the monitor has also shown to capture objective measurements of sleep (eg, sleep duration on-duty) via actigraphy.[43–45] Participants were asked to wear the monitor securely on their wrist for the duration of the study and to go about their job and personal activities as normal. As such, the researchers captured physiological measurements for the entire 6 months (24-hour on-duty, 48-hour off-duty). In addition, subjective measurements were also captured. Upon completion of a 24-hour shift, each participant indicated their level of perceived exertion and sleepiness experienced on-duty via the Borg Rate of Perceived Exertion Scale and the Karolinska Sleepiness Scale. All survey data were collected via Research Electronic Data Capture (REDCap). REDCap is a secure, web-based application designed exclusively to support data capture for research studies.[46] Each 24-hour shift began at 7:00 AM and finished at 7:00 AM the following calendar day (Fig. 1).

Measurement of Emergency Call Volume

Emergency calls reported at each fire station were captured by the local fire department. Fire station call logs were used to quantify the total number of calls each firefighter responded to while on shift. Call logs were provided to the research team on a monthly basis. Emergency call volume was analyzed two ways. Total runs, or the total number of emergency calls responded to during a 24-hour shift, as well as total runs after 11:59 PM, were captured for analysis (ie, count data). In addition, emergency call volume was also captured numerically by a firefighter's total run time, or the total number of minutes a firefighter was away from the fire station responding to emergency calls during a 24-hour shift, along with total run time after 11:59 PM were also collected to evaluate total duration outside of the fire station. Run time was calculated from the time of dispatch to the time the assigned firefighter reported that they completed the emergency call (ie, marked in case log to indicate the apparatus is back online and available). Emergency calls after 11:59 PM were also captured as previous evidence has noted workplace injury is at its highest at night and early morning.[47,48] For the current analysis, only shift cycles that incorporated 24-hour on-duty, followed by 48-hour off-duty were included. Shift cycles that included overtime shifts, any switching of shifts (ie, workback shift), or vacation days were omitted.

Measurement of Occupational Stress

Firefighters wore a physiological monitor (WHOOP, Boston, MA) to track HRV during on-duty tasks. The monitor quantified HRV using photoplethysmography via light-emitted diodes on the bottom of the sensor, with more recent evidence indicating its use as a valid measure of HRV in the absence of gold-standard electrocardiogram (EKG).[43–45] Participants were instructed to place the sensor directly on the skin approximately 10 mm proximal to the styloid process of the ulna. In addition, participants were instructed to clean the area to optimize the sensor's capabilities to capture HRV data.

Measuring heart rate is a common metric used in both clinical and research applications to assess the heart's ability to respond to inbound stimuli.[49] Heart rate variability quantified in the time-domain uses R-R peaks, also referred to as the interbeat interval, to measure the amount of variability between successive beats recorded over time.[49] Previous literature has shown HRV to be a reliable method of assessing autonomic activity (for a review, see Shaffer and Ginsburg, 2017).[49] In addition, its utility has been previously observed and reviewed within the fire service.[17,50,51] As such, HRV is a beneficial method to monitor an individual's adaptability to internal or external stressors.

Measurement of Sleep

The physiological monitor (WHOOP, Boston, MA) also estimated sleep duration experienced on-duty based on measures of movement and heart rate derived from actigraphy.[43] For the purposes of the current study, sleep duration was defined as the number of hours a firefighter slept while on-duty. Sleep duration data was sent on a weekly basis from the monitor's manufacturer to the principal researcher for analysis. The wrist-worn monitor allowed for objective monitoring of sleep duration on-duty.

Subjective Measures of Exertion and Sleep

Measurement of exertion experienced while on-duty was collected using the Borg Rating of Perceived Exertion (RPE) scale. The Borg RPE scale was used to establish subjective measures of intensity each time a firefighter completed a 24-hour shift. The scale was assessed on a range of 6 to 20, with a 6 indicating "no exertion" and a 20 signifying "maximal exertion." The Borg RPE scale is a widely used and reliable indicator to monitor exercise intensity and is considered valuable because of its ability to capture the perceived exertion from central cardiovascular, respiratory, and central nervous system functions.[52] Furthermore, the Borg RPE scale has been shown as a viable measure of assessing firefighter exertion when compared to physical bouts of exercise.[53,54]

In addition to perceived exertion, subjective measures of sleep were also measured after completing a 24-hour shift. The Karolinska Sleepiness Scale (KSS) was used to measure subjective sleepiness upon completion of a 24-hour shift. The one-question assessment was scored on a 10-point scale, with a higher score equating to increased sleepiness (1 = extremely alert; 10 = extremely sleepy, can't keep awake).[55] As previously described, the KSS has been suggested

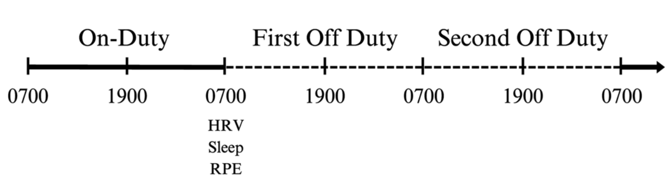

FIGURE 1. Firefighter shift cycle (24-hour on-duty, 48-hour off-duty) and time of assessment. Solid black line, on-duty; dotted line, off-duty.

as a useful alternative to electroencephalographic activity and behavioral indicators of sleepiness.[30] In addition, its use capturing subjective levels of sleepiness has been previously observed with firefighter and rescue service workers while on-duty.[56]

Data Reduction

Each firefighter reported the date they were on-duty upon completion of their regularly scheduled 24-hour shift. In other words, the on-duty day was reported by each participant as the date they were most recently on shift. Each data point (one on-duty shift) was collected from each participant after they completed shift via a secure REDCap link. The reported date the participant started the shift was then cross-referenced with the fire station call logs to determine the platoon and the apparatus (ie, ambulance, fire engine, or ladder) each participant was assigned to, as well as the number of emergency calls. The participant then subsequently responded to the Borg RPE and the KSS using the same REDCap link. The reported on-duty day was then cross-referenced to the reported date of completion of the Borg RPE scale and the KSS to determine perceived exertion and subjective sleepiness experienced on shift. In addition, participant age and years of service were captured for analysis as a plausible link between these factors to levels of stress has been suggested in the firefighter literature.[57] Body mass index was also collected at intake given the relationship between obesity, injury, and absenteeism observed in firefighting.[58,59]

Statistical Analysis

Descriptive statistics were calculated for each variable observed in the current study. A general linear model with repeated measures analysis and compound symmetry correlation measurement was used to identify predictors of RPE, sleepiness, and sleep duration on-duty. A correlation matrix was first performed to determine variable eligibility. Variables were considered eligible for model inclusion if r values ≥0.10 were found. Each predictor variable was further examined for collinearity via bivariate correlations to one another. Should collinearity exist ($r \geq 0.70$), the independent variable more strongly correlated to the dependent variable was included in the model. Strength and interpretation of correlation coefficients were based on previous work,[60] with 0.90 to 1.00 defined as "very strong," 0.70 to 0.89 as "strong," 0.40 to 0.69 as "moderate," 0.10 to 0.39 as "weak," and 0.00 to 0.10 considered "negligible". Akaike Information Criterion (AIC) was used to evaluate model performance and to determine which model was the best fit for the data. Statistical significance was accepted at an alpha level of 0.05. All analyses in the current study were conducted using a statistical software package (SAS, [version 9.4]; SAS Institute Inc., Cary, NC).

RESULTS

Absolute values are presented in Tables 1 and 2. A total of 1240 observations (on-duty shifts) were captured during the study after removal of overtime shifts, shift switches (workback shifts), and vacation days. Table 2 describes the outcomes of 24-hour shift work in the study's sample. The average number of emergency calls per individual per shift across all observations was 8.55 ± 4.95 calls per individual per shift, with an average total run time of 352.90 ± 254.49 minutes per individual per shift. Supplemental Table 1 (http://links.lww.com/JOM/B576) displays the outcomes of 24-hour shift work by apparatus assignment. By comparison, the average total run time when assigned to an ambulance was 235% greater than those assigned to a fire engine and 455% greater than those assigned to the ladder (Supplemental Table 1, http://links.lww.com/JOM/B576).

Table 3 displays the correlation matrix between emergency call volume, RPE, subjective sleepiness, HRV, and sleep duration on-duty. Total runs and total runs after 11:59 PM were weakly correlated with RPE (r = 0.283; r = 0.207, respectively), subjective sleepiness (r = 0.325; r = 0.302, respectively), and sleep duration on-duty (r = −0.386; r = −0.382, respectively). In addition, total run time and total run time after 11:59 PM were weakly correlated with RPE (r = 0.339; r = 0.270, respectively), subjective sleepiness (r = 0.312; r = 0.334, respectively), and moderately correlated with sleep duration on-duty (r = −0.411; r = −0.446, respectively). No significant correlation coefficients were found between HRV and any of the observed emergency call volume variables, including total runs, total runs after 11:59 PM, total run time, and total run time after 11:59 PM. While age was weakly correlated to RPE (r = −0.152), total years of firefighter service was weakly correlated to RPE and subjective sleepiness (r = −0.161; r = −0.148, respectively), and body mass index (BMI) was weakly correlated to subjective sleepiness and negligible to sleep duration on-duty (r = −0.178; r = 0.066, respectively), neither age, total years of firefighter service, nor BMI improved performance of the models. Neither age nor total years of firefighter service correlated with sleep duration on-duty.

To account for the presence of collinearity, total run time and total run time after 11:59 PM were the two independent variables included in the model. The general linear model with repeated measures indicated that total run time and sleep duration on-duty were the strongest predictors of RPE (P = 0.005; AIC = 4070.30) (Table 4). Interestingly, total run time and sleep duration on-duty also accounted for the greatest model performance for subjective sleepiness (P < 0.001; AIC = 3719.20)(Table 5). The current study found that a one-minute increase in total run time was associated with a 0.00582 increase in RPE and a 0.00208 increase in sleepiness. Conversely, a 1-hour increase in on-duty sleep was associated with a 0.228 decrease in reported RPE and a 0.485 decrease in subjective sleepiness. Total run time in tandem with total run time after 11:59 PM was the strongest performing model predicting the amount of sleep experienced on-duty (P < 0.001; AIC = 3598.40). In fact, the current study found that a one-minute increase in total run time was associated with a 0.00130 decrease in hours of sleep on-duty. Moreover, a 1-minute increase in total run time after 11:59 PM was associated with a 0.00740 decrease in hours of sleep on-duty (Table 6).

TABLE 2. Outcomes of 24-Hour Shift Work in Urban Structural Firefighters

		95% CI			
	Mean ± SD	Lower	Upper	Minimum	Maximum
Total runs	8.55 ± 4.95	6.89	10.21	1.00	23.00
Total run time (min)	352.90 ± 254.49	267.36	438.44	11.20	1796.00
Total runs after 11:59 PM	1.22 ± 1.26	0.80	1.64	0.00	7.00
Total run time after 11:59 PM (min)	43.97 ± 53.43	26.01	61.93	0.00	490.80
Resting HRV (ms)	56.07 ± 23.51	48.17	63.97	13.00	165.00
Sleep duration (hr)	5.45 ± 1.57	4.92	5.98	0.63	10.56
Borg Rate of Perceived Exertion	12.73 ± 2.27	11.97	13.49	6.00	20.00
Karolinska Sleepiness Scale	5.92 ± 2.04	5.23	6.61	1.00	10.00

CI, confidence interval; HRV, heart rate variability.

TABLE 3. Correlation Matrix Displaying the Relationship Between Emergency Call Volume, Perceived Exertion, Subjective Sleepiness, Heart Rate Variability, and Sleep Experienced On-Duty

	Total Runs	Total Run Time (min)	Total Runs After 11:59 PM	Total Run Time After 11:59 PM (min)	Borg RPE	KSS	Resting HRV (ms)	Sleep Duration (hr)	Age (yr)	Years of Service With Local FD	Total Years of Firefighter Service	BMI (kg m^{-2})
Total runs	1											
Total run time (min)	0.839**	1										
Total runs after 11:59 PM	0.514**	0.442**	1									
Total run time after 11:59 PM (min)	0.492**	0.501**	0.816**	1								
Borg RPE	0.283**	0.339**	0.207**	0.270**	1							
KSS	0.325**	0.312**	0.302**	0.334**	0.430**	1						
Resting HRV (ms)	0.005	−0.046	−0.009	−0.001	−0.104**	0.014	1					
Sleep duration (hr)	−0.386**	−0.411**	−0.382**	−0.446**	−0.339**	−0.406**	0.081**	1				
Age (yr)	−0.315**	−0.316**	−0.152**	−0.161**	−0.152**	−0.047	−0.179**	−0.025	1			
Years of service with local FD	−0.351**	−0.374**	−0.177**	−0.189**	−0.131**	−0.091**	−0.014	0.083**	0.802**	1		
Total years of firefighter service	−0.278**	−0.300**	−0.115**	−0.141**	−0.161**	−0.148**	−0.081**	0.051	0.723**	0.907**	1	
BMI (kg m^{-2})	−0.121**	−0.061*	−0.127**	−0.094**	0.006	−0.178**	−0.126**	0.066*	−0.213**	−0.083**	0.001	1

BMI, body mass index; Borg RPE, Borg Rate of Perceived Exertion Scale; HRV, heart rate variability; KSS, Karolinska Sleepiness Scale.
*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

TABLE 4. General Linear Model With Repeated Measures Predicting Rate of Perceived Exertion

	Shift Unit	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Intercept		11.264 (0.212)	11.290 (0.226)	12.310 (0.635)	13.545 (2.710)	15.8734 (0.312)	12.715 (0.516)	14.834 (0.411)	18.044 (1.202)	13.099 (2.220)
Total run time (min)		0.00402** (0.000293)	0.00305** (0.000376)	0.00569** (0.00129)	0.0224** (0.00866)		0.00582** (0.000861)			0.0146** (0.00508)
Total run time after 11:59 PM (min)			0.00352 (0.00243)	0.0102 (0.00722)	−0.112* (0.472)			0.00998** (0.00327)		
Sleep duration (hr)				−0.163 (0.0989)	−0.285 (0.449)	−0.590** (0.0447)	−0.228** (0.0799)	−0.444** (0.0627)	−1.123** (0.200)	−0.226 (0.366)
Shift unit	Ambulance				−0.663 (3.306)				−1.233 (1.262)	2.077 (2.446)
	Engine				−1.962 (2.832)				−4.044** (1.265)	−1.729 (2.324)
	Ladder				−1.651 (3.000)				−1.839 (1.436)	−0.463 (2.490)
Total run time x shift unit	Ambulance				−0.0188* (0.00913)					−0.0126* (0.00530)
	Engine				−0.0166 (0.00891)					−0.00761 (0.00535)
	Ladder				−0.00881 (0.00981)					−0.005 (0.00597)
Total run time after 11:59 PM x shift unit	Ambulance				0.142** (0.0504)					
	Engine				0.102* (0.0492)					
	Ladder				0.129* (0.0518)					
Sleep duration x shift unit	Ambulance				−0.0566 (0.564)				0.474* (0.211)	−0.505 (0.413)
	Engine				0.230 (0.463)				0.765** (0.210)	0.210 (0.380)
	Ladder				0.217 (0.491)				0.516* (0.268)	0.04001 (0.407)
Fit statistics										
−2 res log likelihood		4,868.30	4,865.80	4,132.40	4,325.30	4,148.80	4,066.30	4,153.00	4,112.60	4,097.60
AIC (smaller is better)		4,872.30	4,869.80	4,136.40	4,329.30	4,152.80	4,070.30	4,157.00	4,116.60	4,101.60
AICC (smaller is better)		4,872.40	4,869.80	4,136.40	4,329.30	4,152.80	4,070.30	4,157.00	4,116.60	4,101.60
BIC (smaller is better)		4,875.40	4,872.80	4,139.40	4,332.30	4,155.80	4,073.30	4,160.00	4,119.50	4,104.60

Notes: *$P \leq 0.05$; *$P \leq 0.01$; standard error of slopes in parentheses.

TABLE 5. General Linear Model With Repeated Measures Predicting Subjective Level of Sleepiness

	Shift Unit	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Intercept		4.856 (0.208)	4.795 (0.215)	7.529 (0.538)	5.053 (2.39)	9.032 (0.286)	7.825 (0.442)	8.510 (0.356)	8.743 (1.030)	5.613 (1.947)	6.952 (1.337)
Total run time (min)		0.00271** (0.000253)	0.00181** (0.000320)	0.00202 (0.00107)	0.00802 (0.00738)		0.00208** (0.000719)			0.00893* (0.00433)	
Total run time after 11:59 PM (min)			0.00706** (0.00205)	0.00597 (0.00600)	0.0333 (0.0402)			0.00354 (0.00262)			0.0221* (0.0109)
Sleep duration (hr)				−0.438** (0.0824)	0.0405 (0.390)	−0.597** (0.0360)	−0.485** (0.0668)	−0.538** (0.0505)	−0.615** (0.167)	−0.0614 (0.317)	−0.319 (0.216)
Shift unit	Ambulance				2.047 (2.879)				0.725 (1.074)	2.698 (2.132)	2.005 (1.443)
	Engine				3.036 (2.492)				−0.203 (1.071)	2.196 (2.032)	1.165 (1.394)
	Ladder				2.220 (2.626)				−0.232 (1.206)	2.556 (2.167)	1.628 (1.539)
Total run time x shift unit	Ambulance				−0.00519 (0.00778)					−0.00736 (0.00451)	
	Engine				−0.00890 (0.00760)					−0.00771 (0.00456)	
	Ladder				−0.00253 (0.00835)					−0.00790 (0.00508)	
Total run time after 11:59 PM x shift unit	Ambulance				−0.0208 (0.0430)						−0.020 (0.0117)
	Engine				−0.0462 (0.0419)						−0.0184 (0.0119)
	Ladder				−0.0127 (0.0441)						−0.0241 (0.0132)
Sleep duration x shift unit	Ambulance				−0.387 (0.486)				0.0108 (0.9501)	−0.490 (0.356)	−0.249 (0.236)
	Engine				−0.618 (0.402)				0.0493 (0.175)	−0.466 (0.328)	−0.200 (0.225)
	Ladder				−0.3594 (0.425)				0.124 (0.196)	−0.383 (0.351)	−0.1901 (0.249)
Fit statistics											
−2 res log likelihood		4,519.90	4,484.80	3,777.50	4,019.60	3,724.50	3,715.20	3,731.00	3,720.80	3,785.70	3,784.00
AIC (smaller is better)		4,523.90	4,488.80	3,781.50	4,023.60	3,728.50	3,719.20	3,735.00	3,724.80	3,789.70	3,788.00
AICC (smaller is better)		4,523.90	4,488.80	3,781.50	4,023.60	3,728.50	3,719.30	3,735.00	3,724.80	3,789.70	3,788.00
BIC (smaller is better)		4,526.90	4,491.80	3,784.50	4,026.60	3,731.50	3,722.20	3,738.00	3,727.80	3,792.70	3,791.00

Notes: *$P \leq 0.05$; *$P \leq 0.01$; standard error of slopes in parentheses.

DISCUSSION

The purpose of the current study was to determine the impact of emergency call volume on exertion, autonomic activity, and sleep among urban structural firefighters. It was hypothesized that call volume would be associated with greater perceived exertion and subjective sleepiness, along with poorer sleep and decreased HRV values. The results of the current study indicate that total run time and sleep duration on-duty were the strongest predictors of both RPE and subjective sleepiness. These findings are congruous with previous research noting proportional increases in subjective fatigue and sleepiness to frequency of shift work.[61] For example, Shen and colleagues[61] found the frequency with which workers engage in shift work has a significant effect on their subjective fatigue experienced. Furthermore, more fatigued shift workers display poorer sleep quality scores, reduced sleep efficiency, and decreased total sleep time.[62]

Shift work and disrupted sleep is a commonality in firefighting associated with several long-term health ailments (for a review, see Soteriades et al, 2011).[63] Firefighters experience rapid changes in heart rate immediately following an initial alarm often reaching maximum or near-maximum levels,[64] and sometimes occurring during the early morning hours. In fact, disrupted and fragmented sleep has been associated with increased sympathetic nervous system activation.[65] Moreover, heart rate remains elevated when individuals are subjected to reduced sleep times (less than 5 hours).[66] It is possible, therefore, that a reduction in overall sleep time after a high call volume shift may subsequently compromise adequate firefighter recovery after shift.

In addition to recovery, a reduction in sleep time on-duty may also influence a firefighter's risk of MSK injury. Grier and colleagues[26] found in other tactical populations that individuals who slept less than 4 hours were 2.35 times more likely to sustain a MSK injury when compared to those who slept greater than 8 hours. An increase in emergency call volume may impact a firefighter's opportunity to sleep while on-duty. In other populations, injury risk increases when an increase in training load or training intensity is coupled with a decrease in hours slept.[67] However, whether firefighter injury risk is exacerbated with habitual sleep loss with increases in call volume remains unknown. The present study found firefighters, on average, only slept 5.45 ± 1.57 hours on-duty. Although this is above the threshold found by Grier and colleagues,[26] there are instances where firefighters slept less than 4 hours. In addition, previous evidence has shown that less than 6 hours of sleep is enough to impair stress and fatigue,[68] with further impairments (less than 4 hours) impacting both recovery and performance.[69] Moreover, shift work and suboptimal sleep also have been associated with increased fatigue[61] and increased MSK pain.[70,71] In addition, increased job stress among firefighters has been associated with increased frequency of injury and occurrence of occupational injury.[72] As such, further investigation is warranted to determine how chronic exposure to increased emergency call volumes may influence long-term health outcomes. Future work should expand on how emergency call volume and frequency of sleep disturbances may influence firefighter MSK injury risk and long-term health. Moreover, such work should also consider how other factors on-duty, such as apparatus assignment, may impact firefighter outcomes.

When analyzing autonomic activity via resting HRV values, no significant differences were found. These findings contrast previous evidence indicating a decrease in reported HRV values in the time-domain coupled with increased sympathetic nervous system activity after 24-hour shift work.[12] Differences in the collection of HRV may illustrate such discrepancies between studies. Assessing autonomic functions is considered valuable, particularly when measuring neurocardiac function and the system's response to internal and/or external stimuli.[73–75] Surprisingly, no evidence of any changes in ANS activity were found despite a decrease in hours slept on-duty and an increase in RPE and subjective sleepiness reported. Poor sleep hygiene in firefighting has been previously linked to increased occupational stress,[5] daytime dysfunction,[5] and job stress scores.[18] Moreover, increased sympathetic

TABLE 6. General Linear Model With Repeated Measures Predicting Hours of Sleep on-Duty

	Shift Unit	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Intercept		6.311** (0.146)	5.978** (0.136)	5.568 (0.313)	6.355 (0.153)	6.471 (0.382)	5.905 (0.325)	6.202 (0.423)
Total run time (min)		−0.00238** (0.000206)			−0.00130** (0.000256)	−0.00463** (0.00117)		−0.00327* (0.00155)
Total run time after 11:59 PM (min)			−0.0116** (0.000775)		−0.00740** (0.00158)		−0.00588* (0.00285)	0.00640 (0.00592)
Shift unit	Ambulance			−0.696* (0.332)		−0.543 (0.445)	−0.0393 (0.349)	0.206 (0.529)
	Engine			0.273 (0.298)		−0.0450 (0.383)	0.198 (0.315)	0.355 (0.429)
	Ladder			0.255 (0.346)		0.0359 (0.428)	0.223 (0.354)	0.339 (0.465)
Total run time x shift unit	Ambulance							0.00231 (0.00164)
	Engine							0.00121 (0.00160)
	Ladder							0.000145 (0.00184)
Total run time after 11:59 PM x shift unit	Ambulance						−0.00985** (0.00310)	−0.0255** (0.00698)
	Engine						−0.00143 (0.00306)	−0.0128* (0.00646)
	Ladder						−0.00779* (0.00382)	−0.0148* (0.00742)
Fit statistics								
−2 res log likelihood		3,513.50	3,432.10	3,594.40	3,414.10	3,538.30	3,422.20	3,496.50
AIC (smaller is better)		3,517.50	3,436.10	3,598.40	3,418.10	3,542.30	3,426.20	3,500.50
AICC (smaller is better)		3,517.50	3,436.10	3,598.40	3,418.10	3,542.30	3,426.20	3,500.50
BIC (smaller is better)		3,520.50	3,439.10	3,601.50	3,421.10	3,545.30	3,429.30	3,503.60

Notes: *$P \leq 0.05$; *$P \leq 0.01$; standard error of slopes in parentheses.

nervous system activity has been observed secondary to acute sleep deprivation.[7] Lyytikäinen and colleagues[17] found firefighters require at least 2 days to recover from 24-hour shift work to restore changes in ANS activity. However, the use of a wearable device to capture autonomic activity on-duty is one possible explanation for differences between the current study and other studies evaluating autonomic activity in shift work populations.

The current study used a wearable wrist-worn physiological monitor to track both autonomic activity and sleep while on-duty. Wearable sensors have increased in popularity in both general and athletic populations as a 'light-weight' alternative to measuring heart rate without the hassle of using a clinical EKG to capture R-R peaks.[76] However, limitations in measuring autonomic activity do exist between wearable sensors and a clinical EKG. For example, accuracy and reliability for wearable sensors are noticeably diminished with increased movement or alterations in exercise load (for reviews, see Georgiou et al, 2018[77] and Shei et al, 2022[78]). In addition, the HRV values described in the current study were limited by the manufacturer's proprietary algorithm. The resting HRV values reported were values captured at the time of each participant awakening from sleep (as indicated by the device), which coincided with the end of the firefighter's shift. We acknowledge, therefore, that the type of wearable sensor used may have affected the possibility to observe any significant differences. To optimize the performance of the sensor, the participants were asked to securely fasten the monitor to their wrist to deter any accessory movement. In addition, the participants were instructed to clean the surface area of the skin where the sensor was in contact in order to maximize the sensor's capability. At the same time, we also recognize measuring autonomic activity may be influenced by a myriad of extrinsic and intrinsic stressors, as well as factors such as health status, age, dietary intake/metabolism, and sleep.[49,78] In addition, differences in job task responsibilities while on shift may influence individual metrics. For instance, the role of each firefighter on an apparatus may vary on-duty depending on rank and personnel (ie, acting officer, driver, paramedic). For example, Kaikkonen and colleagues[79] estimated the physiological load and psychological stress of Finnish firefighters during a 24-hour work shift. The researchers found that the distribution of psychological stress and recovery varies considerably both between individuals and across shifts.[79] Differences in cognitive or physical demands on shift, and therefore autonomic response, may vary between individuals, particularly when responding to an emergency call. Future research should compare similar wearable technology to a clinical EKG to determine whether similar findings are observed using a standardized approach when assessing the impact of emergency call volume on autonomic activity.

Another limitation of the current study was not accounting for firefighter off-duty responsibilities. For example, a firefighter may work a second job outside of emergency services on their off-duty days. As such, it is unclear how off-duty activities may potentially influence an individual's subjective reporting of RPE and/or subjective sleepiness. In addition, other factors such as a firefighter's physical activity level and/or prioritization of home and family obligations may attenuate firefighter recoverability.[80,81] It is possible, therefore, that stressors outside of a firefighter's shift may illustrate the lack of observable differences in autonomic activity. Future research should also consider off-duty activities and obligations when assessing on-duty activity as both may concurrently influence firefighter recovery. In addition, the current study did not screen for the presence of sleep disorders. As such, it is possible individuals with a diagnosed sleeping disorder, such as Obstructive Sleep Apnea, may have influenced HRV metrics captured in the current study as previous evidence suggests adults with Obstructive Sleep Apnea may demonstrate diminished vagal tone and higher sympathetic responsiveness.[82,83] Lastly, total sleep does not account for naps that may have been taken on-duty. Although napping has been established as an important method in maintaining adequate sleep, methods that utilize wearable technology, such as those used in this study, have not established valid methods of capturing naps. As such, they were not captured in this study.

CONCLUSIONS

The results of the current study showed total run time over a 24-hour shift and sleep duration were the strongest predictors of RPE and subjective sleepiness experienced on-duty. Furthermore, we have also shown that total run time over a 24-hour shift and total run time after 11:59 PM are strong predictors of sleep experienced on-duty. To our knowledge, no study to date has investigated both sleep and autonomic function using a wearable sensor and emergency call volume in a firefighter population. These findings suggest that emergency call volume may compromise a firefighter's on-duty perceived exertion, subjective sleepiness, and sleep experienced after a 24-hour shift.

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