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Original Research

Heart Rate Responses during Simulated Fire Ground Scenarios among Full-Time Firefighters

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ABSTRACT

International Journal of Exercise Science 13(2): 374-382, 2020. Simulated fire ground scenarios (SFGS) provide firefighters with an opportunity to maintain skills, receive feedback, and optimize performance. Although there is extensive research on heart rate (HR) changes in the firefighter population, few examine the differences between positions. Firefighters are primarily responsible for fire suppression and control (23), officers for emergency operations and organizational management, paramedics for providing on-scene emergency medical care, and drivers are responsible for driving the fire apparatus. Utilizing HR analysis to quantify the physical demands of SFGS among firefighting crews by position. Sixty-seven male (age: 38.97 ± 9.17; ht: 177.99 ± 6.45 cm. wt: 88.83 ± 13.55 kg) firefighters (FF) participated in this investigation. FF crews performed two SFGS involving the suppression and control of a structural fire. Participants were outfitted with heart rate (HR) monitors and average heart rate (HRavg) and maximum heart rate (HRmax) data were collected for each of the two SFGS. Significant differences were observed for Age ($P = 0.01$), APMHR ($P = 0.01$), $HRmax^1$ ($P = 0.04$), and $HRmax^2$ ($P = 0.04$) in which firefighters had higher values for Age-predicted maximal heart rate (APMHR), $HRmax^1$, $HRmax^2$ compared to the officers. SFGS can be very physically demanding events that may elicit maximal or near maximal HR responses regardless of position. Based on the metabolic demands of these events and the individual firefighter's capabilities, this information can be used to develop resistance training and conditioning programs that optimize performance at maximal or near maximal heart rates.

KEY WORDS: Firefighter, heart rate variability, SFGS, cardiovascular disease, disease risk

INTRODUCTION

Firefighting is a hazardous profession that often exposes firefighter (FF) crews to unpredictable conditions and complex environments that increase the risk of injury and death (1, 4, 13, 14, 15). Although most may believe that all FFs are directly involved in fire suppression, FF crews are a complex unit of firefighters, drivers, officers, and paramedics. Essentially, all employed members of a fire department can be considered a FF. However, job responsibilities are delineated by rank, and those employed at the FF rank are primarily responsible for fire suppression and control as well as search and rescue (24). Comparatively, drivers are responsible for driving the fire apparatus as well as maintaining and operating the fire pump and aerial ladder (24). Chiefs, captains, and lieutenants can be classified into the officer rank and are primarily responsible for emergency operations, organizational management, and personnel management (24). Paramedics are primarily responsible for fire suppression and control, but possess the knowledge, skillset, and certification to provide on-scene emergency medical care (24). Although it is currently unclear whether the physical demands for each crew member differs by position during simulated or live-fire events, it appears that depending on their level of training, all FFs may be required to perform another rank's job duties at any time while on-scene. Thus, an improved understanding of the physiological and metabolic demands of performing fire suppression tasks by crew position may aid in the development of training programs that can better prepare FFs to perform essential job functions, ultimately, reducing the risk of potential cardiovascular incidents while on the job.

Currently, limited data exists that details the positional cardiovascular demands in FF populations during both, simulated, and live fire events. When attempting to characterize cardiovascular functioning throughout emergent responses, the importance of understanding internal workloads and their influence on performance has become paramount (3). Recently, Bourdon et al. defined internal training loads as stressors that are biological, physiological, or psychological in nature, or a combination of each (3). Measures such as maximal heart rate (HRmax) and average heart rate (HRavg) have been used to assess internal training loads while measures of age-predicted maximal heart rate (APMHR) have provided researchers with values comparable to participant's actual maximal heart rates (2, 3, 4, 5, 7, 13, 14, 15, 19, 23, 25).

Simulated Fire Ground Scenarios (SFGS) are routine training events that usually require FFs to perform duties such as: fire suppression, fire control, stair climbs, hose drags, and search and rescues, that they are asked to perform regularly on the job and are essential to the profession of firefighting. Previous research suggests that these types of training approaches provide FFs with an opportunity to maintain their skills and receive team feedback in order to optimize their performance (9, 10, 12). Additionally, SFGS are dually beneficial: for the FF crew, they are provided with an opportunity to maintain their skills and receive team feedback in order to optimize their performance. As a researcher, we are provided with two exceptional opportunities; one to monitor FF crew's cardiovascular functioning in a controlled, yet specific environment. Secondly, SFGS allow for overall control of the environment, sample demographics, and other factors which contribute to the design of the investigation.

Therefore, the aim of the present study was to compare differences in heart rate responses between firefighters, drivers, officers, and paramedics during two SFGS events by utilizing wearable heart rate monitors. We hypothesized that there would be significant differences in HRavg and HRmax between positions during SFGS events.

METHODS

Participants

Initially, 97 firefighters participated in this study. However, due to missing data points, sixty-seven (n=67) healthy male firefighters (age: 39.00 ± 9.14; ht: 178.08 ± 6.46 cm. wt: 88.87 ± 13.47 kg) were included in the final analysis. As part of their organization's normal annual training procedures, firefighters from a large Midwestern metropolitan area fire department were required to participate in simulated fire suppression tasks. Although participation in this training was mandatory, participation in this study was strictly voluntary. Investigators explained to the participants that abstaining or withdrawing from participation in this study would in no way have any bearing on their employment status. Additionally, ethical approval for this research project was granted by the University of Colorado at Colorado Springs Institutional Review Board (#18-045). All firefighters provided informed written consent prior to participation (17).

Protocol

All tests were overseen by experienced investigators who had been trained in the proper technique, format, and procedures for all tests, which were explained and demonstrated to all participants to ensure uniform procedures prior to their participation in this study. Furthermore, due to the unpredictability of live fire events, training ground rules and attack methods were determined based on the department's standard operation procedures.

Anthropometric Data: After the participants were briefed and signed their written informed consent documents, height, weight, and BMI were measured for every individual. Subjects were asked to remove their shoes as their height was measured to the nearest 0.5 cm. Next, with their shoes remaining off, subjects were weighed in only their underclothes with their weight measured to the nearest 0.5 kg. BMI was calculated as weight in kilograms divided by the height in square meters (kg/m2).

Dressing and Weighing: After their initial anthropometric assessment and prior to the first SFGS event, firefighters were instructed to don their full personal protective equipment (PPE) or standard protective firefighting turnout gear, gloves, flash hood, helmet, and self-contained breathing apparatus (SCBA). All gear met the standards for the National Fire Protection Association (NFPA-1851-14-01). Prior to participants getting dressed, a Zephyr Bioharness 3™ chest strap heart rate monitor were applied to their bodies. Several studies have demonstrated the usefulness and accuracy of the Zephyr heart rate monitor for measuring maximal and average heart rates under stressful conditions (1, 4, 6, 7, 12, 13). After dressing and prior to the start of the first SFGS, subjects were weighed while wearing their PPE.

Heart Rate Measurements: Heart rate was monitored using a Zephyr Bioharness 3™ chest strap heart rate monitor (Zephyr Technology Corporation; Annapolis, Maryland). This heart rate monitor was attached to the participant's chest with an elasticized belt. Heart rate responses were recorded every 5 seconds during the SFGS events and data was downloaded directly to a computer between SFGS events. This device was used to capture both, the HRavg and HRmax for SFGS event 1 ($HRavg^1$ and $HRmax^1$) and event 2 ($HRavg^2$ and $HRmax^2$). Cardiovascular responses of firefighters were investigated by measuring HRavg, HRmax, and APMHR. We defined HRavg as the participant's average HR for the duration (start of finish) of each SFGS event. Participant's HR was recorded every 5 seconds and then all recordings were averaged to determine HRavg. HRmax was defined as the maximal HR obtained during each SFGS event. APMHR was calculated by subtracting the theoretical maximal HR (220 beats per minute) from the participant's age (3, 5, 7, 23). APMHR% was calculated by dividing HRmax by APMHR for each SFGS event.

Simulated Fire Ground Scenarios: After briefing of the fireground training rules, were separated into groups of 8. Two fire engines were dispatched for each SFGS and the teams were comprised of; 2 drivers, 4 firefighters, 1 paramedic, and 1 officer. Next, each of the participant's heart rate monitors were started, and the firefighters proceeded to their vehicles. The simulation was relayed over the radio, firefighters donned their gear, entered their vehicles, and dispatched from the exterior parking lot to the fireground. The SFGS events included two activities that were performed twice by each group; structural fire suppression and structural fire control. The SFGS event utilized for this study was set in an apartment fire simulation. The apartments were recently constructed, the framing was steel with a brick exterior and the roof assembly was covered in asphalt shingles. The apartment building was a single unit that was one-story high. The goal of both SFGS events was to control and extinguish the structural fires as fast and in as safe a manner as possible. After termination of the drill, the firefighters re-grouped and stopped their monitors. The data was then recorded, and the firefighters re-grouped and prepared for their second simulation. A total of two simulations were run per group and all data recording was initiated and terminated within three minutes of starting and finishing the drill. The durations of the SFGS ranged from 9 minutes to 14 minutes and 30 seconds.

Environmental Conditions: SFGS events were conducted at either 9:00am, 12:00pm, 1:00pm, or 2:30pm between late October and mid-November. The climate where the SFGS events were conducted was cool and dry and the average temperature on the SFGS event days ranged from 34 and 59 degrees Fahrenheit (1.11 to 15 degrees Celsius), while average relative humidity ranged from 47 to 88%.

Statistical Analysis

All data was analyzed using PASW software version 24.0 (SPSS Inc, Chicago, IL, USA). Separate one-way ANOVAs [Group (Driver vs. Firefighter vs. Paramedic vs. Officer)] were run for all dependent variables ($HRavg^1$, $HRavg^2$, $HRmax^1$, $HRmax^2$, APMHR, $APMHR\%^1$, $APMHR\%^2$)

and age. A Bonferroni correction was used to determine the nature of the differences between positions. Additionally, a Pearson correlation between Position and $HRmax^2$ was conducted. An alpha level of $P \leq 0.05$ was considered significant for all comparisons.

RESULTS

Means and standard deviations for descriptive statistics for each variable measured are presented in Tables 1 and 2. Significant differences were observed for Age ($F3, 63 = 6.880$; $P = 0.01$), APMHR ($F3, 63 = 6.019$; $P = 0.01$), $HRmax^1$ ($F3, 63 = 2.990$; $P = 0.04$), and $HRmax^2$ ($F3, 63 = 4.892$; $P = 0.04$) in which the firefighters were younger and had higher values for APMHR, $HRmax^1$, $HRmax^2$ compared to the officers. During our statistical analysis, we also observed that drivers had a significantly greater $HRmax^2$ when compared to officers. A significant, weak, positive correlation ($r (65) = .242$, $p < 0.05$) was observed between position ($M \pm SD = 2.299 \pm 0.921$) and age ($M \pm SD = 39.09 \pm 9.18$) (Figure 1). Additionally, a significant, moderate, negative correlation ($r (65) = -.347$, $p < 0.01$) was observed between position ($M \pm SD = 2.299 \pm 0.921$) and $HRmax^2$ ($M \pm SD = 168.63 \pm 15.63$).

Table 1. Group demographics.

Position	*n*	Age (years)	Height (cm)	Weight (kg)	Body Mass Index	PPE Weight (kg)
Driver	11	42.72 ± 8.32	177.91 ± 9.97	95.68 ± 19.29	28.12 ± 3.76	28.15 ± 5.95
Firefighter	36	35.36 ± 8.14*	178.25 ± 6.22	87.00 ± 11.30	28.40 ± 3.81	28.20 ± 1.60
Paramedic	11	39.18 ± 9.42	178.91 ± 4.68	87.68 ± 10.56	27.53 ± 3.99	27.48± 1.89
Officer	10	47.80 ± 5.79	176.75 ± 4.77	89.40 ± 15.66	26.82 ± 3.92	27.45 ± 1.27

* = Significantly different from Officers ($P < 0.05$)

Table 2. Mean ± SD for average heart rate ($HRavg^1$ and $HRavg^2$) and maximum heart rate ($HRmax^1$ and $HRmax^2$) after both SFGS events.

Position	$HRavg^1$	$HRavg^2$	$HRmax^1$	$HRmax^2$
Drivers	120.18 ± 15.22	131.45 ± 16.57	164.18 ± 18.88	170.18 ± 15.40
Firefighters	130.46 ± 17.06*	136.09 ± 15.47	169.26 ± 13.34*	172.57 ± 14.81*
Paramedics	127.27 ± 7.58	132.36 ± 12.10	169.09 ± 9.10*	168.82 ± 11.25
Officers	117.20 ± 12.51	122.40 ± 16.96	154.60 ± 15.84	152.9 ± 14.82

* = Significantly different from Officers ($P < 0.05$)

Table 3. Mean ± SD for age predicted maximal heart rate (APMHR), and age predicted maximal heart rate percentage (APMHR%) for each firefighter role delineation during each SFGS event are also reported here.

Position	APMHR	$APMHR\%^1$	$APMHR\%^2$
Drivers	177.27 ± 8.32	0.9279 ± 0.11	0.9629 ± 0.11
Firefighters	184.06 ± 8.52 *	0.9209 ± 0.06	0.9393 ± 0.08
Paramedics	180.81 ± 9.42	0.9363 ± 0.05	0.935 ± 0.06
Officers	172.2 ± 5.79	0.8964 ± 0.07	0.8867 ± 0.06

* = Significantly different from Officers ($P < 0.05$)

DISCUSSION

The primary purpose of this study was to identify and quantify differences in HR measures between different firefighter positions in a crew. The results from the present study indicated that significant differences in age, APMHR, and HRmax did exist between groups based on position. No significant differences were observed between positions in any of the other measured variables. In the first SFGS event, firefighters achieved a significantly higher HRmax than officers, and in the second SFGS event both firefighters and drivers achieved a significantly higher HRmax than officers. The results of this study may be used by Tactical Strength and Conditioning Facilitators (TSAC-F) to develop conditioning programs to optimize occupational performance within this population. Additionally, the outcomes of this research show the necessity for high intensity cardiovascular training to mimic the demands of a fire scene, as well as minimizing the risk for cardiovascular incident, which is the primary risk factor for on duty death in this population.

Previous research indicates that performing essential firefighting tasks can be extremely physically demanding (2,4,5,7,8,11,13,14,15,18,19,20,23). Based on the results of this investigation, it was discovered that when performing simulated fireground tasks the average maximum HR ranged between 85 – 102% of the participant's APMHR. This is in agreement with previous research conducted by Horn et al. who found that on average firefighters achieved 99% of their APMHR while completing 14 minutes of simulated firefighting activities (12). Additionally, research conducted by Marcel-Millet et al. also supports our findings (16). In their study, firefighters completed simulated rescue interventions with one of three protective equipment conditions: personal protective clothing, self-contained breathing apparatus cylinder, and self-contained breathing apparatus. On average, each firefighter achieved between 81 - 99.5% of their APMHR regardless of their equipment condition. Firefighters participating in SFGS events and live-fire events are likely to attain or surpass their APMHR. This data would suggest that exercise programs for firefighters should induce similar cardiovascular responses. The benefits of such programs are three-fold: not only are firefighters improving their physical fitness, but any positive adaptation to training may enhance the ability to work at a higher percentage of their APMHR without experiencing undue fatigue. Lastly, based on the results of our investigation, we observed that FFs require or often utilize near-maximal cardiovascular functioning to perform their job. Thus, FFs should be prepared to perform at such an intensity. By adhering to training protocols, preferably recommended by TSAC-F, FFs can expect to improve physical fitness and cardiovascular function by regularly performing resistance, aerobic, and anaerobic training at these percentages.

While significant differences were discovered in HRmax between firefighting positions, this was largely a function of the differences in APMHR between position groups. For instance, on average the firefighter group in this study were significantly younger than both drivers and officers. However, when made relative to age (i.e., %APMHR) no significant differences were observed between groups. Based on these findings it appears that when developing a conditioning program for firefighters, it would be more relevant to individualize the program based on their current fitness levels and a percentage of their APMHR rather than by position.

According to Orr et al., an ability based training program resulted in significant improvements in aerobic fitness after training once per week over a 10-week training period (19). In addition to improving aerobic fitness, there were no significant differences in injury rates between groups and ability based training yielded a significantly lower relative risk of injury when compared to traditional training. Additionally, physical fitness standards for FF should be established and regularly evaluated since many of the roles overlap and all FFs on the apparatus should be physically prepared to participate in fire suppression and control efforts.

There are a few potential limitations to this study that should be addressed. First, there were notable disparities in sample sizes for each firefighter position, with there being at least three times as many firefighters compared to officers, paramedics, and drivers. Although, this is likely due to employment preferences and needs, it may be beneficial to increase the sample sizes for the other positions in order to provide a sufficient representation of the firefighter population by position. Additionally, assessing HR changes at the beginning and end of each SFGS event could provide investigators with novel insight on the characteristics of positional HR changes during such events. For example, identifying fluctuations in HR, as well as the total amount of time spent in specific HR ranges or zones, may provide greater insight into the development of specific conditioning programs to enhance occupational performance. Further, it may be more ideal to assess HR fluctuations in this demographic over a longer period of time (i.e. 12-24 hours). Implementing a similar research and assessment model as firefighters begin their shifts may provide a more accurate representation of their HR characteristics while on duty. Finally, this data was collected during simulated firefighting activities. While this provides basic information related to the physical demands associated with these activities, it does not account for the cognitive and psychological stress experienced during live fire or actual callouts.

Employment as a FF may result in an overlap of job responsibilities or roles within a moment's notice. Due to the constraints of what the fire department would allow the investigators to capture, current fitness levels, nutritional status, and caffeine consumption were not investigated nor was it controlled. As much as we would have preferred to account and perhaps control for these variables, it is likely that firefighters will have just eaten or have had some type of caffeine prior to performing their job. Thus, controlling for these factors may actually compromise the contextual specificity of this study. Finally, although age and position based differences in cardiovascular functioning were detected in this study, it appears that FFs generally achieve near-maximal cardiovascular functioning during SFGS. Whether the observed ranges in cardiovascular functioning are due to an external stimulus or the requirements of the job, physical preparedness for duty should be of utmost importance. In the future, TSAC-F can utilize these findings to better understand the requirements of FF, and to improve the design of specific fitness programming that mimics and prepares FFs for the physiological stress they encounter while on a live-fire scene.

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