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Response to thermal and physical strain during flashover training in Croatian firefighters

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ABSTRACT

Flashover training (FOT) for firefighters is a simulation of the flashover phenomenon under controlled conditions. This study assessed arterial blood pressure (BP) and its response to thermal and physical strain during FOT in 48 professional and 18 volunteer firefighters.

A high prevalence of obesity (27%), basal hypertensive (53%) and prehypertensive (33%) BP values was found. FOT induced mild hyperthermia and physical strain (average increase of 1.1 °C in tympanic temperature and 61% of the maximal heart beat predicted for age). Compared to professional firefighters, FOT in the volunteers induced a higher increase in pulse ($P = 0.050$) and tympanic temperature ($P = 0.025$). Systolic BP did not vary significantly, and diastolic BP slightly decreased in both groups.

Results confirm that FOT induced only physiological cardiovascular responses to thermal and physical strain in firefighters. High prevalence of obesity and elevated BP values indicate the need for better physical fitness and BP control among firefighters.

1. Introduction

While performing their duties, professional and volunteer firefighters are exposed to a specific work environment, which requires a significant level of physical and psychological fitness (Bilzon et al., 2001) and heavy specific protective equipment. Besides protective clothing and boots, firefighters are also equipped with heavy self-contained breathing apparatus (SCBAs), which contains either steel or carbon cylinders. It is known that exposure to high environmental temperatures during heavy physical activity represents an additional burden to the cardiovascular system, as it causes an increase in the core body temperature, blood pressure (BP), heart beat frequency and respiration rate. Protective clothing that prevents burns during firefighting operations also diminishes the dissipation of thermal energy that is produced during extreme physical strain (Barr et al., 2010). Shift work, including night shifts and often overtime work, is related to disturbances in the circadian rhythm of firefighters, which leads to increased prevalence of obesity and hypertension. Published data pointed out a sudden cardiac event as the number one cause of death in firefighters, suggesting that 45% of all deaths reported during firefighting tasks are due to the cardiovascular disease (Kales et al., 2009), with myocardial infarction being the leading one (Kales et al., 2003; Calvert et al., 1999). Furthermore, according to the recently published review article by Kales et al. (2009), BP was elevated in approximately 75% of workers employed in different emergency services in the USA including firefighters and police officers.

Legislation that regulates physical and cardiovascular fitness differs across countries around the world (Kales et al., 2009). In Croatia, there are no obligatory tests that would assess the cardiovascular response to physical and thermal strain or precisely define the mandatory weight limits or the body composition. Also, data on the prevalence of hypertension, excess weight and obesity, as well as the cardiovascular response to thermal and physical strain in Croatian firefighters are considerably scarce. Our recent study (Ljubičić-Ćalušić et al., 2012) tested the thermal and physical strain level in firefighters attending flashover training (FOT). FOT was recently introduced in Croatia as a simulation of the flashover phenomenon under controlled conditions. The flashover phenomenon occurs when surfaces exposed to thermal radiation reach the ignition temperature, and the fire rapidly spreads across the enclosed area. FOT aim is to train firefighters to recognize, understand and prevent this phenomenon. In order to train firefighters to recognise this threat in real life and work, but to avoid any unnecessary threats, these trainings are conducted by highly experienced instructors, the FOT containers are built according legally proscribed EU norms EN 14097-3, and all attendees had detailed instruction regarding the rules that they must abide by during the

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drill. All firefighters are advised to drink at least 0.5 L of water before each training session. An Emergency medical service is present during the entire course of the training. The flashover phenomenon that occurs during training is induced in controlled condition and the risk of the unpredicted fire eruption is significantly diminished. The results of our previous study (Ljubičić Ćalušić et al., 2012) suggested that FOT induced mild hyperthermia and consequently, physiological respiratory responses developed during the exercises.

The study aimed to assess and compare the arterial BP and heart rate in professional and volunteer Croatian firefighters and its response to thermal and physical strain during FOT.

2. Subjects and study design

Sixty-six firefighters (48 professional and 18 volunteer) attending FOT, were involved in the study. The response rate was 98% for professional and 95% for volunteer firefighters. All of the subjects were male. The study was approved by the Ethics Committee of the Institute for Medical Research and Occupational Health, Zagreb. Potential participants were informed about the study aim, procedures that would be undertaken, research methodology and the obtained results' implications. Firefighters willing to participate signed an informed consent form prior to their inclusion in the study.

FOT procedure was described in detail previously (Ljubičić-Ćalušić et al., 2012). Briefly, flashover simulator consists of two 14-gauge steel walled chambers: the burn module and the observation module. At the point of auto-ignition of smoke layer, the temperature rises to above 1000 °C in the burn module and to 200 °C in lower parts of the observation module. Three instructors and no more than 12 attendees were simultaneously present in the simulator, either sitting on low benches or kneeling in the observation module. Attendees were instructed to change their positions by moving closer to the burning module. Average temperature was measured at the attendees' protective clothing surface: 136.2 ± 18.9 °C (range 115–160 °C) was measured on the clothes of those closest to the burning module and 79.0 ± 7.9 °C (range 72–85 °C) on the clothes of those farthest away. During the FOT course, attendees were exposed to extreme conditions in the flashover simulator four times during one day: for 20 min during the 1st, 2nd and 3rd exercise and for 30 min during the 4th exercise. The attendees and instructors were equipped with SCBAs containing either steel or carbon cylinders. The total weight of the protective equipment was approximately 30 kg. All of the included subjects had to respond to a medical questionnaire, undergo measurements of tympanic temperature, pulse and systolic and diastolic BP before FOT and after each of the four exercises.

3. Methods

3.1. Medical history

A questionnaire on medical and working history was completed by a physician after interviewing each subject. Smoking habit was expressed regarding current and past smoking status (never smokers, ex smokers and current smokers) and as smoking index for current smokers (number of cigarettes smoked per day multiplied by number of smoking years). In the statistical analysis, the smoking habit was expressed as a dichotomous variable (smokers and non-smokers) in which subjects who never smoked and ex-smokers that stopped smoking at least four weeks before enrolment in this study were designated as non-smokers. Seniority was expressed as years of experience in firefighting activities. According to the occupational history, firefighters were divided in two groups for the purpose of this study. One group comprised professional firefighters and the other group comprised volunteer firefighters.

Tympanic temperature, pulse, BMI and brachial artery BP measurement.

Infrared tympanic temperature (ThermoScan ear thermometer, Braun, Germany) and manual pulse measurement on radial artery was performed in all of the subjects before the beginning of the training and after each exposure to high ambient temperatures in the flashover container. Attached lens filter on ear thermometer was changed after each measurement. All of the measurements were performed by the same person within five to ten minutes time frame after leaving the FOT container (Hansen et al., 1996).

Systolic and diastolic brachial artery BP was measured in the supine position using a mechanical (Hg) oscillometric cuff. All of the BP measurements were made in duplicate and the average of the two values was recorded and used for subsequent analysis. Prehypertensive BP values were defined as systolic BP values between 120 and 139 mmHg and/or diastolic BP values between 80 and 89 mmHg. Hypertensive BP values were defined as values ≥140 mmHg of systolic and/or ≥90 mmHg of diastolic BP. The cut off value for hypertensive post-exercise reaction was defined as systolic blood pressure ≥200 mmHg (Leiba et al., 2013).

Body mass index (BMI) was calculated according to the formula: weight [kg]/height $[m]^2$. Weight and height were self-reported during the medical interview.

3.2. Statistical analysis

General characteristics and baseline spirometry, pulse, tympanic temperature and BP values in professional and volunteer firefighters were compared by Student's *t*-test or Mann–Whitney *U* test. The smoking status and incidence of obesity and respiratory symptoms were compared between groups by Pearson's χ^2 test or Fisher's exact test. The effect of FOT exercises on pulse, tympanic temperature, systolic and diastolic BP, i.e. change from baseline, pre-exercise values, was analysed by Student's *t*-test for paired data, separately for professional and volunteer firefighters.

Mixed-effects regression models were used to test the variation of pulse, tympanic temperature and systolic and diastolic BP after four FOT exercises, with pulse, tympanic temperature and systolic and diastolic BP as dependent variables. In all models predictors included study subjects as a random effect, and FOT exercise, workplace (volunteer *versus* professional firefighters), age, smoking status (smokers *vs.* non-smoker), BMI as fixed effects. In the models with pulse and tympanic temperature, systolic or diastolic BP was also included as a fixed effect. In the models with pulse and tympanic temperature as dependent variables, the effect of FOT was modelled as a square function. FOT in other models, as well as all other predictors, were modelled as linear function. To evaluate the potential effect of the workplace (volunteer *versus* professional firefighters), age, smoking status and BMI on change in dependent variables during FOT course, interaction terms FOT × workplace, FOT × age, FOT × smoking status, FOT × BMI and FOT × systolic BP or FOT × diastolic BP were tested as fixed effects in the regression models.

Statistical analysis was performed using Stata/SE 11.1 for Windows (StataCorp LP, USA).

4. Results

The general characteristics of the study subjects are presented in Table 1. Professional firefighters were on average 13 years older than volunteer firefighters, and had higher seniority. As for smoking status, no difference was observed in the prevalence of smokers and ex-smokers, while the smoking index in current smokers was