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Firefighter salivary cortisol responses following rapid heat stress

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ABSTRACT

This research evaluated the impact of rapid heat stress on the rate of salivary cortisol appearance. We hypothesized that rapid heat stress would result in an increased rate of salivary cortisol appearance. Fourteen adult male participants performed an incremental exercise test to a termination criterion (volitional maximum, core temperature = 39.5 °C, or a 2-h time maximum time) with or without firefighting gear in a laboratory with an ambient temperature of 25-26 °C. Salivary cortisol was collected at each 0.5 °C increase in core temperature. We observed a significant increase ($p \leq 0.01$) in the rate of cortisol appearance when the subjects were wearing the firefighting gear; no change was observed without firefighting gear. Our results demonstrate that rapid heat stress and the resulting physiological stress cause a rapid increase in the rate of salivary cortisol appearance. Our results also support previous research demonstrating that cortisol is a sensitive strain metric of heat intolerance.

1. Introduction

The leading cause of line-of-duty death for firefighters worldwide is cardiac-related. Statistics show that 45%–50% of all firefighter duty-related fatalities are a result of sudden cardiac death (Smith et al., 2016). While there are several causes of cardiovascular disease (CVD), stress is a significant contributor. Firefighters deal with many different types of stressors, with heat stress as a major stressor. Chronic stress has been demonstrated to be a determinant of CVD (Olinski et al., 2002).

The human body responds to stress by dysregulating the hypothalamic-pituitary-adrenal (HPA) axis, which results in increased circulating cortisol (Gawel et al., 1979). This causes the mobilization of free fatty acids, decreased growth and sex hormone levels, increased cardiac output and blood pressure, and decreased immune system response (Bjorntorp 2001; Chrousos and Gold 1992; Whitworth et al., 2005). Chronically elevated cortisol has been linked to accelerated atherosclerosis and subsequent cardiovascular issues (Dekker et al., 2008). In addition to this, elevated cortisol levels have been related to endocrine, metabolic, and hemodynamic disturbances (Rosmond et al., 1998).

Stress also has an impact on the sympathomedullo-adrenal (SMA) axis (Lutgendorf et al., 2001). This pathway involves the release of cytokines such as C-reactive protein (CRP), an acute-phase protein released from the liver that increases its response following interleukin-6 (IL-6) secretion. IL-6 is an important pro-inflammatory cytokine. CRP is a sensitive marker in systemic inflammation, and chronically elevated values are an independent risk factor for CVD in both children and adults (Cook et al., 2000; Ridker et al., 2003). A link has been drawn between the HPA axis and the SMA axis. It has been suggested that high concentrations or prolonged presence of inflammatory cytokines such as IL-6 stimulate the secretion of adrenocorticotropic hormone (ACTH) from the pituitary gland and cortisol from the adrenal cortex (Nijm and Jonasson 2009).

Firefighting is an occupation where individuals are chronically exposed to acute heat stress. Firefighters wear equipment that is very thick, multi-layered, and cumbersome. This personal protective equipment (PPE) is beneficial because it provides protection from environmental hazards and injury. However, the equipment is also detrimental in that it has limited air and water vapor permeability, which prevents wet and dry heat loss to the external environment. The limited permeability creates a microclimate with its own temperature and relative humidity. This microclimate prevents adequate thermoregulation in scenarios that lend themselves to extreme exertion, high ambient temperatures, and high relative humidity (Cheung et al., 2000). This creates an environment where rapid heat stress is possible. Rapid heat stress is a type of acute heat stress in which heat stress storage during exercise

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occurs at double the rate of a normothermic condition (Coehoorn et al., 2020). Acute heat stress scenarios are variable dependent on the rate of core temperature acquisition. It is known that exercise in the heat increases plasma and serum cortisol levels when compared to exercise in a normothermic condition (Brenner et al., 1997; Hoffman et al., 1996). Additionally, salivary cortisol increases during firefighting drills (Perroni et al., 2009) to reflect the state of thermal stress.

In the present study, oral swab stimulated salivary collection method and ELISA analysis were used to better understand the impact of rapid heat stress on the rate of salivary cortisol appearance. Salivary cortisol measurement and analysis correlate with blood cortisol measurements (Burke et al., 1985; Calixto et al., 2002; Raff and Trivedi 2013; VanBruggen et al., 2011; Wong et al., 2004), and research shows that it has been correlated with 24-h urine collection (Neary et al., 2002). Blood and urine cortisol was not measured in the present study. The previous correlation studies mentioned support the reliability and validity of using salivary cortisol measures in this study as an accurate biomarker of thermal stress. The specific focus during this study was placed on evaluating the rate of salivary cortisol appearance with (PPE) and without (CON) firefighting gear. Previous literature with no PPE has demonstrated an effect of heat stress and exercise on cortisol appearance (Brenner et al., 1997; Hoffman et al., 1996; Mitchell et al., 2002). Based on this, we hypothesized that a rapid heat stress (PPE) scenario would result in an increased rate of salivary cortisol appearance relative to a compensable heat stress (CON) scenario.

2. Methods

2.1. Participants

There were fourteen male participants (10 career firefighters, 4 college athletes) in this study (see Table 1). These subjects represent a subset from a larger study that evaluated several variables associated with rapid heat stress (Coehoorn et al., 2020). The sample size (14 subjects) was confirmed to elicit a 0.95 power rating (G*Power; Version 3.1.9.2). The participants completed the Physical Activity Readiness Questionnaire (PAR-Q) and an esophageal constriction questionnaire to determine their ability to exercise safely and their ability to swallow a core temperature capsule (VitalSense, Health Canada License # 70240). Participants who were deemed not ready for physical activity as per the PAR-Q were excluded from participation. No subjects were excluded based on this criterion. One participant was excluded from the study due to esophageal constriction. Additionally, each participant provided written informed consent; and the Human Research Ethics Board at the University of Victoria approved the study (Ethics Protocol #: 17–236).

Table 1
Subject characteristics (including mean ± standard deviation).

Subject	Classification	Age (years)	Height (cm)	Weight (Kg)	VO2max (mL kg^{-1} min^{-1})
1	Firefighter	22	167.0	77.0	48.4
2	Athlete	21	182.0	88.2	46.1
3	Athlete	21	165.0	67.4	54.7
4	Athlete	34	185.0	85.1	49.4
5	Firefighter	53	181.0	82.3	40.2
6	Athlete	20	182.0	84.4	53.9
7	Firefighter	46	188.0	106.7	48.7
8	Firefighter	47	191.5	90.7	63.7
9	Firefighter	21	186.0	76.6	57.5
10	Firefighter	47	175.0	75.1	54.9
11	Firefighter	31	188.0	90.9	48.2
12	Firefighter	47	178.0	86.1	58.0
13	Firefighter	30	182.0	85.2	56.0
14	Firefighter	30	181.0	84.3	51.9
Mean ± SD		33.6 ± 12.1	180.8 ± 7.6	84.3 ± 9.2	52.3 ± 5.9

2.2. Experimental design

Each participant was required to come to the laboratory for three separate testing sessions (VO_{2max} determination, CON, and PPE). The participants acted as their own controls. Though each subject participated in both CON and PPE. The VO_{2max} determination session was used to ensure our sample represented the firefighter population from an aerobic fitness standpoint. Subjects with a relative VO_{2max} of less than 35 mL kg $^{-1}$ min^{-1} were excluded from the study The average VO_{2max} for firefighters has been previously found to be 39.6 kg $^{-1}$ min^{-1} (Storer et al., 2014). Therefore, we wanted to ensure our population represented near the average of the firefighter population. No subjects were excluded from the study based on this criterion. Both CON and PPE sessions were scheduled on separate days but at the same time of day to eliminate diurnal cortisol variation. Before the CON and PPE sessions, each subject was required to follow a pre-testing protocol. This pre-testing protocol had the subjects refrain from alcohol, caffeine, and nicotine for 12 h before testing. The subjects also drank 3.7 L of water in the 24 h before testing, of which 500 ml was consumed within 2 h of the subjects arriving at the lab for the CON and PPE sessions. Thereby meeting the American College of Sports Medicine requirement for pre-exercise hydration (Convertino et al., 1996). The temperature of the drinking water consumed prior to exercise testing was room temperature (~20 °C). No water was consumed after arriving at the lab, and exercise did not begin until at least 1 h following lab arrival. This allowed the core temperature capsule readings not to be influenced by ingested water (Wilkinson et al., 2008). Additionally, the subjects were required to eat their last meal 2 h before testing. Finally, the subjects were required to void their bladders before exercise testing. The CON and PPE sessions were administered in a random, counterbalanced order to prevent crossover effects.

Upon arrival to the laboratory for CON and PPE testing, height was measured using a stadiometer (Tanita, USA). Body mass was measured using a weigh scale (Health-o-meter, Continental Scale Corporation, USA). Height was measured without footwear, with the subjects erect, arms hanging by their sides, feet together, and heals and back in contact with the wall. The subjects looked straight forward, stood as tall as possible, and took a deep breath. Height was measured to the nearest 0.1 cm. Body mass was measured without footwear and in light clothing (shorts and t-shirt). The subject was instructed to remain motionless. Body mass was measured to the nearest 0.1 kg. Participants were then fitted with the Equivital Integrated physiological monitoring system for heart rate (HR) measurement and were also given a Jonah core temperature capsule (VitalSense, Health Canada License # 70240) to swallow for real-time core-temperature observation and analysis. VitalSense core temperature capsules are pre-calibrated to measure ±0.1 °C (32 °C–42 °C) [equivital.com]. The core temperature capsule was ingested 40–45 min before exercise testing (Domitrovich et al., 2010). The laboratory was kept at 25–26 °C during both the CON and PPE sessions to increase ambient thermal stress. The temperature was elevated using portable heaters surrounding the testing area. Thermal comfort and thermal sensation were measured immediately post-exercise test using the thermal comfort scale (TCS) and the thermal sensation scale (TS) (Gagge et al., 1967). The TCS is a scale from 1 to 5 (1 – Comfortable; 5 – Extremely Uncomfortable), which measures an individual's comfort level during thermal stress. The TS is a scale from 0 to 9 (0 – Unbearably Cold; 9 – Very Hot) which measures the thermal sensation an individual feels during thermal stress. Relative humidity in the lab ranged from 30 to 50% for all experimental sessions. The relative humidity was maintained by the laboratory heating, ventilation, and air conditioning systems. The temperature and humidity of the testing area were continuously monitored using an indoor compact weather monitoring system (Davis Perception II, Davis Instruments Corporation, USA).

The exercise protocol for CON and PPE included an initial 5-min stage at 3.5 mph and a 0% grade, the second stage was 5-min at 3.5

mph at 4% grade, the third stage was 50-min at 3.5 mph and an 8% grade, and the final stage was 1-h at 3.5 mph and a 12% grade (Coehoorn et al., 2020). HR recording was captured at each 0.5 °C increase in core temperature during the treadmill graded exercise protocol. HR was measured using the Equivital Integrated Physiological Monitoring System [equivital.com]. The treadmill graded-exercise protocol was completed when the subjects reached one of the three termination criteria: (1) core-temperature reached 39.5 °C (approved by the University of Victoria Research Ethics Board); (2) the subject reached a volitional maximum by voluntarily stepping off of the treadmill; (3) the participant reached the 2-h time limit (Coehoorn et al., 2020). The participants wore shorts, a cotton t-shirt, socks, and running shoes in the CON session, and firefighter personal protective equipment (coat, pants, balaclava, gloves, and running shoes) in the PPE session. Firefighter helmets were not worn during testing due to the need to wear headgear for metabolic analysis. Metabolic data were collected using a ParvoMedics metabolic cart. The subjects wore a backpack during the CON session, which contained weights with equal mass to that of the firefighter turnout gear during the PPE session (Coehoorn et al., 2020). The weights in the backpack changed based on the size of the turnout gear used for each subject. This was done to mimic the weight of the firefighter gear while eliminating the microclimate issue.

2.3. Physiological strain index

The physiological impact of the heat storage during exercise was calculated using the Physiological Strain Index (PSI) (Moran et al., 1998).

$PSI = 5(T_t - T_0) \cdot (39.5 - T_0)^{-1} + 5(HR_t - HR_0) \cdot (180 - HR_0)^{-1}$ (Moran et al., 1998)

T_t = Core temperature at any measurement point.
T_0 = Core temperature at the initial measurement point.
HR_t = Heart rate at any measurement point.
HR_0 = Heart rate at the initial measurement point.

2.4. Saliva sampling and analysis

Saliva samples were collected at the start of exercise, at each 0.5 °C increase in core temperature, and the end of the exercise. Saliva was collected using the SalivaBio Oral Swab (SOS) method (Salimetrics, Inc., State College, PA) and was stored at −20 °C (Salimetrics and SalivaBio, 2011). Samples were thawed and processed in duplicate using a highly sensitive enzyme immunoassay with a range of sensitivity from <0.003 to 3.0 μg dL^{-1} and average intra- and inter-assay coefficients of variation of 4.6% and 6%, respectively (Salimetrics, Inc., State College, PA). Averaged duplicate scores were used for statistical analyses. Saliva samples were stored between 2 and 3 months before analysis (Salimetrics and SalivaBio, 2011).

The rate of salivary cortisol appearance in each exercise condition was calculated by subtracting the beginning of exercise magnitude from the end of exercise magnitude. That number was then divided by the mean time to termination (TTT).

2.5. Statistical analysis

Mean values of cortisol values were compared using a 2 x 3 repeated measure ANOVA - two conditions (PPE, CON) by three times (start, core temperature 38 °C, end). Further affirmation of these tests was provided by a visual comparison of 95% confidence levels. The alpha level for significance was set at $p \leq 0.05$. Mauchly's test was used to test for the assumption of sphericity. Shapiro-Wilk test was used to test for the assumption of normality. Post-hoc pairwise t-tests were used to determine where the differences in means existed. All statistical analyses were conducted in R Studio (Version 1.1.456 – © 2009–2018 RStudio, Inc.).

3. Results

3.1. Rate and magnitude of salivary cortisol appearance

There was a 0.018 μg $dL^{-1} \cdot min^{-1}$ appearance in PPE and a 0.002 μg $dL^{-1} \cdot min^{-1}$ in CON. Salivary cortisol appeared at a rate 10 times faster in PPE when compared to CON. It is important to note that there was no difference between resting salivary cortisol magnitude in both conditions and the resting values correlate to previous research (Hackney and Anderson 2016). Additionally, there was a significant difference in mean cortisol values between the start of exercise and the measurement point associated with core temperature 38 °C ($p \leq 0.01$) and start and end of exercise ($p \leq 0.01$) during PPE (see Fig. 1). There were no significant differences when comparing any time or temperature values to the start of exercise throughout CON (See Fig. 2). When analyzing the magnitude of overall salivary cortisol appearance, there was a significant difference ($p \leq 0.05$) between termination point values when comparing CON and PPE (see Fig. 3). Recovery rates of cortisol elevation were not measured in this study due to time constraints on the subjects. Subjects were asked to come to the laboratory three times (a total of 6 h). We anticipated that additional time would have contributed to subject dropout.

3.2. Metabolic data

There was a difference in V_E/VO_2 from the start of exercise to the end of the exercise in PPE ($p \leq 0.05$) (see Fig. 5). There was no difference in CON (see Fig. 4). Also, the deflection point in V_E/VO_2 occurred at roughly 80% of TTT in CON and roughly 60% of TTT in PPE. This deflection point indicates the respiratory compensation threshold (RCT).

3.3. Thermal strain

There were differences ($p \leq 0.05$) between the end of exercise thermal comfort and thermal sensation. At the end of exercise, the thermal comfort scale (TCS) score was 3.57 ± 0.6 in CON and 4.63 ± 0.3 in PPE (see Fig. 6). At the end of the exercise, the thermal sensation (TS) was 7.57 ± 0.5 in CON and 8.67 ± 0.3 in PPE (see Fig. 7).

3.4. Physiological strain

The rate of heat storage in PPE (0.04 °C·min^{-1}) was double that of CON (0.02 °C·min^{-1}). The physiological impact resulting from the elevated heat storage led to PSI being higher in PPE at core temperature 37.5 °C ($p \leq 0.05$), core temperature 38 °C ($p \leq 0.01$), and end of

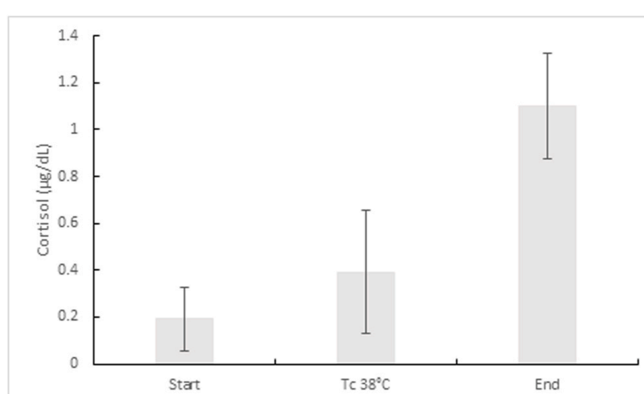

Fig. 1. Comparison of cortisol concentration at start, core temperature 38 °C, and end in PPE. Error bars = 95% confidence intervals.

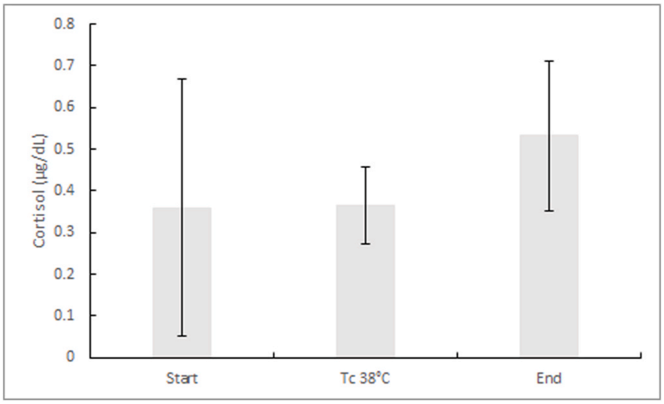

Fig. 2. Comparison of cortisol concentration at start, core temperature 38 °C, and end in CON. Error bars = 95% confidence intervals.

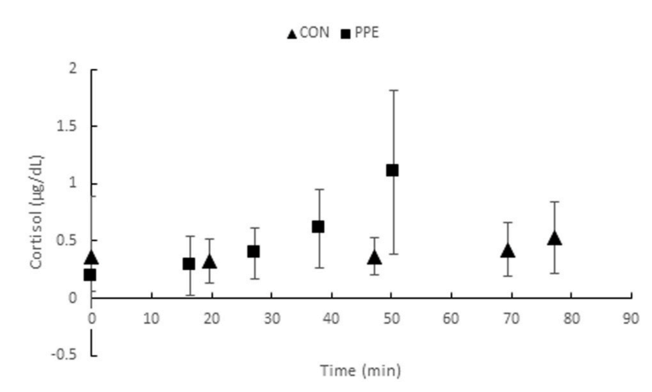

Fig. 3. Comparison of time and cortisol concentration during CON and PPE. Error bars = 95% confidence intervals.

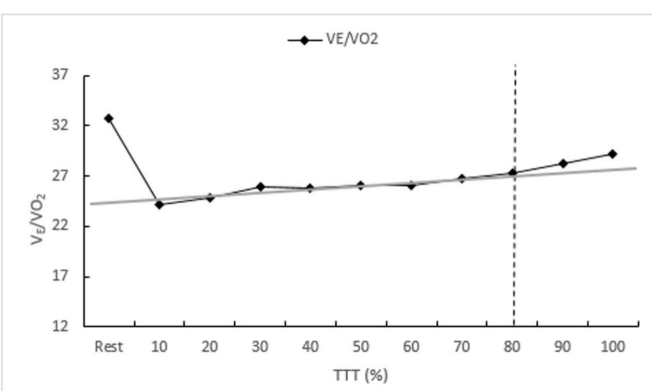

Fig. 4. Evaluation of V_E/VO_2 during CON. The vertical broken line represents the breakpoint for V_E/VO_2. This point is referred to as the respiratory compensation threshold (RCT). The grey line is used to emphasize the deflection point.

exercise ($p \leq 0.01$) (see Fig. 8).

4. Discussion

Cortisol generally contributes to the maintenance of glucose and cardiovascular homeostasis. During stressful events, cortisol is released in a non-specific manner. The amygdala, which plays a role in processing the severity of stress, sends a response to the hypothalamus if the

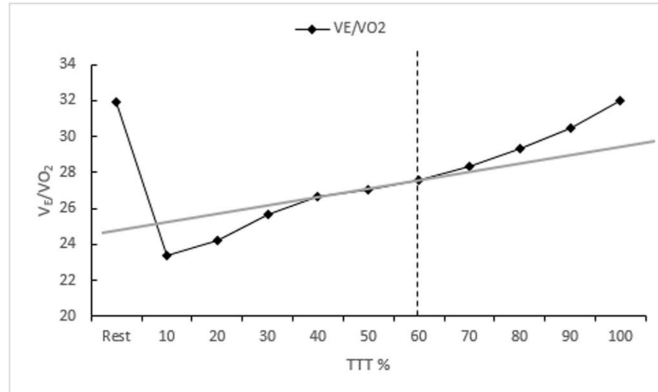

Fig. 5. Evaluation of V_E/VO_2 during PPE. The vertical broken line represents the breakpoint for V_E/VO_2. This point is referred to as the respiratory compensation threshold (RCT). The grey line is used to emphasize the deflection point.

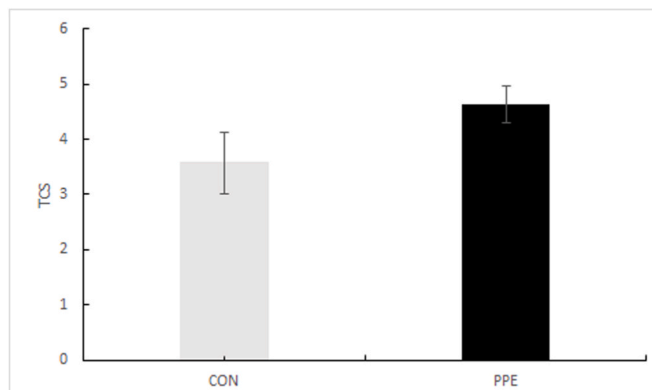

Fig. 6. Comparison of CON and PPE end of exercise values for thermal comfort (TCS). Error bars = 95% confidence intervals.

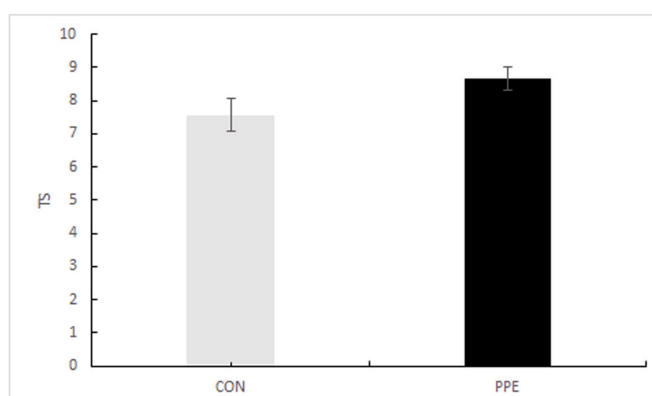

Fig. 7. Comparison of CON and PPE end of exercise values for thermal sensation (TS). Error bars = 95% confidence intervals.

threat deems it necessary (Hakamata et al., 2017). The hypothalamus then activates the sympathetic nervous system, responsible for the fight or flight response. This activation results in the adrenal glands releasing catecholamines, such as epinephrine. These catecholamines cause physiological responses such as increased heart rate and respiratory rate. As the hypothalamus continues to deal with the stressor, the HPA axis is then activated. Cortisol is then secreted in a non-specific manner from the adrenal cortex (Thau et al., 2021). Cortisol levels are enhanced

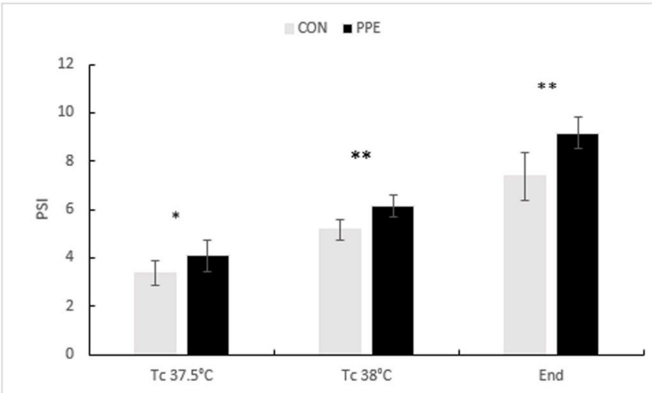

Fig. 8. Physiological strain index (PSI) at core temperature 37.5 °C, core temperature 38 °C, and end of exercise. Significant differences (*$p < 0.05$, **$p \leq 0.01$) between CON and PPE during exercise. Error bars = 95% confidence intervals.

due to physical, psychological, or physiological stressors (Hill et al., 2008). For example, individuals who have recently experienced severe life events show elevated cortisol levels (Cowen 2002). Additionally, individuals who experience chronic difficulty, such as caring for sick relatives, can produce high cortisol secretion (Bauer et al., 2000). One specific physical stressor known to enhance cortisol levels is heat stress. Cortisol is an established indicator of heat intolerance (Follenius et al., 1982). Research has shown that the HPA axis is impaired due to heat exposure (Michel et al., 2007). Also, physical exercise and high ambient temperatures, resulting in physiological strain, can disrupt the HPA axis and cause increased cortisol release (Francesconi 1987). Physiological strain is impacted by the intensity and duration of heat stress and exercise. This increased physiological strain results in an increased non-specific cortisol response (Francesconi 1987).

This research sought to provide insight into why firefighters' number one killer is CVD (Smith et al., 2016). CVD covers many diseases that impact the cardiac muscle and the vascular system that supplies the heart, brain, and other vital organs (Gaziano et al., 2006). The most prominent types of CVD are ischemic heart disease, stroke, and congestive heart failure. The causes of CVD can include tobacco use, high blood pressure, high blood glucose, lipid abnormalities, obesity, physical inactivity, and stress (Gaziano et al., 2006). Firefighters are exposed to acute bouts of rapid heat stress on a chronic basis. The association between acute episodes of stress and cardiovascular mortality and morbidity is well documented (Albert et al., 2000; Mittleman et al., 1993). Additionally, research has demonstrated that acute bouts of stress elicit long-term cardiovascular abnormalities, such as elevated blood pressure (Gerin et al., 2005). Acute stress causes changes in the sympathovagal balance and the tone of the HPA axis; this can accelerate the development of myocardial infarction and left-ventricular abnormalities (Brotman et al., 2007). Chronically elevated cortisol is also a known contributor to CVD (Olinski et al., 2002). Chronic physiological stress causes the acceleration of atherosclerosis and subsequent CVD (Brotman et al., 2007).

Our results revealed a difference in the rate of salivary cortisol appearance when comparing CON and PPE. This supports previous literature that shows cortisol to be a sensitive indicator of heat intolerance (Brenner et al., 1997; Follenius et al., 1982; Hoffman et al., 1996; Wang et al., 2005). Our data also revealed a novel finding by showing that rapid heat stress resulted in increased physiological stress and was commensurate with the rate of salivary cortisol appearance. The increased thermal acquisition resulted in increased PSI at each temperature measurement point. To further support higher physiological stress in PPE, ventilatory equivalent (V_E/VO_2) was higher at the end of exercise in PPE when compared to the end of exercise values in CON. The subject's ventilation increased more during PPE due to reaching the RCT earlier. The RCT is associated with increased ventilation necessary to lower $PaCO_2$ (Bhambhani et al., 2007; Nybo and Rasmussen 2007). Previous research has demonstrated a correlation between exercise strain and cortisol levels (Hill et al., 2008). Previous research also demonstrates a direct association between rapid heat stress and the physiological strain index (Coehoorn et al., 2020). Research consistently demonstrates that exercise at higher intensities induces greater cortisol release (Hill et al., 2008). Increased cortisol due to increased exercise intensity/strain as indicated by physiological measures can be attributed to increased glandular secretion and not decreased metabolic clearance (Kirschbaum and Hellhammer 1994). This increased glandular secretion is due to increased activation of the HPA axis, which results in increased cortisol secretion (Bjorntorp 2001).

The impact of rapid heat stress on cortisol response has an impact on individuals, such as firefighters, who undergo acute bouts of rapid heat stress on a chronic basis. In addition to the cardiovascular consequences of elevated cortisol, previous research has found that increased cortisol as a result of exhaustive exercise causes a decrease in testosterone levels (Brownlee et al., 2005). It has additionally been shown that heat stress resulting in short-term increased cortisol response led to decreased performance during central executive tasks and also perceptions of mood state (McMorris et al., 2006).

Future research should analyze ways to minimize the rapid core temperature increase in occupations such as firefighting. It is also suggested that future research analyze the rate of cortisol disappearance during recovery following exercise that creates rapid heat stress. It would be ideal to know if there is a cumulative cortisol effect following repeated rapid core temperature acquisition bouts. Future research should additionally use all firefighters as research subjects to limit the possibility of potential confounding factors related to heat acclimation. Lastly, future research should perform these types of experiments in an environmental chamber to sustain environmental continuity.

This study had a few potential limitations. One potential limitation in this study was that not all the subjects were career firefighters. Ten of the fourteen subjects were career firefighters, while the remaining four were athletes from the University of Victoria population. The four non-firefighter subjects could have influenced the results obtained. For example, they could have less long-term acclimation to general heat stress, or they may have had less experience wearing personal protective equipment. A second limitation was that portable heaters controlled ambient temperature in the laboratory. Although the testing environment was continuously monitored via an indoor compact weather monitoring system, there may have been environmental continuity issues due to the absence of a climatic chamber. Lastly, the experimental protocol in this study is not a direct representation of the activity of firefighters. The experimental protocol was used to stimulate two levels of core temperature acquisition (CON and PPE).

5. Conclusions

The present study demonstrated that rapid heat stress results in an exponential rate of cortisol appearance and an overall higher cortisol concentration. This exponential rate of cortisol appearance can be attributed to the increased physiological stress during the PPE condition. Acute bouts on a chronic basis could lead to long-term effects. Long-term effects of chronically elevated cortisol result in many conditions and ailments, including CVD. Firefighters in larger centers that deal with regular fire calls are chronically exposed to acute heat stress.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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