PHYSIOLOGIC RESPONSES OF FIREFIGHTING TRAINING OFFICERS IN THE STRUCTURED LIVE-FIRE FIREFIGHTING TRAINING

by

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A thesis

submitted in partial fulfillment

of the requirements for the degree of

Master of Science in Exercise and Sport Studies

Boise State University

May 2015

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BOISE STATE UNIVERSITY GRADUATE COLLEGE

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of the thesis submitted by

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Thesis Title: Physiologic Responses of Firefighting Training Officers in the Structured Live-Fire Firefighting Training

Date of Final Oral Examination: 04 February 2015

The following individuals read and discussed the thesis submitted by student Takahisa Koide, and they evaluated his presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

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DEDICATION

This thesis is dedicated to my parents, Toyoshige and Ikuko Koide for your tremendous support from Japan. Without you, I would not be able to come and study in the U.S.A. and complete my graduate work and thesis at Boise State University. I really appreciate your understanding and encouragement. Thank you for being on my side all the time.

ACKNOWLEDGEMENTS

First, I would like to sincerely thank Boise Fire Department for offering this research opportunity to the Human Performance Laboratory of Boise State University and for letting me conduct all research procedures. Without the support from Boise Fire Department, this research projects would have never happened. I also appreciate the firefighters who participated in this research project. I was very happy and fortunate to contribute to the community through this research.

Secondly, I would like to thank my thesis committee members, Dr. Simonson, Dr. Gao, and Dr. Shimon for serving on my committee. I really appreciate your guidance, support, and patience to complete this research and thesis. Although it took approximately two years to reach this point, without your help this research project would not be successfully completed. Also, thanks to you, I had a fruitful experience of learning, such as ways to design and conduct research, analyze data, and apply the knowledge learned from you to the research project. I have no doubt that all things that I learned from you would discipline myself, being strong elements to construct my brilliant dispositions: diligence, passion, curiosity, willingness, generosity, kindness, and sense of humor.

I would also like to thank the undergraduate and graduate students who volunteered in this research project. Without your help, I would not have been able to efficiently organize and collect data.

Lastly, but not least, I would like to give special thanks to my mentor professor, Dr. Simonson, for providing me with this research opportunity. I really appreciate your endless guidance, encouragement, and support for the past two years. Your faith in me made it possible to complete the extraordinary journey of my graduate work at Boise State University. I have never seen such a dedicated professor who patiently and passionately “educates” students. You quickly became my role model professor. I cannot thank you enough for taking good care of me at Boise State University.

AUTOBIOGRAPHICAL SKETCH OF AUTHOR

Takahisa Koide was born in Aichi prefecture, Japan. He grew up in Nagoya city where he went to Nagoya Koyo High School, Japan. Until his high school days, he was a passionate soccer player. Along with his soccer life, he had interests in taking care of himself for his performance, which eventually led him to study sports medicine and exercise science.

Learning that there is a profession of athletic training and nationally recognized athletic training education programs at the collegiate level in the U.S.A., he decided to study in the States to become an athletic trainer. In 2009, he graduated from Eastern Washington University with an athletic training and exercise science degree and NATABOC certification. After graduation, he worked as an athletic trainer at a local high school in New York. While working at that time, his academic curiosity and desire to study were awakened. Without any hesitation, he decided to go to graduate school to study general exercise science or kinesiology in order to enhance his athletic training knowledge and career.

In 2011, he began the master's program at Boise State University with a biophysical emphasis. He will complete this master's program upon the completion of his thesis and graduate in May 2015. After completing his master's program, he will continue to work in his current athletic training career and he is hoping he can combine his academic and work experience together to become a better athletic trainer and researcher when he has a chance to go to a doctoral program.

ABSTRACT

Introduction: Firefighting is one of the most strenuous and dangerous occupations in the community. Training Officers are senior firefighters who take on the preparation and education of their fellow firefighters. One of the Training Officers' tasks is structured live-fire training. During live-fire training, they are exposed to the stress of fire and high heat multiple times per day. In spite of this issue, there is no research focusing on Training Officers during the live-fire training evolution. **Purpose:** The present study was a pilot study to measure the stress experienced in the live-fire training and possibly reduce this stress by managing hydration status. **Method:** Five training officers from Boise Fire Department participated in the live-fire training. The experimental variables during the live-fire training were relative workload, measured via air consumption rate (ACR), heart rate (HR), and blood lactate; thermal stress measured via core temperature, plasma volume (PV), and body weight. In addition, a hydration protocol to compare between water and high-sodium electrolyte solution was executed to determine the potential effect on reducing the stress response. Laboratory data collected to establish individual fitness levels and determine live-fire training intensity included lactate threshold (maximal oxygen consumption ($\dot{V}O_{2max}$) test) and body composition. Means ± SD were calculated for anthropometric data, lactate-threshold $\dot{V}O_{2max}$ test, and all variables measured in the live-fire training. ACR and HR were compared with percent of oxygen uptake reserve (%$\dot{V}O_2R$) and percent of heart rate reserve (%HRR) during the evolutions, respectively, expecting more than moderate intensity ($\geq 40\%$). One-tailed one-sample t-test was used for blood lactate comparing with OBLA, expecting more than 4.0 mmol/L post-evolution. Paired t-tests were used to compare core temperature between baseline and the peak, PV between baseline and the lowest, and body weight between the pre- and post-training, as well as used to compare between control and treatment conditions in mean ACR, mean HR, mean blood lactate, core temperature change from baseline to the peak, PV change from baseline to the lowest, and body weight change from the pre- to post-training ($p < 0.05$). **Results:** The training evolutions significantly increased core temperature ($p < 0.05$). The other variables (ACR, HR, lactate, PV and body weight) did not reach significant differences. In addition, there was no significant difference between the control and treatment conditions for any variables. Along with the hydration status, urine specific gravity showed the training officers well-managed their hydration from the pre- to post-training and there was no significant difference between the control and treatment conditions. **Conclusion:** The extremely hot environment was a greater stress than the physical exertion during structured live-fire training, greatly affecting core temperature. A high-sodium electrolyte solution did not directly affect the work stress or performance. Yet, it could reduce the degree of hydration and excretion demands, which contribute to physiologic stress and increase training officer comfort.

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LIST OF ABBREVIATIONS

$\%\dot{V}O_2R$	Percent Oxygen Consumption Reserve
%HRR	Percent Heart Rate Reserve
$\dot{V}E$	Minute Ventilation
$\dot{V}E_{max}$	Maximal Minute Ventilation
$\dot{V}E_{peak}$	Peak Minute Ventilation
$\dot{V}O_2$	Oxygen Consumption or Oxygen Uptake
$\dot{V}O_{2max}$	Maximal Oxygen Consumption
$\dot{V}O_{2peak}$	Peak Oxygen Consumption
ACR	Air Consumption Rate
BFD	Boise Fire Department
GI	Gastrointestinal
HR	Heart Rate
HR_{max}	Maximal Heart Rate
HR_{peak}	Peak Heart Rate
NFPA	National Fire Protection Association
OBLA	Onset of Blood Lactate Accumulation

PPE	Personal Protective Equipment
PV	(Blood) Plasma Volume
SCBA	Self-Contained Breathing Apparatus
Hb	Hemoglobin
Hct	Hematocrit

CHAPTER ONE

Introduction

This research project was a pilot study exploring the physiologic responses of firefighting training officers during structured live-fire training. After introducing the nature of the firefighting occupation, this study focused on the change of physiological parameters experienced by the training officers assigned to the ignition team during their work in live-fire training evolutions.

Characteristics of Firefighting Performance

The job of firefighting is very important and necessary for maintaining community safety. Firefighting is one of the most strenuous and dangerous occupations in the community. In addition to the severe environment, the aerobic, anaerobic, muscular strength, and endurance requirements as well as firefighting specific skills are demanding. Likewise, agility, dynamic balance, manual dexterity, and flexibility has been considered necessary for firefighting operations.[1-3] The physically demanding firefighting operations include the following: 1) carrying equipment upstairs in a high-rise, 2) advancing charged hoses, 3) breaking down doors, walls, ceilings, and roofs, 4) raising ladders, 5) working overhead with a pike pole or other equipment, 6) rescuing victims, 7) raising and lowering equipment or victims from high-rise windows via ropes, 8) auto extrications, and 9) carrying equipment long distance from the truck to a fire site.[1]

Although firefighters are not considered athletes, their job-related fitness level and physiologic demands are similar to athletes with the added job-specific psychological and environmental stresses affecting physiological parameters.[4-7] Existence of fire with harming or life-threatening sensation (e.g., fear) enhances the release of stress hormones such as norepinephrine and cortisol.[4] This condition can modulate the physiologic exertion parameters for firefighters.[4] Thus, regardless of the career status, from young recruit firefighters to experienced officer-level firefighters, it is necessary that all active firefighters improve or maintain their overall physical fitness to keep themselves physically and mentally strong enough to fight fires, participate in rescue activities, and protect the firefighters themselves in high-temperature, fire-smog, and other dangerous environments.

Strains of Firefighting Occupation

Firefighting is a very dangerous and life-threatening occupation with many and varied job duties. Fighting fires can be affected by the nature of the emergency response, the structure of fire materials, size of the building, the need for rescue, and environmental conditions such as weather or the physical location of the incident. Firefighters may be required to enter a burning building to rescue victims, suppress the blaze, and protect property. The temperature inside of burning structure can be greater than 400°C near the ceiling level in the room; however, full personal protective equipment (PPE) allows the firefighters to work amidst the heat. Burning structures with high heat causes compromised structural integrity, release of noxious gasses, and limitation of use of the senses during an incident response.

While the protective clothing or turnouts worn by firefighters provide significant protection from the high temperatures and other fire-related hazards, their turnouts and the hauling of a self-contained breathing apparatus (SCBA) can increase the workload and limit the ability to carry out operational tasks.[7,8] The nature of firefighting turnouts, which are encapsulated and impermeable, can compromise the physiological thermoregulating or heat dissipating ability of firefighters and lead to dehydration and heat illness which are detrimental to performance and health.[7,8] During exposure to this challenging environment, it was reported that core temperature rose by 0.3 to 1.3°C from less strenuous to strenuous tasks over a 20-minute period of firefighting with the average heart rate (HR) range from 122 to 151 bpm.[9] An elevated core temperature between 38 and 41°C impairs exercise performance, via compromised muscle activation.[10] The stress that firefighters experience during the fire emergency activities can require high physical fitness and tolerance of the severe/life-threatening environment. Like stress that various types of athletes need to handle, the firefighters are also imposed by such stress.

Firefighting Training Officers

As firefighters become more experienced and highly trained, some firefighters may change their focus to more operational tasks rather than firefighting and victim-rescuing tasks, which make their daily physical requirements less demanding. One such operational career choice is that of a Training Officer. The responsibility of the Training Officer is to create a safe training environment while providing education and skill development opportunities to recruits and firefighters by reviewing, following, and implementing the recent training standards and guidelines such as National Fire Protection Association (NFPA) standards and federal/state/local-base regulations.[11] Also, it is their task to find and determine the needs of training, specifically in the local fire department and its individual divisions and positions.[12]

The training officers within the Boise Fire Department (BFD) are responsible for a thorough knowledge of the General Orders Manual, Standard Operating Procedures Manual, Boise Fire Department Training Guide and any other pertinent department publications (their job description created by the BFD can be found in appendix A).[13,14] While they can still be an active-duty firefighter, training officers are engaged mainly in operating the new recruit academy and managing and scheduling the training drill regimens (continuing education) for the personnel in the Fire Department.[14,15] As a part of their tasks, the structured live-fire training (training evolutions) – burning down an old, abandoned house/building property – is one of the most effective and beneficial simulated fire incident opportunities.

Training Evolutions

One of the most effective tools in the training program is the structured live-fire training, or training evolution. The training evolution is the most accurate simulation of an actual fire incident. An abandoned house or building needing to be torn down is donated and utilized for this purpose. In the days running up to the training evolution, the training officer must first inspect and prepare the structure by making it as safe as possible to fit the necessary training evolutions. All hazardous materials are removed, evacuation routes are prepared, smoke ventilation holes are cut (vertical ventilation), and an external water source is specified and verified. The actual structure is not ignited during the training evolution; rather, hay and pallets that are more easily controlled are used and this must be assembled at each evolution. During the training evolution, the ignition team is responsible for starting and controlling all fires. There are no “mayday” scenarios of extreme severity, which is to require the firefighters to send a radio signal/call for help of the serious danger circumstance of which personal injury or death may be possible. Although the training officers usually work as battalion chiefs or purely within in the training division, during the structured live-fire training they have to stay inside to ignite the fire, control the fire and degree of blazing, and observe front-line firefighters until the fire is extinguished. As the result, the training officers experience the greatest exposure to the fire and extremely hot conditions in the live-fire training.

A single training evolution usually takes 20 to 30 minutes, and the procedure would be executed five or more times in a day. The number, size, and kinds of training evolutions are dependent upon the availability of suitable buildings along with the training objectives and the environmental conditions. Relatively small houses may last one training day (five training evolutions) while larger structures, such as a two-story office building, may be used for two or more days of training. A fire department tries to have as many opportunities for this type of training and many evolutions per day as possible. In the city of Boise, Idaho, they usually have such training opportunities three or four times per year. In addition, according to recent safety levels in Boise, actual service of serious fire incidents, other than wild/forest fires, have not often been reported within the last five years as mentioned by one of the participating training officers.

Training Officers at the Live-Fire Training

While a training evolution is the best training for the firefighting brigades, the environmental exposures of the training officers in the ignition team are severe. They are exposed to fires, smoke, and extreme heat multiple times per training day. Additionally, the variety of physical activity, its intensity and duration in the live-fire training create a unique stress of their own. The extremely high temperature in the burning building and the load of PPE with SCBA can potentially affect physiological integrity. The compromised physiological integrity, such as HR, core temperature, blood lactate, air consumption rate (ACR) or oxygen uptake ($\dot{V}O_2$), and hydration status (i.e., dehydration), can all lead to fatigue, decreased cognitive function, decreased performance, and eventually safety and health problem.[5-7,16] Compared to the front-line firefighters at one single fire suppression during a fire incident, this type of live-fire training can impose greater stress on the training officers who may have already drawn back from the front-line fire attacking jobs.

Training officers are exposed to the severe fire environment more than the front-line firefighters during a training evolution of the live-fire training. Moreover, during this type of training, fire exposure onto the training officers occurs multiple times a day while regular firefighters can be exposed to the fire less than once per incident or once a day. For these reasons, it would be prudent to understand the physiologic response of the training officers in the fire environment and the appropriate health and fitness variables of the training officers to protect their lives, career longevity, and to improve their performance.

Purpose of Study

Because the physiologic stress of the live-fire training on the training officers is not well-known, the present study would identify some stress physiologically responded by the training officers during structured live-fire training with the intention of establishing guidelines to ensure the health and fitness level for the current and future training officers. In addition, efforts were made to identify methods that would enhance officer's hydration status which leads to alleviate the stress focused on during the training evolutions.

Study Variables

For the physiologic demands of firefighting, the present study focused on the following variables: HR, core temperature, ACR or minute ventilation ($\dot{V}E$) with estimated oxygen consumption ($\dot{V}O_2$), blood lactate levels, and hydration status to determine the intensity and stress of the firefighting tasks. Those variables are affected by physical activity, environmental, and possible psychological effects. One previous study, for example, indicated that firefighters need at least 45 ml/kg/min of $\dot{V}O_{2max}$ to accomplish a very strenuous firefighting task, and in regards to anaerobic capacity some firefighting operations have resulted in a lactate accumulation of more than 6 mmol/L.[1]

Also, core temperature and hydration status should be taken into consideration for the firefighting occupation. With heavy physical work and severely high temperatures, monitoring the core temperature and hydration status to determine the body's ability to regulate temperature and physiological functions would be very critical in the prevention of detrimental health issues.

Need of Study

The mission of preparing firefighters is very critical to strive for better and safer firefighting performance and public safety. While there has been considerable research of firefighting and firefighters, training officers have rarely been focused on or studied. To overlook the tasks of training officers can have a detrimental effect on the fire department and its service in the community as well as their safety and health status. Thus, examining the physiologic responses during the live-fire training would be very important for the safety, health, and future of training officers.

Hypothesis

1. The present study was the first to measure the physiologic responses of firefighting training officers in structured live-fire training. Thus, it was hypothesized that, because of the severe environment and intense activity, training officers would experience physiologic stress as evidenced by (a) an increased ACR during a training evolution resulting in the moderate or above intensity relative to percent oxygen consumption reserve (%$\dot{V}O_2R$) calculated with values measured by the lactate threshold – maximal oxygen consumption ($\dot{V}O_{2max}$) test in the laboratory, (b) an elevated mean HR of the active working state throughout the training day which was approximately four hours or more duration of working resulting in the moderate or above intensity relative to percent heart rate reserve (%HRR) calculated with values measured by the lactate threshold – maximal oxygen consumption ($\dot{V}O_{2max}$) test in the laboratory,[17,18] (c) an accumulated blood lactate level exceeding the value of onset of blood lactate accumulation (OBLA) that was 4.0 mmol/L, (d) an elevated core temperature showing difference between the baseline and the peak point, (e) a decreased plasma volume (PV) after a training evolution showing the difference between the baseline and the lowest point, and (f) decreased in body weight from baseline to the post-training.
2. In addition, a comparison between plain water and a high-sodium electrolyte solution was made in this study. It has been said that a high-sodium electrolyte solution helps

an exercising individual increase plasma volume, better control thermoregulatory strain, and increase exercise capacity.[19] Then, in this study, it was hypothesized that the high-sodium electrolyte solution would alleviate these physiologic stress, resulting in lower ACR as the result of less stress on the respiratory system, lower elevation of HR as the result of less stress on the cardiovascular system, less accumulation of blood lactate, less increased core temperature, and better maintenance and less decrement of plasma volume and body weight, compared with water, through the live-fire training.

Operational Definition

- Relative intensity of physical activity – For the variables of HR and ACR, the relative intensity was determined by percent heart rate reserve (%HRR) as the cardiovascular parameter and percent oxygen consumption reserve (%$\dot{V}O_2R$) as the respiratory parameter, and categorized as Maximal (100%), Very hard (≥ 85%), Hard/Vigorous (60 – 84%), Moderate (40 – 59%), Light (20 – 39%), and Very Light (< 20%).[17,18] Heart rate would be measured by a wearable device which can monitor the activity parameters including HR.
- Air consumption rate (ACR) – Equivalent to the minute ventilation ($\dot{V}E$), ACR was calculated directly from the change of gas volume in the SCBA cylinder by measuring the change of SCBA gas gauge during the use of training evolutions. ACR was compared to the $\dot{V}E$ value measured in the lactate threshold – maximal oxygen consumption ($\dot{V}O_{2max}$) test.
- Maximal oxygen consumption ($\dot{V}O_{2max}$) and peak oxygen consumption ($\dot{V}O_{2peak}$) – $\dot{V}O_{2max}$ is the product of the maximal cardiac output (L blood/min) and arterial-

venous oxygen difference (mL O_2/L blood). Also termed aerobic power, it is determined through graded exercise testing to define the peak point of oxygen consumption where the rate of oxygen consumption reaches the apex and then starts decreasing while increasing exercise intensity. Additionally, similar to $\dot{V}O_{2max}$, peak oxygen consumption or $\dot{V}O_{2peak}$ is the highest volume of oxygen consumption when leveling off does not occur or maximum performance appears limited by local muscular factors rather than central circulatory dynamics.[10,18,20] In the present study, $\dot{V}O_{2max}$ was taken during the laboratory testing and $\dot{V}O_{2peak}$ was taken and estimated during the live-fire training relative to the value measured by the laboratory testing referred by measured ACR.

- Blood lactate – Blood lactate was measured by collecting the finger-pricked blood drop into a lactate analyzer. Measured blood lactate values were compared with the value of onset of blood lactate accumulation (OBLA) that was 4.0 mmol/L. Blood lactate is the by-product of anaerobic energy system mainly in fast-twitch muscle fibers. During the strenuous or high intensity exercise, lactate ($C_3H_5O_2$) is created from pyruvate ($C_3H_3O_3$) through pyruvic acid and then lactic acid. This process makes NAD^+ more available from NADH produced in the rapid anaerobic glycolysis; thus more NAD^+ can return to glycolysis, resulting in more available anaerobic energy. While the body does clear and utilize lactate via oxidation in type I muscle fibers, red blood cells, and the liver, as well as increased ventilation, production can exceed clearance and result in increased blood lactate levels and, the accumulation of fatigue and decreased exercise performance.[10,21]

- Core temperature – Core temperature is the temperature of body structures deep to the skin and subcutaneous layer. Exercise in the hot environment induces physiologic changes including (maximum) core temperature, and influences immune response, such as denaturing body proteins or enzymes and their activity.[22,23] In the present study, core temperature was measured by an ingestible thermistor pill and its recorder.
- Hydration status – Hydration status is the degree of fluid maintained in the body, derivative to the fluid balance (water intake versus water output). Hydration status means the fluid balance between fluids that the training officer loses through sweat and elimination and ingestion (i.e., beverage and food). Fluid that has already moved to the bladder is not biologically available and does not contribute to physiologic function but is urinated. In the present study, blood plasma volume (PV) and body weight were measured for the hydration status. Since blood plasma is composed of mainly water (91.5% water content in plasma), measurement of plasma volume is very common for hydration status calculated from hemoglobin level and hematocrit percentage measured by the means of the finger-pricking method. The use of monitoring PV change is because most of the fluid loss through sweating is extracellular and predominantly from blood plasma.[10,22] Losing fluid from the blood plasma, body weight would also be changed. Loss of fluid or retention of fluid alters hydration status. Optimum hydration is critical for maintaining physiologic functions and core temperature.
- Training evolution – Training evolution is a simulated firefighting activity exercise/training within a firefighting squad and among the interrelated brigades,

especially for firefighters in engine and truck companies to develop and enhance the tactical maneuvers of the fire incidence and emergency. Training evolution was the main component in the live-fire training and present study.

- Live-fire training – Live-fire training is a live training exercise to practice firefighting evolution, fire suppression, victim rescue with actual fire in the abandoned structures, conducted and prepared by the training division of fire department and its officers or training officers.

<u>Limitation</u>

Because this research involved data collection in the field during the structured live-fire training, the data collection procedure could not affect the training evolution protocol. Thus, it would be anticipated that some data collection may be missed. Also, unlike the laboratory setting, all testing during the live-fire training took place outdoors which may affect the training officers and the equipment used for data collection. The training would be scheduled mainly in the fall and spring to avoid the extreme hot or cold outdoor temperature. While every attempt was made to control for the smooth and complete date collection, some irregularity and environmental factors may affect the ability to collect complete data sets or result in more deviation of data.

Since the numbers of training burns were limited, in order to accumulate enough data to be analyzed, four days of the structured live-fire training were used for the data collection. There was some day-to-day difference in the health and performance of each participant which may affect the data collected and its analysis. Also, the number of participants were limited, and the sample size was naturally restricted. Based on these limitation, the generalization of the physiologic outcome during the training may not be applicable to other circumstances.

Additionally, this study included training officers specifically in the Boise Fire Department, Boise, Idaho. It may not be generalizable to communities that are larger, smaller, or with different resources. While all fire departments in the United State follow the federal and NFPA standards, each fire department in each city and state may be different. Also, the participants or training officers in this study may participate in multiple evolutions throughout a training day, which can be consecutive or alternated, and the same officers participate in multiple or all training days. Because of the nature of the present study, the sample size was restricted.

Significance of Study

In light of physiologic responses experienced by the training officers during the structured live-fire training, the present study would help build health and physiologic guidelines for the training officers, specifically in the BFD. In the future, data from this study would be able to contribute to the protocols used by the training officers to protect their health and safety, and to the procedural development for safer and more effective structured live-fire training.

CHAPTER TWO

Literature Review

When it comes to the study of firefighting training officers, no data related to their physiologic responses to live-fire training has been found. This circumstance made comparisons impossible. Thus, this literature review focused more broadly on the physiologic responses of the general firefighters with a narrowing to the training officers.

This chapter reviewed previous studies about work of firefighting performance and hydration status. Work in this study defined physiologic changes that were affected by the firefighting work, such as oxygen consumption ($\dot{V}O_2$), heart rate (HR), blood lactate level, and body temperature. The hydration status focused on change in fluid loss or plasma volume and body weight during activity.

Oxygen Consumption ($\dot{V}O_2$)

Both extrinsic and intrinsic physiologic stress, such as increased severity of a working environment and increased intensity of attempting physical activity, is attributed to the response of an increase in the demands of thermoregulation as well as both anaerobic and aerobic metabolism to accomplish the work. Physiologic stress is attributed to the increase in oxygen demand to maintain aerobic work and replenish energy stores used during both anaerobic and aerobic work. It has been that recommended 45 ml/kg/min of $\dot{V}O_{2max}$ as the minimum $\dot{V}O_{2max}$ as standard for the firefighter applicants to meet the demands of the most strenuous 10% of firefighting operations, while 90% of the firefighting operations required a mean $\dot{V}O_2$ of 23.4 ml/kg/min.[1] In spite of the variety of firefighting tasks in different fire incidents, some firefighting tasks require them to work at more than 80% of their $\dot{V}O_{2max}$, though depending on their fitness level.[2,24-26]

While the participants in the previous studies performed at roughly 80% of their $\dot{V}O_{2max}$, it was seen that there was wide variability of attained $\dot{V}O_2$ among firefighters. For example, in a different study, firefighters represented an average 73% (31.0 ± 7.0 ml/kg/min) of $\dot{V}O_{2max}$ (38.9 ± 5.0 ml/kg/min, predicted by the treadmill testing), ranging between 54% and 88% during the simulated fire suppression.[27] Elsner et al.[2] recorded the mean $\dot{V}O_2$ of 31.54 ml/kg/min at the end of the firefighting task protocol (range: 12.48 to 53.12 ml/kg/min, 66% to 100% of $\dot{V}O_{2max}$ measured by the treadmill testing) while 80% of $\dot{V}O_{2max}$ (numerical value was not shown) was reached and 29.1 ml/kg/min of the average $\dot{V}O_2$ was recorded in the entire simulated firefighting protocol. Holmér et al.[25] also showed the range between 25.6 and 42.7 ml/kg/min of $\dot{V}O_2$ for the whole firefighting exercise and between 33.5 and 55.1 ml/kg/min of $\dot{V}O_2$ during the most demanding task which was the second tower training, composed of ascending and descending three flights of stairs in the series of firefighting training activities. Also, von Heimburg et al.[24] recorded that the percentage of $\dot{V}O_{2max}$ and the value of $\dot{V}O_{2peak}$ during the simulated hospital rescue task were 83% and 44 ml/kg/min, respectively. Although there were factors affecting the oxygen demand such as performance time, exercise intensity, task difficulty, and participants' firefighting experience and/or skill efficiency, these factors can also indicate the different fitness level among the firefighters.

As firefighters with higher fitness levels (greater $\dot{V}O_{2max}$) can sustain higher work intensities at or near their $\dot{V}O_{2max}$, there was an inverse relationship between the performance time and oxygen consumption.[2,24,25] In addition to the work demands of firefighting, the existence of fire or high heat environment, and the loads of personal protective equipment (PPE) and self-contained breathing apparatus (SCBA), as well as safe, smooth, and fast completion of the required firefighting operations, firefighting activities require an elevated utilization of oxygen. Thus, it has been the consensus that firefighters need high physical fitness level, with at least a 45 ml/kg/min of $\dot{V}O_{2max}$ minimum.[1] From the previous studies, participants were mainly male firefighters aged 30 years old. The 45 ml/kg/min of $\dot{V}O_{2max}$ in the aerobic fitness category from 30 to 39 years old and from 20 to 29 years old in men has been classified as the top of the average range and middle of the average range, respectively.[28]

Heart Rate (HR)

Firefighting activities have been considered as moderate to strenuous physical activity. Heart rate can increase to near an individual's age-predicted or measured HR_{max}, dependent on task intensity and duration, effects of PPE, load of SCBA, and/or environmental thermal effects. Also, an increased HR is in responses of the increase in thermoregulatory demands and increased demands of both anaerobic and aerobic metabolism to accomplish the work.

Previous studies measured a significant increase in HR during simulated firefighting tasks in both temperate and hot environments, although each study had a different performance time and simulated firefighting task(s) which changed the intensity of work.[2,5-8,16,29-33] In addition, the presence of fire or a hot environment during firefighting placed more stress on the firefighters' cardiovascular system which increased HR. The studies done by Smith et al.[6] and Bruce-Low et al.[8] showed significant difference in HR between their firefighting protocols in high and temperate temperature (approximately 90°C – 175°C versus 14°C – 15°C depending on the area of the training room – hotter at the ceiling level than the ground level). Studies by Smith et al.,[6] and Bruce-Low et al.,[8] represented that firefighters' HR_{peak} between the high-heat condition and neutral condition were 175.5 bpm and 138.65 bpm, and 156 bpm and 102.7 bpm, respectively. Increased HR in the hot environment was caused by the response of the body's demand to dissipate excessive heat in the body as well as by an increase in intensity and time of work. During the moderate to high intensity exercise in the heat, decrease in stroke volume due to fluid deficit and reduced blood volume by sweating and dehydration increased higher HR to maintain the cardiac output.[34,35] Smith et al.[5] analyzed that increased HR could not successfully compensate for the reduction in stroke volume, and identified this reduced stroke volume as a decreased venous return caused by vasodilation in the active muscle and cutaneous vascular beds, reduced plasma volume by profuse sweating, or a combination of these factors. Moreover, the cardiac output was eventually decreased while trying to redistribute the body blood from the core to the periphery; thus, the heart even works harder or rapidly to compensate for this decrement.[36]

Along with the heat stress, intensity of each firefighting task affects HR response, such as multiple tasks in one evolution and/or a task with heavy loads such as carrying a sledgehammer and hose and advancing/carrying tasks at a relatively fast pace. Elsner et al.[2] showed that the average HR during their simulated firefighting protocol was 175 bpm which was 95% of HR_{max}. The study done by Perroni et al.[30] showed that the mean HR among participants was represented as 170 bpm during the last task (250m run), and while the HR_{peak} was reported to other tasks, the point of HR_{peak} was recorded the most frequently in the last task which lasted approximately 12 minutes (80% of HR_{peak} occurred of the entire interventions).

According to previous studies, depending on the degree of radiant heat stress, intensity and duration of firefighting tasks, and burden of PPE and SCBA, firefighting activities seemed to enhance cardiovascular stress and remain elevated HR after the completion of the tasks. In most cases, the HR stayed elevated from the pre-firefighting activities for approximately 10 to 30 minutes.[5,6,30,32] Smith et al.[6] also reported that the firefighting activities in the hot condition made for slower HR recovery than in the neutral, temperate environments.

Existence of a resting period in between the firefighting tasks may not be effective enough to recover the elevated HR to baseline before going to the next task or evolution. While it does not necessarily mean resting between bouts of firefighting tasks is not beneficial, the HR at the end of preceding firefighting activity is higher than the end of the previous training bouts (rest period ranging from 2 minutes to 10 minutes).[5,7,8,16] In addition to the HR recovery, it is interesting that Horn et al.[32] reported that enhanced recovery strategy showed the same trend of HR recovery as the one in the standard recovery strategy, called rehabilitation in the firefighting field, and the recovery phase after completion of all physical exertions showed the delayed return to the baseline HR than the standard rehabilitation procedure. Based on the above, regardless of what type of rehabilitation or recovery strategies, firefighters may need a decent amount of time to recover from the elevated HR and strenuous firefighting state due to the effects of radiant heat loads during the multiple bouts of firefighting tasks.

<u>Blood Lactate Level</u>

Blood lactate accumulation can be used to indicate exercise intensity and performance level, relative to anaerobic or aerobic power ($\dot{V}O_{2max}$). Onset of blood lactate accumulation (OBLA) is often used to identify the exercise intensity at which a person starts to utilize more anaerobic energy during aerobic-oriented exercise.[10] The point of OBLA is defined as 4.0 mmol/L of blood lactate. The lactate threshold, while similar, is defined differently – the point at which blood lactate accumulation transitions from a linear to exponential increase. The lactate threshold and OBLA can be equal, but often one is greater than the other. Though it is still not fully understood, lactate accumulation is caused by more lactate production than total lactate clearance resulting from 1) energy demands greater than that available from aerobic metabolism, resulting in an imbalance between the rate of glycolysis and mitochondrial respiration, 2) decreased redox potential of nicotinamide adenine dinucleotide (NAD^+; increased NADH, or reduced form of NAD^+, relative to NAD^+), 3) lower blood oxygen content, and 4) lower blood flow to skeletal muscles.[10]

Firefighting activities are composed of a mixture of aerobic and anaerobic metabolism, along with significant muscular strength and endurance requirements.[1] Measuring blood lactate level can be helpful and beneficial for firefighters to monitor their activity intensity and the sustainability of tasks. Smith et al.[6] revealed that while indoor temperature (89.6°C vs. 13.7°C) affected the time to reach peak blood lactate levels, ceiling overhauling was mainly aerobic metabolism with 2.25 mmol/L and 1.34 mmol/L, respectively after a 16 min operational task. Other firefighting tasks have proved to be anaerobic. Gledhill and Jamnik[1] measured the blood lactate level at the end of performance in the most physically demanding firefighting operations and found out that the blood lactate level in rope pull was 7.2 mmol/L (range from 6.0 to 9.6 mmol/L), hose carry/climb was 10.0 mmol/L (range from 7.9 to 13.2 mmol/L), and victim carry was 9.2 mmol/L (range from 8.5 to 12.2 mmol/L). When compared to the study by Perroni et al.[30] in which participants achieved peak blood lactates of 8.8 ± 2.0 mmol/L during $\dot{V}O_{2max}$ testing, the firefighting activities used by Gledhill and Jamnik[1] were very strenuous with substantial involvement of the anaerobic energy system. Moreover, von Heimburg et al.,[24] recorded blood lactate levels of 6.4 ± 1.8 mmol/L immediately after the six-floor stair climb with weight in the hospital setting and 13.3 ± 17 mmol/L upon completion of the six patient rescue operation/dragging exercise. Huang et al.[31] reported a significant main effect over time in blood lactate accumulation in a simulated firefighter stair climb (3 min x 2 with rest), with leg strength testing before, between, and after the stair climb protocol, reaching over 6.5 mmol/L right after the second stair climb. Based on the previous studies, firefighters work at both aerobically and anaerobically at high intensities during firefighting operations, which may require them to strategize their working tactics such as frequent rest, hydration, and nutritional intake for safe and efficient operations.

Body/Core Temperature

Body and/or core temperature is often measured during firefighting studies due to the severe work environment. As core temperature rises between 38 and 40°C, muscle activation decreases as high brain temperatures reduce the central drive to exercise resulting in fatigue.[10] The pulmonary artery is considered to be a gold standard site to measure core temperature, yet this invasive technique is not practical in field studies. For the practical and non-invasive mean to provide smooth and efficient field studies, infrared tympanic temperature measurement and gastrointestinal (GI) temperature measurement, through a telemetric temperature sensor pill, are commonly and conveniently used to estimate the core temperature.[37] Especially when tracking core temperature throughout the intervention, GI core temperature measurement is the most effective and practical way to measure the core temperature in field studies. Monitoring skin temperature is also common to compare between the core temperatures and skin temperatures.

For the previous firefighting studies, the estimated core temperature was monitored by means of either tympanic or GI methods. Smith et al.[6,7] and Bruce-Low et al.[8] reported a significant increase in the tympanic/aural temperature throughout firefighting activities in high-heat conditions (between 1.5°C and 3.15°C increments; possibly reaching to over 38°C core temperature). Fahs et al.[16] reported a significant increase in the core temperature for their three hour live-fire exercise with an average increase of more than 2°C, changing from 36.5°C to 38.9°C. Smith et al.[33] found a significant effect on duration of firefighting activity with core temperature regardless of the standard firefighting gear and cooling-enhanced firefighter gear (37.6°C at the pre-firefighting to 38.3°C at the post-firefighting, and 37.5°C to 38.2°C, respectively). Horn et al.[32] reported that core temperature increased significantly during firefighting activities and continued to rise for seven minutes after the activities and while moving onto the rehabilitation protocol. Core temperature did not return to the baseline until approximately 80 minutes post-firefighting activities.

The effect of PPE additionally influences core temperature. Skin temperature monitoring is one of the ways to examine the effect of PPE. Bruce-Low et al.[8] examined the effects of PPE and SCBA as compared to gym exercise attire with the same amount of weight as PPE and SCBA and found heat-retaining properties of PPE during a stepping test at 35 steps/min. In addition, Sal et al.[29] reported a significant increase in skin temperature during the acclimation phase after donning firefighter gear (7.48% increment) and during the work phase (10.62% from the baseline). Smith et al.[33] found the same tendency; more than 14% of the changes from pre-firefighting to post-firefighting activities were seen on skin temperature on the neck and arms in both standard and cooling-enhanced gear.

Hydration Status during the Firefighting

Due to the hot environment and existence of fire during firefighting, along with the loads and effects of PPE and SCBA, dehydration is very likely. Fluid loss of more than 6% of body weight impairs exercise performance lasting longer than a few minutes.[18] Even dehydration by 2% of body weight impacts the physiologic and thermoregulatory systems resulting in elevation of HR and body temperature during exercise.[21] McArdle et al.[10] summarized the factors attributed from fluid loss or dehydration: 1) decreased plasma volume (PV), 2) reduced skin blood flow for a given core temperature, 3) reduced stroke volume, 4) increased near-compensatory HR, and 5) general deterioration in circulatory and thermoregulatory efficiency in exercise, as well as the increased risk of heat illness in the dehydration state.

In firefighting studies that have measured hydration status, monitoring PV between the pre- and post-firefighting activities has been often utilized, as well as monitoring change in body weight. Webb et al.[4] and Horn et al.[32] reported the percent change of PV reduction was up to 7% and averaged about 5.45%, respectively during their interventions. Smith et al.[33] reported over 9% reduction of PV calculated via Greenleaf Hb/Hct method[38] from hemoglobin volume and hematocrit percent between pre-firefighting and post-firefighting.

In addition to the change of PV in determining the hydration status, Smith et al.[7] reported the change of body weight between pre- and post-firefighting was up to 1% loss of body weight. While this percentage was within the safe range, there were 10-minute rests between the second and third drills, and it was not mentioned if the participants had an opportunity to rehydrate during that time. For observation of hydration status, monitoring the change of PV is more reliable, while monitoring the body weight change is more convenient.

Rehydration/Fluid Replacement

Along with the hydration status, fluid replacement strategy is the important point of manners in the physical activity including firefighting. Ruby et al.[39] showed that the total body mass and body water were significantly decreased over the five-day period of wildfire suppression, indicating forest firefighters were more prone to dehydration compared with the total body mass and body water measured among recreationally active college students in their study.

In spite of individual difference of sweating rate and types of physical activities, substantial water and electrolyte losses are happened during sustained exercise, especially in hot environments, leading to dehydration unless water and electrolytes are replaced.[40] In order to help rehydration and hydration status while maintaining or improving exercise capacity, rehydration beverage was created and distributed to the market, which contains a mix of electrolytes. When exercising for a long duration, at a high intensity, and/or in hot environments, exercising individuals start to sweat and some mineral contents of body fluid, especially sodium, are lost because of the thermoregulatory reaction. Electrolyte-added solution, especially high-sodium electrolyte solution, provided better body fluid retention and physiological function or exercise capacity than plain water.[19,41-43]

One previous study related to firefighting showed that the electrolyte-added solution helped decrease the total load of fluid consumption for the 15-hour wildfire suppression deployment, indicating better physiological function with ingested fluid, compared to plain water.[42] There was no difference in body weight change, frequency of fluid ingestion, and core and skin temperature between these two groups.[42] Greenleaf et al.[41] reported that, despite not researching for firefighting, high-sodium (-chloride and -citrate) helped increase the PV at rest (pre-exercise hypervolemic strategy) and better maintained it during exercise. Also, a high-sodium rehydration solution helped increase PV at the altitude with low barometric pressure, compared with plain water ingestion at altitude and ground level, as well as significantly reduced urinary excretion compared with water.[44]

Application of the Reviews to the Training Officer

During simulated firefighting activities, firefighters were imposed to various physiological stresses which affected their cardiovascular, cardiorespiratory, and thermoregulatory system including hydration control. Most of the study interventions were relatively short bouts of firefighting activities, simulating one single firefighting evolution. One study done by Bruce-Low et al.[8] focused on the instructional-position officers which can be a similar position to the training officers. This study lasted approximately 35 minutes (15 min. x 2 with instructional feedback after the second instruction) with fire in one condition (high heat), then compared to the other condition with mock fire (temperate heat). The results revealed significant increase in HR (156 bpm of peak HR) and 17.4 ml/kg/min oxygen cost, as well as significant increase in skin, aural, and micro-climate (the air between PPE and skin) temperatures during the live-fire training exercise. However, these physiologic stresses were considered as relatively moderate intensity of firefighting activities.

Although training officers are not front-line firefighters and do not perform front-line firefighting activities, which imply lower exercise intensity, they would experience more physiologic stress, specifically thermal stress, than regular firefighters in live-fire training. It is also possibility that multiple exposure of live-fire training, lasting all day long, may impact the training officers in their physiologic parameters, compared to one single, short-bout training evolution.

CHAPTER THREE

Method

Experimental Approach to the Problem

The present study had two main purposes: 1) to determine the physiologic stress of training officers and 2) management of this stress via a hydration treatment. To quantify both problems, this study focused on the measurement of work, core temperature, and hydration status as the physiologic stress, and treatment protocol of either high-sodium electrolyte solution or (flavored) plain water (Figure 1). The work in this study was assessed by air consumption rate (ACR) or minute ventilation ($\dot{V}E$) along with the estimated oxygen consumption ($\dot{V}O_2$), heart rate (HR), and blood lactate. Thermal stress was measured via core temperature. Hydration status was assessed by change of plasma volume (PV) and body weight. The hydration treatment was a comparison between a high-sodium electrolyte solution and plain water.

Selection of Participants

As agreed by Boise Fire Department (BFD), participants in the present study were career firefighters recruited from the BFD, holding the rank of Training Officer or above. Due to the demographics of the BFD, all participants were male, age 30–55 years. All participants were in excellent physical condition and approved by the BFD for active duty and to routinely participate in firefighting and rescue duties and training. For

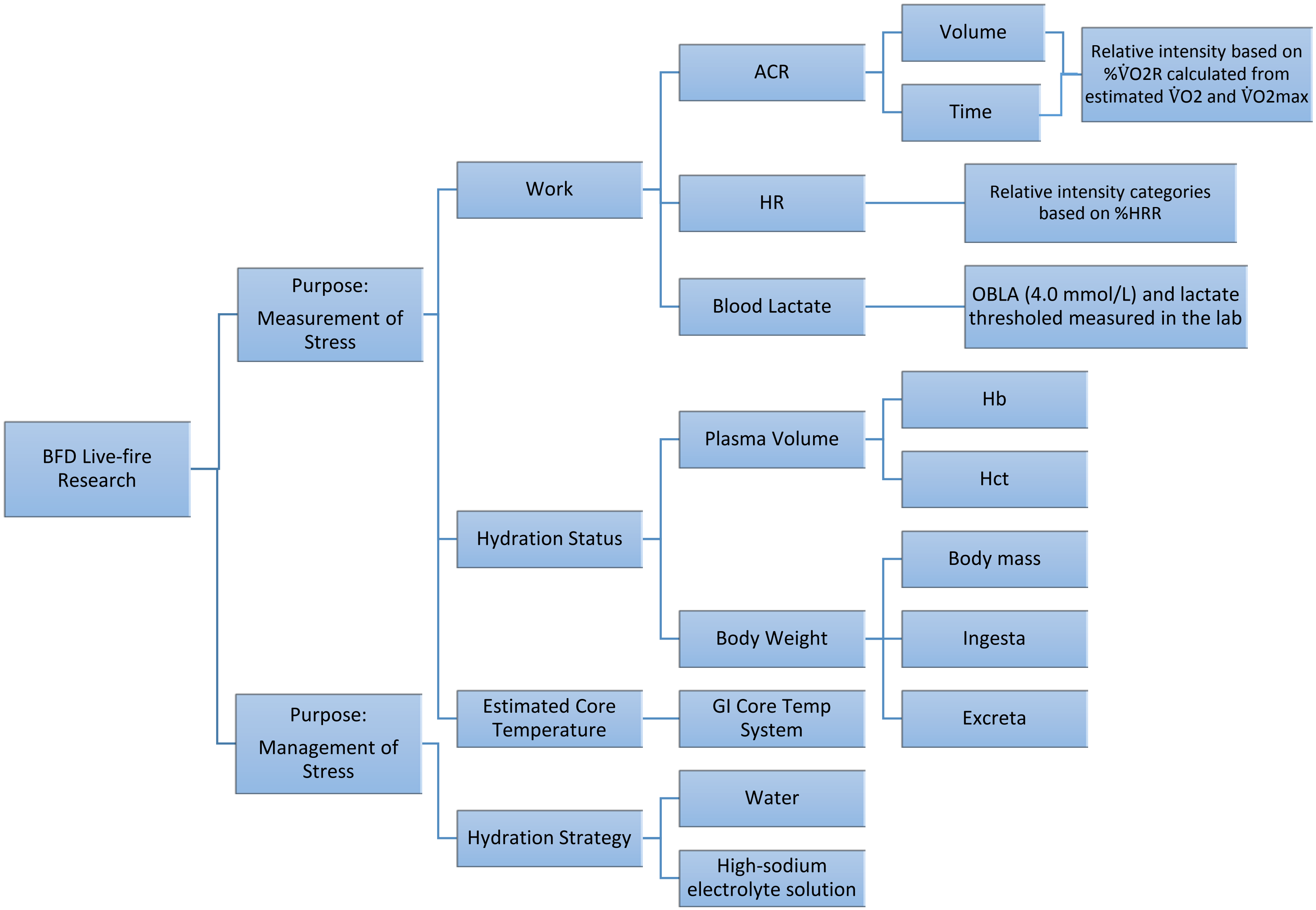

Figure 1. **Schematic Approach to the Overview of Present Study**

exclusion criteria, the study did not involve any participants not approved for active duty or employed by BFD. The present study was approved by the Boise State University Institutional Review Board (IRB). Through BFD internal communications, the recruitment announcement (Appendix B) for this study occurred prior to the training evolutions. Willingness to participate in the study was verified by the principal investigator prior to participants entering the training evolution. Also, the informed consent form (Appendix C) was made available to the participants as part of this communication.

Establishing Baseline and Maximal Exercise Responses

Participants were asked to visit the Human Performance Laboratory for determination of relative intensity of the training evolutions. Maximal minute ventilation ($\dot{V}E_{max}$), maximal oxygen consumption ($\dot{V}O_{2max}$), maximal heart rate (HR_{max}), and lactate threshold were measured. Body composition was measured as an anthropometric indicator of participants' physical fitness.

Body composition (% body fat) was measured by the hydrostatic (hydrodensitometry) weighing method (EXERTECH Weighing and Densitometry Program Ver. 2, EXERTECH®: Body Density Measurement Systems, La Crescent, MN). This testing is considered the gold standard for body composition testing.[20]

To identify the $\dot{V}O_{2max}$, HR_{max}, $\dot{V}E_{max}$ and lactate threshold, participants completed a $\dot{V}O_{2max}$ protocol on a treadmill. Expired respiratory gasses were collected via a mouthpiece and tube and measured by metabolic cart (ParvoMedics TrueMax 2400, ParvoMedics, Sandy, UT). Heart rate was obtained with a Polar 600 Heart Rate Monitor

(Polar Electro, Inc., Kempele Finland). Blood was obtained via a finger prick and was measured for lactate level.

After a five minute warm-up, the protocol began with baseline data collection of HR and blood lactate. The participant started standing on the treadmill with feet on either side of the belt with both hands on the front rail. The treadmill was set to a 10% grade and 1.7 mph. When the participant was ready, he began walking on the treadmill and the clock started. The participant was instructed to let go of the front rail within the first 30 seconds. Speed and grade were increased every three minutes as standard in the Bruce Protocol (Figure 2).[45] The test stopped when the participant reached volitional fatigue,

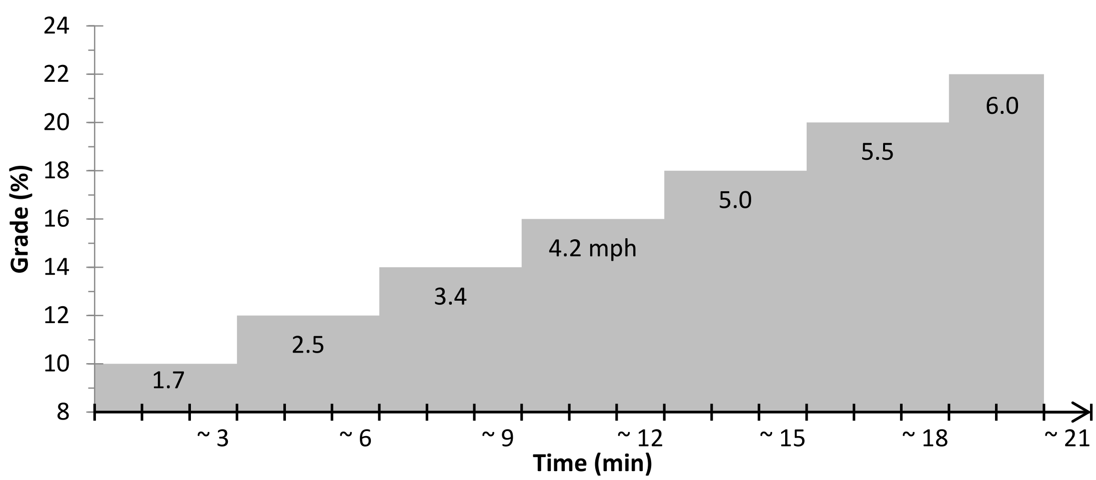

Figure 2. Chart of Bruce Protocol

stated a desire to stop, or the principal investigator determined it was appropriate. The number of stages were dependent on individual conditioning. Expected ranges would be from three to seven stages for a total of 9 – 21 minutes. Heart rate was measured during the last 15 seconds of each minute, and rate of perceived exertion (RPE)[46,47] and blood lactate via finger pricking were measured at the end of each stage (every third minute). Cool down consisted of walking at a participant-selected intensity that allowed the HR to decline to less than 120 bpm.

Boise Fire Department Live Fire Training Evolution

For safety, the research team remained out of the training zone and was stationed by the rehab (water, refreshment, heating/cooling) trailer at all times. The protocol of structured live-fire training during this study followed the standard BFD training evolution. BFD complies with the National Fire Protection Association 1403 or NFPA 1403: Standard on Live Fire Training Evolutions; this training is closely aligned with how they operate on real fires.

The BFD handled all property preparation to make an abandoned structure usable for the training. They also supplied all of the logistical items such as the rehab trailer, the training trailer, the air trailer, traffic/crowd control measures, and medical monitoring.

For the BFD live-fire training evolution, four training officers, three engines with three personnel each, one truck with four personnel, and one Battalion Chief for a total of 18 firefighters were present at each evolution. All tasks and assignments in each training evolution were practiced until the fire was extinguished and the training officers called for completion of the evolution. The next training evolution took place right after a quick performance review was conducted and the training property was prepared again (approximately 45 minutes from one evolution to another). This continuous training lasted all day with a lunch break. More than half of training evolutions occurred in the morning session because the property had to be totally burned down in the afternoon after the last evolution. Usually four or five evolutions occurred in the morning, and two or three evolutions occurred in the afternoon.

Variables of Work Level during the Live-Fire Training Evolutions

The variables monitored during the live-fire training were the participant's physiologic responses to work: ACR with estimated $\dot{V}O_2$, HR, blood lactate, core temperature, and PV and body weight. These variables were recorded either throughout the training day, each post-evolution, or pre- and post-live-fire training.

Air Consumption Rate (ACR)

Air consumption rate (L/min) was directly measured from the change of gas volume in the SCBA cylinder and matched the duration participants were in the burning property. The air consumption rate was calculated via Boyle's Law using a cylinder conversion factor (CF; volume/pressure) with the cylinder specification that the participants used: 4500 psi (310.26 bar), and 1841 L capacity (NxG Snap-Change Carbon-Wrapped Cylinder, Scott Safety, Monroe, NC):

$$\text{CF (L/bar)} = 1841 \text{ L} \div 310.26 \text{ bar} = 5.93 \text{ L/bar}$$

$$\text{ACR (L/min)} = \text{Measured change of pressure rate (bar/min) x CF (L/bar)}$$

Based on this procedure, ACR was identified with $\dot{V}E$ in this study in order to make these values comparable as ACR is a measurement of inspiration while $\dot{V}E$ is a measurement of expiration. The $\dot{V}E$, including the maximal value, was measured during the lactate threshold – maximal oxygen consumption ($\dot{V}O_{2max}$) test in the lab. The measured ACR was applied into this data, and the $\dot{V}O_2$ during the training evolutions was estimated.

A relative intensity of the training evolutions was determined by the percent oxygen uptake reserve (%$\dot{V}O_2R$).[17] A %$\dot{V}O_2R$ was calculated with estimated $\dot{V}O_2$ as the oxygen consumption during the training evolution, $\dot{V}O_{2max}$ measured at the $\dot{V}O_{2max}$ test, and 1 MET (3.5 ml/kg/min) as the resting $\dot{V}O_2$:

$$\%\dot{V}O_2R = ((\dot{V}O_{2estimated} - 3.5) / (\dot{V}O_{2max} - 3.5)) \times 100\%$$

The relative intensity was categorized as Maximal (100%), Very hard (≥85%), Hard/Vigorous (60 – 84%), Moderate (40 – 59%), Light (20 – 39%), and Very light (<20%).[17,18] This category was considered the same criteria as the percentage of heart rate reserve (%HRR).[17,18,48,49]

Heart Rate

Heart rate was monitored and recorded by the BioHarness™ 2 or 3 (Echo BioHarness 2 or 3, Zephyr Technology Corp., Annapolis, MD) and the data downloaded to a computer. As a wearable device, the heart rate was recorded throughout the training from donning to removing this system. The HR data from the BioHarness™ was provided with beat per minute (bpm) in every second, and average bpm was manually calculated in every one minute period. This measured HR was utilized to measure the relative intensity of live-fire training in terms of HR or cardiovascular parameter. It was referred to percent heart rate reserve (%HRR): $HRR = HR_{max} - HR_{rest}$:

$$\%HRR = ((HR_{ex} - HR_{rest}) / (HR_{max} - HR_{rest})) \times 100\%$$

The intensity category was considered the same as the $\%\dot{V}O_2R$ while $\dot{V}O_2R$ was respiratory parameter.[17,18,48,49]

Blood Lactate

Blood lactate were measured by digital lactate analyzer (Lactate+, Nova Biomedical, Waltham, MA). Samples were obtained via a finger prick and then a small drop of blood placed on the analyzing strip.[50] Blood lactate was recorded at the baseline and each post-evolution.

Core Temperature

Core temperature was monitored by the ingestible thermistor pill (CorTemp™ Temperture Sensor, HQInc., Wireless Sensing System & Design, Palmetto, FL) which transmits a signal via magnetic flux to the CorTemp™ Data Recorder (HQInc., Wireless Sensing System & Design, Palmetto, FL). The core temperature was measured at the pre-training as the baseline, and each post-evolution (last post-evolution was considered as the post-training).

Hydration Status

Hydration status was monitored via changes in PV and body weight. Blood plasma volume was calculated via the base-value of hemoglobin (Hb) and hematocrit (Hct) percentage relative to each preceding values:[51]

$$\text{Baseline PV} = 100 - (100 \times \text{baseline Hct\%})$$

$$\text{PV after each evolution} = (\text{Baseline Hb} \times 100/\text{post-evolution Hb}) - ((\text{Baseline Hb} \times 100/\text{post-evolution Hb}) \times \text{post-evolution Hct\%})$$

Measurement of hemoglobin value (g/dL or g/100mL) and hematocrit percentage (HemePoint H2 Photometer, Stanbio Laboratory, Boerne, TX) were obtained via a finger prick and then a small drop of blood placed on the analyzing cuvette. This blood drawing procedure took place at the baseline and each post-evolution.

Body weight (digital weight scale, BWB-800S, Tanita Corp., Tokyo, Japan) was recorded throughout the training day (from the time of the preliminary data collection to post-data collection), the mass of all materials voided (urine and feces) and added to the body (food and beverage) were also recorded. These data were combined to monitor the change in body weight. Any weight loss not due to voiding would then be attributed to loss of body water or sweat in this study. Additionally, whenever a participant voided urine during the training day, urinalysis was undertaken to check the specific gravity (Multistix 8 SG, Siemens Healthcare Diagnostics Inc., Tarrytown, NY) for further hydration monitoring.

Data Collection during the Training Evolutions

For each day of the training evolutions, there were four participating training officers. All participants were assigned to either the control or treatment on the same training day. From this design, there were two groups containing four to five participants: four training officers in control condition and five training officers in treatment condition. The same participants may have participated on different training days and different conditions. The total evolutions per training day varied depending upon the construction of the property utilized.

Participants in this study refrained from strenuous exercise and training three days before a training evolution. Forty-eight hours prior to a training evolution, caffeinated and alcoholic drinks were prohibited as well as smoking cigarette and any medication that could possibly affect physical and/or mental activity.

During the fasting period (three hours before the first evolution), only water (control condition) or the high-sodium electrolyte solution (treatment condition) was consumed. When the participants arrived at the training site 1.5 – 2 hours before the first training evolution, they ingested the core temperature pill. To make the training evolution as close to being an actual live fire incident, participants finished “toilet duty” before the pre-briefing and preliminary data collection. Prior to the preliminary data collection, urinalysis was performed to determine the baseline urine specific gravity as well as PV level. After participants voided their bladder and colon, they immediately started the pre-briefing and preliminary data collection process (25 minutes before the first evolution). Food and fluid intake were monitored through the data collection in the training day to monitor body weight. After the pre-briefing for the training evolution (including safety items, pertinent details regarding the training), preliminary data were collected. Body weight was recorded and the BioHarness™ donned and data recording verified. SCBA gas volume was checked through the standard pressure gauge installed in the SCBA gas cylinder. Baseline blood lactate and hemoglobin and hematocrit percentage, and core temperature were established. The participants then completely geared up.

Before each training evolution began, two or all training officers, depending on the size of training structure, were assigned as the ignition team and entered the property to ignite the pallets and straw and to control the fire. Then the training evolution began by sending the mock dispatch over the radio and the assessment commenced.

After each evolution, blood lactate level, hemoglobin level, hematocrit percentage, core temperature, SCBA gas volume, and SCBA usage time were recorded. This recording cycle was repeated continuously until the last training evolution. At the end of data collection of the live-fire training, the BioHarness™ was removed from the participants and the data downloaded. Immediately after the last training evolution, without ingesting any fluid or food, participants were asked to provide the last urine sample and then proceeded to the remaining post data collection (Figure 3), which included SCBA gas volume, blood lactate level, hemoglobin level and hematocrit percentage, core temperature, and body weight.

Hydration Intervention: High-sodium Electrolyte Solution versus Flavored Water

To identify how the high-sodium electrolyte solution could alter the physiologic stress responses, the present study also assessed the effect of a high-sodium electrolyte solution (The Right Stuff®, Wellness Brands Inc., Boulder, CO) on hydration status of the participants compared to flavored water (CrystalLight, Kraft Food Global, Inc., Northfield, IL) to mock the electrolyte drink. For the procedure of fluid intake (Figure 3), both the high-sodium electrolyte solution and flavored water were kept chilled and ready to serve participants. The hydration procedure was started at 60 minutes before the first training evolution with the participants drinking 10 ml/kg-body-weight fluid of either the high-sodium electrolyte solution or flavored water. The next hydration time was 30 minutes before the evolution started; participants drank 5 ml/kg-body-weight fluid. This procedure would initiate the pre-exercise hypervolemic effect to maintain hydration status during the training.[18,43] During the training evolutions, participants had a quick hydration time and rest between each training evolution and consumed 5 ml/kg-body-weight fluid. This treatment was provided as long as the training evolutions continued.

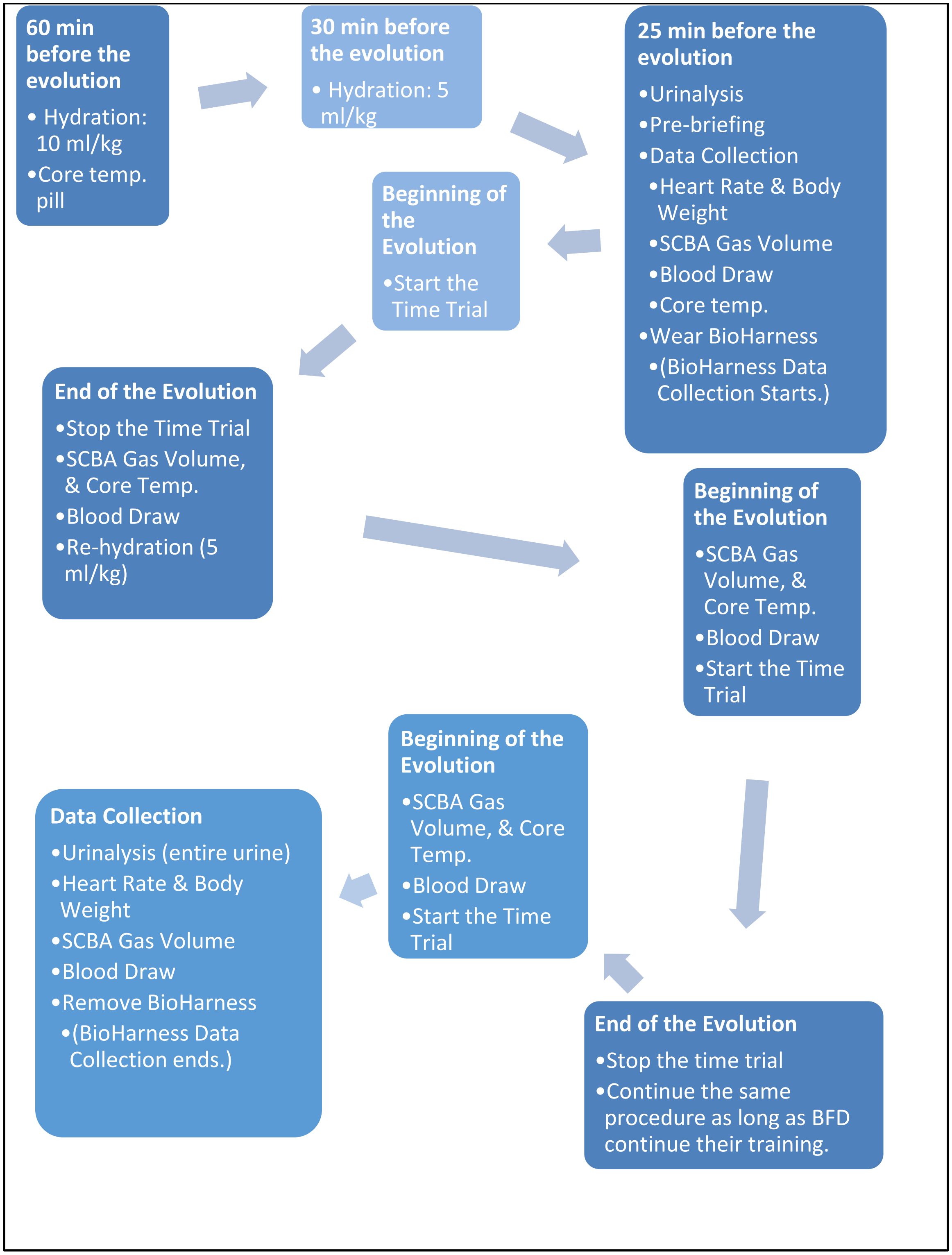

Figure 3. The Hydration and Data Collection Scheme for the Live-Fire Training Evolution Demonstrates the Protocol Followed during Training Evolutions.

Statistical Analysis

Means ± standard deviation were calculated for anthropometric data, lactate-threshold $\dot{V}O_{2max}$ test, and all variables measured (HR, ACR, core temperature, PV, blood lactate, and body weight) during the training evolutions. Data were entered into an Excel spreadsheet (Microsoft Office 2013, Redmond, WA). Data were analyzed using SPSS, version 21.0 (SPSS Inc., Chicago, IL). Statistical analysis of each variable and the associated hypotheses were set up in the following description. First, it was hypothesized that 1) training officers would experience physiologic stress as evidenced by (a) an increased ACR during a training evolution resulting in the moderate or above intensity relative to %$\dot{V}O_2$R, b) an elevated mean HR of the active working state throughout the training day resulting in the moderate or above intensity relative to %HRR, (c) an accumulated blood lactate level exceeding the value of OBLA (4.0 mmol/L), (d) an elevated core temperature showing difference between the baseline and the peak point, (e) a decreased PV after a training evolution showing the difference between the baseline and the lowest point, and (f) decrease in body weight from baseline to the post-training, and then that 2) the high-sodium electrolyte solution would alleviate these physiologic stress, resulting lower ACR, lower elevation of HR, less accumulation of blood lactate, less increased core temperature, and better maintenance and less decrement of PV and body weight, compared with water, through the live-fire training.

For ACR, the percentage of $\dot{V}O_2$R (%$\dot{V}O_2$R) during the live-fire training evolutions calculated from the estimated $\dot{V}O_2$ and $\dot{V}O_{2max}$ would be utilized to assess the physiologic response to the stress, expecting more than the moderate intensity or 40%. To assess the effect of high-sodium electrolyte solution, a paired *t*-test would be executed to compare the mean ACR of each participant's control and treatment conditions, which is expected that the mean ACR is greater in the control condition than the treatment condition.

For HR, the percentage of HRR (%HRR) calculated from resting HR, mean HR, and HR_{peak} would be utilized to assess the physiologic response to the stress, expecting more than the moderate intensity or 40%. To assess the effect of high-sodium electrolyte solution, a paired *t*-test would be executed to compare the mean HR of each participant's control and treatment conditions, which is expected that the mean HR of actively working throughout the training day is significantly greater in the control condition than the treatment condition.

For blood lactate, the peak blood lactate level of the post-evolution would be compared with the point of OBLA (4.0 mmol/L), where a participant starts to feel accumulated fatigue and rely more on the anaerobic energy system other than the aerobic energy system. A one-sample *t*-test (one-tailed) would be executed to exam if the peak lactate level is significantly greater than 4.0 mmol/L of OBLA. To assess the effect of high-sodium electrolyte solution, a paired *t*-test would be utilized to exam if the mean blood lactate of post-evolution of each participant's control and treatment conditions is significantly greater in the control condition than the treatment condition.

For core temperature, based on the baseline, that is the pre-training core temperature, and the peak core temperature of post-evolutions, a paired *t*-test would be utilized to exam if the peak core temperature is significantly greater than the baseline. To assess the effect of high-sodium electrolyte solution, a paired *t*-test would be executed to exam if the change of core temperature from the baseline to the peak is significantly greater in the control condition than the treatment condition.

For the assessment of hydration status, in terms of PV level, paired *t*-test would be utilized to exam if the peak PV of post-evolutions, which is the lowest PV point throughout the post-evolutions, is significantly lower than the baseline that is the pre-training PV value. For the assessment of the effect of high-sodium electrolyte solution, a paired *t*-test would be executed to exam if the change of PV from baseline to the lowest value of post-evolution is significantly less in the treatment condition than the control condition.

For body weight, the post-training body weight would be compared with the baseline or pre-training body weight by a paired *t*-test to exam if the post-training body weight is significantly lower than the pre-training body weight. To assess the effect of high-sodium electrolyte solution, a paired *t*-test would be executed to exam if the change from the pre- to post-training body weight is significantly less in the treatment condition than the control condition.

CHAPTER FOUR

Results

Five male firefighting training officers from Boise Fire Department participated in this research: four completed both laboratory testing and live-fire training. Three participated in all four live-fire training days, one participated in three days, and the last participated in one day. Two training days were the control condition and two days were the treatment condition – hydration protocol using a high-sodium electrolyte solution. Due to structure integrity, each training day had a different number of live-fire evolutions; the control training days had eight and seven evolutions, the treatment training days had eight and six evolutions. In addition, the training was conducted in spring and fall seasons in Boise, Idaho. Environmental conditions such as air temperature, humidity, and barometric pressure could have affected the physiologic parameter of participants in this field study. The weather conditions of the data collection days are shown in Table 1.

Table 1. Weather Conditions of the Live-Fire Training Days

Date	Nov. 10th, 2012	Nov. 11th, 2012	Mar. 28th, 2013	Nov. 1st, 2013
Condition	Clear	Clear	Clear	Clear
Mean Temperature (°C)	-0.56	-1.7	13	8.9
Max Temperature (°C)	4.4	3.9	19	15
Min Temperature (°C)	-5.6	-7.8	5.6	2.8
Average Humidity (%)	66	64	47	74
Precipitation (Rain) (mm)	0	0	Trace	0
Snow (mm)	0	0	0	0
Sea Level Pressure (hPa)	1015	1029	1015	1024

Mean Wind Speed (kph)	8	6.4	9.7	4.8
Visibility (km)	14.48	20.92	16.09	16.09

Anthropometric and Laboratory Data

The anthropometric characteristics were measured in the laboratory (height, weight, age, BMI, body fat percentage). Mean height of the participants was 174.2 ± 5.56 cm, mean weight was 87.9 ± 9.69 kg, and mean age was 41.4 ± 5.75 years old. Mean BMI (kg/m^2) of the participants was 29.0 ± 2.96, representing the overweight category. Mean percent of participants' body fat measured by the hydrostatic weighing was 20.1 ± 9.79 %.

Lactate threshold/$\dot{V}O_{2max}$ testing data ($\dot{V}O_{2max}$, HR_{max}, $\dot{V}E_{max}$, and lactate threshold) were obtained during the participants' laboratory visit (Table 2). The values of HR_{max} and $\dot{V}O_{2max}$ were estimated for one participant who did not complete threshold testing, therefore his $\dot{V}E_{max}$ and lactate threshold were not available: HR_{max} = 206 – 0.67 x age; $\dot{V}O_{2max}$ (L/min) = 0.046(ht, cm) – 0.021(age) – 3.389.[52-54]

Table 2. Lactate Threshold-$\dot{V}O_{2max}$ Data

$\dot{V}O_{2max}$ (ml/kg/min)	$\dot{V}E_{max}$ ATPS (L/min)	Lactate threshold (mmol/L)	HR_{max} (bpm)
46.8 ± 12.3	124.4 ± 24.4	3.4 ± 1.5	187 ± 10.8

Physiologic Variables

Air Consumption Rate/Minute Ventilation

Air consumption rate (ACR) was measured directly via the SCBA pressure gauge that each participant used during the live-fire evolutions and minute ventilation ($\dot{V}E$) was calculated. The ACR data was compared to the lactate threshold-$\dot{V}O_{2max}$ testing data and the estimated $\dot{V}O_2$ based on the percentage of $\dot{V}E_{max}$ was calculated. Then, percentage of $\dot{V}O_2$ reserve (%$\dot{V}O_2$R) was calculated.

The mean ACR in the control condition and treatment condition were 30.51 ± 3.88 L/min and 37.38 ± 5.17 L/min, respectively. The mean estimated $\dot{V}O_2$ in the control and treatment condition were 10.9 ± 1.50 ml/kg/min and 13.5 ± 3.10 ml/kg/min, respectively. Based on the estimated $\dot{V}O_2$ and $\dot{V}O_{2max}$, %$\dot{V}O_2R$ in the control and treatment conditions were 19 ± 6 % and 25 ± 6 %, respectively, which meant very light intensity (< 20%) in the control condition and light intensity (20 – 39%) in the treatment condition (Table 3).

As opposed to the hypothesis, the training officers did not experience a physiologic stress response in regards to the respiratory parameter at the moderate or higher intensity. Also, with paired *t*-test, no significant difference in mean ACR between the control and treatment conditions was found when consuming a high-sodium electrolyte solution, $t(3) = -1.607$, $p = 0.206$ ($p > 0.05$).

Table 3. Respiratory Parameters

Variables	Control	Treatment
ACR (L/min)	30.51 (± 3.88)	37.38 (± 5.17)
VO2 (est.) (ml/kg/min)	10.90 (± 1.50)	13.50 (± 3.10)
Percent $\dot{V}O2R$ (%)	19.00 (± 6)	25.00 (± 6)
Intensity level	Very light	Light

Heart Rate

Heart rate data were measured via the BioHarness monitoring device. The data were downloaded into an Excel spreadsheet and the active working times determined by the training schedule, BioHarness activity scale, and researchers' observation. During control data collection, there were only three measurement devices available on each training day while there were four participants in each day. In addition, two devices malfunctioned and only three participants' data were available as the complete HR data sets in the control condition. During the treatment data collection, all participants wore the monitoring device. One device malfunctioned for the first couple of hours, and approximately 95 minutes of valid data were retrieved and used in data analysis.

Mean HR and HR_{peak} were calculated based on the BioHarness data. The mean HR in the control and treatment conditions were 115.7 ± 14.0 bpm and 129.2 ± 18.8 bpm, respectively. The mean HR_{peak} in the control and treatment conditions were 166.0 ± 8.2 bpm and 167.7 ± 14.7 bpm, respectively. Based on the mean HR from the live-fire training and HR_{rest} and HR_{max}, the %HRR in the control and treatment condition were 38.2 ± 12.0 % and 43.7 ± 11.4 %, respectively, which meant the light intensity (20 – 39%) in the control condition and the moderate intensity (40 – 59%) in the treatment condition (Table 4).

As opposed to the hypothesis, the training officers did not experience significant stress specifically in the cardiovascular parameter with the intensity level lower than the moderate intensity while the treatment condition fell into the moderate intensity. Also, comparing between the control and treatment conditions to see the effect of high-sodium electrolyte solution, a paired *t*-test showed that there was no significant difference in mean HR between the control and treatment conditions, $t(2) = -3.038$, $p = 0.093$ ($p > 0.05$).

Table 4. Cardiovascular Parameters

Variables	Control	Treatment
Mean HR (bpm)	115.7 (± 14.0)	129.2 (± 18.8)
HR_{rest} (bpm)	69.3 (± 9.0)	67.4 (± 10.6)
HR_{max} (bpm)	187.3 (± 13.1)	186.8 (± 10.8)
Percent HRR (%)	38.2 (± 12.0)	43.7 (± 11.4)
Intensity level	Light	Moderate
HR_{peak}	166.0 (± 8.2)	167.7 (± 14.7)

Blood Lactate

The samples of blood lactate were measured using a digital lactate analyzer via finger prick. Blood lactate was recorded at each post-evolution to calculate for mean post-evolution lactate level and to find the peak lactate level. The mean blood lactate level in the control and treatment conditions were 0.96 ± 0.24 mmol/L and 1.97 ± 0.50 mmol/L, respectively. The peak lactate level in the control and treatment condition were 1.29 ± 0.29 mmol/L and 2.87 ± 0.79 mmol/L, respectively.

To see the physiologic response to the stress in terms of the blood lactate level compared with OBLA (4.0 mmol/L), a one-sample t-test (one-tailed) showed that the peak blood lactate level at post-evolutions was significantly lower than the OBLA, $t(3) = -18.54$, $p = 0.00025$ ($p < 0.025$). This result was opposite to the hypothesis which expected that the peak blood lactate of post-evolution would be greater than the OBLA. Also, for the comparison between the control and treatment conditions to see the effect of high-sodium electrolyte solution, a paired t-test showed that the mean blood lactate in the treatment condition was significantly accumulated compared to the control condition, $t(3) = -4.669$, $p = 0.019$ ($p < 0.05$). This result was opposite to the hypothesis.

Core Temperature

Core temperature was measured via an ingestible thermistor pill. The mean baseline (pre-training) core temperature was 36.5 ± 0.58 °C. The peak core temperature of post-evolution was 38.1 ± 0.24 °C. A paired t-test showed that there was significant increase from the pre-training to the peak core temperature of post-live-fire evolution, $t(3) = -5.842$, $p = 0.01$ ($p < 0.05$). Also, to determine the effect of high-sodium electrolyte solution to the core temperature increment, a paired t-test showed that there was no significant difference in the change of core temperature from the pre-training to the peak temperature between the control and treatment condition, $t(3) = -1.421$, $p = 0.25$ ($p > 0.05$).

Plasma Volume

The baseline (pre-training) mean PV and lowest PV of post-evolution were 53.6 ± 3.6 mL and 46.9 ± 10.1 mL, respectively (Table 5). Examining the physiologic response to hydration status during the live-fire training and its training evolutions, a paired *t*-test showed that there was no significant difference in PV between pre-training and lowest point of PV at the post-live-fire evolution, $t(3) = 1.706$, $p = 0.187$ ($p > 0.05$). Also, for the effect of high-sodium electrolyte solution to the hydration status, a paired *t*-test showed that there was no difference in the change of PV from the pre-training to the lowest point between the control and treatment conditions, $t(2) = -2.982$, $p = 0.096$ ($p > 0.05$).

Table 5. Plasma Volume and Urine Specific Gravity

Variables	Control	Treatment
PV Baseline (pre-training) (mL)	53.600 (± 3.6)	57.300 (± 5.9)
PV Peak/lowest post-evolution (mL)	46.900 (± 4.7)	41.100 (± 7.7)
Specific gravity (pre-training)	1.017 (± 0.006)	1.019 (± 0.010)
Specific gravity (post-training)	1.012 (± 0.004)	1.008 (± 0.003)

In addition to PV, the urine specific gravity between the pre-training and post-training was compared. The mean specific gravity of pre-training and post-training were 1.017 ± 0.006 and 1.012 ± 0.004, respectively (Table 5). A paired *t*-test showed that there was no significant difference in urine specific gravity between the pre-training and post-training, $t(3) = 1.633$, $p = 0.201$ ($p > 0.05$). Comparing between the control and treatment condition to see the effect of high-sodium electrolyte solution to the hydration status, specifically in urine specific gravity, a paired *t*-test showed that there was no significant difference in change of specific gravity from pre- to post-training, $t(3) = -0.816$, $p = 0.474$ ($p > 0.05$).

Body weight

As an adjunct estimate of hydration status, body weight among the participating firefighting training officers was compared from the pre-training to the post-training. To ensure that changes in body weight were due to changes in hydration, the summary of participants' total ingesta and excreta between the control and treatment conditions was recorded and listed in Table 6.

The mean body weight of pre-training and post-training were 91.3 ± 8.6 kg and 89.5 ± 10.1 kg, respectively. A paired *t*-test showed that there was no significant difference between the pre- and post-training body weight, $t(3) = 1.298$, $p = 0.285$ ($p > 0.05$). The effect of high-sodium electrolyte solution to the hydration status in terms of body weight maintenance demonstrated that there was no significant difference in the change of body weight from the pre- to post-training between the control and treatment conditions, $t(3) = 1.326$, $p = 0.277$ ($p > 0.05$).

Table 6. Ingesta and Excreta

Variables	Control	Treatment
Total ingesta (g)	6572 (± 1255)	4684 (± 1200)
Total excreta (g)	1436 (± 434)	666 (± 484)
Total fluid intake (mL)	6087 (± 1046)	4141 (± 1090)
Total urine output (mL)	1414 (± 432)	628 (± 418)
Total sweat weight (g)	6937 (± 2293)	3628 (± 1457)

Table 7. Acceptance/Rejection of Each Variable in Each Hypothesis

Variables	Hypothesis 1: Stress response	Hypothesis 2: Effect of high-sodium electrolyte solution
ACR	Rejected	Rejected
HR	Rejected	Rejected
Blood lactate	Rejected	Rejected
Core temperature	Accepted	Rejected
PV	Rejected	Rejected
Body weight	Rejected	Rejected

CHAPTER FIVE

Discussion

The responsibility of the Training Officer is to create a safe training environment while providing education and skill development opportunities to recruits and firefighters. While training officers within the Boise Fire Department (BFD) can still be active-duty firefighters, they engage in more operational tasks rather than firefighting and victim-rescuing tasks, which make their daily physical requirements less demanding. They are engaged mainly in operating the new recruit academy and managing and scheduling the training drill regimens (continuing education) for the personnel in the Fire Department.[14,15] As a part of their tasks, they organize and facilitate structured live-fire training (training evolutions) for firefighters.

The present pilot study focused on assessing the physiologic stress of live-fire training for the Boise Fire Department training officers (air consumption rate (ACR), heart rate (HR), blood lactate, core body temperature, plasma volume (PV), and body weight) and the effect of high-sodium electrolyte solution to manage this stress. Overall, the stress levels of live-fire training and its evolutions was relatively light for the training officers. Elevated core temperature was the only significant finding to meet the hypothesis in response to the live-fire training. The high-sodium electrolyte solution did not significantly affect to manage the physiologic stress during the live-fire training. However, there were some potential effects which could be more significant if the intensity level was higher, changing the levels of physiologic stress and degree of effect of high-sodium electrolyte solution.

Physiologic Stress

Results of this study showed relatively low levels of physiologic stress during live-fire training with training officers. The only variable that was significantly impacted was core temperature. An ingestible thermistor pill was used to measure core temperature after each training evolution throughout the training day. As core temperature rises over 38°C, muscular activation decreases and is manifested as fatigue.[10] In the present study, the mean training officers' core temperature surpassed 38°C as the change from baseline was approximately 2°C. While the respiratory (ACR) and cardiac (HR) stress were from very light to potentially moderate levels, the result of elevated core temperature indicated significant effects of the very hot live-fire environment. This is a similar outcome with previous studies although participants included more physically active individuals.[6-8,16,33] As compared with this study, core temperature of previous firefighting studies increased by more than 1.5 °C and up to 3.2°C at the post-firefighting training or activities.[6-8,16,33,55] The study done by Eglin et al. which was similar to this study focusing on the firefighting instructors, showed the increased core temperature over 38°C, reaching more than 39°C in some participants. With lack of appropriate management of heat dissipation, core temperature can be increased more than 40°C, possibly reaching 41 to 42°C, which would be the dangerous range and possibly lead to heat illness (e.g., heat stroke).[56] However, firefighting research indicates that heat stress was well-managed. The effect of PPE was reduced and accumulated heat between the skin and PPE was dissipated by removing the outer jacket after each evolution in this study. From the previous studies and present study, the effect of the very hot live-fire environment was evident which can increase core temperature possibly up to the physiologically dangerous range to initiate heat illness unless well-managed.

Also, there could have been several factors that contributed to the limited findings in this study. The intensity level requirements of the training officers during live-fire training episodes may have played a role. Based on the results of this study, intensity levels required of training officers was lightly to moderately demanding. Their lactate threshold was below OBLA (4.0 mmol/L) ($\bar{x}$ = 3.4 mmol/L, ± 1.46) which indicated the intensity was relatively light. In addition, the mean estimated $\dot{V}O_2$ calculated from the mean ACR during the training evolutions was 10.9 ± 1.50 ml/kg/min, which was close to the value of 3.5 METs. This value is similar intensity with walking at 4.8 km/hr (3.0 mi/hr) or house chore activities (e.g., sweeping and vacuuming floors), which indicated that their physical intensity did not require high oxygen demand.[57] This outcome was reasonable because the tasks during the evolution were to ignite and control the fire, and to stay in the burning structure until the evolution was completed. Within the structured live-fire training evolutions, the training officers did not participate in much physical activity. It could be assumed that the participating training officers have the experience and skill set to modify their work load to limit the effect of fatigue on the training schedule.

Also, the participants in this study were officer-ranked firefighters and had significant experience working in the high-heat environment; their familiarity with working in such condition, regardless of the heat-retaining property of PPE and load of SCBA, may have resulted in very light-to-light respiratory stress. Taking into consideration the effects of PPE and SCBA, previous studies indicated the weight effect of PPE and SCBA increased oxygen cost without ambient heat effect.[8,58] Dreger et al.[59] showed that the PPE and SCBA condition led to a greater oxygen cost than the regular exercise condition. Also, breathing resistance through the SCBA may affect $\dot{V}O_2$, $\dot{V}_E$, and breathing rate at higher or heavier work load.[59,60] However, since training officers were experienced firefighters and managed PPE and SCBA as part of their duties in this study, they may not have felt significant respiratory stress by wearing the PPE and utilizing SCBA in such light intensity situations. One previous study showed no effect of high ambient temperature on the oxygen consumption during low-to-high intensity aerobic exercise.[36]

Furthermore, the mean HR was lower, the mean HR_{peak} was higher, and working duration was much longer in the present study. This result indicated that the working tasks of training officers during structured live-fire training imposed lighter physical intensity requirements, with sporadic higher intensity as evidenced by HR spikes during sudden high-intensity physical activity. The training officers worked near 90% of their HR_{max} as evidenced by the higher mean HR_{peak} compared to previous studies.[8,55] However, based on activity monitoring and observation, it appears that the peaks in HR occur during the setup of training evolutions, rather than during the evolutions. During the live-fire portion of the training, the intensity in most of their tasks was light-to-moderate; however, during setup they carried wood pallets and hay to the designated ignition room with the PPE on. However, this could not be accurately confirmed as research team members were not permitted inside the structures and could not observe the training officers while they were inside the training structures.

For the major physiologic components in physical activity, respiratory and cardiovascular stress were used with the same intensity classification in terms of %$\dot{V}O_2R$ and %HRR.[17,18] However, this study found a discrepancy in intensity between HR (light-to-moderate) and ACR (very light-to-light). It may be due to the impact on HR of the thermal stress experienced during live-fire training evolutions. HR is elevated under thermal stress in response to cutaneous vasodilation moving blood to the surface of the body to enhance heat loss via evaporation or sweat, called cardiovascular drift.[10,21] Lusa et al.[61] showed that percentage of HR relative to HR_{max} was higher than the percentage of estimated $\dot{V}O_2$ relative to $\dot{V}O_{2max}$ during the simulated smoke-dive training, or entry to smoky room, in the heat (110 °C at the level of 2m). Although the study done by Lusa et al.[61] was more physically demanding, the heated chamber was not as hot as the conditions found in the present study. As heat stress more readily affects HR compared with ACR,[62] the outcome obtained in this study indicated extrinsic heat stress was a greater HR stimulus than intrinsic oxygen demand related to muscular activity. Despite less physical activity, this extreme heat stress increased HR and created potential cardiovascular stress once more physical activity and higher intensity are required. While the training officers felt very light to light intensity in terms of respiratory stress or ACR due to less physical activity, their cardiovascular system evidenced more intensity in an effort to dissipate extrinsically accumulated heat.

Another physiologic variable also explained the lower intensity requirements of training officers in this study. Onset of blood lactate accumulation (OBLA) is often used to identify the exercise intensity at which a person starts to utilize more anaerobic energy during aerobic-oriented exercise.[10] Usually, firefighting activities are composed of a mixture of aerobic and anaerobic metabolism, along with significant muscular strength and endurance requirements.[1] The result of mean blood lactate and even peak blood lactate level at the post-evolutions in the present study showed less than 2.00 mmol/L, which was significantly lower than OBLA. Previous studies showed accumulated blood lactate level exceeding OBLA of 4.0 mmol/L.[1,24,30,31] Due to the very light intensity of respiratory levels, the intensity in the live-fire evolutions in terms of blood lactate level was light enough for the training officers to clear the slightly accumulated lactate in the blood while requiring the occasional moderate-high intensity surges in very short durations. Despite heat stress, this result was understandable since this study focused on the training officers who were less physically active than regular firefighters. While they were exposed to high heat, they were staying close to a resting state during the exposure. This environment partially created a passive recovery condition for the training officers. At the same time, with effect of high heat resulting in slightly elevated HR, increased blood circulation initiated active recovery. These physiologic mechanisms stimulated lactate clearance possibly more than lactate accumulation.[10] For the structured live-fire training evolutions in the present study, the training officers ended up with only light and possibly up to moderate aerobic-oriented physical activity without significant amount of muscular strength and endurance requirements.

For the hydration status during the live-fire training, change of PV is one of the most accurate indications to the training officers as well as their trainees. The present study showed that mean PV of post-evolutions was only approximately 0.3 mL lower than mean baseline levels, which indicated that the participating firefighting training officers managed their hydration level well. However, looking at the lowest point of PV as comparing to mean baseline, there was 6.7 mL decrement of PV (12.5%), which was close to a percent of PV reduction generally seen at the onset of prolong endurance exercise at about 70% $\dot{V}O_{2max}$.[63] This result was similar to previous studies in which the more intense work of firefighting physical activity was completed.[4,32] With more physical activity during the live-fire training, the mean peak PV reduction could be over 9%, similar to the study by Smith et al.,[33] although the activity intensity may be less than 70% $\dot{V}O_{2max}$. Since this study had more environmental/extrinsic thermal stress (approximately 232°C compared to 71 to 82°C) and less physically demanding activity than previous studies, the extreme heat stress contributed to PV reduction as well as the elevated core temperature and possibly HR. Because work intensity was low, but the heat stress was high, it is safe to assume that heat stress led to dehydration. By an interrelation of physiologic variables and extrinsic factors, dehydration results in elevated HR at similar workloads as the heart beats faster to move a smaller volume of blood around the same size vascular bed.[10,21] Decreased PV leads to more viscous blood and decreased skin blood flow; as such, decreased thermoregulatory function due to decreased heat dissipating, leads to increased core temperature and increased cardiovascular demands as seen in increased HR.[64,65] HR, core temperature, and dehydration are interrelated under the umbrella of thermal strain (Figure 4).[66] While the heat stress is an inevitable factor in the structured live-fire training, maintaining a hydrated state is manageable and must be followed to minimize physiologic stress of a high-heat environment.

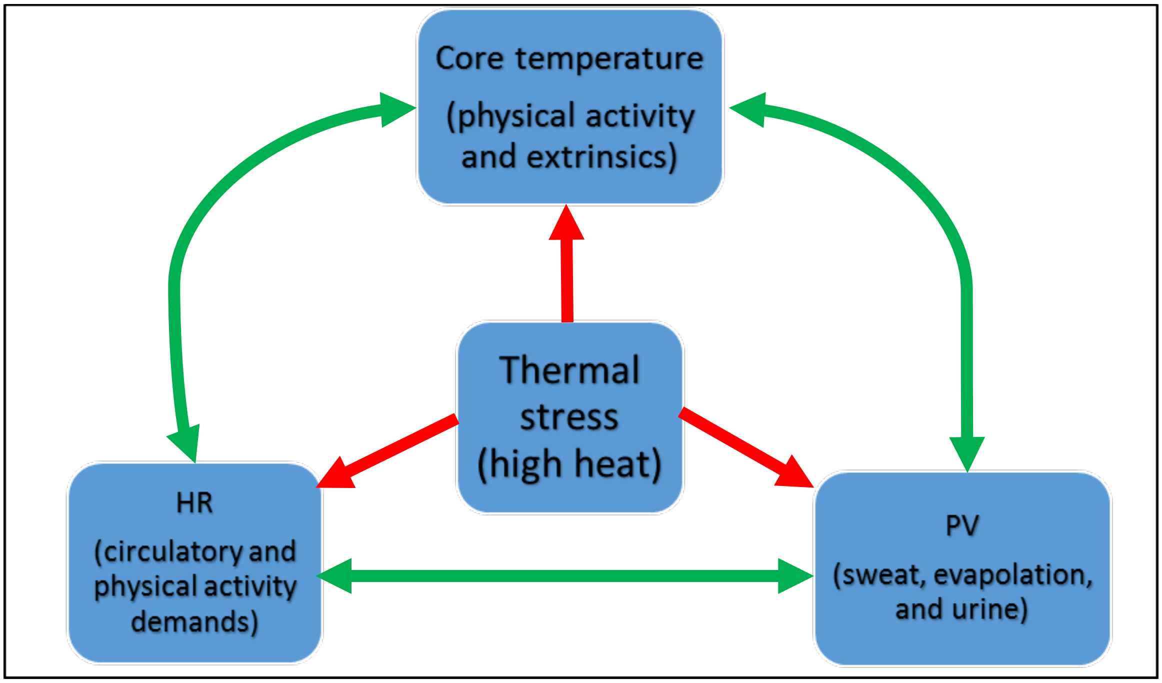

Figure 4. Interrelation of Core Temperature, Heart Rate, and Plasma Volume in Response to Thermal Stress

Additionally, there was different physical conditioning levels among the participating training officers based on their body fat percent and $\dot{V}O_{2max}$. Although the level of intensity requirements in this study did not tax their physiologic systems enough resulting in no obvious work performance difference among the training officers, there was some discrepancy in terms of %$\dot{V}O_2$R and %HRR compared with body fat percent and $\dot{V}O_{2max}$ among the fit and unfit training officers. As the range of participants' body fat percent and $\dot{V}O_{2max}$ were from 9.7% to 32.1%, and from 60.5 ml/kg/min to 29.4 ml/kg/min, respectively, their %$\dot{V}O_2$R and %HRR were from 13% to 26%, and from 25.2% to 47.6%, respectively. The more lean and fit a training officer was, the less stress he perceived in terms of respiratory and cardiovascular parameters. This wide range of outcomes were because some of the training officers were truly working for the recruiting academy as constant firefighting exercise with their students and the others were more in charge of administrative duties for the training division which does not require physical demands. More sedentary tasks indicates high fatness and unfit condition which increase the risk of cardiovascular disease.[18,67] Since they still work with high-heat environment and some physical demands (i.e., live-fire training), it would be better to minimize the cardiovascular risks and increase safe participation in structured live-fire training via effective weight management and fitness as shown with different perception of %$\dot{V}O_2$R and %HRR among the fit and unfit training officers.

High-sodium Electrolyte Solution

The present study could not find any significant effects when consuming high-sodium electrolyte solutions to manage stress during the live-fire training. The mean ACR between the control and treatment groups were not significantly different, which indicated that the high-sodium electrolyte solution did not reduce the aerobic stress. A previous study investigating the hypervolemic effect with high-sodium electrolyte solution before endurance exercise showed no significant effect on the aerobic parameters compared to no fluid consumption and multi-ionic carbohydrate beverage.[68] Moreover, the control-condition mean relative $\dot{V}O_2$ during the training evolutions was 10.9 ml/kg/min and the treatment was 13.5 ml/kg/min. These $\dot{V}O_2$ values were much less than the oxygen demand during regular firefighting operations (23.4 ml/kg/min).[1] The aerobic intensity of the tasks completed by the training officers during the live-fire training evolutions might not have been high or long enough to demonstrate an effect of the high-sodium electrolyte solution as compared to plain water.

Despite the fact that heat stress was evident, the hydration treatment did not significantly affect HR. It can be inferred that the high-sodium electrolyte solution did not influence the cardiovascular system as long as hydration status was maintained (both groups followed the hydration protocol with either water or the high-sodium electrolyte solution). However, the mean HR in treatment condition was slightly higher (falling into the moderate intensity level) than the control condition. The high-sodium electrolyte solution might have some physiologic effects to stimulate or enable the training officers to work harder as shown by higher mean ACR in the treatment condition. Shirreffs[69] summarized that sodium, which is the main element of electrolytes for exercise, helps stimulate water and sugar absorption, resulting in maintaining or improving exercise performance when prolonged exercise in heat where sweat loss is large. Generally, electrolyte depletion makes individuals more susceptible to heat illness, such as heat cramps, heat exhaustion, and heat stroke as well as excessive water loss in the body.[10] Electrolyte replacement, along with water intake, can help training officers maintain their heat tolerance in the extreme conditions of live-fire training.

The high-sodium electrolyte solution used in this study contained sodium-citrate (1780 mg of sodium, 1379 mg of chloride, and 2953 mg of citrate). The citrate portion in the electrolyte solution possibly enhanced (aerobic) energy metabolism, specifically in the citric acid cycle as the first product of this energy cycle. High-sodium and chloride components have played an important role in acid-base balance, body water balance in blood PV and extracellular fluid. It may also affect nerve function as seen by the previous case study showing post-marathon seizure-like condition or muscular cramping caused by hyponatremia.[70] These roles of high-sodium electrolytes mentioned above as the physiologic function may have enabled the training officers to work harder, resulting in more elevated HR as well as higher ACR.

However, it should also be considered that high-sodium and chloride contents can induce hypertension in the general population.[71] With the treatment of high-sodium electrolyte solution in the live-fire training study, blood pressure will need to be monitored to further analyze the effect of high-sodium electrolyte solution. The trend found in this study could determine a high-sodium electrolyte solution as a physiologic stimulant rather than a stress alleviator.

Seen by higher ACR and more elevated HR in the treatment condition, the participants in the treatment condition also had more blood lactate accumulation resulting in higher peak blood lactate level than the control condition although peak blood lactate levels in both conditions were significantly lower than the OBLA. The benefit of high-sodium electrolyte solution to the blood lactate management might be limited to higher intensity activity in athletic performance as seen in previous studies.[72-75] Similar to the tendency of HR and ACR, a high-sodium electrolyte solution may have some potential to increase working capacity or tolerance, so that the training officers can comfortably work harder, resulting in more accumulation of blood lactate. However, blood lactate accumulation did not reach to the statistical significance as shown by the previous studies which used carbohydrate-contained electrolytes solutions and did not show the blood lactate change between water and treatment conditions.[72-74,76]

In this study, ingesting a high-sodium electrolyte solution did not create significant differences in core temperature between control and treatment conditions. Previous studies showed significantly lower temperature with a high-sodium electrolyte beverage as opposed to water, although it was not in similar high heat conditions or the same solution formula.[19,43,77,78] While some studies did demonstrate decreased core temperatures, others showed no significant difference in core temperature, with different types of treatment and recovery intervention as compared with this study.[32,72,73,79] Additional research should be conducted to determine the effect of high-sodium electrolyte solution on the core temperature and further establish an appropriate rest interval between evolutions to bring the elevated core temperature back to the safe range.

A comparison of the hydration protocols of water and high-sodium electrolyte solution did not show any difference in the peak PV reduction during training. A high-sodium electrolyte solution has been used to increase fluid retention and re-hydration by balancing PV and extracellular fluid in disparate areas (i.e., astronaut's after-landing and athletes exercising in heat).[19,42-44,72,73,75,79] However, a high-sodium electrolyte solution seemed no more effective than water during the structured live-fire training – as long as the training officers kept themselves hydrated with water. Regardless of the heat stress, because the intensity of the live-fire training evolutions was light-to-moderate, it would be challenging to see the effect of high-sodium electrolyte solution in the PV level.

A reduction in body weight after strenuous activity can be used to indicate hydration status. There was no significant difference between pre- and post-training body weight as well as the comparison between the control and treatment conditions. The participating training officers were encouraged to hydrate with their assigned drink during the structured live-fire training. The hydration protocol set by this study (10 mL/kg at 60 min. and 5 mL/kg at 30 min. before the training, and 5 mL/kg in between evolutions) created a hyperhydrated state to prevent dehydration and enhance work capacity as suggested by previous studies.[41] Thus, because of maintaining a hyperhydrated state, it was reasonable that there was no significant difference between the pre- and post-training body weight.

As adjunct to the PV and body weight change analyses, the results of urine specific gravity between the pre- and post-training also showed that the training officers were hydrated. In addition, results demonstrated no difference between the pre- and post-training as well as comparison between the control and treatment conditions. However, the difference of individual participant's drinking behavior between the control and treatment condition was seen throughout the live-fire training. It was reported that occasionally the participants could not drink the complete amount of assigned fluid due to short duration of resting, and low intensity or severity of a live-fire training evolution which decreased an individual's desire or need to hydrate. Based on the observation and collected data, the training officers in the treatment condition consumed less than the control condition, which meant that they could not completely ingest the individually designated amount of beverage. As the training officers in the treatment condition consumed less fluid throughout the training, their urine output was less than the control group. While the end results of PV and body weight were not significantly different between these two conditions, the high-sodium electrolyte solution did influence the fluid retaining or absorbing function in the body. Previous studies also showed decreased total fluid consumption and urine output when the participants ingested an electrolyte-contained drink compared with plain water.[42,44] This alone might make the training officers more comfortable during the day.

While the participating training officers worked in the ignition team and managed their hydration level well, there were ins (ingesta) and outs (excreta) to manage their hydration and energy demands throughout the training day. As a part of excreta, sweat weight played a role in the body weight maintenance and hydration level along with total ingesta (i.e., fluid and food) and other excreta (i.e., urine and feces). For the sweat function in response to heat, interestingly there was no significant difference in HR and core temperature between the control and treatment condition. The increased sweat rate with more fluid consumption in the control condition did not attenuate the heat stress. This result could be caused by the heat-retaining PPE which prohibited the heat-dissipating evaporation of sweat. However, since each condition was exposed to similar environmental stress and training procedures, it can be concluded that the high-sodium electrolyte solution improved the heat tolerance of the training officers.

Additionally, through ACR, HR, and blood lactate physiologic parameters, the high-sodium electrolyte solution might have the potential to increase work capacity due to the decrease in sweat and fluid consumption rate. Although it can be a very small amount, the more sweat created, the more energy is consumed by the sweat glands.[80] Participants in the treatment condition were able to work harder since they did not have to drink more, which also put less stress on the GI tract to absorb ingested fluid. Yet, as Greenleaf and Castle[81] mentioned, one single factor cannot determine the physiologic changes and its stress affecting physical performance. While change of body weight between the pre- and post-training and between the control and treatment conditions was not significantly different, the contents of physiologic process such as body fluid dynamics should be taken into consideration as the physiologic stress can affect the physical performance in the long-duration activity and eventually health issues.

Conclusion

Overall, the results of this study demonstrated that the significant elevated core temperatures associated with live-fire training was indicative of the very hot live-fire environment and not due to the physiologic responses of work-condition intensity levels. While the firefighting training officers were not required to participate in physically demanding activities compared with the front-line firefighters, multiple exposures to high-heat stress in short periods of time during training evolutions may potentially affect their physiologic integrity, especially the cardiovascular systems. This heat stress is inevitable and needs to be managed.

Stress levels experienced by the training officers in this study during the structured live-fire training and its evolutions were light. The firefighting training officers were exposed to cardiovascular stress according to the elevated HR with short intervals close to maximal HR, and elevated core temperature while the aerobic demand and respiratory stress were of very light intensity.

Finally, the structured live-fire training and its evolutions had a potentially dehydrating effect on the training officers. However, as long as the training officers hydrated themselves, their hydration status was well-controlled regardless of the plain water or high-sodium electrolyte solution. As a result, a high-sodium electrolyte solution did not reduce the work stress or show a significant effect to reduce dehydration.

Practical Application

Findings from this research can be applied to the practical setting for the firefighting training officers. As heat stress was evident and inevitable for training officers, adequate hydration can minimize this stress as well as improved cardiovascular fitness to resist to the heat-affected cardiovascular stress, regardless of whether they drink a high-sodium electrolyte solution or water. Acclimatization and development of physical fitness are important factors to minimize and tolerate the heat stress towards work efficiency.[65,66] Sawka et al.[82] summarized that heat acclimation had possible effects of PV expansion alleviating cardiovascular strain, and endurance exercise elicited the physiological adaptation resulting in increased $\dot{V}O_{2max}$ supported by increased blood volume. As a previous study shown, warming up or acclimatization to the heat after donning their PPE would help alleviate heat stress of the live-fire training and its evolutions.[83] Along with increased blood volume resulted in PV expansion and increased erythrocyte volume which increased oxygen carrying capacity, acclimation and endurance exercise help minimize hypohydration leading to reduced PV and decreased heat-dissipating function against increasing thermal and cardiovascular strain.

When it comes to the BFD and their structured live-fire training, they follow appropriate training schedules and safety protocols. While the live-fire training evolutions in the summer are important and should be available to simulate firefighting activities in the most severe environment, the high-heat condition of summer time should be avoided during live-fire trainings. The frequency of summer trainings should be limited with long enough break intervals between evolutions.

Future Research Recommendation

Future studies should be more focused on the variables related to the cardiovascular system, such as detailed HR status both on and off the live-fire evolution, blood contents affecting cardiovascular disease, and arterial stiffness. Core temperature should still be monitored carefully. Hydration status should be well-monitored as well, especially PV change, amount of fluid consumed, and urine output and specific gravity, and sweat rate. Although there was no significant difference of work stress between the control and treatment conditions, the use of a high-sodium electrolyte solution should be continued to find evidence of reducing dehydration and moderating the heat and working stress. Moreover, it would be interesting and helpful to investigate the difference of stress level perceived by training officers to actual cardiovascular fitness levels.

Postscript: Review of Research

Firefighting training officers from the Boise Fire Department are in charge of preparing, setting up, conducting, and evaluating the evolutions of structured live-fire training. Because this type of training involved Boise firefighters and their brigades, dependent on structure characteristics, the number of evolutions included in this pilot study were different on each training day. One of the participating training officers described their structured live-fire training as following: “Because training fires have so many variables, we usually do not stick to a strict, defined schedule. If we get ahead on burns, we will bump the afternoon crews to an earlier time and if we get behind, we may forego a burn.” Also, the present pilot study was considered an adjunct to their training, which made the research data collection difficult. Maintaining measuring equipment would be the key as well, due to the semi-arid climate in Boise, Idaho, which lead to some equipment malfunction and missing data. Future research must be conducted in a more controlled environment to manage missing data due to equipment malfunction and flow of training schedules, besides more pre-instruction to the participating training officers to follow the research procedure while working on their own duties. Moreover, since the total participants in this pilot study were five training officers, obtaining bigger sample size of more participants either within the BFD or across neighbor fire departments would create more reliable and prominent research outcomes.

Finally, the study of firefighting training officers in the structured live-fire training evolutions has great research potential. Firefighting training officers are important personnel who train valuable firefighters. Disregarding their safety and health issues could harm the fire department and its community. While a live-fire training operation is one of the training officers' duties, it should not create occupational health issues in their career and after. Further research for the physiologic responses and managing the stress during the live-fire training and the appropriate fitness levels would be very beneficial for the current and future firefighting training officers, their department, and community.

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APPENDIX A

Job Description of Firefighting Training Officer

Job Description of Firefighting Training Officer

<u>Definition</u>

The Captain Training Officer shall be the second level officer in the Training Division as classified by the Boise City Civil Service Rules and Regulations. He shall be under the supervision of the Drill Master.

<u>Work</u>

The Captain Training Officer shall be responsible and held accountable for the work load assigned to him and to assist the Drill Master as per the job description that the Drill Master shall be responsible and accountable for:

1) Directing and supervising personnel assigned to the Training Division.
2) Establishing and updating a training guide for the Boise Fire Department.
3) Establishing Training and Training Goals for each position of the Fire Department.
4) Managing, budgeting, and implementing all programs relating to training.
5) Preparing and managing an Annual Budget for the Training Division.
6) Administering and grading oral, written, and manipulative performance tests that may be required for student and lesson evaluation to meet accepted standards developed for minimum levels of performance in all fire service.
7) Scheduling training subjects, teaching the techniques and methods according to department policy, coordinating and supervising training and planning training sessions for all the divisions of the Fire Department.

8) Keeping and reviewing personnel training records and keep the Deputy Chief informed of the findings.
9) Maintaining and updating training equipment and training materials.
10) Witnessing operations at emergencies and training sessions from time to time to determine progress, effectiveness, uniformity and that it follows the policy and procedure of the department.
11) The subjects in which training is to be given the program shall be related to the personnel needs of the department and shall utilize all available resources within the community, region, state and nation.
12) Assisting the Training and Qualifications Standards Committee Chairman.

APPENDIX B

Recruitment Announcement

Physiologic Assessment of Firefighting Training Officers During

FireFighting Training

Recruitment Announcement

Physiologic Assessment of Firefighting Training Officers During FireFighting Training

Recruitment Script

To be included in Training Evolution notification email.

During the next live-fire training evolution, Dr. Shawn Simonson and graduate students from the Human Performance Laboratory at Boise State University will be measuring physiological work and strain. We will be monitoring your heart, respiration, core body temperature, fluid loss, work intensity, and response to a rehydration beverage. Measure to be taken before and after the training evolution include: blood pressure, body temperature, body weight, blood lactate, blood sugar, blood hemoglobin and hematocrit. The blood analysis will require two 5 mL blood draws.
You will be provided with a rehydration beverage and/or flavored water during the training evolutions. The rehydration beverage is similar to a sports drink and may reduce the potential for dehydration.

Before and during the training evolution we will measure your heart, respirations, and core body temperature. This will require that you wear a rubber chest strap beneath your turn outs and swallow a temperature sensing pill that is the size of a standard 200 mg ibuprofen tablet. We will also ask that you consume either water or a rehydration beverage before and during the training evolutions.

Within a month of completing the training evolution you will be asked to visit the Human Performance Laboratory on the Boise State University campus for a maximal oxygen consumption test. This test entails walking/running on a treadmill with grade and speed increase every three minutes until you can no longer continue. Expired gasses are collected as well as heart rate and blood lactate finger a finger stick similar to what you will have experienced during the training evolution.

The consent form is attached.
Your participation benefits you in that you will learn how hard you are working during the performance of your job. Individual results will be provided and explained to you. Suggestions for methods to improve your work capacity are available upon request. This study will determine the metabolic costs of firefighting, the efficacy of the rehydration beverage, and may help improve firefighter training and safety.

If you have questions or concerns please contact:
Dr. Shawn Simonson
426-3973
ShawnSimonson@BoiseState.edu

Mike Walker, Captain, Training Officer
570-6542
mkwalker@cityofboise.org

APPENDIX C

Informed Consent Form

CONSENT TO BE A RESEARCH PARTICIPANT

BOISE STATE UNIVERSITY

A. PURPOSE AND BACKGROUND

Dr. Shawn Simonson, in the Department of Kinesiology at Boise State University, and the Boise Fire Department are conducting a research study entitled "Physiologic Assessment of Firefighters During FireFighting Training." There have been a few studies measuring the physiologic demands of simulated firefighting in laboratory and training facility settings. Data obtained during actual firefighting is more limited. These few studies estimate that physical exertion ranges from 60 – 110% of maximal oxygen uptake and includes sustained aerobic activity with bouts of extreme anaerobic effort, muscular power, and muscular endurance – all of this while wearing protective garments and carrying their own air supply and equipment in a dangerous and hot environment.

An improved understanding of the physical demands of firefighting can aid in the design of firefighting clothing and equipment. It can also lead to more effective physical training protocols and training evolutions. All of this resulting in enhanced safety and better firefighting performance.

The Boise Fire Department periodically conducts training burns in abandoned buildings and this controlled situation presents a unique opportunity to monitor firefighter physiologic responses to their work. While not exactly the same environment as a live fire, training fires provide a more accurate estimate of the demands of structure-fire firefighting than laboratory or field testing. Thus, the purpose of this study is to determine the human metabolic demands of structure fire firefighting. This initial study is an assessment of the demands of firefighting and no treatment or training programs will be implemented.

B. PROCEDURES

Who we are looking for:

Boise Firefighting Training Officers on activie duty with no duty restrictions or contraindications for vigorous maximal exercise.

Participants will participate in two data collection sessions:

- A live-fire training evolution.
- A maximal exercise session.

The first data collection will be during a live-fire training evolution.

You will be asked to permit us to measure some variables before and after the evolution as well as to wear a monitoring system (Equivatal chest strap) under your clothes.

Data to be collected before and after the training evolution:	Data to be collected by the Equivital during the training evolution:
• Heart rate	• Heart rate
• Blood pressure	• Breathing frequency/regularity

- Body weight – to monitor fluid loss
- Blood cyanide
- Blood glucose
- Blood lactate
- SCBA gas volume
- Skin temperature
- Sweat production
- Posture
- Activity level

The protocol will follow the standard BFD training evolution. When all of the involved participants have assembled, a standard pre-briefing will be conducted. At this point preliminary data will be collected. Heart rate, blood pressure, and body weight will be obtained via standard protocols. SCBA gas volume will be measured using an industry standard pressure gauge. A blood draw will be performed by an Idaho State Department of Health nurse to measure blood cyanide, glucose, and lactate. The Equivital will be donned and data recording verified. You will then conduct the training evolution as you normally would.

At the conclusion of the training evolution, post data will be collected. Heart rate, blood pressure, and body weight will be obtained via standard protocols. SCBA gas volume will again be measured. A blood draw will be performed by an Idaho State Department of Health nurse to measure blood cyanide, glucose, and lactate. The Equivital will be removed and data downloaded.

The second data collection will be performed in the Human Performanc Laboratory (HPL) at Boise State University and will be the maximal exercise test:

To allow for the comparison and determination of relative intensity of the data collected during the training evolution, similar data will be collected during a maximal exercise test. During a one hour visit to the HPL we will measure your maximal oxygen consumption, lactate threshold, and body composition.

You will be asked to run on a treadmill while the air you breathe out will be collected and measured via a mouthpiece and tube. Heart rate will be obtained with a Polar Heart Rate monitor chest strap. Blood glucose and lactate will be measured via periodic finger sticks. You will start with a five minute warm-up and then baseline data will be collected (heart rate, blood pressure, blood glucose and blood lactate).

The protocol will start with the treadmill set to a 10% grade and 1.7 mph. You will walk at this intensity for three minutes. Speed and grade will be increased every 3 min as is standard in the Bruce Protocol. The test will stop when you can no longer continue, desire to stop, or the principal investigator determines it appropriate. Your heart rate will be measured during the last 15 seconds of each minute and rating of perceived exertion, blood pressure, lactate, and glucose every third minute. At the conclusion of the treadmill test you will cool down by walking at a comfortable pace.

Your body weight and body composition (BodPod) will also be measured.

In total, blood lactate and glucose will be analyzed from two samples during the training evolution and for four to eight finger sticks (depending on how long it takes you to reach maximum) during the maximal exercise test. The test will require a small drop of blood from the fingertips of three different fingers (each drop will be less than the amount of blood that it would take to fill this letter o).

C. RISKS/DISCOMFORTS

The *potential risks* to you when participating in this study are as with any physical activity: there is always the risk of orthopedic injury, skin damage, chest pain, leg pain, dizziness, nausea, and even death.

Risk Management:

All participants will be experienced and currently employed Boise Firefighters. This study will be conducted during your training evolution and in a single laboratory session. You are used to maximal exertion and strenuous activity and this should not be an unusual experience for you. In addition, safe methods will be followed for the handling of all samples.

Dr. Simonson is a Certified Strength and Conditioning Specialist and ACSM certified Health Fitness Specialis and has conducted numerous similar training and testing protocols in over 20 years of coaching, research, and performance enhancement.

D. BENEFITS

You may improve your job performance through a greater understanding of your physiological response to the demands of the job. This information can then be used to help you better target your personal fitness routines and diet to better meet your own needs and improve your safety.

This study may improve the understanding of the physical demands of firefighting and how to better prepare firefighters for these rigors. It will also further develop a working relationship between the University, BFD, and the city of Boise.

E. COSTS

There will be no costs to you as a result of taking part in this study, other than the time spent participating.

F. PAYMENT

There will be no payment to you in return for taking part in this study; your participation is completely voluntary.

G. CONFIDENTIALITY

Confidentiality of data will be maintained by assigning you a unique code. All data will be labelled with this code and no references will be made to link you with your data. The code key will be kept in a locked filing cabinet in Dr. Simonson's office. Data will be stored on BSU Kinesiology department owned computers. No data will be transported outside of these facilities.

For this research project, we are requesting demographic information. Due to the make-up of Idaho's population and your particular employment, the combined answers to these questions may make an individual person identifiable. We will make every effort to protect participants' confidentiality. However, if you are uncomfortable answering any of these questions, you may leave them blank.

H. QUESTIONS

If you have any questions or concerns about participation in this study, you should first talk with the investigator:

Dr. Shawn Simonson
Department of Kinesiology
Boise State University
1910 University Drive
Boise, ID 83725-1710

(208) 426 – 3973
ShawnSimonson@BoiseState.edu

If for some reason you do not wish to do this, you may contact the Institutional Review Board, which is concerned with the protection of volunteers in research projects. You may reach the board office between 8:00 a.m. and 5:00 p.m., Monday through Friday.

Institutional Review Board
Office of Research Compliance
Boise State University
1910 University Drive
Boise, ID 83725-1138
(208) 426 – 5401
HumanSubjects@BoiseState.edu

Should you feel discomfort due to participation in this research, you should contact your own health care provider.

I. CONSENT

You will be given a copy of this consent form to keep.

PARTICIPATION IN RESEARCH IS VOLUNTARY. You are encouraged to ask questions at any time and are free to decline to be in this study, or to withdraw from it at any point. Your decision as to whether or not to participate in this study will have no influence on your present of future status as a patient, student, or employee at Boise State University or the Boise Fire Department.

I give my consent to participate in this study:

______________________________________ ____________

Signature of Study Participant Date

I give my consent to be video recorded in this study:

______________________________________ ____________

Signature of Study Participant Date

______________________________________ ____________

Signature of Person Obtaining Consent Date

THE BOISE STATE UNIVERSITY INSTITUTIONAL REVIEW BOARD HAS REVIEWED THIS PROJECT FOR THE PROTECTION OF HUMAN PARTICIPANTS IN RESEARCH.

APPENDIX D

Bruce Protocol (Data Sheet with Blood Lactate Measurement)

Bruce Protocol (Data Sheet with Blood Lactate Measurement)

Data Collection Sheet				
Stage	$\dot{V}O_2$ (mL/kg/min)	Lactate (mmol/L)	HR (bpm)	RPE (1-10)
Rest				
1				
2				
3				
4				
5				
6				
7				

APPENDIX E

Picture of Bioharness 3

Picture of Bioharness 3

Retrieved from Zephyr on-line store: http://www.zephyranywherestore.com/bioharness3SDK.
***Picture may be different from the exact product as you see.**

APPENDIX F

IRB Approvals

Office of Research Compliance
1910 University Drive
Boise, Idaho 83725-1138
HumanSubjects@boisestate.edu | 208.426.5401

DATE: September 13, 2012

TO: Shawn Simonson (PI)

FROM: Institutional Review Board (IRB)
Office of Research Compliance

SUBJECT: IRB Notification of Approval
Project Title: *Physiologic Assessment of Firefighting Training Officers During Firefighting Training*

The Boise State University IRB has approved your protocol application. Your protocol is in compliance with this institution's Federal Wide Assurance (#0000097) and the DHHS Regulations for the Protection of Human Subjects (45 CFR 46).

Review Type: Full Board	**Approval Number:** 103-MED12-006
Date of Approval: September 12, 2012	**Expiration Date:** September 11, 2013

Your approved protocol is effective for 12 months. If your research is not finished within the allotted year, the protocol must be renewed before expiration date indicated above. The Office of Research Compliance will send a reminder notice approximately 30 days prior to the expiration date. The principal investigator has the primary responsibility to ensure a RENEWAL FORM is submitted in a timely manner. If the protocol is not renewed before the expiration date, a new protocol application must be submitted for IRB review and approval.

Under BSU regulations, each protocol has a three-year life cycle and is allowed two annual renewals. If your research is not complete by September 11, 2015, a new protocol application must be submitted.

All additions or changes to your approved protocol must also be brought to the attention of the IRB for review and approval before they occur. Complete and submit a MODIFICATION/AMENDMENT FORM indicating any changes to your project. When your research is complete or discontinued, please submit a FINAL REPORT FORM. An executive summary or other documents with the results of the research may be included.

All relevant forms are available online. If you have any questions or concerns, please contact the Office of Research Compliance, 426-5401 or HumanSubjects@boisestate.edu.

Thank you and good luck with your research.

Ron Pfeiffer

Dr. Ronald Pfeiffer
Chairperson
Boise State University Institutional Review Board

Office of Research Compliance
Institutional Review Board
(Phone) 208.426.5401 | (Fax) 208.426.2055
HumanSubjects@boisestate.edu

ADDITIONAL PERSONNEL

INSTRUCTIONS: Indicate additional investigators and key personnel below. Download additional pages as necessary. Submit this form with your IRB protocol application to HumanSubjects@boisestate.edu.

Project Title: **Physiologic Assessment of Firefighters During FireFighting Training**
Principal Investigator
(listed on the original application): **Shawn R. Simonson**

Name: **Takahisa Koide**
☐ Principal Investigator
☐ Co-Principal Investigator
☐ Key Personnel

☐ Director
☐ Faculty
☒ Graduate Student: ☐ Thesis ☐ Dissertation
☐ Other:
Department: **Kinesiology** Phone: **509/230-8083**
E-mail: **TakahisaKoide@u.boisestate.edu**
Completed CITI Training: ☒ **YES** ☐ **NO**
Roles and responsibilities in this study:
Play a key role in protocol development and data collection and analysis as well as manuscript preparation.

Name:
☐ Principal Investigator
☐ Co-Principal Investigator
☐ Key Personnel

☐ Director
☐ Faculty
☒ Graduate Student: ☐ Thesis ☐ Dissertation
☐ Other:
Department: Phone:
E-mail:
Completed CITI Training: ☐ **YES** ☐ **NO**
Roles and responsibilities in this study:

Name:
☐ Principal Investigator
☐ Co-Principal Investigator
☐ Key Personnel

☐ Director
☐ Faculty
☒ Graduate Student: ☐ Thesis ☐ Dissertation
☐ Other:
Department: Phone:
E-mail:
Completed CITI Training: ☐ **YES** ☐ **NO**
Roles and responsibilities in this study:

FOR ORC USE ONLY	*DATE RECEIVED:*	*PROTOCOL #:*