Effect of a Simulated Mine Rescue on Physiological Variables and Heat Strain of Mine Rescue Workers

by:

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Abstract

Workplace Safety North (2015) reported 945 injuries related to mining in 2014 in Ontario, requiring the deployment of 53 emergency response teams. These statistics demonstrate the high risks of serious injury and fatality in the mining industry. Frequently occurring accidents include: underground fires, falls-of-ground, mobile equipment collisions, exposure to harmful environments, and falls from heights, which often require rescue (Government of Ontario, 2015b; *Handbook of Training in Mine Rescue and Recovery Operations*, 2014, *Workplace Safety North Injury Statistics*, 2015; Stewart, McDonald, Hunt, & Parker, 2008). Therefore, Mine operators rely on mine rescue teams, who have specialized skills in these issues, to save lives during an underground emergency.

Mine Rescuers regularly participate in training simulations, which require teams of five to seven members, to solve a hypothetical rescue problem while timed and observed by judges (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). Simulations typically involve trapped miners who have to be found and rescued under challenging circumstances (T. Hanley, personal communication, December 15, 2017). Mine rescuers carry heavy gear (approximately 100lbs), including a metal stretcher, spare breathing apparatus, hydraulic equipment, and first aid supplies; while wearing personal protective equipment (e.g. Self-contained breathing apparatus (SCBA), gloves, helmet, coveralls, boots etc.) (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). Research studying mine rescue participants demonstrate metabolic workloads between 400-700 Watts, with short bouts exceeding 1000 Watts; and often have concurrent heart rates nearing 100% of estimated maximum heart rate ($HR_{max\ estimated}$) (Stewart et al., 2008; Tomaskova, Jirak, Lvoncik, Buzga, Zavadilova, & Trlicova, 2015). In addition to extreme physical demands, underground mine

conditions are often characterized by temperatures exceeding 40 °C, as well as humidity exceeding 60%, which can exacerbate physiological loads on the mine rescue worker (Kenny, Vierula, Maté, Beaulieu, Hardcastle, & Reardon, 2012). However, research examining the physical demands; energy expenditure, physical activity levels, and recovery time associated with event specific mine rescue tasks are limited. Such that current literature does not identify differences between positions, and records data primarily during circuit-type tasks, which allow for more than adequate rest (unlike real conditions).

The present study documented heart rate (HR), respiration rate (RR), energy expenditure (EE), oxygen consumption ($\dot{V}O_2$), core temperature (T_c), and skin temperature (T_{skin}) of mine rescuers to produce descriptive statistics and determine vulnerability to heat illness' (heat exhaustion, crams, syncope, and stroke) during a simulated rescue emergency. The simulation closely mimicked a real emergency because: rest was limited, participants lacked information about the tasks, and the rescue was performed in an operational, underground mine; which provided realistic physiological responses. Physiological responses were documented with a heart-rate-variability (HRV), body-worn monitor, and a T_c ingestible capsule on each team member, which included a Captain, Vice-Captain, #2person, #3person, and #4person. They performed the following tasks: locating and performing first aid to an unconscious casualty (task 1); building a barricade to extinguish a fire (task 2); provide advanced first aid to a conscious casualty (task 3); and carry the casualty up a steep ramp out of the mine (task 4).

The present work highlights the physiological differences between mine rescue tasks and members of a mine rescue team. Laborious tasks were more strenuous than casualty care, however all tasks required a vigorous effort as mean HR of the entire sample exceeded 70% of the age predicted maximum heart rate (%APMHR). Captains exhibited a lower physiological load in comparison to Vice-Captains, #2persons, #3persons, and #4persons during the simulated emergency scenario. Captains also elicited lower T_c compared to other team members. Heat strain was evidenced via an increase in mean T_c to 38.6 ºC; 14 participants (non-Captain) registered a T_c above 39 ºC.

This research is expected to lead to an improved understanding of the physiological challenges faced by Mine Rescuers. These physiological measures affect worker fatigue and risk of heat stress, both of which increase the risk of injury, and are therefore essential to understand in the development of prevention strategies.

Co-Authorship Statement

Chapter 2 is presented as a manuscript for publication. The manuscript was submitted for publication to the *Journal of Occupational and Environmental Medicine*

Author contributions:

Justin Konrad assisted with the conceptualization of the study, led data collection, conducted all data analyses, and wrote the manuscript.

Dr. Sandra C. Dorman conceptualized the study, supervised the collection of data, assisted with data analyses and reviewed the manuscript.

Dr. Dominique Gagnon assisted with conceptualization of the study, assisted with data analyses and reviewed the manuscript.

Dr. Olivier Serresse assisted with conceptualization of the study and reviewed the manuscript.

Mr. Caleb Leduc reviewed the manuscript.

Dr. Bruce Oddson assisted with the data analyses.

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Abbreviations

%APMHR – Percentage of age predicted maximum heart rate

APMHR – Age predicted maximum heart rate

Bpm – Beats per minute

EE – Energy expenditure

HR – Heart rate (bpm)

HR_{max} – Maximum heart rate

HRV – Heart rate variability

ILO – International Labour Organization

IMRC – International Mine Rescue Competition

Kcal – Kilocalories

MOL – Ministry of Labour

OMR – Ontario Mine Rescue

PWI – Physiological Wellness Index

Rpm – respirations per minute

RR – Respiration rate (rpm)

SCC – Supreme Court of Canada

SCBA – Self-Contained Breathing Apparatus

SSR90 – Single Self Rescuer 90

T_c – Core Temperature

T_{skin} – Skin temperature

$\dot{V}O_2$ – Rate of oxygen consumption

$\dot{V}O_{2max}$ – Maximal rate of oxygen consumption

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Chapter 1

1.0 Introduction

Mining is responsible for extracting minerals for energy, jewelry, construction, and many other purposes (*Mining Readiness Strategy: An Integrated Regional Economic Development Plan Final Report*, 2013, *ONTARIO'S MINERAL DEVELOPMENT STRATEGY*, 2015; Hardcastle, 2006). In order to extract these minerals, companies dig deep into the earth's core by means of drills and explosives (*Mining Readiness Strategy: An Integrated Regional Economic Development Plan Final Report*, 2013, *ONTARIO'S MINERAL DEVELOPMENT STRATEGY*, 2015; Hardcastle, 2006). Due to the challenges associated with this process, mining is considered one of the most dangerous occupations (Government of Ontario, 2015). Major risks for participants, when mining, include: falls-of-ground, mine collapse, fires, and toxic contamination; due to lack of ventilation, all of which mine rescue responds to (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). Considering that these are part of daily operations at a mine, a mine rescue program is an essential part of mining.

Outlined in Ontario Mine Rescue's Training and Recovery Operations Handbook (2014), Mine Rescue as an operation, consists of teams of five to seven members, who respond to mining emergencies. Rescuers are required to carry heavy gear (approximately 100lbs), including a metal stretcher, spare breathing apparatus, hydraulic equipment, and first aid supplies; while wearing personal protective equipment including: self-contained breathing apparatus (SCBA), gloves, helmet, coveralls, boots, amongst others. Underground mine conditions are often characterized by environmental temperatures exceeding 40°C, as well as humidity exceeding 60%, which can impose a dangerous physiological load (Hardcastle, Reardon, Kenny, & Allen, 2009; Kenny et al., 2012; Kenny, Stapleton, Lynn, & Binder, 2009). However, research examining the physical demands, energy expenditure, physical activity levels, stress levels, and recovery time associated with event-specific mine rescue tasks are limited, in part due to the difficulty associated with extracting physiological readings during real-life emergencies (Hardcastle et al., 2009; Kampmann & Bresser, 1999; Kenny et al., 2012).

In 2008, Stewart and colleagues had participants perform three common, mine rescue tasks: shoveling, incremental carries, and hose drags; to replicate physiological measures that may be observed during a real emergency. These tasks had been previously validated work tasks in underground miners utilizing focus group discussions, observations, and surveys; the work-related tasks were then evaluated and validated on incumbent workers (Stewart, Latimer, & Jamieson, 2003). Extremely high heart rate (HR) responses were recorded: above 70-85%, characterized as vigorous intensity, of the Percent Age Predicted Maximal HR (%APMHR), during these tasks (Stewart et al., 2008; "Target Heart Rate and Estimated Maximum Heart Rate," 2015). The *mean* %APMHR across these three aforementioned activities was approximately 91%. The *peak* %APMHR across the three activities was approximately 98%. Shoveling, incremental carries, and hose drags were performed in a circuit where each task was approximately three minutes, totaling nine minutes for the entire circuit. After which, the participants were given minimum of 24 minutes for recovery, which is more than what is normally permitted in a real emergency. Stewart et al. (2008), thus demonstrated concerns for volunteers performing work during real-life emergencies where rest time may be limited; as mean %APMHR of 91% and peak %APMHR of 98% occurred in a simulation with ample periods of rest.

In addition to the high physical demands, as outlined by Stewart et al (2008) above, heat illness (heat exhaustion, cramps, syncope, and stroke) is a major concern for these participants.

Kampmann and Bresser (1999) studied the risk of heat illnesses for mine rescue volunteers during an exercise to simulate a mine rescue emergency. The exercise was designed as an obstacle course in which participants would pull dummies, ascend/descend ladders, reach specific watts on rowing machines, and run; all while wearing standard protective equipment including breathing apparatus. Core temperature (T_c) was assessed over the two hour simulation and peaked at 39.1 ºC. This is clinically significant, as heat illness begins at a T_c of 38 ºC and the risk of heat-exhaustion collapse is about 25% at a T_c of 39.2 °C, associated with a T_{skin} of 38 °C (Jacklitsch, Williams, Musolin, Coca, Kim, & Turner, 2016; Kampmann & Bresser, 1999). Kampmann and Bresser (1999) concluded that mine rescue participants are at significant risk for heat illness during emergency response operations.

Due to the high risk associated with mine rescue and the multivariate situations that can arise during a rescue mission, globally, it is a common practice to host mine rescue competitions annually, to maintain and develop the skills required and to ensure that training is standardized (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). However, it was not until 1998 that the first International Mine Rescue Competition (IMRC) was held. This competition, held biennually, provides an opportunity to share global practices from all mining countries. Between alternating years these best practices are reviewed and discussed by the International Mine Rescue Body (IMRB): a research group with the goal to prevent mine rescue disasters.

In 2015, the Ministry of Labour (MOL) of the province of Ontario conducted a comprehensive, underground mining health, safety, and prevention review; led by Ontario's Chief Prevention Officer (CPO), which identified six key health and safety issues to have the greatest impact on improving health and safety outcomes. One identified issue was: 'Emergency preparedness and mine rescue' (Government of Ontario, 2015b). As underground mining constantly reaches new depth, it raises concerns that it will become more difficult for mine rescue responders to reach these areas during an emergency. Greater depth leads to longer rescues times and exposure to harsher environments (i.e. higher temperature and humidity). Taking this into consideration, the MOL recommended incorporating fitness and competence of volunteer emergency responders into the review. Specifically: general fitness, acclimatization, critical incident stress, impact of new technology, medical skills, training programs/skills competency, and role of mine rescue competitions (Government of Ontario, 2015b). Therefore, Ontario Mine Rescue (OMR), the body responsible for overseeing the training and competency of all mine rescue volunteers, would like to implement fitness testing that would require volunteers to achieve a certain score to be eligible to join Mine Rescue. For example, the Queensland Australian team is required to perform a step test and achieve an estimated $\dot{V}O_{2\ max}$ score of 40 $ml{\bullet}mg^{-}1{\bullet}kg^{-1}$ for eligibility as an active mine rescue volunteer ("Guideline for the Medical Assessment of Mines Rescue Personnel," 2010). However, it is important that any standard developed be criterion-based and validly linked to the critical, life-threatening, physical demands of the job. Specifically, in Canada there are legal requirements, which were implemented by the Supreme Court of Canada known as the "Unified Test," to justify if a fitness standard is suitable (Jamnik, Gumienak, & Gledhill, 2013). The Unified Test is as follows:

1. Is the standard, policy or practice discriminatory and based on a prohibited ground?

2. Was the adoption of the standard, policy or practice rationally connected to the performance of the job?

3. Did the employer adopt the particular standard, policy or practice in an honest and good faith belief that it was necessary to fulfill that legitimate work-related purpose?

4. Is the standard, policy or practice least discriminatory and reasonably necessary to fulfill that legitimate work-related purpose such that it would be impossible to accommodate individual employees without imposing undue hardship on the employer?

*The Unified Test was retrieved from Jamnik et al, (2013).

The assignment of Safe and Efficient policies is the responsibility of the occupation-specific participant-matter experts (OMR). In addition, these standards must take into account the diverse individualities of the participants (age, sex, experience) (Jamnik et al., 2013; Taylor, Tipton, & Kenny, 2014). Such that any physiological standards required be based on the worker's *current* ability to perform the tasks; not, because of health problems that may impact their *future* ability to carry out the tasks (e.g. body composition and over-fatness) (Jamnik et al., 2013). Developing a fitness standard that meets these requirements is problematic given that comprehensive reports detailing the physiological demands of mine rescue participants is limited.

Other than collecting physiology data during an actual mine rescue, the closest approximation to this is a simulated mining emergency. Arguably, the most realistic simulated mine emergency would occur in an underground mine, under stressful conditions. These stressful conditions can be characterized as the high ambient temperatures and humidity, and dealing with simulated emergencies (e.g. fires and wounded casualties). The 10th International Mine Rescue Competition (IMRC) was hosted in August 2016, in Sudbury, ON. Twenty-seven teams from 13 countries took part in the competition, including four Canadian teams. This competition took place in an operational, underground mine and competitors were challenged to four common mine rescue events over a roughly 2 hour time frame: *i)* unconscious victim requiring first aid; *ii)* simulated fire; *iii)* a victim requiring first aid; and *iv)* victim rescue. This simulated rescue was developed by the Chief Mine Rescue Officer and provided an ideal opportunity to collect physiological data that would mimic real life conditions. In comparison to previous studies, this study captures physiological readings in a competition setting, in which demerits are given; real people are used as casualties who can mimic pain; props (e.g. screams, fake blood) are utilized; and spectators are present. In addition, the rescue tasks are performed as outlined in training protocols and subdivided accordingly amongst team members allowing the added benefit of examining role-specific physiological demands. This is important to Ontario Mine Rescue, because anecdotally, there is concern that a too-stringent fitness standard will induce the retirement of the most experienced mine rescue participants. These participants often lead mine rescue teams (captain) and therefore qualifying role-specific fitness standards is important to the organization. In contrast, studies to date have examined few tasks with large amounts of rest, with untrained participants, and did not consider the difference in physical strain between positions. This study will acknowledge physical strain of different and frequent types of tasks, and the difference in requirements amongst positions and determine if risk is greater for particular positions. The study will also utilize a simulated emergency designed by Mine Rescue specialists, in order to mimic real emergency conditions.

Therefore, the purpose of this thesis was twofold: *i)* to provide a detailed description of the physiological demands of mine rescue personnel, including sub-analysis of the physiological data of specific team roles; *ii)* to observe body temperature for the onset of heat strain experienced by mine rescues.

The following chapter will provide a literature review of the process of mine rescue and competitions. In particular, emphasis will be placed on the description of physical demands of mine rescue in the extreme environmental conditions associated with the mining environment. Current practices will be explained and potential areas requiring intervention will be highlighted.

Chapter 2

2.0 Literature Review

2.1 Background Information about Mining

According to the International Labour Organization (ILO) in 2009, while mining employs around 1% of the global labour force, it generates 8% of fatal accidents (Rutter, 2012). It is clear the mining industry is a high risk occupation: the Ontario mining sector reported 945 injuries in 2014, for which, 53 emergency response teams were deployed (*Workplace Safety North Injury Statistics*, 2015). Frequently occurring mining-related accidents include: underground fires, falls-of-ground, mobile equipment collisions, exposure to harmful environments, and falls from heights; all of which often require rescue (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014, *Workplace Safety North Injury Statistics*, 2015). Mine operators rely on mine rescue teams, who have specialized skills in these issues, to save lives during an underground emergency.

Ontario Mine Rescue (OMR) is an organization that is under legislation to provide mine rescue training to all operational underground mines within the province as outlined in the Handbook of Training and Recovery Operations (2014). This involves providing mine rescue training to approximately 25% of employees working at any given mine (e.g. if there are 100 employees, there should be 25 employees that are mine rescue trained). For active duty, mine rescue employees must complete six training sessions throughout the year to maintain and acquire new skills. Further, OMR hosts two competitions annually (district and provincial) to simulate real emergencies to better prepare the rescuers (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014).

2.2 Mine Rescue Team Roles

Mine rescue teams are composed of six members: captain, vice-captain, #2person, #3person, #4person, and the briefing officer (B.O.). In practice, the numbered positions (e.g. #2person) are still referred to as #2-man etc.; however, for the purposes of this thesis, and recognizing women in mining and mine rescue, this thesis has modified the terms to: person.

The Captain is responsible for communication with the B.O. and providing orders to the team. The Vice-Captain is responsible for assisting the Captain with orders, but will also assist other members in laborious tasks (e.g. carrying equipment) (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). Vice-Captain and positions #2, #3, and #4 perform any task that is ordered by the Captain, which may range from first aid amongst casualties to fighting fires (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). Other differences between these highlighted positions are mainly technical and performed prior to proceeding underground. Outlined in the Ontario Mine Rescue Handbook, Vice-Captain field tests the Captain's equipment (e.g. probe stick, clipboard, whistles, etc.); #2person field tests the MX6 (gas monitoring device) and Kestrel (ambient conditions device); #3person field tests first aid kit; and #4person field tests an SSR90 (breathing device). Once underground, the team members are responsible for operating their designated devices. In our description of the physical demands, we did not consider these as it should be understood that differences, if any, in physical demand in operating the devices is miniscule. Ted Hanley, the General Manager of OMR, states (personal communication) that during competition the Captain is responsible for discipline, general safety, and work performed by other members and does not perform work as (s)he can receive demerits for doing so. Due to the executive nature of the Captain's role, it is common for the Captain to be the most experienced member of the team, and thus is often the oldest team member with the most years served as a mine rescue volunteer.

The OMR Handbook (2014) also outlines duties performed by remaining members on the team. They follow direct orders from the Captain and perform any tasks required (e.g. firefighting, casualty care, carrying equipment, etc.), which is normally divided equally amongst the other members. The Briefing Officer (B.O.) is the exception, as (s)he remains on surface during a mine rescue, relaying information to and from the Captain underground, via radio. A component of the B.O.'s duty is to monitor the health of the underground team and (s)he can order the evacuation of the team if the B.O. has reason to believe the health of a team member is compromised. Currently this is done by scheduled team checks: every 20 minutes, during which the Captain verbally 'checks in' with each member and relays a report to the briefing officer. Specifically, the Captain is checking to ensure everyone's breathing apparatus is functioning correctly and to allow the members of the team to rest periodically. Furthermore, the Captain will check and report cylinder pressure for each member and document it; this is to ensure everyone has sufficient oxygen and is fit to continue the rescue (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014).

2.3 Mine Rescue Simulations

Mining accidents can involve a variety of complex issues including, but not limited to: hazardous materials, fires, search and rescue, vertical ascent, and vehicular accidents (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014, *Workplace Safety North Injury Statistics*, 2015; I. B. Stewart et al., 2008). Mine rescue team members are required to commit to regular training to best prepare them for the wide range of potential emergencies (*Handbook of*

Training in Mine Rescue and Recovery Operations, 2014). Mine rescue simulations are an important component of this training to, sharpen skills and test knowledge, particularly given that the literature has shown that workplace simulations enhance learning and memory (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). Training by replicating a frequently-occurring mining emergency or an emergency that has occurred in the past is important to prepare participants for future incidents. Performing these scenarios 'as if they were real' is a useful training method, which helps individuals to react optimally in the event of the real emergency. This also allows opportunity to measure physiological response which may not be feasible in a real rescue. For example, in a real emergency, rescuers do not have time to spare to take subject characteristics or be fitted for a HR monitor prior to responding, additionally, administration of a core temperature pill is not practical as it will not have time to move to the small intestine.

Mine rescue simulations, as a regular practice, have been developed as contests, requiring teams, to solve hypothetical rescue problems while being timed and observed by judges, and according to precise rules. The simulated problem(s) often involve an underground mine setting and typically includes trapped miners who have to be found and rescued under challenging circumstances. The participants are required to carry heavy gear, including a stretcher and first aid supplies, and work while wearing respiratory protective equipment (e.g. SCBA) (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). The B.O., remains on surface and coordinates/monitors the team (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). For example, team members may have to search for victims, while mapping available passageways, building temporary stoppings and ventilating smoke-filled entries; often fire simulations are included, as this is a common mining-related emergency (*Handbook of Training* *in Mine Rescue and Recovery Operations*, 2014). Under competition settings members are conforming strictly to their positions and are typically well prepared (optimally hydrated, ample rest days prior etc.). Arguably, competition-based simulations better mimic a real emergency because performing tasks in a competition setting includes a component of perceived stress and a sense of urgency to perform the tasks, mimicking the stress of real situations (Moharib, 2017; "Volunteer emergency responders collect three awards at provincial competition," 2017).

Ontario Mine Rescue organizes two annual competitions: districts and provincials (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). The seven districts are held in community arenas, in which tarps are used to simulate underground walls and props, such as smoke machines, are used to simulate fire (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). Provincials, on the other hand, have fewer competitors and are conducted in an operational or training mine in the hosting district, but again props must be used to simulate emergencies (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). For example, in 2016 the provincials were held in the NORCAT training mine in Onaping, Ontario and the 2017 provincials were held in Sifto's Salt mine in Goderich, Ontario.

Of note, in the real-world setting, other factors remain unaccounted for during simulations. In particular Mine Rescue participants called to an emergency may not be sufficiently hydrated upon arrival and may already be fatigued from performing work-related or personal tasks, the same day as an emergency. Mine rescue policy does not stipulate exclusion of rescue participants based on personal circumstances during an emergency, but rather relies strictly on whom is first to arrive on site where the event has occurred. Typically, during an emergency, mine management is trying to get a team underground as quickly as possible in order to assess the situation and attempt to find missing miners. Of course it is ideal to have rescuers in top condition (i.e. hydrated and rested), but that is not always feasible and therefore the first to arrive are most likely the first to go underground.

Other differences between these training scenarios and an underground mine emergency include environmental temperature and humidity, which are usually much higher in an operational mine (i.e. exceeding 30^0C and 70% RH) (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014; Kenny, Stapleton, Lynn, & Binder, 2009). Miners underground also experience rough terrain, lack of visibility, particularly in drifts and especially when smoke is present (Kenny et al., 2009). It is difficult to simulate the complete darkness, which exists in the mine setting. However, in recent years Shawn Rideout, the Chief Mine Rescue Officer of OMR, has been organizing competitions in operational underground mines to better simulate the mine-rescue experience. This type of competition provides the most realistic mine rescue simulation possible. Refresher training, performed by Mine Rescue Officers, is also performed in underground mines, for the same reason: to ensure that training is as realistic as possible and that mine rescuers are exceptionally prepared, for an actual emergency. This practice is supported by the literature which shows that simulation training is a key method for improving crisis management (DeVita, Schaefer, Lutz, Wang, & Dongilli, 2005; Jamnik, Gumienak, & Gledhill, 2013; Moharib, 2017).

2.3.1 International Mine Rescue Competition (IMRC)

This concept of 'training through competition' has been a mainstay of mine rescue organizations around the world; but was not practiced in a global competition until 1999, when the inaugural International Mines Rescue Competition (IMRC) was hosted in Kentucky, Illinois ("IMRB : International Mines Rescue Body," n.d.). The initiative for the IMRC came in the aftermath of a mine-rescue tragedy in 1998, which claimed the lives of six Polish mine rescuers during a mission ("IMRB : International Mines Rescue Body," n.d.). The IMRC has since become a biennial event, which facilitates the testing of underground emergency response capabilities across global mining and mine rescue jurisdictions ("IMRB : International Mines Rescue Body," n.d.). The IMRC competitions are hosted through bids, similar to the Olympics. The 2016 IMRC was hosted in Sudbury, Ontario at Vale's 114 ore body; an underground, metalliferous mine. The purpose of the IMRC is to present realistic simulations that will allow organizers to:

1. Evaluate skills required to perform rescue operations in a mining environment.
2. Judge participants in an open and transparent manner.
3. Provide feedback to all participants.
4. Promote a successful rescue through improved collaboration between responders, mine operators, suppliers, regulators, and educators ("IMRB : International Mines Rescue Body," n.d.).

The Poland tragedy, led to the creation of the International Mines Rescue Body (IMRB) ("IMRB : International Mines Rescue Body," n.d.). The IMRB is an informal association, representing mine rescue organizations globally, and also meets biennially, in alternating years between IMRCs ("IMRB : International Mines Rescue Body," n.d.). This Body promotes mine rescue and mine rescue knowledge and practices by supporting global cooperation and by sharing best practice, in part, learned from the IMRCs website (http://www.minerescue.org/).

2.4 Physical Demands of Mine Rescue Participants

Mine rescue is undoubtedly high-risk work, as individuals are required to perform labour-intensive tasks, under extreme ambient conditions, in as little time as possible: mine rescuers are expected to be able to perform for a maximum working time of two hours in emergencies (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014; Kampmann & Bresser, 1999). Therefore, the physical demands of a rescue will put mine rescuers at risk of injury, which may complicate the rescue.

A study performed by Kampmann and Bresser (1999), tracked physiological measures during a two-hour training protocol to determine the physical demands of 52, experienced mine rescue participants. The participants had a mean age of 36.5 years and mean Body Mass Index (BMI) of 26 $kg \cdot m^{-2}$, which according to the Center of Disease Control (CDC) is considered overweight (Bhaskaran, Douglas, Forbes, dos-Santos-Silva, Leon, & Smeeth, 2014; Kampmann & Bresser, 1999). The study mentioned a mean Dynavit score of 109, which indicates a 'good' fitness for this test's scale, which is derived from a submaximal ergometer bicycle test; in other words cardiorespiratory endurance (Kampmann & Bresser, 1999). The 2 hour training protocol, which combines the ergometer bicycle test and job-task simulation, assesses the mine rescuers' physical fitness by employing tests that measured: cardiovascular endurance, muscular endurance, and muscular strength. Tasks included in the protocol were: cycle ergometer, incremental carries, hose drags, and shoveling (Kampmann & Bresser, 1999). These tasks were meant to reflect work required in a real rescue; however, individuals were given scheduled rest breaks, which does not reflect an emergency scenario. For the duration of the training protocol, the mean heart rate (HR_{mean}) was 153 bpm, and core temperature (T_c) peaked at 39.1 °C* (Kampmann & Bresser, 1999).

*Note: A normal resting T_c for adults is approximately 37 ºC (Kenney, Wilmore, & Costill, 2015).

**Note: A normal resting HR for adults ranges between 60-80 bpm. Generally, a lower HR at rest implies more efficient heart function and better cardiovascular fitness. (Kenney et al., 2015).

A study performed by Stewart et al. (2008), who replicated the study above by Kampmann and Bresser (2009), measured health-related fitness by assessing the following attributes: aerobic capacity ($\dot{V}O_{2\ max}$), abdominal endurance, abdominal strength, flexibility, lower back strength, leg strength, elbow flexion strength, shoulder strength, lower back endurance, and leg endurance. They had 91 rescue personnel participate, who were described as average or below average for muscular endurance and estimated $\dot{V}O_{2\ max}$. The tasks performed were the same as above (cycle ergometer, incremental carries, hose drag, and shoveling), but allocated ample resting periods after each circuit of work, which equaled approximately nine minutes of work and 24 minutes of rest. During periods of work, peak heart rate (HR_{peak}) were recorded as high as 184 bpm, and average HRs were 174 bpm (Stewart et al., 2008). These HR are not recommended for extended periods as it will increase risks of overexertion and injury from fatigue, which is usually necessary during a mine rescue emergency (I. B. Stewart et al., 2008). For example, a 34 year old should have a $HR_{max\ predicted}$ of 184 bpm (according to the calculation of 208 – (age x 0.7)) (Stewart et al., 2008; Tanaka, Monahan, & Seals, 2001). According to Tanaka (2001) et al., the previously used $HR_{max\ predicted}$ equation (220 – age) has been shown to underestimate maximum HR in older individuals compared to 208 – (age x 0.7). In reference to the $HR_{max\ predicted}$ of 184 bpm these participants reported HR_{peak} 100% of their maximal heart rate. It is important to note that this is under *experimental* conditions, above ground; during a real emergency they are almost certain to exceed these 9-minutes of work, would have significantly less rest, and would be working under more environmentally- and emotionally-challenging conditions. These two studies were similar in terms of the subject characteristics and use of PPE and breathing apparatus during training; however, Kampmann and Bresser (2009), had their subjects working for approximately two hours with ad libitum rest, opposed to scheduled 24 minute rest observed in Stewart et al (2008). These differences will likely affect how their subjects perform work, for example, if 24 minutes rest is allocated after nine minutes of work, intensity will likely be much higher than performing work continuously for two hours. Therefore, the subjects, tasks, and equipment utilized in Stewart et al (2008) reflected mine rescue; however to truly compare to a real emergency, work-rest schedule should follow that of Kampmann and Bresser (2009).

Another study that examined the physical demands of mine rescue participants was performed by Hardcastle et al. (2009). This study was executed in an operational, metalliferous mine to reflect the environment these participants face, in a real emergency; although the environmental conditions at the time were characterized as 'non-thermally stressful,' to avoid limiting rescuer's performance. The experiment involved ten mine rescue-trained volunteers to perform seven phases of lifting, carrying, and setting down objects; while walking up an inclined ramp and repairing steel piping at shoulder height (weight of steel piping was 87.7 kg and 129.7 kg). The average age of these volunteers was 47 ± 9 years of age and an average BMI of 27.6 $kg \cdot m^{-2}$ and body fat percentage of 19.7 ± 3.9% calculated with the Brozek equation via *skinfold thickness*. During phase 7 of the experiment, the team was required to carry a basket (stretcher and various tools), with a casualty, up the ramp (weight of basket is 141.7 kg) (Hardcastle et al., 2009). Rest periods were set based on the observation of teammates, by the Team Captain. Ascending the ramp with the casualty in the basket required a mean metabolic rate of 538 Watts. These metabolic rates reflect heavy work when referencing the ACGIH (Bernard, 2006), and were under normal environmental conditions (United States Department of Labor, 2016). The subject characteristics amongst the three studies are comparable, except for the age in Hardcastle et al (2009), but all demonstrate trained and experienced mine rescue workers. In reference to average age of the 20 Canadian mine rescue participants that participated in the IMRC was 36.3 ± 6.8 years of age. It should be noted this is a small sample of 898 active mine rescue volunteers in Ontario, and a true value should be determined. Therefore we can infer if experienced and relatively healthy workers (according to BMI and body fat), are at risk, some standard should be considered.

None of the above studies adequately represented a real mining emergency, in particular given that the physical tasks would likely: occur under adverse environmental conditions (i.e. high temperature/humidity), would occur under mental duress, and would potentially pose larger physical demands for individual team members; all of which would have an associated increased risk of injury. Additionally, no study to the authors' knowledge has organized participants by positional role on a team. This is important considering Captains are instructed not to perform physical labour, which may skew the results and underestimate the risk of other team members.

2.5 Importance of Physical Fitness of Mine Rescue Participants

2.5.1 Defining Fitness

The definition of physical fitness is multi-faceted where it can be defined as being healthy, without disease; or the ability to perform work and leisure effectively or efficiently (Caspersen, Powell, & Christenson, 1985; Parker & Worringham, 2004). Mine rescue however, is more focused on the aspect of the ability to safely perform work. Furthermore, fitness encompasses many aspects such as cardiorespiratory endurance, muscular endurance, muscular strength, flexibility, and body composition (Caspersen et al., 1985; Vanhees, Lefevre, Philippaerts, Martens, Huygens, Troosters, & Beunen, 2005). In understanding the physical demands of mine rescue participants, it is reasonable that the mine rescue literature has focused on cardiorespiratory endurance, muscular endurance, and muscular strength. For example, Stewart et al. (2008), measured: muscular strength (abdominal strength, bicep curl, shoulder press, seated row, and deadlift); endurance ($\dot{V}O_{2\ max}$, abdominal endurance (max sit-ups/60 seconds), and lower back endurance (hold low back extension until failure – Biering-Sorenson test); and flexibility (sit and reach test). However, a broader definition of fitness should be examined for the purpose of developing a fitness standard.

In Canada, two types of physiological employment standards are recognized by the Supreme Court of Canada (SCC) and Human Rights legislation: fitness component testing and job task simulations (Jamnik et al., 2013). Fitness component testing involves a fitness standard to screen potential applicants; based on baseline fitness testing (e.g. a set $\dot{V}O_2$ value and set deadlift weight), which would ideally, ensure that a worker would be able to maintain the physical demands of a rescue event. Job task simulations would occur once potential applicants have met the fitness criteria, with standardized training that mimics real-life emergencies (e.g. IMRC), to ensure participants can perform technical tasks and laborious tasks without eliciting dangerous physiological values. This type of hybrid testing will ensure applicants are physically fit and ensure they are able to complete tasks.

To achieve these goals, a clear understanding of the extensive physical demands of mine rescue participants must first be described.

2.5.2 Current Fitness Requirements of Mine Rescue Participants

Currently in Ontario there is no legislation that sets a specific physical fitness standard for active duty amongst Mine Rescue participants; like those seen in Firefighting or Policing. OMR has outlined some basic requirements to begin training as a mine rescuer and to wear a breathing apparatus; although not always enforced as some communities have limited access (T. Hanley, personal communication, December 15, 2017). Outlined in the mine rescue handbook include: an electrocardiogram (ECG), Pulmonary Function Test, complete blood count, and biochemical profile of blood (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). These tests are performed to exclude persons with respiratory or cardiovascular disease due to the risk associated with these diseases when wearing a breathing apparatus (required personal protective gear for a mine rescue). Some communities, with better access to health care facilities, will also perform a stress test, to measure the capability of the heart in terms of workload, heart rhythm, and cardio symptoms experienced under stress (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). The stress test is not mandatory, particularly since many rural communities do not have access to the laboratory equipment and team to perform it (T. Hanley, personal communication, December 15, 2017). However, using a normative standard will create gender bias, because typically males have higher $\dot{V}O_{2\ max}$ values compared to females due to physiological and biological differences. For example, in 1994 a female wildland firefighter experienced undue hardship because of implementation of a normative standard of $\dot{V}O_{2\ max}$, which she nor other females could not achieve despite being able to perform the required work for years prior (Jamnik et al., 2013). Therefore, consideration when developing criteria for a standard must follow the "Unified Test" by the Supreme Court of

Canada so there is no undue hardship caused due to discrimination and current ability to complete the task (Jamnik et al., 2013).

Prior to becoming an active mine rescue volunteer, a worker must complete a five day introductory course, in which the last two days involve scenario-based training in an underground mine. These two days are informal and do not document any physiological readings, but rather is contingent on whether or not the worker feels comfortable wearing the breathing apparatus and is able to complete a mock rescue. The mock rescue typically involves locating a casualty in an underground mine, performing first aid, and then carrying the casualty out of the mine; this normally lasts approximately two hours. This is considered to be the final test, which confirms that the individual is capable of performing a rescue under realistic conditions; however, no physiological monitoring is done, and participants might be at risk of overexertion during this trial (T. Hanley, personal communication, December 15, 2017).

Some mining companies have gone beyond the requirements outlined in the Mine Rescue Handbook and have implemented further requirements, for example, Glencore Canada, requires a Stage 1 bicycle test (a submaximal cycle ergometer test) to estimate $\dot{V}O_{2max}$, a measure of cardiovascular and aerobic fitness. However, they were unwilling to disclose their threshold value.

Globally, other organizations implement fitness testing similar to Glencore's, in which a $\dot{V}O_{2\ max}$ test, with a set threshold value is used to screen potential mine rescuers to remain active. For example, Queensland, Australia implements the step-test to determine estimated $\dot{V}O_{2\ max}$, and have a threshold value (40 ml•kg^{-1}•min^{-1} for men and 35 ml•kg^{-1}•min^{-1} for women) to remain active. The difference between male and female is due to the different equations used (Men: 111.33 – (0.42 x HR); Women: 65.81 – (0.1847 x HR), based on the difference in physiology (e.g. males having larger hearts to pump more blood and larger lungs to take in more oxygen) ("Guideline for the Medical Assessment of Mines Rescue Personnel," 2010, "VO2 Estimation Method Based on Heart Rate Measurement," 2005). Furthermore, Germany monitors rescuers during a two hour training protocol where they are evaluated based on performance and deemed active/ non-active accordingly (Kampmann & Bresser, 1999).

2.6 Heat Stress and Mine Rescue

A global, mine rescue concern is heat illness during an emergency response. In fact the tragedy that led to the development of the IMRB and IMRC was due to heat-related deaths ("IMRB : International Mines Rescue Body," n.d.). Mine rescue participants are at high risk of heat illness for several reasons. First, because they are volunteer responders, they may be requested to attend to an emergency during or just after their regular job duties; mine rescue volunteers are miners by profession, (e.g. operators, drillers, and others) and emergencies often demand the volunteers closest-to-hand and of first response, irrespective of current/recent activities (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). Secondly, given that many mine occupations involve working in these hot/humid conditions with aspects of physical labour, a volunteer rescuer may enter an emergency scenario under-hydrated, with an elevated T_c and physically fatigued. Furthermore, these factors are amplified during a mine rescue as participants are required to wear extensive personal protective equipment (e.g. Self-Contained Breathing Apparatus (SCBA), gloves, helmet, coveralls, boots etc.), participate in moderate-to-high levels of physical exertion, abstain from water, and face potentially stressful challenges (e.g. injured participants, fires, and others), all of which can contribute to heat accumulation and put the individual at risk for heat illness (*Handbook of Training in Mine*

Rescue and Recovery Operations, 2014; Varley, 2004). In Canada, the growing need to combat worker heat exposure in mines, as a function of increasing mine depth, is becoming an increasingly important issue. For example, Miners in Sudbury confront rock temperatures of approximately 50°C at 2,400 meters and approximately 42 °C ambient temperature in drifts, at Vale's Creighton Mine (Scales, 2002; Tollinsky, 2008). For mine participants, acclimatization to their working conditions is a process that transpires over several days, allowing the worker to adjust to underground temperatures (Hardcastle, 2006; Karlsen, Nybo, Norgaard, Jensen, Bonne, & Racinais 2015). In contrast, mine-rescue missions undertaken at depth, limit the potential for acclimatization, and are further exacerbated by the physical demands of the rescue itself. For this reason, mine rescue volunteers who are acclimatized to these temperatures prior to an event should be able to function more effectively (Hardcastle, 2006; Karlsen et al., 2015). Although Ontario Mine Rescue has adopted criteria for limiting mission duration to prevent heat-related events, there is still concern that this strategy alone is not enough to ensure responders are sufficiently protected.

Heat stress is defined as the net load to which a worker may be exposed, and heat strain is the physiological response to heat stress (Hardcastle, 2006; Donoghue, 2004; Xiang, Bi, Pisaniello, & Hansen, 2014). When the human body is thermally neutral, the T_c is approximately 37°C, and is said to be under normal homeostatic conditions (Buller, Tharion, Hoyt, & Jenkins, 2010; Kenney et al., 2015; Taylor et al., 2014). When the body is exposed to increasing ambient temperatures, such as those experienced in underground mining, this thermal balance is disrupted. Heat stress causes T_c to increase, in turn causing the body to respond by activating heat loss mechanisms, such as vasodilation and sweating in attempt to reduce T_c (Buller et al., 2010; Kenney et al., 2015; Taylor et al., 2014). Failure to reduce T_c to normal ranges causes a state of hyperthermia (e.g. higher than normal body temperature), which may progress into heat-related illness such as: heat cramps, heat syncope, heat exhaustion, and heat stroke (Buller et al., 2010; Kenney et al., 2015; Taylor et al., 2014). Heat cramps are painful, brief muscle cramps that occur during or after exercise or work in a hot environment. Muscles may spasm or jerk involuntarily. Cramping may also be delayed and occur a few hours later and is considered the mildest form of heat illness (Kenney et al., 2015; Donoghue, 2004). Heat syncope or fainting occurs when your body, in an effort to cool itself, causes the blood vessels to dilate to such an extent that blood flow to the brain is reduced (Kenney et al., 2015; Donoghue, 2004). Symptoms of heat exhaustion may include heat cramps and heat syncope, heavy sweating and a rapid pulse, weakness, nausea/vomiting, headache and light headedness. Heat exhaustion can progress to heat stroke, where temperature regulation fails (Kenney et al., 2015; Donoghue, 2004). Heat stroke is considered the most serious of heat-related illnesses and can be defined as having a T_c equal to or greater than 40 °C ("Heat Stress | Ministry of Labour," 2008; Taylor et al., 2014). If heat stroke is not identified and treated immediately it can cause systematic inflammation, multiple-organ failure, or even death (Lim, Byrne, & Lee, 2008). When referring to the literature surrounding mine rescuers and heat strain as described by Hardcastle et al (2009), it is evident rescuers experience increased T_c and likely are at high risk of developing the aforementioned heat illnesses. However, the conditions of the Hardcastle et al (2009) study are approximately an hour and do not capture the conditions during a fire. Therefore, our study will attempt to replicate a real emergency in all aspects (e.g. high ambient conditions, approximate time, PPE, and tasks) to describe the risk of these rescuers adequately.

Heat illness can be measured by T_c and HR, or understanding the symptoms. According to Davies and Maconochie (2009), for each degree increase of body temperature HR increases 10 beats per minute on average. There are multiple other ways to understand the relationship between HR and T_c, for example, as the body temperature increases blood is pushed to the extremities of the body in an attempt to reduce the internal temperature (Lim et al., 2008; Taylor et al., 2014). Therefore, this will increase ones HR to meet the demand of the blood moving to the extremities of the skin. As for T_c, heat strain normally begins at a T_c of 38ºC, and heat stroke is characterized at 40 ºC ("Heat Stress | Ministry of Labour," 2008; Taylor et al., 2014). Since understanding the relationship between these when measuring T_c is not feasible; visible symptoms such as flushed and red skin should be of focus (Kenney et al., 2015; Lim et al., 2008).

It is important to note: mine rescue participants are emergency responders and if they are unable to perform the rescue, the consequences are life-threatening for themselves, their team members, as well as the casualty they are responding to. Therefore, interventions to monitor physiological and behavioural cues are warranted in harsh environments at rest and during physical activity to identify and prevent temperature-related illness for those at highest risk.

Currently, speaking with General Manager Ted Hanley of OMR, mine rescue organizations locally and globally do not have a system on how rescuers identify or measure injury risk, there are many fatalities that have occurred, but this data is not accessible (T. Hanley, personal communication, May 15, 2017). Furthermore, there are minimal safety features provided to mine rescue participants and instead they rely on self-reports of injury, and/or team members to recognize symptoms (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). However, with the extensive personal protective equipment worn, it is difficult to identify visible symptoms of heat illness such as flushed skin, excessive or no sweating, and/or shortness of breath (Varley, 2004; Xiang et al., 2014). Personal body-worn monitors for each team member, during an emergency response, have been suggested for use, to alleviate the need to rely on self-reports or visible symptoms and may provide timely and meaningful indicators of heat illness, which could avert a secondary emergency (e.g. when the mine rescue team requires rescue). However to date, no research has been done examining these devices in a mine rescue environment.

2.6.1 Thermoregulation

T_c, is defined as the temperature of the deep structures of the body, such as the liver (Cheung, 2010; Hardy, 1961; Kenney et al., 2015). T_c is normally maintained within a narrow range so that essential enzymatic reactions can occur (Cheung, 2010; Hardy, 1961; Kenney et al., 2015). In static conditions the internal homeostatic mechanisms (e.g. shivering, sweating, blood vessel dilation and constriction) keep a relatively stable internal T_c of approximately 37 °C (Cheung, 2010; Hardy, 1961; Kenney et al., 2015). Total body temperature however is not uniform; typically temperature decreases as measures become closer to the peripheral tissues (e.g. skin), with lowest temperatures normally found in the extremities (Kenney et al., 2015). Significant T_c elevation (hyperthermia) or depression (hypothermia) is related to increased temperatures across body structures; however, prolonged T_c change is incompatible with human life (Cheung, 2010; Hardy, 1961; Kenney et al., 2015).

The Heat Regulation Model describes the overall homeostatic net balance of heat gained versus heat lost as the principle variable, whereas T_c is a secondary result of the body's attempt to regulate overall heat balance (Jacklitsch, Williams, Musolin, Coca, Kim, & Turner, 2016). In other words, the model does not propose a set T_c, but is more concerned with heat production equaling heat loss (Jacklitsch et al., 2016). For example, when an individual performs work, heat production starts immediately and heat loss mechanisms lag behind (Jacklitsch et al., 2016). This explains why individuals can perform work with elevated T_c, but once these heat loss mechanisms equal the heat production, T_c will plateau (Jacklitsch et al., 2016). Once work ceases, again the decline of heat loss mechanisms will lag behind, allowing T_c to returning to pre-work conditions (Jacklitsch et al., 2016).

Heat regulation operates via negative feedback mechanisms (Jacklitsch et al., 2016). That is when the body temperature decreases; internal systems are activated to increase heat production. Conversely, when body temperature increases, internal systems are activated to induce heat losses, to lower temperature.

The reciprocal inhibition of thermoregulation model proposes that thermal stimuli will induce an increase in skin and T_c, thus activating heat loss effectors (e.g. sweating) and inhibiting heat gain effectors (e.g. shivering) (Cheung, 2010). Four strategies are employed to reduce T_c in an attempt to prevent hyperthermia: radiation, evaporation, conduction, and convection (Hardy, 1961; Kenney et al., 2015). When the internal organs and body's T_c increases, a thermal gradient is produced, such that heat is greatest at the center of the body (Hardy, 1961; Kenney et al., 2015). Blood circulating between gradients can therefore allow a mechanism of heat transference from the deep tissues to the extremities (Hardy, 1961; Kenney et al., 2015). Normally, the temperature of the extremities, including the skin is warmer than the external environment and another thermal gradient exists with ambient temperature, and thus heat is allowed is transferred via radiation from the body to the air (Cheung, 2010; Hardy, 1961; Kenney et al., 2015).

The two main mechanisms of thermoregulation include radiation and perspiration, which are also greatly reduced in hot and humid environments (Díaz & Becker, 2010; Sessler, 2008).

Radiation accounts for the majority of heat loss 60% of thermoregulation by the body and works by a thermal gradient between the skin and ambient temperature. The blood vessels and capillaries near the skin increase in size and the heart beats faster to increase the blood flow to the skin. Heat is then lost in the form of infrared and electromagnetic waves; thermal protective clothing can inhibit this. It is important to note that radiation is only successful as a heat-reduction method, when the T_{skin} exceeds ambient temperatures. If ambient temperature is high, as is often the case in mining underground, radiation may be impeded (Díaz & Becker, 2010).

Evaporation accounts for approximately 25% of thermoregulation and works via sweat production, via eccrine glands secreted on the surface of the skin (Díaz & Becker, 2010). The skin will begin to produce sweat at almost precisely 37 ºC (remember T_{skin} is typically less than T_c). Perspiration rate increases rapidly with increasing T_{skin} and this cooling effect is due to the large effect of 'heat of vaporization of water (Díaz & Becker, 2010; Lim et al., 2008). At normal T_{skin}, 580 calories/gram of sweat is lost as heat (Jacklitsch et al., 2016). Heat is lost via evaporation when heat travels to the skin to elicit sweating, this sweat turns to water vapour (Díaz & Becker, 2010). Miners and mine rescue workers are wearing extensive personal protective equipment and heat loss is severely inhibited, for example the sweat is absorbed by clothing, and the person won't benefit from the cooling mechanism of evaporation.

In dry ambient conditions sweat evaporates quickly, and thus heat lost is rapid (Díaz & Becker, 2010). Conversely, in humid ambient conditions, such as underground mines, air is saturated with water, and the ability for sweat to evaporate is significantly hindered; this explains why people 'feel' much hotter in humid conditions (Kenny et al., 2009). In addition, clothing that soaks up the sweat will impede the body's ability to cool and increase the risk of heat illness. Therefore humidity interacts with temperature, such that high environmental humidity is as problematic as high environmental temperature. Underground conditions implement a heat index which incorporates temperature and humidity.

Notably as sweat is largely water, hydration is a key factor for heat loss through evaporation. Guyton (1971) reported that normal perspiration rate is about 1.5 liters/hour and with acclimatization, this can reach 3.5 liters/hour. This is particularly problematic for mine rescue participants, whose hydration is limited during a rescue: this may impact their risk for heat illness (Kenny et al., 2009; Xiang et al., 2014). Therefore miners and mine rescue workers need to be sufficiently hydrated, as inadequate hydration will limit the body's ability to produce sweat and ultimately cool itself.

2.7 Personal Conditioning and Heat Stress

Individuals performing work or exercising in hot ambient conditions will likely exhibit fatigue before compared to those performing in normal ambient conditions (González-Alonso, Teller, Andersen, Jensen, Hyldig, & Nielsen, 1999; Prieto, González, Del Valle, & Nistal, 2013). Findings by González-Alonso (1999) et al., determined fatigue were related to high body temperature. Furthermore other factors such as dehydration, training status, heat acclimation, and environmental conditions, as well as duration and intensity of exercise, might interact and alter the tolerance to hyperthermia (González-Alonso et al., 1999; Prieto et al., 2013).

2.7.1 Role of Fitness in Heat Stress

The literature suggests that short-term, aerobic training is relatively ineffective in conditions of intolerable heat stress; that is, conditions where the body is unable to maintain a thermal steady state, as in deep underground mining (Cheung, 2010; Selkirk & McLellan, 2001).

However, long-term improvements in physical fitness appear to provide some degree of protection, as it has been found that greater aerobic fitness allows individuals to reach higher T_c prior to exhaustion (Selkirk & McLellan, 2001). For example, González-Alonso et al. (1999) states individuals with greater aerobic fitness are better able to tolerate heat strain (T_c of 39.2 °C vs. 38.8°C) while performing exercise in hot environments to exhaustion. In addition, individuals with higher proportions of body fat have a lower heat tolerance because of increased capacity to store heat (Cheung, 2010; Selkirk & McLellan, 2001). Therefore, it is reasonable to assume that those who engage in regular physical activity will be more conditioned and better able to tolerate internal heat increase.

2.7.2 Heat Acclimatization

Heat acclimatization is defined as a complex series of physiological changes or adaptations that occur in response to heat stress in a controlled environment over the course of 7 to 14 days (Hardcastle, 2006; Karlsen et al., 2015). These adaptations are beneficial to exercise in the heat and allow the body to better cope with heat stress (Hardcastle, 2006; Karlsen et al., 2015). When the body is not properly acclimatized it is less efficient in thermoregulation and people are therefore more susceptible to heat stress (Karlsen et al., 2015; Stolwijk, Roberts, Wenger, & Nadel, 2012). It is important to note that heat acclimatization can be lost after only a few days, typically three to five days (Karlsen et al., 2015). This becomes relevant for those miners who work camp jobs where a rotation of three weeks at the work site and one week at home, these individuals can lose their acclimatization to heat during the off-period.

An experiment performed by Karlsen et al. (2015) observed that the body adapted to high ambient temperatures by moderating physiological measures. This study observed nine trained cyclists, who underwent a two-week heat acclimation procedure. Participants exercised at an intensity of 140 Watts, which is the equivalent to moderate level activity ("Target Heart Rate and Estimated Maximum Heart Rate," 2015), in order to determine the effects of two weeks of acclimatization on power output and physiological measurements. Results demonstrated lower levels of power output and physiological performance at the beginning of the two-week period compared to only 6 days later. Therefore, when considering the results from the Karlsen et al., (2015), heat acclimatization is an important aspect to consider for mine rescue participants performing as acclimatization will reduce the time until exhaustion in hot conditions, and improve physical performance. Also important to note, the researchers followed up post study at 3-4 days and 10-11 days, and it was found that heat acclimation was lost after a mere 3-4 days and were nearly back at starting levels 10-11 days following heat acclimation. Therefore, it is also important consideration whether mine rescue participants need to continuously maintain heat acclimation as a component of safety for their job.

A recent study evaluated heat exposure on firefighter work performance and physiology, carried out by Larsen, Snow, Vincent, Tran, Wolkow, & Aisbett (2015), This study separated participants based on conditions; control conditions were 19 °C, 58% Relative Humidity (RH); and hot conditions were 33 °C, 40% RH. Participants were required to wear firefighting protective equipment, which is similar to mine rescue gear (e.g. helmet, gloves, boots, etc.), except firefighting coat and pants are heavier. Work circuits included 55 minutes of work followed by 20-25 minutes of physiological data collection, 20-25 minutes of cognitive testing, and 15-20 minutes of rest. Work involved common firefighting tasks such as charged hose advance, hose rolling, raking materials, and others. Reported measures of interest include work performance (measured in meters travelled), T_c, HR, and rating of perceived exertion, as these indicated heat had a significant impact on work performance. Of these measures only T_c was significantly different between trials where the mean T_c was 0.24 °C higher for individuals in the hotter conditions (HOT) trial. The control group had a higher perceived exertion for the majority of tasks performed. It was found that participants in the HOT group would rotate tasks and take more frequent breaks. The results from Larsen et al. (2015) demonstrate these strategies were effective in lowering the risk of heat strain in firefighters, and considering mine rescuers have similar occupation, these results can be extrapolated to mine rescue.

2.8 Wearable Technology

2.8.1 Equivital LifeMonitor^{TM} (Hidalgo, UK)

The Equivital body worn monitor (Hidalgo, UK) collects and transmits several readings, but those of interest for this thesis include: T_c, HR, heart rate variability, and respiration rate (RR) (*Equivital User Guide*, n.d.). These variables demonstrate physical demand based on previous literature by Stewart (2008) et al. The monitor includes a chest strap, which houses a pocket for a Sensor Electronic Module (SEM). The SEM is responsible for storing all the data measured and has a built-in tri-axial accelerometer which can be used to derive other measures with this device (i.e. motion and body position) (*Equivital User Guide*, n.d.). The SEM also has an infrared thermometer that is responsible for measuring T_{skin} at a fixed location under the armpit (*Equivital User Guide*, n.d.; Liu, Zhu, Wang, Ye, & Li, 2013).

The belt component has a two-lead Electrocardiogram (ECG), meaning it reads the electrical activity of the heart at two separate positions (chest and abdomen). The ECG is responsible for collecting cardiovascular data, including HR and rhythm of the heart (HRV) (*Equivital User Guide*, n.d.; Liu, Zhu, Wang, Ye, & Li, 2013).

Using the T_{skin} and ECG measures, the manufacturers have developed an algorithm to estimate T_c. This algorithm has been shown to be a reliable and valid method in comparison to an ingestible T_c pill; Liu et al (2013) reported the mean difference between methods was relatively low (<0.1°C) between methods, and Equivital predicted slightly lower T_c on average.

The RR can be recorded via thoracic expansion of the belt or ECG derived; however, the expansion-derived RR is considered the gold standard for Equivital's system, as the ECG derived RR may be prone to noise during ambulation (*Equivital User Guide*, n.d.; Liu et al., 2013). According to Liu et al (2013), the mean difference for RR was not significantly different from zero for validity and reliability for all testing.

These measures have confidence thresholds that will allow the user to know how precise the readings are, which may also be predetermined by the user (e.g. confidence level 90% for all readings) (*Equivital User Guide*, n.d.; Liu et al., 2013). Additionally, the software program associated with the device provides alerts and indications if physiological measures exceed pre-defined boundaries based on the participant's anthropometric measurements.

The Equivital Life monitors can therefore continuously measure and record physiological data for mine rescuer personnel during a rescue response. In principle, this information would be provided in real-time to the Briefing Officer to relay information to the Captain, regarding the health of the team.

2.8.2 Vitalsense™ (Respironics, US) T_c Capsule

There are multiple methods to measure T_c; the most commonly employed in research are: esophageal, rectal, oral and tympanic. These can be sub-categorized as invasive or non-invasive (Taylor et al., 2014), with the more accurate measures being increasingly more invasive. The majority of research suggests pulmonary artery or esophageal temperatures as the gold standard, and is also used to assess the accuracy and validity of various other methods for measuring T_c (Casa, Becker, Ganio, Brown, Yeargin, Roti, Segler, Blowers, Glaviano, Huggins, Armstrong, & Maresh, 2007; Easton, Fudge, & Pitsiladis, 2007; Taylor et al., 2014). However, this is the most invasive method and is impractical for use during physical activity or obtaining measures in the field (i.e. workplace) (Stolwijk, Roberts, Wenger, & Nadel, 2012; Taylor et al., 2014). Anecdotally, having asked some mine rescue participants their position on this method; they have indicated that they would not volunteer for this method, particularly during emergency circumstances.

A novel method for measuring T_c is the thermometric pill, produced by Vitalsense. The thermometric pill is an ingestible thermometer with blue-tooth technology, designed to be continuously measure temperature and relay this data, via Bluetooth, to a secondary device; thereby recording internal temperature throughout its transit time through the participants' digestive tract (~8-12 hours, but will stop recording measurements following the competition).

This method is not considered invasive, but it requires participants to ingest a pill-like device that emits a radio wave signal that is sent to a small external receiver (Casa et al., 2007; Taylor et al., 2014). Multiple studies suggest this method of measuring T_c may be influenced by its placement within the gastrointestinal tract or its interaction with food or fluid in the body (Bridges & Thomas, 2009; Casa et al., 2007; Taylor et al., 2014). For example, consumed fluids may heavily influence readings, and thus researchers attempt to have participants avoid consuming fluids during active monitoring sessions (Taylor et al., 2014). This "after-drink" effect was evaluated in a study where they tracked gastrointestinal temperatures following hourly drinking (Taylor et al., 2014). It was determined that consuming cold fluids caused an error in measurement for up to 32 minutes following and thus fluids should be limited or absent when using this method (Taylor et al., 2014). This is likely due to the telemetry pill residing in the stomach, and thus this can be avoided by using the pill as a suppository (Bridges & Thomas, 2009; Casa et al., 2007; Taylor et al., 2014). However, this is not without error, as it can become lodged in the stool and yields inaccurate measures of T_c (Casa et al., 2007; Taylor et al., 2014). Despite these potential errors, Easton et al. (2007) determined that T_c from a thermometric pill did not provide significantly different results from rectal temperature under rest conditions. Furthermore, the telemetry pill provided more accurate results under dynamic conditions when compared to rectal and esophageal temperature (Bridges & Thomas, 2009; Easton et al., 2007).

Although there is a risk of inadequate readings, a study performed by Easton et al. (2007), suggests it is one of the more favourable methods when measuring T_c. This is because ingestion of the pill does not cause the participants any discomfort, and allows for monitoring of T_c for up to 12 hours, or until it is excreted (Easton et al., 2007; Steck, Sparrow, & Abraham, 2011). Easton et al (2007) also determined measuring T_c by the telemetry pill provides reliable measures, which are statistically similar to both rectal and tympanic measures in stable conditions and esophageal during dynamic conditions. In addition, telemetry was able to detect changes in temperature better than both esophageal and rectal measurements during dynamic environments (Casa et al., 2007; Easton et al., 2007).

A major issue with this method is that it cannot be used to identify hyperthermia immediately and readings are only retrievable after approximately two hours after ingestion (Hardcastle et al., 2009). A study involving mine rescue trained personnel by Hardcastle et al. (2009), had participants ingest the pill and they started recording measurements two hours following. Their claim is the metabolism of this cohort is above-average and the pill would be digested quickly enough to enter the lower intestine and provide accurate readings after two hours. This method can be an excellent preventative measure against heat stress and illness for mine rescue participants in extreme environments. With that being said, it is an expensive method, in which it would be undesirable for experiments with a large sample (Taylor et al., 2014). Therefore, research suggests that the thermometric pill, to determine T_c, is an accurate and reliable measurement. Furthermore, it provides similar results to rectal temperatures under stable conditions, and esophageal under dynamic conditions, which suggests its validity (Casa et al., 2007; Easton et al., 2007).

2.9 Physiological Measurements Related to High Demand Activities and Heat Strain

2.9.1 Heart Rate Variability (HRV)

HRV can be defined as the variation in time intervals between consecutive heartbeats (Karim, Hasan, & Ali, 2011; Kazmi, Zhang, Aziz, Monfredi, Abbas, Shah, Kazmi, & Butt, 2016). Thus, HR and HRV are understood to have an inverse correlation, as HR increases, HRV decreases (Kazmi et al., 2016). HRV analysis can provide an understanding of the activation of the autonomic nervous system (ANS), more specifically the physical stress endured by participants during a simulated mine rescue. The ANS is the part of the nervous system associated with non-conscious functions such as breathing and HR (Camm, Malik, Bigger, Breithardt, Cerutti, Cohen, Coumel, Fallen, Kennedy, Kleiger, Lombardi, Mallani, Moss, Rottman, Schmidt, Schwartz, & Singer, 1996; Karim et al., 2011). The ANS can be further categorized into parasympathetic (rest and digest) and sympathetic (fight or flight) processes (Camm et al., 1996; Karim et al., 2011). Thus, variation in time between heartbeats indicates fluctuations in the activation of the parasympathetic and sympathetic (Camm et al., 1996; Karim et al., 2011; Kenny, Periard, Journeay, Sigal, & Reardon, 2003). Analysis of HRV provides a ratio of high frequency (HF) and low frequency (LF) waveforms, which indicate which branch of ANS is activated. Increased LF indicates periods of moderate-intense work and mental stress, whereas HF indicates periods of rest.

As HRV is inversely correlated with heart rate, results can be derived from real-time monitoring of HR and following current guidelines set by ACGIH (Karim et al., 2011). Although HRV monitoring would be more difficult than HR and T_c to practice in real-time monitoring, detailed analysis can provide desirable values for work intensity and risk of overexertion of mine rescuers during emergencies. Thus the Equivital documents the real-time HR and HRV data, which can be examined at a later date.

2.9.2 Heart Rate

HR is the measure of the number contractions of the ventricles of the heart in one minute (Kenney et al., 2015). This measure reflects both metabolic heat production and amount of blood directed toward the skin to dissipate heat (Kenney et al., 2015). HR is frequently used to indicate intensity and strain during physical activity (Kenney et al., 2015). For example, in reference to the general population, sustained HR levels associated with excessive heat strain can be calculated as 180 bpm minus the person's age; whereas, people who engage in cardiovascular training regularly, can be calculated as 220bpm minus the persons age (Varley, 2004). Thus, a cardio-conditioned person aged 22 years; would be estimated to have a maximum HR of 198 bpm (Varley, 2004). Although a more current and frequently equation used is 208-age x 0.7 that is meant to be more accurate, as it does not underestimate $HR_{max\ predicted}$ in older adults stated by Tanaka et al (2001). A meta-analysis performed with 351 studies and a total of 18 712 participants, the previous equation (220-age) underestimates HR_{max} in older adults, and the equation 208-age x 0.7 strongly correlated HR_{max} with age (r=0.9) (Tanaka et al., 2001). As our group deals with older adults, the equation 208-age x 0.7 is suitable for our sample population.

The American Conference of Governmental Industrial Hygienists (ACGIH) is the professional organization responsible for establishing the Threshold Level Values (TLVs) for chemical substances, physical agents and Biological Exposure Indices (BEIs) (Ave, 2014; Jacklitsch et al., 2016). The ACGIH have established a standard for heat strain, which is assessed by observing 'recovery heart rate,' that is: the HR must be a maximum of 110bpm after one minute of rest (Varley, 2004). Standard mine rescue operations require team checks at intervals not to exceed 20 minutes (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). Before putting on the breathing apparatus and at each team check, each rescuer's resting HR should be checked (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). The rest period should be extended until all team members have resting heart rates no more than 10% greater than their previous check or 110bpm, whichever is less (Varley, 2004). If any team member cannot obtain these levels within a reasonable time retreat is required. Although useful, HR does vary significantly between individuals based on: age, physical fitness, and hydration, and thus is not always a reliable method (Kenney et al., 2015; Prieto et al., 2013).

HR is a common variable used to track physical strain as observed in several studies involving mine rescue participants (Kampmann & Bresser, 1999; Stewart et al., 2008). A study performed by Kampmann and Bresser (1999), utilizes HR via ergometry in order to raise HR to 200 – age, as a means to represent the physical strain of a mission. Forty of the 52 participants surpassed a HR of 200 – age, and 15 of these participants surpassed a HR of 220 – age. These demonstrate a vigorous physical activity with supra-maximal values achieved at times during the mission. The study concluded that mine rescue work is considered the upper limit of tolerable strain, and advised these participants to increase their physical fitness in order to be able to tolerate this strain. If they cannot tolerate this level of physical strain they risk overexerting themselves, as well as putting the casualties at risk. In another study, performed by Stewart et al. (2008), they confirmed these results by reporting HR values nearing approximately 100% APMHR. For example, during the task of hose drags, which is a common mine rescue task, the mean HR_{peak} for 79 participants was 183 bpm (the age predicted max HR for the sample was 184 bpm), therefore translating to 98% of their APMHR (Stewart et al., 2008). These studies demonstrate the stress on cardiovascular endurance during these training sessions and therefore during real life emergencies. With little rest during real-life emergencies, it is unlikely that these participants would be able to meet the ACGIH standards of a HR recovery of 110bpm in one minute of rest, since heart rates are peaking at 183 bpm.

Kenny et al. (2009) states mine rescuers are at a much higher risk of heat strain, as they are required to wear extensive PPE and thus. Kenny et al. (2009) study also supports the importance for heat strain interventions for mine rescue participants, such as safety devices to monitor T_c and HR to avoid overexertion.

2.9.3 Body Temperature

T_c represents the temperature of deep internal structures such as the organs (e.g. liver) (Díaz & Becker, 2010; Hardy, 1961; Kenney et al., 2015). For normal, internal processes to continue, the internal temperature of the body must stay within a narrow range of approximately 36.5-37.5 °C (Díaz & Becker, 2010; Hardy, 1961; Kenney et al., 2015). Individual values may differ somewhat, based on anthropometric factors (e.g. age, body fat%, etc.) (Kenney et al., 2015;

Prieto et al., 2013). Elevations and declines in T_c activate internal heating or cooling mechanisms to maintain homeostatic conditions (Kenney et al., 2015; Prieto et al., 2013). The ACGIH have guidelines to prevent T_c from exceeding 38°C when performing work (Hardcastle et al., 2009). These guidelines must be revaluated as T_c of mine rescue personnel have been documented to reach 39.1 °C (Kampmann & Bresser, 1999).

T_c is an effective measure to predict wellness of individuals when performing work. However, an effective method to continuously monitor T_c is difficult in field-testing as well as real emergency.

T_c of 38 °C is associated with an impaired ability to make decisions, and impaired reaction time (Racinais, Gaoua, & Grantham, 2008; Sessler, 2008). Furthermore, at a T_c of 38.6 °C and above, physical heat strain has begun and, if not mitigated, will progress to acute heat illness and eventually the life-threatening condition of heat stroke (Sessler, 2008). In a study performed by Gonzalez-Alonso et al (1999), trained participants cycling at a workload of 228 Watts, characterized as moderate workload (Bernard, 2006), until exhaustion were assessed to determine if exhaustion occurred at the same critical level of T_c in intolerable heat (40 °C; 19% RH – corresponds to a WBGT of 31 °C) ("Wet Bulb Globe Temperature Monitoring," n.d.; Wilson, 2005). It was determined that all participants fatigued at approximately 40 °C, regardless of initial T_c (Wilson, 2005). For example, individuals with a starting T_c of 37.4 °C (control – no intervention) fatigued at a mere 46 minutes (Wilson, 2005). Given that mine rescue participants, are wearing extensive PPE and may be performing bouts of work ranging from 400 Watts to 700 Watts, it can be assumed they will produce heat at a faster rate and experience levels of heat strain more rapidly than the aforementioned study (Tomaskova, Jirak, Lvoncik, Buzga, Zavadilova, & Trlicova, 2015). Importantly, in an emergency situation participants are typically allocated two hours for each mission, significantly longer than the 46 minutes measured by Wilson (2005), highlighting the risk for that majority of participants will experience heat strain and have difficulty sustaining physical demands before completing the mission. Given that these individuals are responding to an emergency and therefore stopping before the completion of their mission is undesirable, T_c monitoring may be a useful tool to identify the onset of heat strain during a rescue event. Real-time monitoring of the T_c of mine rescue participants during a rescue has not been reported in the literature.

T_{skin} is also considered an important index to understand physiological increases in body temperature. By observing changes in T_{skin} over the period of a mine rescue, we might better understand the influence of ambient temperature and humidity, and potentially the effect of personal protective equipment on the body's ability to cool itself (Taylor et al., 2014). For example, if we observe an increase in T_c, we are likely to observe an increase in T_{skin} before and during this period of increase. Therefore, when considering both T_c and T_{skin} we will be able to better describe heat stress and the efficiency of thermoregulation once heat stress has begun. T_{skin} has not previously been measured amongst Mine Rescue participants while conducting a mission.

2.9.4 Total Energy Expenditure

In a study performed by Yamamoto, Hughson, & Peterson (1991), it was shown that as work rate increased, the ratio of LF/HF also increased, indicating activation of the sympathetic nervous system. The study incorporated eight healthy individuals to perform varying levels of rates of work (30%, 60%, 90%, 100%, 110% of ventilatory threshold) (Yamamoto, Hughson, & Peterson, 1991). Thus, HRV may be also used to classify the intensity of exercise. In addition, using HR data, it is possible to estimate energy expenditure (EE) values to assist in classifying task-specific intensities. Confirming the results by Yamamoto et al (1991), another study by Cabral-Santos, Giacon, Campos, Geros-Neto, Rodrigues, & Vanderlei (2016), involving 14 male volunteers (mean age = 25+/-5), proved HRV analysis is effective in classifying exercise intensity. Results showed that during exercise, parasympathetic withdrawal and sympathetic activation occurred, with a higher LF/HF ratio (Cabral-Santos et al., 2016). Interestingly they also found that individuals in the study with higher intensity activity exhibited longer recovery of HRV, post-exercise (Cabral-Santos et al., 2016). Combining this ratio of LF to HF with levels of heat strain, obtained from T_c and heart rate, it is possible to extrapolate values that signify heat strain. Firstbeat Technologies Ltd. applies a beat-by-beat based HR method, to estimate EE ("An Energy Expenditure Estimation Method Based on Heart Rate Measurement," 2007). The software works by estimating maximum oxygen consumption from HR in order to estimate energy expenditure. Supported by Smolander, Rusko, Ajovita, Juuti, & Nummela (2007) et al., these methods have been proven to provide adequate estimations of EE in light and heavy activities as well as when dynamic changes occur in physical activity, meaning changing of intensity of the activity being performed. This is important because when performing vigorous activity HRV data can be affected when intensity changes dramatically (Smolander, Rusko, Ajoviita, Juuti, & Nummela, 2007).

Currently, there are no industry standards associated with HR values to suggest appropriate times to rest or cease work. However, HR can be used to estimate EE (kilocalories) and physical demand (Watts) of important tasks performed during training and emergency situations based on calculations (Strath, Swartz, Bassett, O'Brien, King, & Ainsworth, 2000). According to Strath et al. (2000), once age and fitness are adjusted for, HR is very reliable (r = 0.87) when estimating energy expenditure. Thus, classifying tasks as low to high intensity may indicate whether task rotation is necessary, or lead to alternate methods in order to complete mine rescue tasks safely. For example, consider a work-rest rotation for the 'working members' (Vice-Captain, #2person, #3 person, #4person) alternate working periods in arduous labour tasks. Also if values of work (Watts) are derived, there are recommendations by the ACGIH of acceptable work to rest schedules based on level of intensity (light-moderate-heavy-very heavy). Although it may not be feasible to rest for emergency participants, this may give valuable insight regarding workload estimations during a rescue block, for known environmental conditions; for example, according to the ACGIH guidelines, WBGT index values of 32 °C require participants to perform 50% rest and 50% work for light work intensity tasks (~200 Watts), and 75% rest and 25% work for moderate work intensity tasks (~400 Watts) (Jacklitsch et al., 2016; Kjellstrom, Holmer, & Lemke, 2009).

2.9.5 Maximal Volume of Oxygen Uptake ($\dot{V}O_{2max}$)

Estimated $\dot{V}O_{2\ max}$ (the maximal volume of oxygen uptake) is frequently used to characterize the physical fitness of an individual, in comparison to standard values (Aklan, Robergs, & Kravitz, 2008). This variable takes into consideration a person's age while characterizing their fitness into categories of: poor, fair, average, above average, and excellent; so as your age increases, it will require a lower value to achieve a classification of average. For example, age 18-25 years requires 38-41 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ and 46-55 years requires 28-30 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ to achieve the same classification of average aerobic fitness, respectively ("Automated Fitness Level ($\dot{V}O_{2\ max}$) Estimation with Heart Rate and Speed Data," 2014). Estimated $\dot{V}O_{2\ max}$ is important because it represents the upper limit for exercise tolerance and many activities performed can be expressed as a percentage of $\dot{V}O_{2\ max}$ (Aklan et al., 2008). Therefore, if the $\dot{V}O_{2\ max}$ is low then the level of endurance required is less constrained compared to higher $\dot{V}O_{2\ max}$, which would indicate a particular task or job that requires a higher level of aerobic endurance. For countries that track their mine rescue personnel fitness by estimated $\dot{V}O_{2\ max}$ values, they must maintain a certain level (Queensland, Australia requires 40 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$) annually, thus it will become more difficult for participants to maintain the this value as they age ("Guideline for the Medical Assessment of Mines Rescue Personnel," 2010). To expand on this, $\dot{V}O_{2\ max}$ values fall in categories which correspond to age, for example a 20 year old achieving 40 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$would be considered 'below average' for fitness; whereas a 45 year old with the same value (40 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$) is considered 'above average' fitness ("Automated Fitness Level ($\dot{V}O_2max$) Estimation with Heart Rate and Speed Data," 2014). This classification means that as one ages, it will become more difficult to achieve the Queensland fitness standard, due to the naturally decreasing function of the cardiovascular system (Kenney et al., 2015). Gender differences are also important to consider, as the equation to determine $\dot{V}O_{2\ max}$ values is different (Men: 111.33 – (0.42 x HR); Women: 65.81 – (0.1847 x HR). Furthermore, it is more difficult for a female to achieve a higher $\dot{V}O_{2\ max}$, when compared to a male, therefore ability to complete the task must also be considered ("Guideline for the Medical Assessment of Mines Rescue Personnel," 2010; Jamnik et al., 2013). In essence, it is a reproducible value that measures the functional capacity of the cardiovascular system and ways to categorize physical requirement of tasks and activities. This index is a good measure to ensure rescuers are capable of meeting the baseline requirement, as mine rescue work does not get easier as you age, therefore, the fitness standard to remain active should not either.

Estimated $\dot{V}O_{2max}$ is strongly correlated with Respiration Rate (RR) as well as HR, and should be considered when predicting $\dot{V}O_{2max}$ ("$\dot{V}O_2$ Estimation Method Based on Heart Rate Measurement," 2005). This is for two reasons: first, RR is less affected by changes in body position; and second, RR can differentiate between metabolic (e.g. exercise induced) and non-metabolic (non-exercise or mental stress induced) changes in HR ("$\dot{V}O_2$ Estimation Method Based on Heart Rate Measurement," 2005). Therefore, in addition to improving the accuracy of an estimated $\dot{V}O_{2\,max}$, RR can be analyzed as a constituent of physical demand alongside HR. It is known that as a person increases their physical intensity, both HR and RR increase, due to the increased demand of oxygen to the muscles for maximum physical output (Kenney et al., 2015).

2.10 Statement of Problem

Mine rescue participants are faced with a plethora of challenges during a mine rescue as they are wearing a breathing apparatus for up to four hours at a time, performing vigorous physical activity, and are very limited with respect to personal respite, due to the urgency of the situation. Recognizing the health risks associated with this work for mine rescue participants, it is important to document the physical demands of a mine rescue, according to team position, to develop prevention policies and technologies to mitigate these risks. Outlined in previous literature by Stewart (2008) et al. and Hardcastle (2009) et al., when all positions are grouped together they are working at nearly 100% of their %APMHR and exceeding 38.0 ºC core temperatures. However, according to the Ontario Mine Rescue Handbook, Captains are not required to perform laborious tasks; therefore, differences in positions should be considered when describing physical demands. Given the difficulty associated with taking these measures during an actual emergency scenario (e.g. lack of time to be fitted for an HR monitor, and not enough time for the T_c pill to reach the small intestine), the most realistic alternative, is to capture this data during a simulated mine rescue competition. To date, no one has reported upon the physical demands of mine rescue participants during a simulated mine rescue competition; only a circuit of tasks with ample rest. In addition, no one has examined differences in the physical demands required by the different positions on a mine rescue team.

2.11 Thesis Objectives and Hypotheses

The purpose of this thesis is to describe the physiological exertion (defined by HR, RR, EE, and $\dot{V}O_{2\ mean}$) and heat strain of the different members of a mine rescue team while performing the primary tasks for each of four stages during the culminating mine rescue simulation. These will help us further understand the risk of overexertion and heat strain they experience and extrapolate to real emergencies.

By better understanding the heat and physiological strain these individuals are enduring during a typical rescue mission, we will be better able to provide solutions to mitigate these risks; through our collaborative efforts with Workplace Safety North (WSN) and Ontario Mine Rescue (OMR). Additionally, we can provide insight to the development of a fitness standard; as advised by the Ministry of Labour in their 2015 mining review. By providing a detailed analysis of physiological data, current rescue procedures and task protocols can be re-evaluated, considering task- and position-related levels of physical strain. Lastly we will comment on the value of including a body worn monitoring device as part of the required equipment for mine-rescuer personnel.

The questions we hope to answer include:

1. Does there exist a difference in the physiological measures (HR, RR, EE, and $\dot{V}O_{2\ mean}$) recorded in this study between the four primary tasks, subcategorized into: Arduous Labour, and Casualty Care, during the IMRC?
2. Does there exist a difference in the physiological measures (HR, RR, EE, and $\dot{V}O_{2\ mean}$) recorded in this study between the Captain and the four 'worker' positions on a mine rescue team?; and
3. Are Mine Rescue volunteers at significant risk of heat illness as recorded by the Vitalsense T_c capsule and T_{skin} measured by the Equivital Life Monitor?

Chapter 3

3.0 Manuscript

3.1 Title page

Effect of a Simulated Mine Rescue on Physiological Variables and Heat Strain of Mine Rescue Workers

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Short title: Physiological Responses of Mine Rescuers

3.2 Abstract

Introduction: Mine rescue participants have a fundamental role in health and safety in the mining industry. Yet, little to no information is available pertaining to the physical demand or risks these participants are facing during rescues.

Objective: This study was designed to assess the physiological loading of members of a mine rescue team during a simulated mine rescue emergency.

Methods: Heart-rate-variability (HRV) body-worn monitors (n = 74) and core temperature (T_c) capsules (n=54) were utilized to assess heart rate (HR), HRV, respiration rate (RR), energy expenditure (EE), oxygen consumption ($\dot{V}O_2$), as well as T_c and skin temperature (T_{skin}), in mine rescue team members, during four mining rescue tasks (two laborious and two casualty care), while participating in an underground mine-rescue simulation. A multivariate analysis was performed with team positions, tasks, and measures as factors.

Results: HR_{mean} and HR_{peak} values demonstrate that all tasks required vigorous efforts percentage predicted max heart rate (%APMHR) (78.6% for HR_{mean} and 94.5% for HR_{peak}), but arduous labour tasks elicited higher HR, RR, and $\dot{V}O_{2mean}$ than casualty care tasks. Captains exhibited lower HR_{mean}, HR_{peak}, RR, RR_{peak}, $\dot{V}O_{2mean}$, T_c and T_{skin} compared to other positions. At the end of the rescue, $T_{c\ mean}$ exceeded 38.6 ºC, with 17 participants (non-Captain) registering T_c above 39 ºC.

Conclusions: Captains' physical loading and heat stress was lower compared to other positions. This is critical because they make decisions and give instructions to other members, which can be impaired by overexertion and heat stress, putting the entire team at risk for injury or fatality. The current study also demonstrated that all mine rescue tasks induced a high physical load and

elicited heat strain, even those associated with casualty-care, a previously unexplored task in the mine rescue literature.

3.3 Introduction

Mining is a dangerous occupation, as underlined by its high rates of serious injury and fatalities.[3,38] According to the International Labour Organization (ILO), mining industry employs 1% of the global workforce, whereas it is responsible for 8% of its injuries.[26] Common accidents in mining include: fires, mobile equipment collisions, exposure to hazardous environments, and falls-from-heights; many of which all require rescue operations.[2,12,38] In fact, in Ontario alone, 53 emergency response teams were utilized in 2014 for mine-related rescues.[2,38] Currently, mine rescue does not require a fitness standard. The Supreme Court of Canada (and outlined by Jamnik et al, 2013) states that any fitness standard developed for a workforce be: criterion-based and validly linked to the critical, life-threatening, physical demands of the job. Consideration when developing criteria for a standard must follow the "Unified Test" by the Supreme Court of Canada so there is no undue hardship caused due to discrimination and current ability to complete the task (Jamnik et al., 2013). This is because in 1994 a female wildland firefighter experienced undue hardship because of implementation of a normative standard of $\dot{V}O_{2\ max}$, which she nor other females could not achieve despite being able to perform the required work for years prior (Jamnik et al., 2013). Specifically, in Canada, for an organization to require a physiological employment standard, the standard must be based on both 'safe' (properly executing the life-threatening, physically demanding emergency task) and 'efficient' (completing these tasks in a time frame that is suited to the emergency circumstance) requirements. When referring to the Unified Test, the implemented standard must not be discriminatory, legitimately represent the difficulty of the job or task, be implemented on good faith, and be achievable for employees and not cause undue hardship. In addition, these standards must take into account the diverse individualities of the participants (age, sex, experience).[17] With that in mind, a recent report published by the Ministry of Labour (2015) in Ontario recommended assessment and implementation of a fitness standard to mitigate risks associated with high heat and physical demands of mine rescue work.[11] Therefore, describing physical demands and the frequency of the tasks performed is a primary priority.[17]

Mine rescues are performed by a team of volunteer mine employees who are extensively trained in mine-related emergencies such as: hazardous materials management, fire management, search and rescue, and first aid.[12,31] During an emergency involving a casualty, rescuers are required to carry a metal stretcher, spare breathing apparatus, hydraulic equipment, and first aid supplies; weighing approximately 142 kg.[12,13] Furthermore, all tasks performed require personal protective equipment (approximately 22 kg), which includes: self-contained breathing apparatus (SCBA), gloves, helmet, coveralls, boots, etc.[12,13] Considering these facts, it is clear that Mine Rescue is a physically demanding job and supported by research showing rescue-related tasks can elicit heart rate (HR) responses averaging 88 %APMHR.[31] Demonstrating the health implications of performing tasks at this level, individuals are at high risk of overexertion which can lead to more complex issues surrounding fatigue.

Mine Rescue teams consist of six members, a Captain, Vice-Captain, #2, #3, #4 persons, and a Briefing Officer: who remains on surface for the duration of the emergency.[12,13] The Captain is responsible for leading the team, providing instructions, and ensuring the wellbeing of all members.[12] Vice-Captain is responsible for providing some instruction, but will also assist in rescue-related tasks such as carrying tools.[12] Number 2, #3, and #4 persons have similar roles: work according to the Captain's instructions and perform the majority of arduous tasks, such as eliminating hazards, treating a casualty, and firefighting.[12] This creates inherent differences in physical loads, particularly between the captain and other members of the team. Theoretically, this would suggest the Captain having a lower physical requirement than other members, however further research is required.

Research studying mine rescue work has shown that the rescue-related tasks (e.g. carrying casualties, firefighting, carrying tools, and etc.) are all extremely physically demanding;[13,18,22,31] however rescuers have never been studied during an actual mine rescue event. Stewart et al. (2008) reported a mean increase to 91% of age-predicted maximum heart rate (APMHR) of mine rescue volunteers across three validated tasks during a controlled, simulated mine rescue environment: namely during fire suppression, incremental carries, and shovelling.[31,34] The American Conference of Governmental Industrial Hygienists (ACGIH) sets a recovery HR threshold of 110 bpm after 1-minute of rest following activity, which is another way to assess heart strain.[38] This study determined rescuers could only get their HR between 139-149 bpm after 90 seconds following fire suppression; and nearly 120 seconds after shovelling and incremental carries.[31] HR in this range of 139-149 bpm, is still considered high and well above ACGIH threshold level values of 110 bpm.[20,31,34,38] This is significant given that, in an actual emergency, there may not be time to adequately recover, and underlines the high risk for rescue participants during a mission.

The elevated physical loads described in the previous study can be further exacerbated by underground mine conditions because they are characterized by temperatures exceeding 40 °C, and 60% humidity.[21,22] The body's main mechanism of heat loss is perspiration,[23,29,35] which is inhibited by high humidity and extensive protective equipment.[18,22] Impaired cooling mechanisms combined with high physical activity will result in higher than normal core temperature (T_c) , significantly increasing the risk of heat-related illnesses.[18,22]

Literature suggests short-term (six-to-eight weeks) aerobic training is relatively ineffective in preventing heat stress under adverse condition; that is - conditions where the body is unable to maintain a thermal steady state, as in deep underground mining.[6,27] However, long-term improvements (greater than eight weeks) in physical training appear to provide some protection against heat strain. This is due to the rationale that greater aerobic fitness allows individuals to reach higher T_c prior to exhaustion. Demonstrated in a study by Gonzalez-Alonso et al (1999), participants who are aerobically fit can tolerate higher T_c (39.2ºC versus 38.8ºC).[27] This is due to the increased function of the cardiovascular system, by being able to better pump blood to extremities and uptake more oxygen.[27] These physiological functions are correlated with a better aerobic fitness, therefore rationalizing our interest recording mean HR (HR_{mean}), peak HR (HR_{peak}), respiration rate (RR), peak RR (RR_{peak}), energy expenditure (EE), and mean oxygen consumption ($\dot{V}O_{2\ mean}$). Long-term improvements in aerobic fitness are key in mitigating heat strain at higher temperature and thereby, mandatory routine fitness training for mine rescue volunteers would add protection when working under hot and humid conditions.[10,11,19]

Studies to date have been conducted in controlled, artificial settings, following precise work-rest schedules, in which individuals knew tasks beforehand and had ample time allocated for rest and often were not professional mine rescue participants.[13,18,21,22,32] Mine rescuers often work supra-maximally for short bouts of their recommended maximum heart rate, often exceeding workloads of 1000 Watts.[31,36] Hardcastle et al. (2009) stated that real life emergencies will endure greater physiological responses due to inadequate rest and hydration for the duration of the rescue.[13]

Together, this information supports Ontario Mine Rescue's decision to implement a fitness standard for their mine rescue volunteers. However, any standards developed should be criterion-based and validly linked to the critical, life-threatening, physical loading of the job. Therefore, an established research process is required to ensure this connection.[17]

Our goal was to inform international Mine Rescue organizations of the physiological load and potential heat strain experienced by mine rescue work during a simulated emergency. In addition, describe the physiological differences for current task-distribution amongst team members, predominantly between Captain and other team members; and comment on possible fitness requirements based on specific positions. To achieve this, during the 10th International Mine Rescue Competition (IMRC), participants were recruited to wear body-worn monitoring devices and ingest T_c capsules during the underground, two-hour mine rescue simulation event. Tasks involved in the IMRC were locating and performing first aid on an unconscious casualty, building a barricade to extinguish a fire, providing advanced first aid on a conscious casualty, and escaping the mine carrying said casualty.

Therefore the purpose of this study was threefold: *i)* to describe the HR_{mean}, HR_{peak}, RR_{mean}, RR_{peak}, EE, and $\dot{V}O_{2\ mean}$ of the primary tasks performed in a mine rescue; *ii)* to describe differences (if any) between the captain and other appointed positions on mine rescue teams; and *iii)* to describe the T_c and skin temperature (T_{skin}) of mine rescuers during a simulated mine rescue emergency.

3.4 Methodology

3.4.1 Participants

At the 10th biennial International Mine Rescue Competition (IMRC), 27 teams comprised of six members each, competed. They included a: Captain, Vice-Captain, #2person, #3person, #4person, and a briefing officer. We only recruited participants going underground and therefore did not recruit the briefing officer (who we excluded, as they remain above-ground relaying information to the team during the rescue), leaving us with a total of 135 eligible participants. Seventy-six mine rescue personnel agreed to participate in this study (56.3% response rate). Of the 76 participants, 57 provided additional consent to ingest a thermometric T_c pill (42.2% response rate). All participants provided written, informed consent prior to the start of data collection. This study was approved from the Institutional University Research Ethics Board (2016-02-10).

All participants were trained, mine rescue personnel who were currently participating in, and had regularly performed mine rescue training activities in the past. With the exception of one team (a team of experts put together from multiple countries), all team members had previously trained together as a team and had been selected by their home country as their 'best' to represent them at the International Mine Rescue Competition (IMRC).

There was no difference in laborious roles for Vice-Captain, #2person, #3person, and #4person; however their technical roles slightly differ. For example, #2person is responsible for gas monitoring, Vice-Captain is responsible for carrying the Captain's clipboard, #3person is typically best at first aid and #4person is carrying extra assisted breathing equipment.[12]

Table 1: Participant characteristics (n=76) across all tasks

	Total (n=76)	Captain (n=15)	Vice (n=15)	#2 (n=16)	#3 (n=15)	#4 (n=15)
Age (years)	36.5±0.70	37.5±1.73	35.2±1.55	35.4±1.01	36.0±1.16	38.5±2.17
Height (m)	1.8±0.01	1.8±0.02	1.8±0.02	1.8±0.02	1.7±0.02	1.8±0.02
Weight (kg)	87.5±1.65	90.4±4.29	94.4±3.87	82.8±3.13	83.0±3.74	87.0±2.92
BMI (kgm^{-2})	27.8±0.39	28.7±1.20	29.2±0.88	26.0±0.6	26.8±0.88	28.2±0.53
[1]$HR_{max\ predicted}$ (bpm)	182±1	182±1	183±1	183±1	183±1	181±2
[2]Estimated $\dot{V}O_{2max}$ ($ml\cdot min^{-1}kg^{-1}$) (n=70)	45.4±1	43.6±1.66	44.1±1.21	47.7±0.47	46.4±0.80	44.9±0.83

[1]$HR_{max\ predicted}$ was derived from the equation 208-age x 0.7.[33]
[2]Highest value from all conditions during the IMRC; derived from Firstbeat Analysis Software via HR data. BMI: Body mass index; HR: Heart Rate; bpm: beats per minute; IMRC: International Mine Rescue Competition; HRV: Heart Rate Variability; $\dot{V}O_{2max}$: the maximum volume of oxygen the person can utilize, measured in millilitres, per minute, per kilogram body weight.

3.4.2 Experimental Design

The competition was organized by Ontario Mine Rescue personnel who created a series of scenarios to reflect common real-life emergencies. The competition took place in an operational, underground mine in Sudbury's 114 ore body and is the most realistic mine rescue scenario possible, barring an actual event. Actors played the part of victims, and smoke was actively produced for the fire simulation. Participants recruited for the study were experienced mine rescue volunteers and experience in mine rescue competitions. The participants did not know what the competition consisted of, until the briefing occurred, just prior to mine entry; mimicking an actual emergency.

The day before the competition, baseline data was collected for individual participants characteristics (height, weight, age, team role, and chest-circumference for the body worn monitor).

Prior to the mine-rescue event, participants were equipped with the body-worn monitoring devices and (for n=57 participants) also directed to ingest a T_c pill two hours prior, both of which recorded and collected data continuously for the approximately two-hour underground portion of the mine rescue simulation event.

The experimental design is presented in (Fig. 1). Up to four teams competed at a given time, as the starting of teams was staggered to process all teams over the three days (one team completing a task at any given time).

These tasks were time stamped, to allow for a coordinated examination of the physiological data with individual tasks.

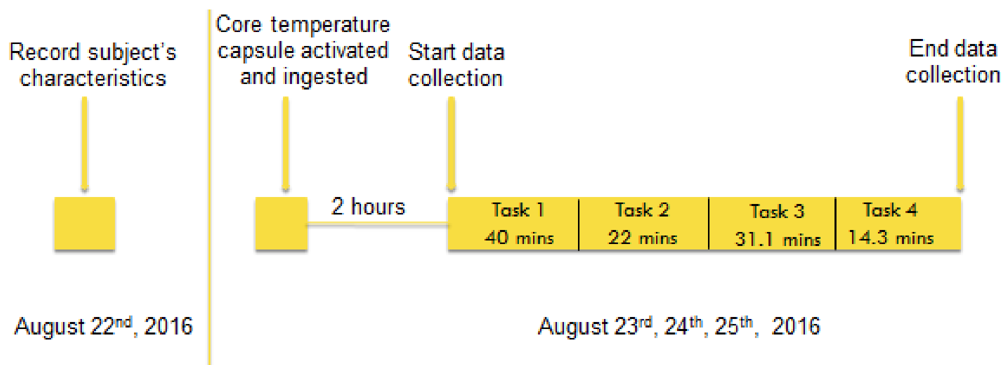

Figure 1 Experimental Design

To reiterate, the competition was organized by Ontario Mine Rescue personnel who created a series of scenarios to reflect common real-life emergencies. During the underground competition, competitors were challenged by four key tasks, which are commonly experienced by workers during a mine rescue. They descended underground via a jeep with a heavy basket containing various tools (weighing approximately 100 kg). Then leading into the four tasks are as follows:

i. The first task involved an unconscious casualty and a casualty in shock; rescuers treated the casualties and prepared them to be transported to surface.

ii. The second task involved a simulated fire, in which rescuers constructed a barricade composed of various materials (e.g. bricks, fire retardant wrapping, and beams).

iii. The third task involved a conscious casualty impaled on a steel post (alive and requiring first aid and rescue). This required rescuers to utilize extrication tools and perform precise first aid treatment to the wound.

iv. The forth task, rescuers loaded the casualty into a basket with a trolley to perform removal of the impaled victim via an exit route with a steep incline. This basket, with tools and the casualty, weighed in excess of 180 kg. Tasks 1 and 3 were similar in nature (casualty care) as are tasks 2 and 4 (arduous labour).

3.5 Measures

3.5.1 Mining Environmental Conditions

Captains recorded ambient conditions with a portable weather meter (Kestrel 3500 Pocket Weather (Nielson-Kellerman, US) meter immediately upon arrival at each task site and these are the averages.

Table 2 Ambient conditions of the mine in the IMRC

Task	Dry-Bulb Temperature (ºC) (T_{db})	Wet-Bulb Temperature (ºC) (T_{wb})	Relative Humidity (RH) (%)
1	25.7	22.0	72.4
2	34.7	24.7	43.8
3	18.0	17.0	90.6
4	18.0	17.0	90.6

3.5.2 Heart and Respiration rates

A heart and respiration rate monitor (Equivital Life Monitor™, Hidalgo, UK) with integrated technology continuously measured and recorded HR, HRV, RR, T_{skin}, body position, and accelerometry. A Sensor Electronic Module (SEM) integrated within the belt, recorded T_{skin} via infrared thermometry, as well as saved all other recordings for later analyses. This device weighs 38 grams, measures 78 mm x 53 mm x 10 mm, is water resistant, intrinsically safe, and is utilized via a fitted-chest strap, containing a two-lead electrocardiogram located underneath the pectorals (ECG) (256 Hz). The ECG collects cardiovascular data, including HR and rhythm (HRV). HR and HRV were continuously recorded from before entering the mine up until the belt was removed following the underground competition. This device was fitted on participants approximately 10 minutes prior to competition briefing. Energy expenditure (EE) and estimated $\dot{V}O_{2\,max}$ were estimated from HR (First Beat Technologies Software, Jyväskylä, Finland). EE and estimated $\dot{V}O_{2\,max}$ were derived from equations that were not disclosed from First Beat Technologies Software. EE and $\dot{V}O_{2\,mean}$ described the physical load of each task performed by team positions and estimated $\dot{V}O_{2\,max}$ provided insight on the cardiorespiratory fitness of the participants. Respiration rate (RR) was measured and recorded via thoracic expansion (around the lower part of the thorax) during breathing which can also describe physical load when comparing to resting rate (12-20 bpm).

3.5.3 Core Temperature

T_c was measured via an ingestible thermometric pill (Vitalsense^{TM}, Respironics, US) which measured T_c every 15 seconds and relayed recordings to the SEM for data storing. This medical-grade capsule has dimensions of 23 mm long x 8.6 mm diameter and weighs 1.6 grams and is composed of biocompatible polycarbonate. Current literature involving ingestible T_c pills suggests ingestion of two hours prior.[13,36] Described by Hardcastle et al. (2009), they administered the thermometric capsule two hours prior to recording with 10 trained mine rescue participants with Ontario Mine Rescue at an underground mine.[13] The justification was that these individuals are assumed to be average to above-average in terms of physical fitness, which is comparable to our sample based on subject characteristics. Therefore, they could digest the pill quickly enough where it would reside in the small intestine approximately two hours following ingestion to provide accurate readings.[13]

3.6 Statistical Analysis

The participants' characteristics (Table 1) and physiological measures displayed in the tables depict the mean plus/minus the standard error of the mean. Figures display the mean plus/minus the standard error of the mean.

Participants were organized by positions (Captain, Vice-Captain, #2person, #3person, and #4person) and tasks (Casualty Care: tasks 1 and 3; and Arduous Labour: tasks 2 and 4); unless otherwise specified.

Age, Weight, Body Mass Index, $HR_{max\ predicted}$ and Estimated $\dot{V}O_{2max}$ were not normally distributed, as determined by Shapiro-Wilks test ($p < 0.05$), thus the Mann-Whitney U test was used to compare the role of the Captain and all other positions (Vice-Captain, #2, #3, #4persons).

Height was normally distributed, as determined by the Shapiro-Wilks ($p>0.05$) and thus an independent t-test was utilized.

There were no statistical differences found between Captain and other positions (Vice-Captain, #2, #3, and #4persons), for any baseline measure (age, height, weight, BMI, $HR_{max\ predicted}$, Estimated $\dot{V}O_{2max}$) See Table 1.

Data from the Equivital Life Monitor for two participants was lost due to equipment malfunction, resulting in a final sample size of 74 participants. However, these two participants produced good quality data from the ingestible T_c pill, and therefore were included for the T_c data analysis. Data from three participants for the ingestible T_c pill was lost due to equipment malfunction, resulting in a final sample size of 54 participants for the ingestible thermometric T_c pill.

Linear mixed models were performed on all physiological variables across positions (Captain vs other positions). Linear mixed models, with Scheffe's post hoc tests, were performed on all physiological variables across tasks (Casualty Care vs Arduous Tasks) examining pairwise comparison of all interactions between tasks. Significance was accepted at $p<0.05$.

3.7 Results

3.7.2 Heart Data

Position

The HR_{mean} for all participants during the four tasks was 143 ± 1 bpm, representing 78.6% of APMHR, which was 182 bpm for our sample (Fig. 2a). The equation used for this was 208 – age x (0.7). Captains reported the lowest HR_{mean} (135 ± 3 bpm) compared to Vice-Captain (149 ± 3 bpm, $p = 0.020$) and #2persons (147 ± 3 bpm, $p = 0.044$). The HR_{peak} for all participants was

172 ± 1 bpm, which translates to an APMHR of approximately 94.5% (Fig. 2b). Captains (161 ± 3 bpm) reported the lowest HR_{peak} when compared to Vice-Captain (177 ± 3 bpm, p = 0.002); #2persons (173 ± 3 bpm, p = 0.019); #3persons (172 ± 2 bpm, p = 0.023); and #4persons (176 ± 2 bpm, p = 0.002).

Task

Overall, HR_{mean} values were high for all tasks ranging from 71.4% to 86.8% APMHR for all participants, which reflect vigorous intensity (70-85% of APMHR – 182 bpm for our sample, this would equate to 127 – 155 bpm) (Fig. 2c). Task 4 (158 ± 2 bpm) reported higher values than task 1 (130 ± 2 bpm, p = 0.000); task 2 (146 ± 3 bpm, p = 0.002); and task 3 (143 ± 3, p = 0.002). Also, task 3 reported higher values than task 1 (p = 0.011) and task 2 was also higher than task 1 (p = 0.011). Overall, HR_{peak} values were high for all tasks ranging from 91.8% to 98.9% of the calculated APMHR for all participants (Fig. 2d). Only task 4 (180 ± 2 bpm) reported higher HR_{peak} when compared to task 2 (169 ± 2 bpm, p = 0.000).

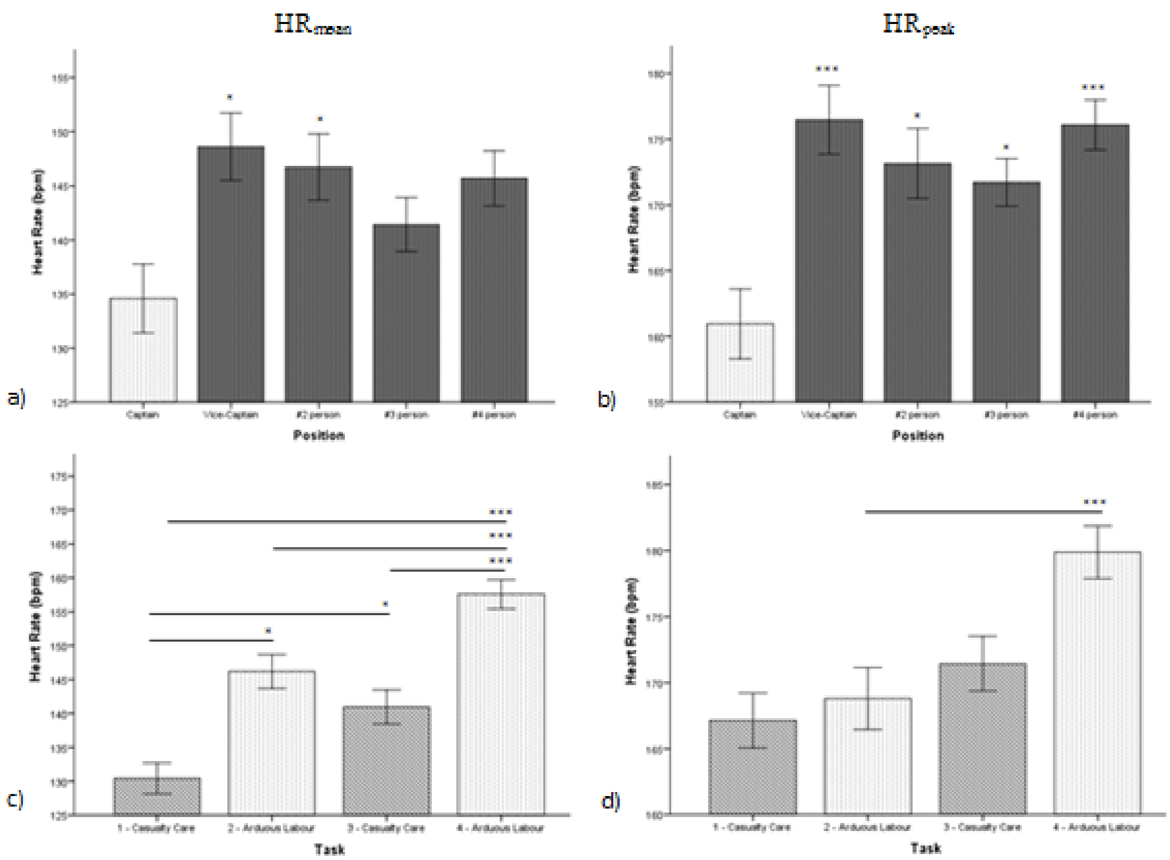

Figure 2. (a) Mean heart rate for all positions across all tasks; (b) Mean heart rate for each task across all participants; (c) Peak heart rates for each position across all tasks; (d) Peak heart rates for each task across all participants; Significance was accepted at $p < 0.05$ (* = $p < 0.05$, ** = $p < 0.01$, and *** = $p < 0.005$).

3.7.3 Respiration Rate (RR)

Position

RR_{mean} for all participants was 34 ± 0 rpm (Fig. 3a). Captains (31 ± 1 rpm) reported lower RR_{mean} when considering mean of all tasks when compared to the Vice-Captain (35 ± 1 rpm, $p = 0.019$), #2person (35 ± 1 rpm, $p = 0.024$), and #3person (35 ± 1 rpm, $p = 0.012$). RR_{peak} for all participants was 44 ± 0 rpm (Fig. 3b). Captains (41 ± 1 rpm) reported lower RR_{peak} when compared to #3person (45 ± 1 rpm, $p = 0.035$) and #4person (45 ± 1 rpm, $p = 0.037$).

Task

Overall, RR_{mean} values were high for all tasks ranging from 31 ± 1 rpm to 38 ± 1 rpm (Fig. 4c). Task 4 (38 ± 1 rpm) reported higher RR_{mean} than all other tasks, Task 1 (31 ± 1 rpm, p = 0.000); Task 2 (33 ± 1 rpm, p = 0.000); and Task 3 (33 ± 1 rpm, p = 0.000). Also, Task 3 reported higher RR_{mean} when compared to Task 1 (p = 0.000). Overall, RR_{peak} for all tasks was 44 ± 0 rpm (Fig. 4d). Task 4 (47 ± 1 rpm) reported higher RR_{peak} when compared to Task 1 (42 ± 1 rpm, p = 0.037) and task 2 (42 ± 1 rpm, p = 0.000). Task 3 (45 ± 1 rpm) also reported higher RR_{peak} from tasks 1 (p = 0.023) and task 2 (p = 0.000).

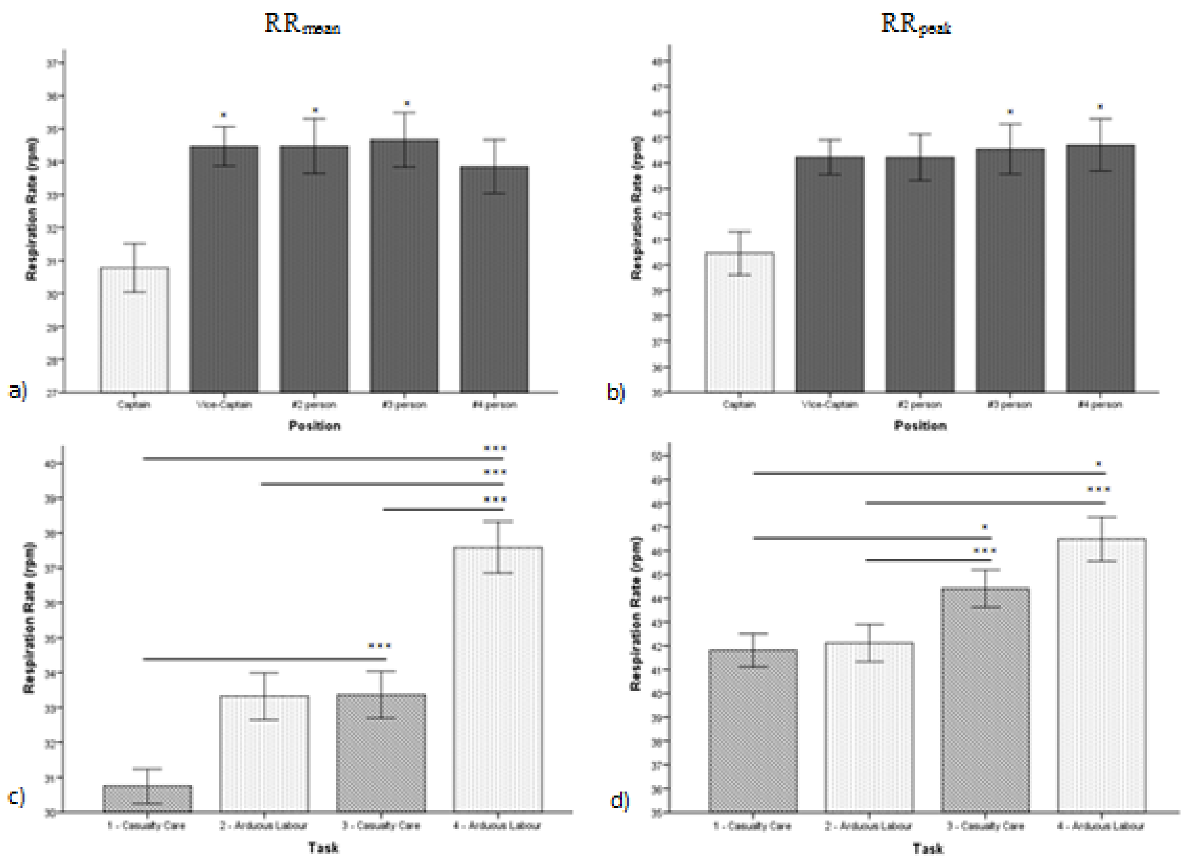

Figure 3. (a) Mean respiration rate for each position across all tasks; (b) mean respiration rate for each task across all participants; (c) peak respiration rate for each position across all tasks; (d) Peak respiration rate for each task across all participants; Significance was accepted at $p < 0.05$ (* = $p < 0.05$, ** = $p < 0.01$, and *** = $p < 0.005$).

3.7.4 Energy Expenditure (EE) and Oxygen Consumption ($\dot{V}O_{2\ mean}$)

Position

There were no significant differences reported for EE between positions. The lowest reported mean EE was Captains (11.0 ± 0.60 kcal•min^{-1} or 769 ± 42 Watts) (1 Watt = 0.0143 kcal•min^{-1}). The reported mean EE for positions was Vice-Captains (13.2 ± 0.63 kcal•min^{-1} or 923 ± 42 Watts); #2persons (12.8 ± 0.76 kcal•min^{-1} or 895 ± 56 Watts), #3persons (11.6 ± 0.52 kcal•min^{-1} or 811 ± 35 Watts); and #4persons (12.3 ± 0.46 kcal•min^{-1} or 860 ± 35 Watts). The $\dot{V}O_{2\ mean}$ value for all positions was 27.2 ± 0.45 ml•kg^{-1}•min^{-1}, which translates to approximately 60% $\dot{V}O_{2\ max}$ effort (Fig. 5a). Captains (24.1 ± 1.18 ml•kg^{-1}•min^{-1}) reported lower $\dot{V}O_{2\ mean}$ when compared to #2person (29.5 ± 1.03 ml•kg^{-1}•min^{-1}, p=0.005), #3person (27.6 ± 0.88 ml•kg^{-1}•min^{-1}, p = 0.039), and #4person (27.8 ± 0.87 ml•kg^{-1}•min^{-1}, p = 0.037).

Task

There were no statistically significant differences reported for EE between tasks. The lowest reported mean EE was 9.5 ± 0.43 kcal•min^{-1} or 661 ± 28 Watts for task 1. The highest reported mean EE was 15.2 ± 0.50 kcal•min^{-1}, or 1063 ± 35 Watts for task 4. The mean EE for task 2 was 12.9 ± 0.51 kcal•min^{-1} or 902 ± 35 Watts, and for task 3 was 11.4 ± 0.50 kcal•min^{-1} or 797 ± 35 Watts. $\dot{V}O_{2\ mean}$ values were high for all tasks ranging from 22.3 ± 0.81 ml•kg^{-1}•min^{-1} to 32.4 ± 0.66 ml•kg^{-1}•min^{-1}, which translate to 49.1% to 71.4% of the estimated $\dot{V}O_{2\ max}$ (Fig. 5d). Task 4 (32.4 ± 0.66 ml•kg^{-1}•min^{-1}) was higher than task 1 (22.3 ± 0.81 ml•kg^{-1}•min^{-1}, p = 0.001) and task 3 (26.1 ± 0.84 ml•kg^{-1}•min^{-1}, p = 0.015). Also, task 2 (28.7 ± 0.81 ml•kg^{-1}•min^{-1}) reported higher $\dot{V}O_{2\ mean}$ than task 1 (p = 0.024).

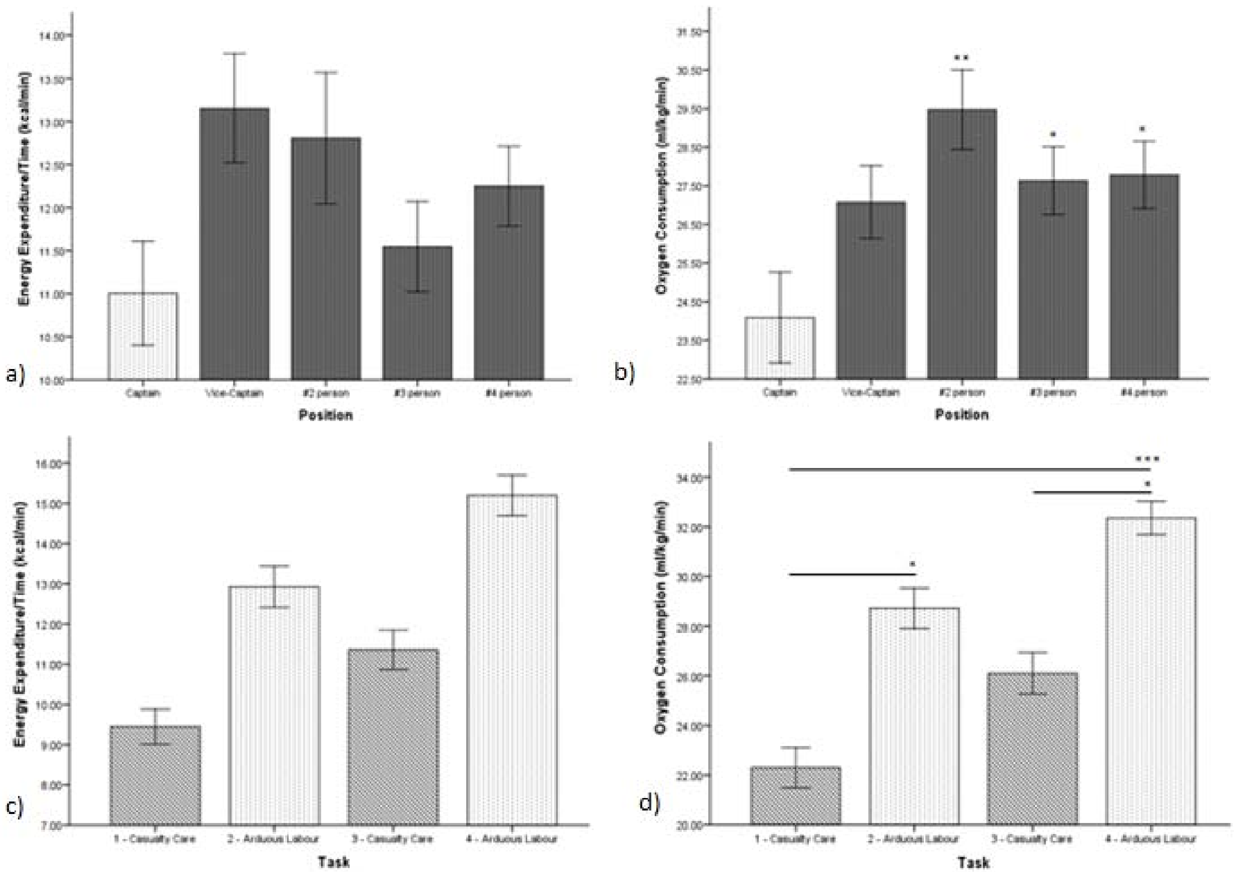

Figure 4. (a) Mean energy expenditure for each position across of all tasks; (b) mean energy expenditure for each task across all participants; (c) mean oxygen consumption for each position across all tasks; (d) mean oxygen consumption for each task across all participants; Significance was accepted at $p < 0.05$ (* = $p < 0.05$, ** = $p < 0.01$, and *** = $p < 0.005$)

3.7.6 Temperature

Position

$T_{c\ mean}$ for all participants was 38.3 ± 0.04 ºC when considering mean of all tasks (Fig. 5a). The only difference for $T_{c\ mean}$ reported was for Captains (38.0 ± 0.09 ºC) when compared to #4persons (38.5 ± 0.10 ºC, $p = 0.005$). $T_{c\ peak}$ for all participants when considering the mean of all tasks was 38.5 ± 0.04 ºC (Fig. 5b). Captains (38.2 ± 0.08 ºC) reported lower $T_{c\ peak}$ when compared to Vice-Captains (38.6 ± 0.10 ºC, $p=0.040$) and #4persons (38.7 ± 0.10 ºC, $p = 0.002$). $T_{c\ peak}$ for remaining positions was: #2persons 38.5 ± 0.08ºC; and #3persons 38.6 ± 0.08ºC. T_{skin} for all participants were 37.2 ± 0.06ºC when considering mean of all tasks (Fig. 5e). Captains

(36.8 ± 0.13 ºC) reported lower T_{skin} compared to Vice-Captains (37.2 ± 0.13 ºC, p = 0.013), #2persons (37.6 ± 0.10ºC, p = 0.001) and #3persons (37.4 ± 0.10ºC, p = 0.002). $T_{skin\ peak}$ for all participants were 37.7 ± 0.48ºC when considering all tasks (Fig. 5g). Captains (37.3 ± 0.12 ºC) reported lower $T_{skin\ peak}$ compared to Vice-Captain (37.8 ± 0.11ºC, p = 0.001), #2person (38.0 ± 0.08ºC, p = 0.000), #3person (37.9 ± 0.08 ºC, p = 0.000), and #4person (37.7 ± 0.12ºC, p = 0.005).

Task

For $T_{c\ mean}$, task 4 (38.6 ± 0.07 ºC) was higher than tasks 1 (37.8 ± 0.06 ºC, p = 0.000) and task 2 (38.3 ± 0.07 ºC, p = 0.000). Task 3 (38.6 ± 0.07 ºC) was higher than tasks 1 (p = 0.000) and task 2 (p = 0.000). Additionally, task 2 was higher than task 1 (p = 0.000).

For $T_{c\ peak}$, task 4 (38.7 ± 0.07 ºC) was higher than tasks 1 (38.1 ± 0.05 ºC, p = 0.000) and task 2 (38.4 ± 0.08 ºC, p = 0.000). Task 3 (38.7 ± 0.08 ºC was higher than tasks 1 (p = 0.000) and task 2 (p = 0.000). Additionally, task 2 was also higher than task 1 (p = 0.000).

For T_{skin}, task 4 (36.6 ± 0.13 ºC) was higher than tasks 3 (37.6 ± 0.08 ºC, p = 0.000) and task 2 (37.8 ± 0.07 ºC, p = 0.000). Task 3 was higher than task 1 (37.0 ± 0.10 ºC, p = 0.000). Also, task 2 was higher than task 1 (p = 0.000).

$T_{skin\ peak}$, task 4 (37.1 ± 0.13 ºC) was higher than task 2 (38.1 ± 0.06 ºC, p = 0.000) and task 3 (38.1 ± 0.06 ºC, p = 0.000). Task 3 was higher than task 1 (37.7 ± 0.07 ºC, p = 0.000). Additionally, task 2 was higher than task 1 (p = 0.000).

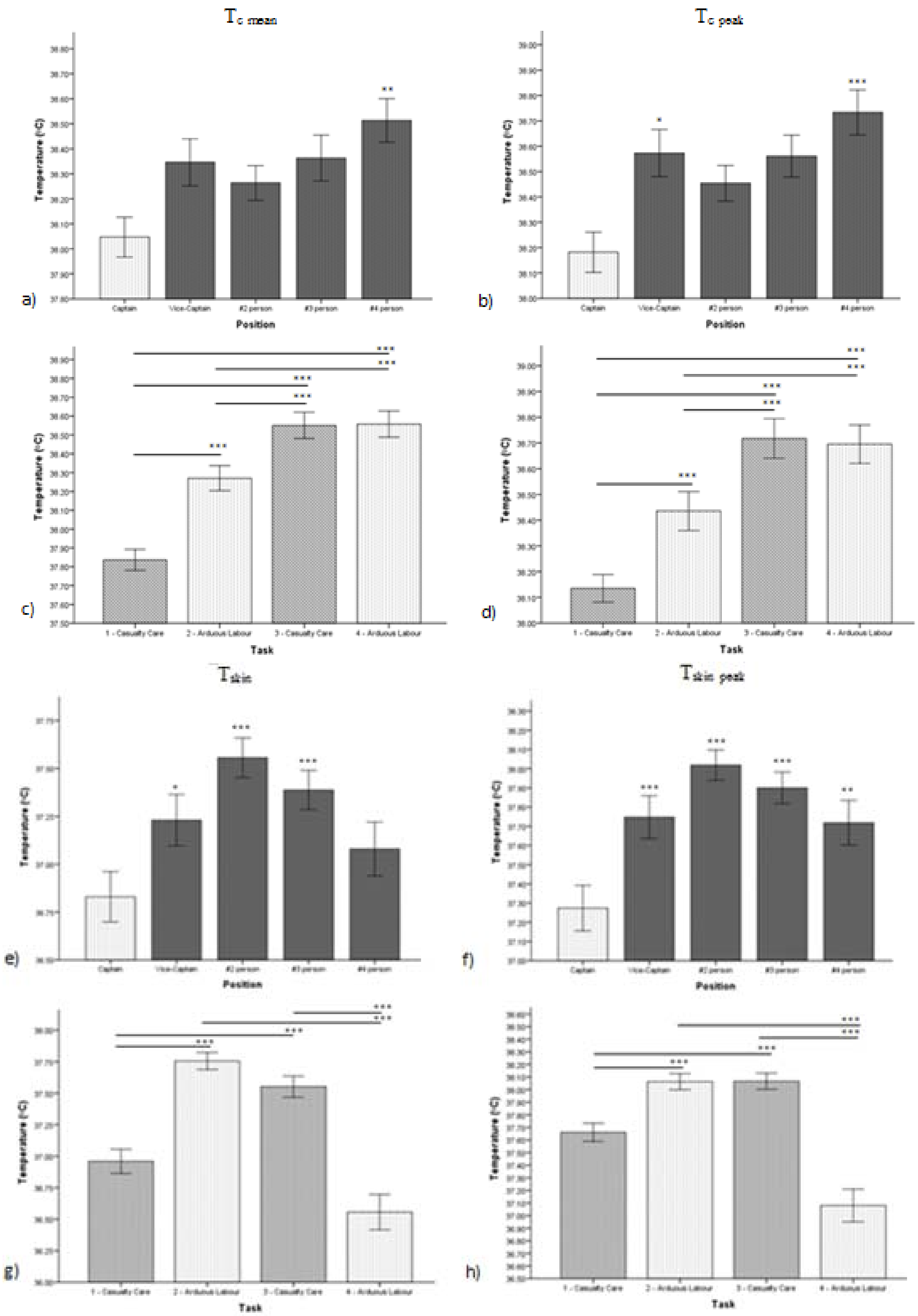

Figure 5. (a) Mean core temperature for each position across all tasks; (b) mean core temperature for each task across all participants; (c) peak core temperature for each position across all tasks; (d) peak core temperature for each task across all participants; (e) mean skin temperature for

each position across all tasks; (f) mean skin temperature for each task across all participants; (g) peak skin temperature for each position across all tasks; (h) mean of all peak skin temperature for each task across all participants; Significance was accepted at $p < 0.05$ (* = $p < 0.05$, ** = $p < 0.01$, and *** = $p < 0.005$).

3.8 Discussion

To our knowledge, this is the first study to assess the influence of team position and task on physiological loading of mine rescue participants during an underground, simulated emergency. We employed objective methods to examine the following physiological measures: HR, RR, EE, $\dot{V}O_2$, $T_{skin,}$ and T_c to gain insights on physiological responses and risk of heat-related events during a simulated mine rescue emergency. Captains displayed lower physiological loads, except for EE, when compared to other positions. Concerning tasks, both arduous labour and casualty care tasks, but arduous labour required a high physical demand with higher HR, RR, and $\dot{V}O_2$ measures. Finally, all participants displayed elevated T_{skin} and T_c values. Our results also highlight that all positions, including Captains, are performing strenuous work during all mine rescue tasks performed in hot and humid conditions. As a consequence, this increases the risk of heat-related events, as well as affect ones' ability to make decisions;[6,10,13,21,27] The tasks demonstrated in the IMRC are essential to complete the tasks in real rescues and cannot be accommodated (e.g. first aid, carrying casualty in a basket, and firefighting). They would be considered bona fide Occupational Requirement (BFOR), as they are part of the regular training being performed and are demonstrated in previously documented rescues (T. Hanley, personal communication, May 16, 2018). Therefore, the description of the physiological responses in this study will provide insight when recommending a fitness standard, in addition to the current medical assessment considered prior to commencing training to be an active mine rescue volunteer.[11]

Simulated mine rescue-related tasks examined in similar studies (e.g. shovel, casualty-carry, walk, etc.) have been well documented describing the intense workload required to perform these tasks in comparison with the implementation of allotted rest intervals.[13,18,32].

Stewart et al. (2008) reported mean %APMHR of 91% for the duration of a nine minute simulated work-circuit comprised of incremental casualty carry, coal shoveling, and hose drag. This demonstrated the level of intensity required to perform the work necessary in emergencies, which is difficult to sustain for long durations.[10,38] The implications of working at this intensity for long durations pose the risk of overexertion, which may lead to further complications such as fatigue. Fatigue is a multi-faceted complication, which results in tiredness, inability to concentrate, amongst others, which can impact daily life.[10,38] Thus, it is important fatigue is mitigated by first understanding the risk these workers face. Similar findings form Hardcastle et al. (2009) highlighted mine rescuers performing mean workloads of 538W for an average of 66 minutes that resulted in mean T_c of 38.14 ºC in 10 individuals. This study was performed in an operational shallow mine with much cooler conditions when compared to our study and without realistic mining conditions (T_{db} = 16.9 ºC; T_{wb} = 14.9 ºC).

Our study took place in an operational, underground mine and props were used where necessary to add to the credibility of the scenario. For tasks involving casualties, real persons were used to provide a more realistic experience, for example, this casualty elicited negative reactions (e.g. screaming) if the participants were not being careful while providing first aid. Conditions of a fire were simulated with a heat generator and a smoke machine to mimic an actual fire, such that ambient temperature was notably higher (see Table 2). Another factor that contributed to the reality of the scenario was the secretive nature of the event: participants had no prior knowledge of what to expect and were called upon when the scenario was ready, as if they were responding to a real emergency. Therefore to our knowledge, this is the best scenario that has been employed in research with mine rescue participants to date.

Task-Specific Demands

The IMRC involved four primary tasks; we sub-categorized these into Casualty Care (Tasks 1 and 3) and Arduous Labour (Tasks 2 and 4). The first task was rescuers treating the casualties and preparing them to be transported to surface. The second task rescuers constructed a barricade composed of various materials to extinguish a simulated fire (e.g. bricks, fire retardant wrapping, and beams). The third task involved a conscious casualty impaled on a steel post, which required rescuers to utilize extrication tools and perform precise first aid treatment to the wound. The forth task, rescuers loaded the casualty into a basket with a trolley to perform removal of the impaled victim via an exit route with a steep incline. This basket, with tools and the casualty, weighed in excess of 180 kg. These tasks were developed by specialists in mine rescue (OMR), which are reflective of past and frequently occurring emergencies. Both laborious and casualty care tasks required a high physical demand, where arduous labour displayed higher HR, RR, and $\dot{V}O_2$ measures. This suggests fighting a fire requires the same physical efforts as treating a casualty, which seems unrealistic. Thus factors such as the inability to rest before the beginning of subsequent tasks, which could lead to a sustained or greater HR and RR, should be considered. Other factors contributing to lack of differences between Task 2 and 3 are the details of casualty care tasks. For example, although casualty care involves kneeling and seemingly a chance to recover; participants remain in hot ambient conditions while wearing approximately 40 lbs of gear. These are not ideal conditions to adequately recover and thus will impact physiological differences between tasks 2 and 3. For HR_{peak} (Fig. 2b) and RR_{peak} (Fig. 3b), task 3 reported higher values than task 2 (arduous labour). During task 3, the casualty was impaled by a steel bar through their abdomen and anecdotally, was very realistic and distressing for the competitors. This would have caused an increase in HR and RR, from activation of the sympathetic system due to the visual stressors.[20]

Our results demonstrated that 31 (41.9%) participants exceeded 100% of the APMHR (182 bpm for the total sample), during tasks 2 and 4. Tasks 1 and 3 also demonstrated moderate-vigorous intensity (70-85% of APMHR). These values are much higher than previous findings.[13,18,31] Given that previous research examined mine tasks over a short duration, with scheduled rest breaks, this is not surprising.[18,21] In our study, participants performed work for approximately two hours, where 'rest' consists of either walking or kneeling for brief periods (less than five minutes), which is more representative of this work compared to that observed in previous literature.[12] In comparison, Stewart (2012) et al., utilized a job-task circuit composed of 9 minutes of work followed by 24 minutes of rest, in which they still reported APMHR of nearly 100%.[31] Twenty-four hours rest following vigorous intensity is recommended to properly recover and prevent overtraining.[2] However, these individuals are responding to an emergency and are expected to complete the tasks, as lives are in danger. Therefore, future research should focus on methods to improve or maximize opportunity to rest (e.g. hydration, rest protocol, or utilize back-up teams to reduce rescue mission time).

Participants' mean and peak T_c were higher in task 3 compared to tasks 1 and 2, but not different from task 4. Whereas, mean and peak T_{skin} depicted a decrease from task 3 to task 4 (Fig. 5e and 5f). This can be attributed to a decrease in ambient conditions (Table 2). T_c is less influenced by ambient conditions compared to T_{skin}, which is in direct contact with the environment.[20] The resulting gradient between T_{skin} and T_c would improve the ability to dissipate heat and balance heat gained versus heat lost, ultimately stagnating T_c.[20] Nonetheless, 30 of the 54 participants reported measures of mean T_c at 38.6 ºC or above and the highest T_c recorded in the competition was 39.88 ºC, which nearly meets the criteria (40 ºC) for heat stroke as defined by the Ministry of Labour and Taylor et al. (2014), or hyperpyrexia defined by NIOSH.[14,16,35]

A study performed by Varley (2004) studied the effects of heat in mine rescuers during regular training and determined that, following an increase in T_c, active cooling did not begin until approximately 25 minutes following training.[38] This is important because tracking T_c is not currently practiced during real emergencies. Current post-emergency policies include six hours of rest between shifts, and 24 hours of rest for those exposed to extreme heat.[12] When emergencies exceed 24 hours, doctors must be made available 24 hours a day and each team member must be examined by the doctor at least once a day.[12] During competitions paramedics are made available and remain at the end of the scenario to examine any individual experiencing any heat illness symptoms (e.g. weakness, nausea, cramps, etc.) (T. Hanley, personal communication, December 15, 2017). Closer attention immediately following a rescue event should be given to all mine rescue personnel, including testing for ongoing heat stress. This monitoring should continue for at least an hour following team-exit from the mine after an emergency. Paramedics or doctors should be present at the exit, and examine all workers for visible symptoms of heat illness (e.g. excessive sweating, lack of sweating, red skin, complacency, etc.) and to make certain they are rehabilitating properly (e.g. drinking plenty of water, resting, etc.). Future research should focus on practices to actively cool rescuers throughout an emergency and immediately upon exit from the mine, which would be beneficial and potentially life-saving.

Team Position Demands

For HR_{mean}, Captains were different from Vice-Captain and #2person ($p<0.05$), but not different from #3person and #4person (Fig. 2a). Other physiological measures that followed this pattern included RR_{mean}, RR_{peak}, and oxygen consumption, in which the Captain differed from a few positions, but not all. We hypothesize this is because the Captain is not as physically fit as the other members and would result in eliciting higher physiological measures when performing lower intensity work.[1,19] On the other hand, for HR_{peak}, Captains displayed lower values than all other positions (Fig. 2b). Again these can be attributed to the difference in responsibilities of roles during a competition; however, in real-life emergencies, Captains will help for the best outcome and therefore could elicit higher physiological responses.

Although Captains displayed lower physiological measures, except for EE, compared to other positions, Captains HR_{mean} for the duration of the competition was 74.2% of APMHR, which still reflects vigorous physical activity. Considering HR, $\dot{V}O_2$, and EE are linearly correlated and there is no difference in EE, we can suggest this may be due to the calculation used by Firstbeat Software to calculate values, which was not provided. Captains are required to wear the same PPE (approximately 22 kg) and walk the same distance, so it is expected that the Captain should have sufficient cardiovascular and muscular endurance to keep up with other members. Concern regarding a fitness standard is that it may prevent these members from active duty; causing a significant loss in experience and expertise.[12] Captains are not lifting or carrying heavy equipment and casualties, so in theory, should not be required to meet the same muscular strength standard as other members. However, it should be considered that in a circumstance another member is injured and the Captain must fill this role, and would be required to perform heavy lifting. Therefore, a multi-faceted fitness standard that encompasses all aspects of fitness (e.g. muscular strength and endurance, cardiovascular endurance) should be implemented and should be the same for all positions.

When referring to T_{skin} and T_c, Captains were different from most other positions. In agreement with Hardcastle et al. (2009), the metabolic work performed (mean of 856.6 Watts for all positions) by mine rescue volunteers was sufficient to produce mean T_c values of 38.31 ºC for all positions, and 38.10 ºC for Captains.[13] This is important as T_c of 38.0 °C are associated with an impaired ability to make decisions, and impaired reaction time.[25,29] Captains are responsible for making decisions on behalf of the team, as well as any casualties encountered in the mine, making heat strain a major concern.[12] Based on the results from Racinais et al. (2008), the Captain was making impaired decisions in the IMRC (T_c >38.0 ºC).[25] As for other positions, the highest reported T_c was 39.88 ºC, which is nearly considered heat stroke, and if not treated immediately can be fatal.[14,36] Furthermore, at a T_c of 38.6 °C and above, physical heat strain has begun and, if not mitigated, will progress to acute heat illness and eventually the life-threatening condition of heat stroke.[29]

Health and Safety Recommendations

Mine rescue is an occupation that requires great physical demands to efficiently perform intense tasks (e.g. carrying heavy equipment, firefighting, tending to casualties, and many others), while doing so in extreme ambient environments and wearing extensive protective equipment.[12] In our study 37 participants reported HR_{peak} above 100% of their APMHR, as well as three participants reported T_c above 39.5 ºC. Based on these findings, mine rescue participants are at high risk of overexertion and heat related illness.[13,18,21]

Karlsen et al. (2015) studied an acclimatization protocol and the results of training in hot and humid conditions and found decreased HR, reduced onset of time to sweating, and lower perceived exertion.[19] This process takes approximately 10 days for non-acclimatized individuals, but 3-4 days for previously acclimatized individuals. Hindered acclimatization also results after only a few days, typically three to five days.[19] This is relevant for mining companies operating on shift rotation with more than three days off, such as camp jobs. For example, these employees are scheduled 7 working days and 7 vacation days, which would impact heat acclimatization every off-rotation (T. Hanley, personal communication, December 15, 2017). To combat this, companies should stagger their schedule into three rotations to ensure there are ample active volunteers that are adequately acclimatized and prepared to respond, and ensure employees follow a recognized acclimatization protocol when returning to work.

In addition to heat acclimatization, physical fitness can protect mine rescuer participants from heat strain and allow them to work longer. Research by González-Alonso et al (1999) determined individuals with greater aerobic fitness are better able to tolerate heat strain (T_c of 39.2 °C vs. 38.8 °C) while performing exercise in hot environments to exhaustion.[10] Increased physical fitness is correlated with a better ability to tolerate physical strain and lower levels of adipose tissues, thereby lowering capacity to store heat and tolerate higher temperatures.[6,26] Implementing a fitness standard that requires individuals to be physically fit will better protect mine rescuers against heat and physical exhaustion.

As suggested by the MOL in 2015, implementing a fitness standard can improve physical fitness of rescuers, thereby reducing their risk of heat related events and improve their capability of performing strenuous work. A meaningful fitness standard should reflect demands of a real-life emergency and encompass all aspects of a mine emergency (e.g. harsh environments, casualty care, frequent laborious tasks, extensive protective equipment, etc.).[12,17] Currently, mine rescue organizations in Queensland Australia utilize estimated $\dot{V}O_{2\ max}$.[7] Thus, implementing a standard value for estimated $\dot{V}O_{2max}$ will ensure participants can perform tasks with less fatigue and for longer durations.[8] However, a fitness standard should be composed of multiple components of fitness and should not be developed based on aerobic fitness alone.

Siddall et al. (2016) evaluated physical demand in terms of roles in structural firefighting (incident commander vs. operational firefighter), they determined an adequate fitness standard to be approximately 90% of the maximum mean oxygen consumption value documented by any individual participating in the training exercise.[30] Group mean metabolic demand for Captains ranged from 8 ml•kg^{-1}•min^{-1} to 38 ml•kg^{-1}•min^{-1}, and the remaining positions had group mean metabolic demands ranged from 10 ml•kg^{-1}•min^{-1} to 41 ml•kg^{-1}•min^{-1}. These positions are relatable to Captain vs. remaining positions mine rescue personnel, and would suggest aerobic standards of 34.2 ml•kg^{-1}•min^{-1} for Captains, and 36.9 ml•kg^{-1}•min^{-1} for the remaining positions. These values do not differ by a significant degree and thus it may not be worth having a separate standard for aerobic fitness for roles. For the participants in this study the estimated $\dot{V}O_{2\ max}$ for positions excluding Captains versus including Captains was: 45.8 ml•kg^{-1}•min^{-1} and 43.7 ml•kg^{-1}•min^{-1}, respectively. Future research should make attempts to determine an adequate screening value for aerobic fitness using estimated $\dot{V}O_{2\ max}$.

A combination of a fitness evaluation (e.g. $\dot{V}O_{2\ max}$) and job simulation tasks (e.g. IMRC) for a hybrid physical standard would be the best approach.[17] Fitness evaluation would screen potential candidates and provide general insight of their general fitness and can be extrapolated for consideration regarding their ability to complete the job-simulation tasks. Aerobic standards, discussed above, utilize standardized tests to compute a value (e.g. estimated $\dot{V}O_{2\ max}$). It will also be important to consider different fitness standards based on roles within the mine rescue team. OMR should do further research on this, and analyze past events where the Captain was required to fill other roles, in event of an emergency.

Other Considerations/Recommendations

Even with the best physical fitness standard it may not be enough to completely protect these workers from injury and heat strain due to the other, unrelated factors, such as pre-fatigue and inability to sufficiently hydrate prior to an actual emergency. Safety equipment such as an HRV body worn monitor could provide additional protection to a well-developed fitness prerequisite. The current check-in system occurs every 20 minutes where the Captain simply gets thumbs up or down in reference to the wellness of other members (T. Hanley, personal communication, December 15, 2017).[12] It can be argued that if lives are in danger, members may ignore feelings of fatigue or injury to avoid terminating the active mission putting themselves and the rest of the team in danger. Therefore, the Equivital or similar personal monitoring equipment overrides the need to entirely rely on the individual's self assessment by displaying physiological responses in real-time to persons external to the underground operation, ideally the Briefing Officer, who is in constant communication with the Captain.[12] The Briefing Officer could then notify the Captain if any member of the team is displaying unsafe physiological measures (e.g. HR exceeding APMHR), and could demand the team take a break; ultimately removing guesswork of the wellness of others. Additionally, built-in alarms would be beneficial to notify the Captain and/or Briefing Officer, in case they become preoccupied with other tasks. Other factors to improve the safety of these participants involve sufficient hydration and active cooling, which should be further investigated.

Limitations

Although competing in a scenario prepared by mine rescue experts and based on previous mining disasters, there are some limitations of this research, which may result in less than true physiological responses, or performance of individuals. First, participants had knowledge of when they were competing; thus, participants had time to prepare physically. For example, they could ensure sufficient hydration and ample rest the night prior. On the contrary, it should also be noted that this may have affected their ability to sleep due to nervousness which could have also impaired their performance the following day. Second, a baseline collection of physiological responses was not possible due to scheduling of the event. We could not influence or modify the schedule of the IMRC to fit our needs as there were other aspects of the competition following the underground scenario. We were given a strict allocated time to get anthropometric measures the day prior to the event, which was not enough to gather baseline data. Third, we were unable to conduct a post competition survey to assess perceptions of heat illness and perceived exertion, again due to time constraints and language barriers. We never attempted to measure symptoms of heat illness after the competition; however, extrapolating from the results of T_c and HR, it is likely participants experienced them. Therefore, future research should utilize district and provincial competitions to allow ample time to collect baseline data (e.g. HR, RR, T_c, etc.) and post competition data (e.g. heat illness symptoms and perceived exertion).

Conclusion

This study demonstrated, in the most realistic scenario possible, short of an actual event, the extreme physical demands faced by mine rescue volunteers. Despite having different responsibilities, Captains display lower physiological loads, compared to all other positions. Laborious and casualty care tasks both required a high physical demand, demonstrated by HR, RR, and $\dot{V}O_2$ results. Moreover, mine rescuers exhibited further increase in HR, RR, $\dot{V}O_2$ in laborious. Lastly, all participants displayed high T_{skin} and T_c. Importantly, our results also highlight that all positions, including Captains, are performing strenuous work regardless of task, in hot and humid mining conditions. Furthermore, participants are at a serious risk for heat illnesses and heat-related events; action must be taken to mitigate these risks, which may include implementation of a strict fitness policy and should include live-monitoring of participants during an emergency. The fitness standard should be a hybrid standard, a combination of a fitness component test to screen applicants for baseline aerobic and muscular fitness and a job-task simulation to ensure they can complete a realistic emergency under similar conditions.

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Chapter 4

4.0 General Discussion

4.1 Main Objectives for Current Study

Our first hypothesis suggested there would be differences in physiological measurements between the four primary tasks of the IMRC and between the sub-categorization of types of tasks into Arduous Labour (tasks 2 and 4) and Casualty Care (tasks 1 and 3). Specifically, the Arduous Labour tasks would report significantly higher values compared to Casualty Care tasks on average. This proved true for mean values for responses defining physical demand (heart rate, respiratory rate, oxygen consumption) where there were significant differences between nearly every task, but not the case for HR_{peak} and energy expenditure (EE). These differences between the primary tasks and sub-tasks for the majority of physiological responses demonstrate some tasks performed for the IMRC required more or less physical work than others. It is reasonable that Arduous Labour would require a larger physical effort since Casualty Care involves primarily technical work, such as first aid, speaking with the casualty, and/or getting equipment ready; whereas Arduous Labour involves moving heavy materials (e.g. cinder blocks and lumber) to build a barricade and carrying a basket full of equipment (~100 lbs) and casualty (~200 lbs) up a steep inclined ramp. However, it is interesting to note Task 2 and Task 3 (Arduous Labour vs. Casualty Care) were not statistically different for the majority of physiological variables. This is likely attributed to the inability for rescuers to recover following Task 2 - barricading the fire; as HR and RR can stay elevated for up to 24 hours following vigorous activity (Almeida & Araújo, 2003).

Further analysis of the same types of tasks (Casualty Care vs. Casualty Care) also reported differences. It was reported that mean HR, mean and peak RR were significantly higher

($p<0.05$) in Task 3 compared to Task 1. When referring to descriptions of the two, we note that this is likely due, in part, to the differences in the casualty-related tasks. During Task 1 they had to locate one unconscious casualty (unconscious due to inhalation of Carbon Monoxide) and put the casualty in a basket, treat for shock, and ensure the casualty made it to surface via a vehicle. In contrast, Task 3 required mine rescuers to utilize heavy equipment (extrication tools weighing approximately 50 lbs) to cut the steel beam protruding through the causality's abdomen, provide first aid, and place the casualty into the first aid basket. Differences in physical demands include the use of heavier equipment (~50lbs) and more maneuvering of the casualty. In addition, in this scenario, the casualty was awake, bleeding, and screaming; which may have created more personal stress for the rescue participants. Significantly, Task 3 followed an Arduous Labour task (Task 2) and insufficient recovery likely also contributed to higher readings in HR_{mean} and peak RR_{mean} compared to Task 1. As HR and RR may remain elevated for up to 24 hours following intense exercise (Almeida & Araújo, 2003; Kenney et al., 2015).

When comparing the order of tasks, we found Task 4 was the most demanding, and Task 1 was the least demanding, as defined by physiological measures (HR, RR, oxygen consumption, and energy expenditure). HR_{mean} for all participants in Task 1 was 130 bpm compared to 158 bpm for Task 4; and EE for Task 1 was 9.45 $kcalmin^{-1}$ (661 Watts) versus 15.2 $kcalmin^{-1}$ (1063 Watts) for Task 4. The EE required for Task 4 was nearly double required in Task 1. All measurements defining physical demands reported the same trend; as depicted in the results section (Fig. 2-5).

Despite the differences in tasks performed, we would describe all the tasks as being physically challenging; as even the lowest reported mean HR for Task 1 was still 130 bpm on average, which reflects 71% of the APMHR for the entire sample. According to the Center for

Disease Control an APMHR of 70-85% indicates ‘vigorous physical activity’ (“Target Heart Rate and Estimated Maximum Heart Rate,” 2015). Although the four Tasks were performed in succession, which may have influenced readings to an extent, the EE required to perform each task highlights the physical demands required for all mine rescue tasks examined. The lowest EE reported was 9.5 kcal•min^{-1}, which is the equivalent to 664 Watts or ‘very heavy work’ (Bernard, 2006). In other words, the equivalent of a 70 kg person running at a speed of 15 km/h is equal to 256 Watts; therefore, the ‘simplest’ of the tasks in this study requires over twice the physical demand of running at a fast pace (Jetté, Sidney, & Blümchen, 1990). Overall the average of all four tasks took approximately two hours to complete with a HR_{mean} of 143 bpm (78.5% APMHR), in which participants had little to no rest and could not hydrate. Typically mine rescue participants are deployed for an average of two hours, and rarely with a maximum time of four hours (breathing apparatus lasts four hours), to ensure teams have ample time to exit the mine circumstances (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014; T. Hanley, personal communication, February 7, 2018). Rescue missions may be less than two hours in environments classified as hot and humid as measured by the Kestrel Weather meter, but this is a relatively new protocol (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014; T. Hanley, personal communication, February 7, 2018). Future research should work to develop equipment and PPE that is lighter, attention should be given to off-loading tasks for participants while underground and perhaps a robot that can travel with the participants and carry the tools.

The second question we posed when designing this study was whether Captains would expend less physical demands, as measured by physiological responses, in comparison to the other ‘worker’s’ positions (Vice-Captain, #2person, #3person, and #4person), given the differences in their defined duties. Based on our results, Captains performed significantly less physical work compared to the other team positions. We think this is due to the differences in their primary duties (i.e. communication, delegating tasks, and taking notes) compared to the other positions who are responsible for all labour-related and technical-type (e.g. first aid) tasks during a mine rescue. When considering the data in its entirety, Captains provided consistently lower physiological measures in comparison to the remaining positions both statistically and observably (Fig. 2-5) in the results section. However, the EE data showed no significant differences between Captain and the other positions. Further when we examine the statistical differences in heart rate, respiratory rate, oxygen consumption, T_c, and T_{skin} we question whether these differences are meaningful clinical differences. Specifically, for the application of a fitness standard (which should include an aerobic fitness): we do not think that Captains should be considered separately. Particularly since they are supposed to be able to replace a team member, in a circumstance where another team member becomes injured, or in a catastrophic event, which would also require them to perform physical labour. To date Captains have not been studied separately from other members on the team, but future research should continue to do so. Also, the demographic in this study did not indicate statistical significant differences ($p > 0.05$) between the participants' characteristics of Captain versus 'other' team members; however retrieving participants characteristics from all mine rescue personnel in Ontario may provide a different result. This measure has been recommended to Ontario Mine Rescue for future research.

According to the Ministry of Labour of Ontario, there will be a labour shortage due to retirements in coming years; prior to this demographic shift, it would be interesting to determine whether there is a statistical difference in age between Captains and Other team members

(Government of Ontario, 2015a). Anecdotally, Captains are the most experienced members of the team, suggesting that they would be an older population of participants. We would recommend the continued study of Captains separately from other positions for two reasons. First, the year prior to this mass retirement, Captains mean ages will be higher than normal, and would therefore be expected to report high physiological responses; due to reduced cardiovascular function related to age (Kenney et al., 2015; Strait & Lakatta, 2012). Secondly, when the majority of experienced participants retire, younger rescuers taking on Captains roles may report higher physiological responses because they cannot rely on familiarization, which has been shown to reduce physiological measures (Jamnik et al., 2013). Our recommendations for the application of a fitness standard will be discussed below in Section 4.2.1, with applications for Ontario and Global Mine Rescue; however this data could help inform the parameters.

The third question we asked was whether mine rescue participants in this study would experience high levels of heat strain and be at risk of heat-related illness. When referencing the literature, heat strain begins at a T_c of 38.6 ºC, and if not mitigated or treated it will progress into heat illness (Sessler, 2008). An increase in T_c will result in an increase in heart rate, for an average of 7.2 bpm per every increase in degree Celsius (Jensen & Brabrand, 2015). This will further stress the cardiovascular system, result in rescuers reaching fatigue at a faster rate, and making it difficult to dissipate heat (Jensen & Brabrand, 2015; Kenney et al., 2015). This is relevant because these factors will then further increase the risk of developing heat illness. There were 30 individual participants' recordings for mean T_c and 32 recordings for peak T_c that exceeded 38.6 ºC, indicating nearly half of the participants in this study experienced heat strain. Additionally, there were three participants that reported peak T_c that exceeded 39.5 ºC and one participant registered a peak T_c of 39.88 ºC. This is particularly worrisome given that 40 ºC is considered heat stroke and can be fatal ("Heat Stress | Ministry of Labour," 2008; Taylor et al., 2014) and this level was reached (and not identified) in a *simulation* of mine rescue. It suggests that participants are commonly having instances of unreported heat stress. This is likely due to high levels of metabolic heat being generated in response to high levels of work being performed and low levels of heat lost, and the use of the heat generator in Task 2 to simulate a fire. Clearly, participants in this study and mine rescuers in general are at high risk of heat strain and potential heat illness. Furthermore, it can be argued that individuals may experience higher levels of heat strain during a real emergency if the rescue is to be performed on a deeper level in the mine due to pressurized rock emitting heat, or if the fire cannot be extinguished quickly. Future research should further explore the extent to which participants are exhibiting signs of heat stress and post-rescue policy needs to be developed and implemented. Post-rescue care should screen for heat stress and treat for it - future research should look to measure how many participants are suffering from some form of heat stress when they exit the mine. Post-emergency recommendations and heat strain guidelines will be discussed below in section 4.2.3 in this discussion.

4.2 Application for Mine Rescue and Global Mine Rescue

4.2.1 Fitness Standard

This study has demonstrated that mine rescuers are performing work that is nearly double what is characterized as 'Very Heavy,' in hot and humid conditions and is supported by previous work (Bernard, 2006). Other factors such as dehydration, fatigue, and heat strain contribute to the dangers of this occupation. Considering the spontaneous nature of emergencies, it is nearly impossible to ensure these individuals are adequately prepared for a rescue. However, given the high risk of fatality associated with this job, the Ministry of Labour (MOL) and Ontario Mine Rescue are committed to developing and improving policies to protect these participants. A primary consideration for preparedness includes fitness status prior to mine rescue.

In fact, the Mining Health, Safety and Prevention Review, conducted by the MOL in 2015, identified ‘Emergency preparedness and mine rescue’ as a actionable recommendation and specifically included physical fitness and heat acclimatization as components of the recommendation (Government of Ontario, 2015b). As OMR is the body responsible for overseeing training and competency of all mine rescue volunteers, they would like to implement fitness testing that would require volunteers to achieve a minimum standard in order to be eligible to join and retain membership to a Mine Rescue team in Ontario. Outlined by Jamnik et al. (2013), occupations with tasks that do not change with age and are physically demanding should implement a hybrid testing; first pre-screen with a fitness test that combines aerobic and strength testing and follow up with a job-task simulation. Our proposed components of a fitness standard would include:

1. *Aerobic component*
2. *Strength component*
3. *Job-task simulation*

Aerobic Component:

The Queensland Australia Mine Rescue participants are already required to perform a step test and achieve an estimated $\dot{V}O_{2max}$ score of 40 ml•min^{-1}•kg^{-1} in order to be eligible to continue required training and to become an active mine rescue volunteer (“Guidelines for the Medical Assessment of Mines Rescue Personnel,” 2010). We believe this type of physical assessment is warranted, since the job requirement for mine rescue participants does not change with age, provided you are not working in the role of Captain. The mean estimated $\dot{V}O_{2\ max}$ value for all participants in this study was 45.4 ml•min^{-1}•kg^{-1}; Captains were 43.6 ml•min^{-1}•kg^{-1}; and remaining positions were 45.8 ml•min^{-1}•kg^{-1}. We believe 40 ml•min^{-1}•kg^{-1} is reasonable to achieve according to the results from our study. , However, using a normative standard will create gender bias, because typically males have higher $\dot{V}O_{2\ max}$ values compared to females due to physiological and biological differences. For example, in 1994 a female wildland firefighter experienced undue hardship because of implementation of a normative standard of $\dot{V}O_{2\ max,}$ which she nor other females could not achieve despite being able to perform the required work for years prior (Jamnik et al., 2013). Consideration when developing criteria for a standard must follow the "Unified Test" by the Supreme Court of Canada so there is no undue hardship caused due to discrimination and current ability to complete the task (Jamnik et al., 2013). With that being said, of the 70 participants reporting estimated $\dot{V}O_{2max}$ values, eight were below 40 ml•min^{-1}•kg^{-1}; these comprised three Captains, two Vice-Captains, one #3person, and two #4persons. Therefore, further research should be done in order to determine values that will legitimately reflect the work being performed and not cause undue hardship due to gender bias.

$\dot{V}O_2$ testing is meaningful as a measure, although it does become more difficult to achieve high scores, with age, because of reduced cardiovascular function, much like the tasks being performed by mine rescue participants (Strait & Lakatta, 2012). In fact, a study of structural firefighters and front-line participants performed by Antolini et al. (2015), demonstrated a negative correlation between $\dot{V}O_{2\ max}$ and age, where age increased and $\dot{V}O_{2max}$ decreased on average. However, decreased cardiovascular function can be compensated for by experience, as outlined by Jamnik et al. (2013), where improving skill while performing specific tasks can reduce the energy expended in doing the task. Therefore, $\dot{V}O_{2\ max}$ by itself is not sufficient for a fitness standard, as it only measures one component of fitness. Given that $\dot{V}O_{2\ max}$ decreases with age, but experience increases with longevity on-the-job, we think some considerations should be given to experienced participants whose familiarization of tasks may have reduced their physiological responses during a rescue. Work conducted by Siddall et al. (2016) evaluated physical demand in terms of team role in structural firefighting (incident commander vs. operational firefighter); a job with many similarities to Mine Rescue, including the role of team leader. They determined that an adequate fitness standard would be 90% of the maximum $\dot{V}O_{2\ max}$ value in the metabolic range documented for a simulation. This value was derived from monitoring minimum acceptable performance of essential tasks, and they state 'it is estimated that healthy adults can sustain the total duration of these tasks at ≤90% maximum oxygen uptake' (Siddall et al., 2016). The current study demonstrated a metabolic range for Captains of 8 $ml \cdot min^{-1} \cdot kg^{-1}$ to 38 $ml \cdot min^{-1} \cdot kg^{-1}$, while the remaining positions had mean metabolic demands of 10 ml/kg/min to 41 ml/kg/min. When implementing Siddall's (2016) method we would suggest aerobic standards of 90% of 38 $ml \cdot min^{-1} \cdot kg^{-1}$ (34.2 $ml \cdot min^{-1} \cdot kg^{-1}$) for Captains, and 90% of 41 $ml \cdot min^{-1} \cdot kg^{-1}$ (36.9 $ml \cdot min^{-1} \cdot kg^{-1}$) for the remaining positions. Based on the results of the current study, we would not suggest that Captains have a lower aerobic standard value. This is again because they are expected to replace a team member, in a circumstance where another team member becomes injured, or in a catastrophic event, which would also require them to perform physical labour.

Strength Component

In addition to aerobic fitness, muscular strength should be considered as a component of the fitness standard. This can be replicated as per Stewart et al. (2008), by assessing muscular strength (e.g. 1 rep max for deadlift) and endurance (e.g. static back hold and/or maximum sit-ups in one minute). In a report performed by Sell and Hoffman (2017), the utility of grip strength has an important influence on overall strength development and injury prevention.

In the current study, we did not measure the muscular strength of the participants. Future work should measure this component of fitness and identify whether differences exist between positions. To our knowledge, no other study has examined separate positions for muscular strength and endurance in similar occupations. Theoretically, Captains would benefit from a lower standard for muscular strength, as they are not involved in lifting, but in reality emergencies occur, Captain is not performing any physical lifting, in a circumstance where another team member becomes injured, or in a catastrophic event, and this would require them to perform physical labour.

Job Task Simulation:

OMR already implements job-task simulation training, but we recommend the addition of pre-screening individuals with an aerobic and strength test, as described above. Studies examining these levels in participants to date could inform these recommendations as well as inform on a strategy for a fitness program. The Task Simulation test functionally combines specialized skills, in addition to aerobic fitness, muscular strength and endurance; while also testing whether recruits can perform these job tasks while wearing required PPE, for a lengthy period. This is the current training protocol required by OMR to remain active and when joining mine rescue. Recruits must complete an introductory course and during the last two days of this course they are required to perform a simulated emergency that lasts approximately two hours, usually including first aid component and carrying a casualty out of the mine. Given the results from our study, and the potential risks associated even with simulation testing, we think pre-testing should be required as a safety standard prior to this simulation.

Currently when conducting a job-task simulation, all positions are evaluated equally; that is – in their ability to solely complete the simulation. We would recommend that OMR consider modifying their scoring for this component of the fitness standard. Specifically, Captains should also be evaluated based on their success in decision-making, whereas remaining positions should be evaluated on their ability to complete their roll specific tasks. There is unfortunately no standardized scoresheet currently, but we suggest OMR should implement this in the future.

It is important to consider different fitness standards based on roles within the mine rescue team. However, we must make note of the possibility of unfortunate emergencies where the Captain may be required to compensate for other members due to injury. In theory, Captains would benefit from a lower standard for muscular strength, as they are not involved in lifting, but should be held to the same aerobic standard. Therefore, OMR should investigate further whether Captains should be held to a different standard for all accounts.

4.2.2 Live Monitoring

Of the 20 participants that participated from Ontario, 11 of them reported T_c that exceeded 38.6 ºC, which according to NIOSH is when heat strain begins. It is clear mine rescue volunteers are at risk of developing heat strain, due to the immense physical work being performed in hot and humid environments. Furthermore, these risks can be increased due to the types of tasks performed, such as firefighting where there is additional heat generated from the fire. Considering these participants are the first line of defence and often are uncertain what they are dealing with, they could greatly benefit from live monitoring. The T_c capsule is a useful method, in theory, to employ as it can continuously track internal temperature over approximately 12 hours. However, this capsule must be ingested approximately two hours prior for most accurate readings, is contra-indicated in some individuals, and as in our study, T_c alone does not accurately predict an event. Therefore we would not recommend its use in mine rescue as a regular practice.

However, other wearable technology exists that could provide meaningful information about the health status of each team member during a mine rescue deployment and we strongly recommend that this type of monitoring become a component of mine rescue work. In our study, we used the Equivital heart-rate variability monitor. This wearable, can estimate T_c, while also measuring HR, RR and HRV, with no time lag before readings can be displayed. This monitor is also certified as intrinsically safe for use in a mine; which was a key reason for its selection. To our knowledge, it is currently the only wearable with this certification. Given that HR and T_c are interrelated and good predictors of heat stress (Davies & Maconochie, 2009); by utilizing a live monitoring device we can improve the safe-monitoring of all mine rescue team members. Currently, Mine Rescue Protocol requires the Captain to verbally check-in with each member every 20 minutes regarding their health and then relaying this report to the briefing officer (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). The goal of this policy is to ensure the safety of the team and keep continuous communication with surface. However, given the limitations of this method (lack of visual cues due to PPE, potential for misinformation, and etc.) a better solution is the real-time monitoring of the team's vital measurements. This also allows for a more immediate alert to the Briefing Officer of an issue and bypasses the need to rely on the Captain (who may also be experiencing heat stress). The safety of the team is the first objective of any rescue, and if the safety of any member is of concern, immediate evacuation is required (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). This may be particularly important given that participants may ignore or be reticent to report personal health concerns during a rescue because they don't want to impact the rescue or because they fail to believe in the significance of their symptoms.

4.2.3 Heat Strain Policies

As outlined by the Ministry of Labour's 2015 Safety and Prevention review, focus should be paid to preventative methods in addition to post-emergency policies. For example, developing an acclimatization protocol and implementing a body-worn physiological monitor can prevent the occurrence of heat illness. For acclimatization, results following a two-week acclimatization protocol a clear increase in power output and physiological performance followed after only 6 days (Karlsen et al., 2015). However, heat acclimation was lost after a mere 3-4 days and participants were nearly back at starting levels 10-11 days following heat acclimation (Karlsen et al., 2015). Therefore those involved in mine rescue would be required to undergo an acclimatization protocol once a week by cycling in a hot environment to ensure it is not completely lost. Further, those who take extended vacation would also need to be reintroduced by performing a week-long acclimatization period. At this time, we do not know whether this practice is feasible.

For this reason, we would emphasize the requirement of a physiological monitor, for all mine rescue personnel such that they be continuously monitored during a rescue. We specifically recommend that termination of rescue be based on the status of an individual by quantitative means rather than the current practice of self-assessment. We would also question whether four-hour rescue duration should be reconsidered – i.e. the limits of the rescue should not be based upon the limits of the breathing apparatus, but on the average physical capacity of rescuers using a breathing apparatus. As described by Varley (2004), members with abnormally high T_c and/or resting heart rates should be considered for exclusion, prior to beginning a mission, as this will significantly increase their risk for heat stress during the mission.

In line with the European Guidelines on mine rescue we also underline the importance of frequent rests during a mission with continuous heart rates monitored. These guidelines recommend HR monitoring for each rest no more than 20 minutes apart. We would extend these guidelines by recommending continuous monitoring of physiological measures, such that the capacity for the rescue worker to recover during the rest is also assessed. One way to assess recover time is to compare recovery HR to fully resting heart rate. As described in Varley (2004) recovery HR can be taken as the HR 2 minutes after resting and be compared to a baseline resting HR collected prior to the mission. A rise in this resting rate indicates accumulated strain in the person. Regularly use of monitoring would allow the Briefing Officer to individualize these values and they could then be compared to the ACGIH limits of 110 bpm for a recovery time of one minute (ACGIH 2001). In addition, the Briefing Officer can use the continuous monitoring to enforce a rest, if HR levels for any team member rose precipitously.

Additionally, as outlined by ACGIH, who have identified the thresholds to protect participants is a T_c of 38.5 ºC and above (Bernard, 2006). Therefore, an estimated T_c equal to or exceeding 38.5 ºC and/or a HR nearing estimated maximum heart rate, the team should be ordered to rest to determine if T_c can be stagnated or lowered, if not they should be recalled (Bernard, 2006; Sessler, 2008). HR and T_c should be co-considered, as they are interdependent. We would also like to explore the emergency system built in to the Equivital in future research.

These two preventative methods should be used in conjunction with post-rescue guidelines to ensure heat strain is mitigated. Of note, the Equivital Life monitor does offer a heat stress evaluation with alerts for participants. However, the algorithm used to assess this risk is not provided by the company and has not been tested for applications in this population of participants. Further work needs to be done to establish the parameters of these alerts for use in recall guidelines.

Currently, there are some measures in place to ensure mine rescue participants recover from heat illness post-competition, such as having medical personnel available when they exit the mine and a cooling station. Although, policies for post-emergency activities are vague, they include at least six hours of rest between shifts, and 24 hours of rest for participants exposed to extreme heat, and working under the time limits of the OMR Heat Exposure Standard (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014). When emergencies exceed 24 hours, doctors must be made available 24 hours a day and each team member must be examined by the doctor at least once a day (*Handbook of Training in Mine Rescue and Recovery Operations*, 2014).

This study shows T_c reaching nearly 40 ºC in some participants, so it can be postulated if the competition continued beyond the two hours some participants would have been in danger. We recommend that mandatory practices be put in place that would assume all participants have some degree of heat stress post rescue. Ice-water immersion has been successful in reducing the mortality caused by exertional heat stress. For example, road race competitors, with rectal temperatures of >42 ºC and profound CNS dysfunction, who are identified and treated immediately in ice water baths, often leave the medical tent without hospitalization (Bouchama, Dehbi, & Chaves-Carballo, 2007). Ice-water immersion provides the fastest whole body cooling method, normally within 10-60 minutes to return T_c below 38.8 ºC (Bouchama et al., 2007; Lawrence Armstrong et al., 2007). Another profound study showed 100% survival rate from exertion heat stress (EHS), in which 274 cases were documented over 18 years of races; the average initial T_{rectal} was 41.44 ºC ± 0.6 ºC, and the average cooling rate from cold water immersion for patients with EHS was 0.22 $ºC•min^{-1}$ ± 0.11 $ºC•min^{-1}$ (Demartini et al., 2015). Therefore, mine rescue organizations should implement cold water immersion for all participants immediately following competition and real emergencies to ensure no one suffers injury from EHS.

In addition to OMR's current policies, we therefore also recommend that a policy be developed to treat all mine rescue personnel for heat stress post rescue, and to include a screen for heat illness symptoms (excessive sweating, cessation of sweating, confusion, etc.), ice bath and administration of IV fluids, and two hour check in with health care professionals. We recommend these in emergencies involving firefighting in particular, as rescuers are exposed to hot environments, and may be required to complete multiple rescue trips.

4.3 Limitations

A primary limitation to this study was the inability to collect baseline physiological data. This was not possible due to scheduling of the event. We were given a strict allocated time to collect anthropometric measures the day prior to the event, which was insufficient to gather baseline data on all participants. Although participants put on the equipment just prior to the start of the event, we did not consider this data to be a true baseline, as they were about to start the competition and their measures were observably elevated.

A second limitation was that we did not conduct a post-competition survey in order to look at things like: perceptions of heat illness and perceived exertion. We never attempted to measure symptoms of heat illness after the competition; however, extrapolating from the results of T_c and heart rate, it is likely participants experienced them. Future research conducted with OMR should utilize district and provincial competitions in Ontario to allow ample time to collect baseline data (e.g. heart rate, RR, T_c, etc.) and post competition data (e.g. heat illness symptoms and perceived exertion).

4.4 Future Research

The current study utilized field research and objective measurement methods to determine the physical demands of mine rescue participants during a simulated emergency composed of frequently occurring tasks, as assessed by Ontario Mine Rescue. Physical demands and heat strain is of significant concern for mine rescue and requires immediate attention due to the high risks for a fatality. However future research should also attempt to account for psychosocial factors contributing to fatigue and injury risk (Weaver, Patterson, Fabio, Moore, Feiberg, & Songer, 2015a, 2015b), in particular – mental duress and perceived stress/anxiety during the rescue event may be significant contributors to injury occurrence (LeBlanc et al., 2012). For example, advanced medical care professionals demonstrated vulnerability to acute stress, and made higher errors in decision making in response to high-stress scenarios (LeBlanc et al., 2012). Given the personal risks associated with rescue work and the potentially stressful situations, which can arise during the rescue (discovering fatalities, wounded miners, etc.) this area or research would also provide valuable information for Mine Rescue, globally.

A second avenue of study we would highlight is to developing and administering a questionnaire to mine rescue participants for when they are not conducting a rescue; (e.g. pre-shift, mid-shift, end-shift) to determine their preparedness in the event of an emergency. This data could inform policy makers on ways to better prepare or to screen mine rescuers before deployment during an emergency. Enhanced preparedness of these participants can further protect them and reduce their incidence of injury. Primary considerations should include hydration status and nutrition status, which can indicate overall health.

4.5 Conclusions

It is without doubt that mine rescue individuals are at extreme risk for overexertion, and heat illness when performing rescue; but this is not the only population that will benefit from this type of research. The two aspects of this study we would highlight are the differences in physiological responses due to team position and job tasks; as well as need for live monitoring during a mine rescue. Understanding the differences in requirements due to position and task can taper a physiological assessment that is appropriate for all participants in particular to the Captain position in order to not lose expertise on the team amongst older participants. Live monitoring should improve the safety of the works by providing key information about their health status during a rescue to those responsible for their safety; specifically for monitoring the onset of heat illness and overexertion to guide the evacuation of a team. To conclude, Mine rescue organizations globally should continue to research and advance preventative methods to reduce the risks of overexertion and heat illness.

Chapter 5.0

5.0 Bibliography

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Appendices

Appendix A: Research Ethics Board Certificate

APPROVAL FOR CONDUCTING RESEARCH INVOLVING HUMAN SUBJECTS
Research Ethics Board – Laurentian University

This letter confirms that the research project identified below has successfully passed the ethics review by the Laurentian University Research Ethics Board (REB). Your ethics approval date, other milestone dates, and any special conditions for your project are indicated below.

TYPE OF APPROVAL / New X / Modifications to project / Time extension	
Name of Principal Investigator and school/department	Ayden Robertson and Justin Konrad with Sandra Dorman and Dominique Gagnon, supervisors School of Human Kinetics
Title of Project	Assessing physiological factors in Mine Rescue volunteers
REB file number	2016-02-10
Date of original approval of project	April 22, 2016
Date of approval of project modifications or extension *(if applicable)*	
Final/Interim report due on: *(You may request an extension)*	April 22, 2017
Conditions placed on project	Immediate cessation of study and notification of REB of any adverse event during the pilot study to be conducted at district and provincial Mine Rescue Competitions June 9-10, 2016

During the course of your research, no deviations from, or changes to, the protocol, recruitment or consent forms may be initiated without prior written approval from the REB. If you wish to modify your research project, please refer to the Research Ethics website to complete the appropriate REB form.

All projects must submit a report to REB at least once per year. If involvement with human participants continues for longer than one year (e.g. you have not completed the objectives of the study and have not yet terminated contact with the participants, except for feedback of final results to participants), you must request an extension using the appropriate LU REB form. In all cases, please ensure that your research complies with Tri-Council Policy Statement (TCPS). Also please quote your REB file number on all future correspondence with the REB office.

Congratulations and best wishes in conducting your research.

Rosanna Langer

Rosanna Langer, PHD, Chair, *Laurentian University Research Ethics Board*

Appendix B: Supplementary Results

Table 1 Summary data for physiological measures for each task and position for participants in the 2016 IMRC

Task	**Position**	**N**	**HR mean (bpm) ±SD**	**HR peak (bpm) ±SD**	**RR mean (rpm) ±SD**	**RR peak (rpm) ±SD**	**TEE/time (kcal/min) ±SD**	**$\dot{V}O_2$ mean (ml/kg/min) ±SD**	**Skin Temp mean (°C)**	**Skin Temp peak (°**	**N**	**Core Temp mean (°C)**	**Core Temp peak (°C)**
1 (casualty care)	Captain	15	125±5	157±5	28±1	39±2	9.1±1.03	20.6±1.99	36.8±0.19	37.4±0.16	10	37.8±0.15	38.1±0.13
	Vice-Captain	15	132±4	171±4	32±1	43±1	9.9±1.01	21.2±1.52	36.9±0.18	37.6±0.15	10	37.8±0.16	38.1±0.15
	#2person	15	138±6	171±5	32±1	42±2	10.1±1.08	25.7±2.14	37.4±0.21	38.1±0.04	12	37.8±0.10	38.1±0.10
	#3person	15	125±4	164±4	31±1	42±2	8.3±1.08	21.1±1.34	37.1±0.18	37.7±0.15	9	37.8±0.14	38.1±0.11
	#4person	14	133±5	173±4	31±1	43±2	9.8±0.91	22.9±1.71	37.7±0.27	37.6±0.17	10	38.0±0.07	38.3±0.11
	Total	74	130±2	167±2	31±1	42±1	9.5±0.43	22.3±0.81	37.0±0.10	37.7±0.07	51	37.8±0.06	38.1±0.05
2 (arduous labour)	Captain	14	132±7	152±7	30±1	38±2	10.8±1.28	23.6±2.54	37.4±0.16	37.7±0.17	11	38.0±0.16	38.1±0.17
	Vice-Captain	14	151±5	173±5	35±1	43±2	13.5±0.91	29.0±1.12	37.7±0.15	38.0±0.13	10	38.3±0.14	38.5±0.16
	#2person	14	150±5	171±5	34±2	43±2	14.5±1.47	31.3±1.82	38.0±0.17	38.2±0.14	12	38.3±0.12	38.5±0.14
	#3person	14	147±5	173±3	35±2	45±2	12.8±1.07	29.6±1.28	38.0±0.09	38.3±0.08	8	38.3±0.15	38.6±0.18
	#4person	14	150±5	175±4	33±1	43±2	13.0±0.78	30.0±1.47	37.7±0.14	38.1±0.13	9	38.5±0.15	38.7±0.16
	Total	70	146±3	169±2	33±1	42±1	12.9±0.51	28.7±0.81	37.8±0.07	38.1±0.06	50	38.3±0.07	38.4±0.08
3 (casualty care)	Captain	14	131±7	162±5	30±1	42±2	10.1±1.28	22.2±2.51	37.1±0.20	37.6±0.16	11	38.2±0.16	38.3±0.17
	Vice-Captain	13	148±7	175±7	34±1	45±2	13.3±1.39	26.3±1.89	37.6±0.24	38.1±0.14	11	38.7±0.15	38.9±0.17
	#2person	14	144±5	174±5	34±2	45±2	10.8±1.07	28.6±1.58	37.8±0.13	38.2±0.12	13	38.5±0.12	38.7±0.13
	#3person	14	139±4	172±3	35±2	45±2	11.1±0.88	26.9±1.52	37.7±0.17	38.2±0.11	8	38.7±0.11	38.9±0.12
	#4person	14	143±5	175±3	34±1	45±2	11.7±0.80	26.6±1.55	37.6±0.16	38.2±0.12	9	38.8±0.17	39.0±0.20
	Total	69	141±3	171±2	33±1	44±2	11.4±0.49	26.1±0.84	37.6±0.08	38.1±0.06	52	38.6±0.07	38.7±0.08
4 (arduous labour)	Captain	14	151±5	173±3	39±1	43±1	14.2±0.83	30.1±1.68	36.1±0.34	36.5±0.30	9	38.2±0.15	38.3±0.16
	Vice-Captain	11	170±3	190±3	39±1	48±1	17.0±1.06	33.5±1.03	36.7±0.43	37.2±0.40	10	38.7±0.16	38.8±0.18
	#2person	12	157±8	179±3	39±2	48±2	16.5±1.93	33.1±2.34	37.0±0.24	37.5±0.17	10	38.5±0.12	38.7±0.13
	#3person	14	156±3	179±3	38±2	46±2	14.2±0.78	33.4±0.78	36.8±0.19	37.4±0.18	8	38.7±0.13	38.7±0.13
	#4person	13	157±4	182±4	38±2	48±3	14.6±0.75	32.0±1.16	36.3±0.33	36.9±0.31	9	38.8±0.17	39.0±0.17
	Total	64	158±2	180±2	38±1	47±1	15.2±0.5	32.4±0.66	36.6±0.14	37.1±0.13	46	38.6±0.07	38.7±0.08

Legend
N: number of participants
HR: heart rate
RR: RR
TEE: total energy expenditure
Skin Temp: T_{skin}
Core Temp: T_c

Table 2 Metabolic Rate Categories

Reference Metabolic Rate	Watts
Baseline	115
Light	180
Moderate	300
Heavy	415
Very Heavy	520

Adapted from ACGIH 2006 (Bernard, 2006).