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AN EXPLORATORY STUDY OF CARBON MONOXIDE EXPOSURES IN ICE RINK VOLUNTEERS

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AN EXPLORATORY STUDY OF CARBON MONOXIDE EXPOSURES IN ICE RINK VOLUNTEERS

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Abstract

Hockey has grown in popularity in the United States substantially in the last fifty years. The combustion engine has primarily been utilized to power the ice resurfacing equipment to make the ice smooth and able to support the next activity. The exhaust from the combustion engine creates a source of CO that could be harmful to the bystanders if the exhaust is not ventilated from the area properly. Many studies have investigated CO concentrations in ice rinks, but few have evaluated carboxyhemoglobin (COHb) levels as a biological indicator of CO exposure, in order to evaluate the potential health effects of CO exposure to volunteers and participants during hockey games.

This study evaluated twelve volunteers and users of the Butte Community Ice Center (BCIC) to determine if they were exposed to levels of CO exceeding established Occupational Safety and Health Administration exposure limits, and whether the levels of carboxyhemoglobin in the participant's blood were high enough to cause adverse health effects. Over a 3 day period, area CO concentrations were measured using a multi-gas monitor, and a non-invasive pulse-oximeter for measuring the COHb percent in the blood. Thirty-two area CO (ppm) measurements were taken from two locations. During the same period ninety-two COHb (% COHb) measurements were collected from study participants.

Statistical analysis using Minitab's Two Sample t-test compared concentrations of CO on-ice and off-ice air concentrations and pre- and post-activity % COHb in the blood to determine if study participants were overexposed to CO. In addition, a correlation analysis was performed to determine if there was a correlation between airborne CO concentration and % COHb in the blood. The study determined that CO concentrations exceeded recommended airborne exposure limits; and %COHb exceeded 10% COHb, the level indicated by literature to cause adverse health effects. Analysis revealed a positive correlation between post activity airborne CO concentrations and post activity %COHb blood concentrations. It is recommended that this facility evaluate engineering and administrative controls to reduce the risk of CO over exposure within the BCIC.

Keywords: Ice resurfacer, Butte, Carbon monoxide, Carboxyhemoglobin, ice rink, Exposure

Dedication

I would like to dedicate this to my friends and family who have supported me through this process, as well as Sally Bardsley and my thesis committee. Without their guidance and assistance I would not have succeeded in this endeavor. Bev Hartline and the Sloan scholarship committee also deserve credit for my accomplishments. The financial assistance and kind words have been influential in my completion of my degree, and I could have not accomplished this task without their support. Also I would like to dedicate this to the volunteers at the Butte Community Ice Center who not only helped me with this thesis, but have supported me while I have lived in the great city of Butte, MT.

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1. Introduction

Carbon monoxide (CO) is a poisonous gas that cannot be seen, smelled or tasted by the human body. Carbon monoxide is a common hazard associated with the incomplete combustion of carbon containing fuels, such as gasoline, kerosene, oil, propane, coal and wood. CO can be found in many workplace environments such as, boiler rooms, breweries, warehouses, petroleum refineries, pulp and paper production facilities, and steel production mills (OSHA, 2002). Sources of CO in homes include furnaces, fireplaces, stoves, barbecues, garden equipment, and generators. Vehicles, such as operating cars, trucks, boats, and planes; and cigarette smoke can lead to CO exposures (Guide to Prevent Carbon Monoxide Poisoning, N.D). Although workplace environments tend to produce higher emissions of CO, it is important to be aware of all possible sources of CO exposure. In the United States an average of 170 people die each year from CO produced from non-automotive products (Carbon, N.D.). In a report produced by NBC News, in the years 2009 and 2010, 250 people became ill from poor indoor air quality within an ice arena (Rosen, 2014).

Breathing carbon monoxide is very dangerous. It is the leading cause of poisoning death in the United States. Ice rinks make up a very small fraction of these deaths. Most poisonings are due to automobiles running in residential buildings (garages), but the hazards still remain in ice rinks. When carbon monoxide is breathed into the body, the CO replaces the oxygen in a human's bloodstream, starving the heart, brain, and body of oxygen. Health effects include breathing problems, chest pain, confusion, drowsiness, fainting, headaches, nausea and vomiting, and unconsciousness. CO poisoning can cause death, and for those that do survive an over exposure to CO, recovery can be a slow process. This process depends on the duration of time the person was exposed to CO and the concentration of CO present. If the individual has impairments in mental ability beyond two weeks, the chances of a complete recover are unlikely (Kao, 2006).

For the first time in its history, during the 2010-11 season, USA hockey enrollment reached 500,579 players (Thomas, 2011). This number demonstrates the growth of hockey in the United States, and indicates the increased usage of ice rink facilities among individuals in the United States. According to the International Ice Hockey Federation (IIHF), in 2013 there were approximately 1,800 indoor rinks located in the United States (IIHF, N.D). Each indoor rink represents a potential CO gas exposure hazard created by ice resurfacing equipment.

An ice resurfacer is a tractor-like vehicle that smooths the ice surface damaged by activities, such as ice hockey or figure skating. During ice resurfacing, a blade is used to shave a thin layer of ice from the surface, and water is applied to wash away imperfections and fill remaining holes or low areas. The water then freezes to create a fresh sheet of ice on the rink surface (Zamboni, N.D). The two main types of ice resurfacers utilized in ice facilities are battery powered and propane powered. In most facilities the propane operated ice resurfacer is utilized because it is less expensive and requires less maintenance. A propane operated ice resurfacer is utilized by the Butte Community Ice Center (BCIC)**.**

The Butte Amateur Hockey Association is composed of volunteers from Butte and surrounding communities, many of whom may lack the safety recognition skills necessary to understand the health risks that their local facility represents. The BCIC is currently operating without any industrial hygiene oversight. Because the BCIC is manned by volunteers, Occupational Safety and Health Administration (OSHA) standards are not applicable, and the Environmental Protection Agency (EPA) standards are only applicable to outdoor air quality. Also the Montana Department of Health does not have regulations associated with indoor exposure to CO. This set of circumstances leaves the facility vulnerable by lack of knowledge to the risk of overexposing participants, volunteers, and the public to CO gas.

The BCIC provides services for hockey, figure skating, and curling organizations, supports approximately 300 sporting participants and volunteers each year from September to May (Ewanic, 2013). It is important to measure whether carbon monoxide (CO) concentrations at BCIC have the potential to cause adverse health effects to the individuals utilizing the facility. This study benefits BCIC and other ice rinks with potential exposure to CO by measuring ambient CO exposure concentrations, and it will evaluate the need to install a ventilation system to improve air quality.

1.1. Purpose

Three aspects related to CO exposure in ice rinks were studied in this research. The first purpose was to determine if there is a significant exposure to CO in the BCIC when compared to OSHA exposure limits. The second purpose was to determine whether carboxyhemoglobin (COHb) levels were high enough to cause adverse health effects. For this determination 10% COHb was used as the action level. When COHb is present below this criterion the human body can maintain normal functions and remove the excess COHb successfully (Carbon, N.D.). The third purpose was to determine if there was a significant correlation between the airborne CO levels (measured in parts per million) and that observed in the bloodstream of the individuals participating in the research measured as percent carboxyhemoglobin (%COHb).

1.2. Research Questions

Prior to beginning this study, the following six research questions, and associated hypotheses were developed:

1. Are the CO levels in the viewing stands (off-ice) outside the ice surface above the OSHA PEL of 50 ppm?
2. Are the CO levels in the penalty box (on ice) near the ice surface above the OSHA PEL of 50 ppm?
3. Are the CO measurements at the viewing stands and penalty box area significantly different from one another?
4. Are the COHb levels obtained from the participants after their designated activities above the 10% COHb value where symptoms can be apparent?
5. Are the post-activity COHb measurements statistically different than the pre-activity COHb measurements?
6. Is there a significant correlation between the concentrations of CO in the facility and concentrations of % COHb found within the participants' bloodstream?

1.2.1. Hypotheses

The following hypotheses were developed and evaluated to answer the previous research questions:

1.2.1.1. Hypothesis 1

- Null Hypothesis
    - The mean CO concentration in the off-ice area during activities is less than or equal to 50 ppm at a 95% ($p<0.05$) confidence level.
- Alternative Hypothesis
    - The mean CO concentration in the off-ice area during activities exceeds 50 ppm at a 95% ($p<0.05$) confidence level.

1.2.1.2. Hypothesis 2

- Null Hypothesis
  - The mean CO concentration of the on-ice area during activities is less than or equal to 50 ppm at a 95% ($p<0.05$) confidence level.
- Alternative Hypothesis
  - The mean CO concentration of the on-ice area during activities is greater than 50 ppm at a 95% ($p<0.05$) confidence level.

1.2.1.3. Hypothesis 3

- Null Hypothesis
  - There is no significant difference ($p<0.05$) between mean CO levels in viewing stands and the penalty box.
- Alternative Hypothesis
  - There is a significant difference ($p<0.05$) between mean CO levels in viewing stands and the penalty box.

1.2.1.4. Hypothesis 4

- Null Hypothesis
  - Mean percent COHb levels approximately five minutes after participants have completed their activities will be less than or equal to 10% at a 95% ($p<0.05$) confidence level.
- Alternative Hypothesis
  - Mean percent COHb levels approximately five minutes after participants have completed their activities will be greater than 10% at a 95% ($p<0.05$) confidence level.

1.2.1.5. Hypothesis 5

- Null Hypothesis
  - There will be no statistically significant ($p < .05$) difference in mean pre-activity and post-activity % COHb measurements.
- Alternative Hypothesis
  - There will be a statistically significant ($p < .05$) difference in mean pre-activity and post-activity % COHb measurements.

1.2.1.6. Hypothesis 6

- Null Hypothesis
  - The correlation coefficient between post activity air concentration of CO and post activity blood % COHb is less than or equal to 0 at a 95% ($p<0.05$) confidence level.
- Alternative hypothesis
  - The correlation coefficient between post activity air concentration of CO and post activity blood % COHb is greater than 0 at a 95% ($p<0.05$) confidence level.

2. Background

The first recorded evidence that humans were aware of the presence of CO was when Aristotle (384-322BC) noted that burning coals produced a noxious gas. This discovery led to the development of a method of execution in which a criminal was confined to a room that contained smoldering coals until the criminal was deceased. During this time in history it was not known that CO was the specific compound that caused death. The Greek physician Galen (129-199 AD) hypothesized that there was a change in the composition of the air that caused harm if inhaled (Penny, 2000). In 1776 de Lassone, a French chemist, produced CO by heating zinc oxide with coke. Although de Lassone was the first to produce CO in a laboratory setting where it could be analyzed, he was not the first to identify it. De Lassone mistakenly concluded that his mixture was Hydrogen instead of CO because it burned with a blue flame. Scottish chemist William Cumberland Cruikshank was the individual, who is credited with identifying CO in the year 1800 as a compound containing carbon and oxygen (Cruishank, 1801).

2.1. Carbon Monoxide

CO is an odorless, colorless and poisonous gas that can cause mild to serious health effects. When CO is inhaled, an interaction with the hemoglobin protein on erythrocytes occurs to create COHb. Hemoglobin is known as a tetramer with four possible sites at which oxygen can bind. If CO attaches to one of these binding sites, hemoglobin's affinity for oxygen at the remaining three sites will increase. Once CO is bound to hemoglobin, oxygen bound to hemoglobin is harder to set free. Because CO has a higher diffusion coefficient than oxygen, hemoglobin readily absorbs CO with an affinity approximately 230 times stronger than oxygen (Prockop, 2011). CO binds to the hemoglobin and produces COHb shifting the disassociation curve to the left, resulting in tissue hypoxia and an oxygen deficiency is created in the individual

(Medical Dictionary, N.D.). Organs deprived of oxygen for a prolonged period of time will cease to function (Raub, 2000). The organs most vulnerable to hypoxic tissue injuries are the heart, brain, and central nervous system (Gorman, 2003).

Potential adverse health effects include: shortness of breath, mild nausea, and mild headaches at approximately 0-30% COHb (Environmental Protection Agency, 2014). Since many of these symptoms are similar to those of a common cold, food poisoning, or other illnesses, individuals exposed to CO may not consider CO poisoning to be the contributing factor. CO exposure symptoms such as shortness of breath or mild nausea are also common with strenuous exercise. Thus, symptoms from CO exposure may mistakenly be attributed to other factors (Humphrey, 2006).

Table I: COHb Levels With Associated Symptoms (Carbon, N.D.)

0-10%	None.
10-20%	Tension in forehead, dilation of skin vessels.
20-30%	Headache and pulsating temples.
30-40%	Severe headache, weariness, dizziness, weakened sight, nausea, vomiting, prostration.
40-50%	Severe headache, plus increased breathing and pulse rates, asphyxiation and prostration.
50-60%	Same as above, plus coma, convulsions, Cheyne-Stokes respiration.
60-70%	Coma, convulsions, weak respiration and pulse. Death is possible.
70-80%	Slowing and stopping of breathing, death within hours.
80-90%	Death in less than 1 hour.
90-100%	Death within a few minutes.

At CO levels of 30-50% COHb, individuals can experience severe headaches, become dizzy, mentally confused, nauseated, or faint. At high CO levels, approximately 50%-100% COHb, individuals may experience convulsions, stroke, and a loss of consciousness or death

(Environmental Protection Agency, 2014). These symptoms are not common with strenuous exercise, so when these symptoms are present in individuals, CO poisoning is considered.

2.2. Absorption and Mode of Action

In environmental and occupational atmospheres the primary exposure route for CO is through inhalation. CO first enters the body through the mouth or nose, then quickly moves to the pharynx (throat), passing through the larynx (voice box), entering the trachea, which then branches into a left and right bronchus within the lungs and further divides into smaller and smaller branches called bronchioles. The smallest bronchioles end in tiny air sacs, called alveoli, which inflate during inhalation, and deflate during exhalation. This is where CO binds with hemoglobin, a protein on red blood cells. Hemoglobin function is to move oxygen into the blood stream and throughout the body (Dugdale, 2012).

Myoglobin is an iron and oxygen binding protein in the blood and muscle tissue. Myoglobin is found in the bloodstream after muscle use, and allows for storage of oxygen in muscle. When oxygen is needed in the body the myoglobin will release the oxygen into the blood stream, to travel to the location where it is needed. As with hemoglobin, myoglobin has a high affinity for CO that is approximately 60 times greater than its affinity for oxygen. When CO attaches to myoglobin, it may cause an inability for myoglobin to utilize oxygen. This will cause a reduction in cardiac output and hypotension and could result in brain ischemia (Ordway, 2004).

Percent carboxyhemoglobin is the unit of measure to describe the percent amount of carbon monoxide in the blood. Carboxyhemoglobin has a half-life in the blood of 4 to 6 hours. This time can be reduced to 35 minutes when individuals are given pure oxygen. Also medical professionals may use a hyperbaric chamber as a more effective manner of reducing the half-life of COHb rather than administering oxygen alone. This treatment involves pressurizing the chamber with pure oxygen at an absolute pressure close to three atmospheres allowing the body's fluids to absorb oxygen and to pass free oxygen on to hypoxic tissues instead of the crippled hemoglobin bonded to CO. this in essence by passes the need for blood and provides oxygen to the tissues directly (Penney, 2000).

2.3. Cardiovascular Response to Exercise

Significant physical exertion was required by on-ice participants of the study. The cardiovascular system will produce five responses to exercise: heart rate increase, stroke volume increases, artery-vein differential, blood distribution deviations, and oxygen deficiencies. Uptake of CO during exercise has been shown to be three to four times greater than at rest (Anna, 2012). At the time of vigorous skating, the respiratory rate can be 10 times higher than at rest. Therefore, upon exposure to a similar concentration of CO, the rate of COHb in the blood will increase much more rapidly in the active hockey player, for example, than in the arena employee. This tendency is particularly true for children who have a higher metabolic rate than adults (World Health Organization, 1999).

Sensitive groups are children, the elderly, people with cardiovascular inefficiencies, pregnant women, and those with chronic heart disease. Medical evidence suggests that these populations are more susceptible to increased concentrations of COHb (Carbon, 2007). Epidemiologic studies have provided evidence that ambient levels of CO in air may contribute to respiratory problems and aggravation of ongoing respiratory disease. These studies have also investigated the possibility of associations between CO concentrations found in air sampling and hematologic biomarkers of coagulation and inflammation. Some studies support significant associations between CO exposure and respiratory disease, but collectively findings from these studies are inconclusive (ToxGuide, 2012).

Another factor is Adenosine triphosphate (ATP), which is the bodies' intermediate that provides energy for all forms of biological work and is essential for muscle contraction. Each mole of ATP releases 7.3 kcal (30.7 kJ), and of that mole only a small amount of ATP is stored in the muscle. However, when exercise occurs there is an immediate requirement for increased supply of energy and there is only enough ATP stored for 1–2 seconds of activities within the muscle initially. This causes the necessity for rapid resynthesizing of ATP for use by the muscles. In the case of CO exposures, CO binds to and inhibits mitochondrial cytochrome oxidase, thereby directly limiting aerobic metabolism. In the brain, CO binds to cytochrome c oxidase, which will result in the lack of production of ATP synthesis and increase production of reactive oxygen species. Inflammatory changes in acute CO poisoning include intravascular neutrophil activation due to interactions with platelets. This leads to neutrophil degranulation and perivascular oxidative stress. Damage may also be caused by the marked oxidative stress, free radical production, inflammation, and apoptosis this happens when oxygenation improves and CO concentrations fall after severe poisoning (Chiew, 2014).

2.4. Carbon Monoxide Exposure Standards

OSHA and the EPA have both set regulatory standards for occupational and environmental CO exposure. The OSHA permissible exposure limit (PEL) is 50 parts per million (ppm) for a time weighted average over an 8-hour time period. The OSHA ceiling value for CO allows a worker to be exposed to 200 ppm for no longer than fifteen minutes (OSHA, 2002). The EPA first set air quality standards for CO in 1971. This standard was intended to protect both public health and welfare. The EPA standard for an 8-hour average concentration is 9 ppm CO, and for a 1-hour exposure limit it is 35 ppm (EPA, 2014).

The difference between the EPA and OSHA is that the EPA has national jurisdiction over the protection and enforcement of environmental laws, pollution emission, and air quality standards. The EPA's main concern is to control pollution that may threaten public health, or the environment. EPA standards apply to all businesses, regardless of size. OSHA is different in that it is limited to the workplace. The Occupational Safety and Health Act of 1970 requires that every employee has a work place that is free from recognized hazards that are causing or are likely to cause death or serious physical harm. OSHA standards apply to most businesses that have employees, not matter how small. The only exception is for family farms with only family workers and for companies in industries with specific workplace rules set forth by other federal agencies (Merritt, N.D.).

In addition, the American Conference of Governmental Industrial Hygienists (ACGIH), and the National Institute for Occupational Safety and Health (NIOSH) provide recommendations for occupational CO exposures. The ACGIH threshold limit value (TLV) is 25 ppm over an 8 hour work day. The NIOSH recommended exposure limit (REL) is 35ppm for an 8-10 hour day, 40 hour work week (Spengler, 2001).

These standards and recommendations are relevant in industries where workplace environmental exposure to CO occurs. But currently there are no federal regulations associated with CO exposure for indoor air quality specific to indoor ice rinks. The regulatory agencies have no jurisdiction on these facilities to assess or prevent overexposure to CO. Massachusetts, Minnesota, and Rhode Island have put forth regulations on CO that are enforced by their Department of Health. These regulations outline air sampling requirements, record keeping requirements, air action levels, and required corrective measures that must be taken in order to operate an ice facility (Theiler, 2011).

3. Literature Review

The following is a literature review of previous studies performed on CO exposure within ice rinks. This literature review dates back 50 years. This information indicates that the topic of CO poisoning in ice rinks is not a new subject, and yet there are very few standards that relate to atmospheric conditions within these facilities.

3.1. Minnesota Ice Arena Incident

The first recorded observation of CO illness among individuals skating was in a Minnesota ice arena during 1966. During this exposure girls ages 7 to 11 described headaches and nausea while figure skating. During this event an internal combustion engine was used to resurface and maintain the ice surface. This arena was like many that used a combustion engine ice resurfacer, and to this day internal combustion engines are still used to maintain local ice arenas (Minnesota Department of Health, N.D).

3.2. CO in Indoor Ice Skating Rinks: Evaluation of Absorption by Adult Hockey Players

A study performed in Quebec City, Canada measured CO levels in 122 adult male hockey players over a one month period. The exposure was measured by collecting seven air samples at 15 minute intervals, from the time the players arrived at the facility to the time they exited the facility. The subjects inhaled deeply and held their breath for 20 seconds, then exhaled into a bag and then into two other bags joined by plastic tubing. For each player the alveolar CO was measured within 15 minutes before and after the game, using the samples collected. These bags were analyzed to determine if there was an increase in the CO levels during the game. A correlation between CO concentration in the alveolar air in ppm and the percentage of COHb was established (Levesque, 1990).

Variables that could explain the difference between measurements, but were undocumented, include player stamina, the ratio of tidal air to the dead space of the lung, and the diffusion constant of the lung. Results showed 17% COHb, a level at which symptoms due to CO overexposures are evident. Participants in this study did not report any symptoms. Researchers concluded that a healthy young male will have decreased maximal oxygen consumption during strenuous exercise, and this may increase the risk of over exposure to CO due to CO limiting the absorption of oxygen in the body. During the time of this study there were no reliable data on cardiac pathology among hockey players. The study concluded that a sudden increase in COHb would trigger an irreversible ischemia, and that hockey can be considered a strenuous activity and can in itself cause cardiovascular strain. All of these considerations can create an environment that allows for CO to be an even bigger threat to the studied population (Levesque, 1990).

3.3. An Experiment to Evaluate CO Absorption by Hockey Players in Ice Skating Rinks

In this study fourteen male adult non-smokers unexposed occupationally to CO played four hockey games in different concentrations of CO. The source of the CO was attributed to the exhaust of an ice resurfacing machine. Alveolar CO was measured, as was the average airborne CO level in parts per million (ppm) during the game. The airborne exposure concentrations ranged from 0 ppm to 76.2 ppm. A linear regression of the airborne concentrations of CO showed an r^2 of 0.93. These results suggest that for each 10 ppm of CO in the indoor air, the players absorbed enough CO to raise their alveolar CO concentration by 4.1 ppm. Figure 1 is a representation of the Haldane equation, which relates the partial pressure of carbon monoxide in the air, the partial pressure of oxygen in the air and the concentrations of carboxyhemoglobin and oxyhemoglobin in the blood.

$$\frac{[HbCO]}{[HbO_2]} = M\frac{(pCO)}{(pO_2)}$$

Figure 1: Haldane Equation (Haldane, 2001)

It revealed a 0.76% COHb increase for every 10 ppm of CO in the air. The game durations, and regression coefficients were almost similar to those of an earlier study made with 122 adult male hockey players playing in recreational leagues of the Quebec City area. These results show the exposure-absorption relationship for an acute 60-minute exposure. It again emphasizes the importance of prevention for CO pollution in indoor skating rinks (Levesque, 1991).

3.4. Study Finds Health Hazards at Rinks

Nichols (2009) tested 34 ice rinks in 14 states for CO, nitrogen dioxide, and ultrafine particles. Prior to this study nearly 200 people had become ill from exposure to CO, nitrogen dioxide or ultrafine particles produced from ice resurfacers in indoor ice facilities unmaintained in the previous six months. Nearly one-third of those rinks were found to have dangerous levels of CO, nitrogen dioxide, or ultrafine particles. USA hockey has no direct control over the 2,000 rinks in the United States, and only Minnesota, Massachusetts, and Rhode Island have laws regulating air quality at indoor rinks (Nichols, 2009). Although no data were readily available to review, this study further represents how important recognition of possible CO contaminants is to health and safety during indoor ice rink operation.

3.5. Public Health: CO Exposure in Indoor Ice Arenas

A study performed in 1984 by the Colorado Pitkin County Health Department monitored the CO concentrations at an indoor ice rink. To perform the necessary monitoring NIOSH's assistance was requested to analyze the exhaled air from eight rink employees after they had performed their rink duties, as well as to monitor the ambient air concentration of CO at the rink. An 8-hour time weighted average concentration of 53.8 ppm of CO was measured, with a peak concentration of 80.5 ppm during the study. Blood analysis produced an average result of 5.7 %COHb between the eight employees. Even though the CO TWA was above the recommended health standards of 25 ppm, these workers did not visibly show any adverse health effects nor did they complain of any discomfort.

The author attributes the lack of recognition of the workforce to CO exposure to the small number of ice rink workers and that CO is more harmful over an extended period of time compared to short durations. The short duration of exposure is common in skating rinks due to the variety of tasks being performed outside the facility or in different parts of the facility (Center for Disease Control, 1986).

4. Methods

The purposes of this project were to obtain data on the air concentration of CO present in the BCIC during usage, and to investigate if there was a correlation between the amount of CO found in the air and the amount absorbed by the volunteers (% COHb measurements). After approval was received from the University of Montana Institutional Review Board (IRB) under the number 75-13 on April 14^{th} of 2013. Approval was also received on April 12^{th} 2013 from my thesis committee. This study was conducted during a tournament weekend, where 13 games were played from April 19^{th}, 2013 through April 21^{st}, 2013, and the ambient air CO concentrations of the BCIC were measured along with the % COHb of the participants.

4.1. Participants

There were 12 participants in this study; ten males and two females, 25 to 60 years of age (mean 41 years). All individuals signed the informed consent approved by the IRB. Study participants were non-smokers thus eliminating a source of error due to smoking contributing to a higher baseline COHb level. Participants included the ice resurfacer operators, the referees, score clock operators, and penalty box operators present during these scheduled activities. These individuals were divided into two categories, on-ice officials (referees) and off-ice officials (ice resurfacer operators, score clock, and penalty box operators).

4.2. Equipment

The equipment used for the measurement of CO air concentration was the iTX Multi-Gas Meter. The Rad-57 Instrument Signal Extraction Pulse CO-Oximeter was used to measure % COHb. The individuals for whom COHb was measured with the pulse CO-Oximeter performed an activity in the ice rink facility during the time air monitoring was conducted with the iTX. Subjects monitored for COHb participated in a variety of activities, such as officiating, score keeping, working a penalty box, and operating the ice resurfacing machine. The methods for each piece of equipment are explained in the following sections.

4.2.1. iTX Multi-gas Meter

Two iTX multi-gas Meters were used in this study. The iTX Multi-Gas meter is a device designed to detect and monitor hazardous gas levels. This equipment continuously detects levels (in ppm) of oxygen, CO, hydrogen sulfide, and combustible gases. The iTX alerts users to potentially hazardous environment with alarm settings, at levels pre-set by the user for notification when threshold limit levels are reached (Industrial Scientific Corporation, 2011). The iTX Multi-Gas Monitor was fitted with an iSP pump attachment, to increase the area sampled. With this attached pump the iTX can sample a 100ft square area. For this instrument CO can be measured between 0 ppm and 999 ppm with a resolution of 1 ppm.

The OSHA sampling method for measuring CO in Workplace Atmospheres- ID-209 calls for the use of a direct-reading passive sampling instrument capable of recording data at given time intervals (Carbon, 1993). The iTX Multi-Gas Monitor has the ability to sample for CO and nitrogen dioxide in parts per million and for percent oxygen. This equipment was calibrated prior to use each day as recommended by the manufacturer.

4.2.2. Rad-57 Instrument Signal Extraction Pulse CO-Oximeter

A Rad-57 Instrument Signal Extraction Pulse CO-Oximeter is a continuous and non-invasive method of measuring the level of arterial oxygen saturation in blood. The measurement is taken by placing the sensor on the subject’s index finger. This instrument noninvasively measures the levels of hemoglobin in arterial blood (MASIMO, 2011).

The Rad-57 uses a multi-wavelength sensor to distinguish between oxygenated blood, deoxygenated blood, blood with CO, oxidized blood, and blood plasma. The Rad-57 uses a sensor with multiple light-emitting diodes (LEDs) that push light through the site to a photodiode (detector) on the other side of the finger, having passed through the capillary bed. The measurement is obtained by the changes in light absorption in the blood passing through. The RAD-57 then uses Masimo Rainbow SET signal extraction technology to calculate the patient's functional oxygen saturation, total hemoglobin concentration, blood levels of % COHb, methemoglobin, and pulse rate. For this instrument CO can be measured between 0 % COHb and 99 % COHb with a resolution of 1 %. This equipment does not require internal adjustments or recalibration, and should only be serviced by qualified individuals (Rad-57, 2011).

4.3. Sampling plan

Intent of this study was to compare the concentrations of CO inside the rink boards to the concentration of CO outside the rink boards. Figure 1 is a schematic of the rink that shows the placement of the gas monitors.

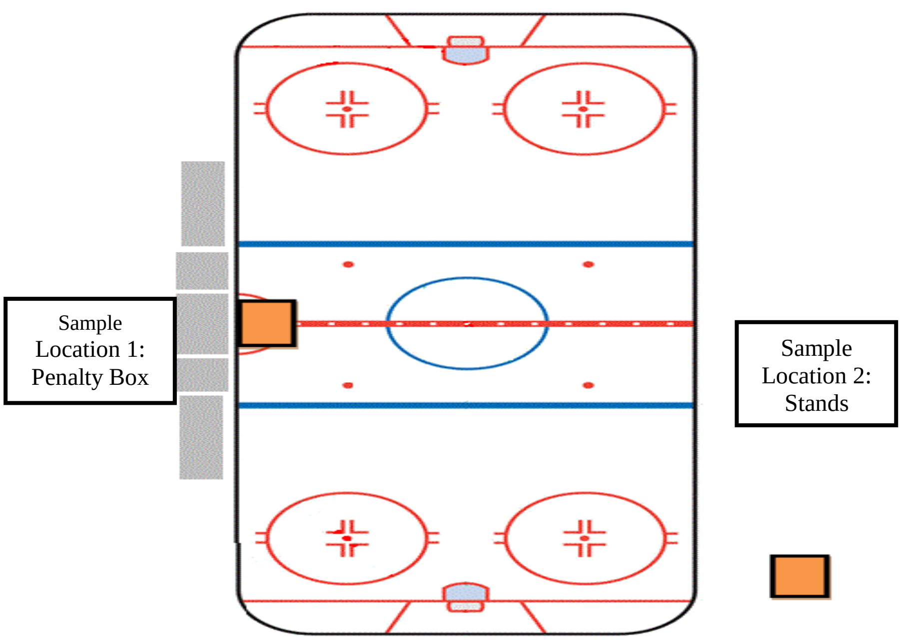

Figure 2: iTX Multi-Gas Meter Placement

An iTX was placed in the penalty box, behind the glass with tubing placed on the end of the sampling pump, and fed through a hole in the glass in front of the penalty box area. This hole, used by the on-ice officials to communicate with the off-ice officials in the penalty box, approximately four feet above ice level within the breathing zone of any individual taking part in activities on the ice. This location was chosen because it protects the instrument from possible damage due to on-ice activities; and the penalty box area is the best place to obtain air samples that are representative of exposure.

The second iTX was placed on the top seat located in the stands on the north–west corner of the building, located approximately five feet above the ground level. This location was chosen because it was far away from the spectators at the tournament to prevent disturbance of sampling, and because this location would yield the concentration of CO present in the air outside the rink surface. These locations are represented in Figure 1.

4.3.1. Rad-57 Pulse CO-Oximeter

The Pulse CO-Oximeter was used to measure the % COHb of the study volunteers. The sensor was placed on a site that is not too thick, has sufficient perfusion, and provides proper alignment of the LED’s photo-detector. The site chosen was the participant’s index finger where blood flow was unrestricted. Measured % COHb levels of the individuals in the on-ice category were compared to on-ice airborne CO levels, and those in the off-ice category were compared to off-ice CO levels during the time of their activities. Each participant was present in the facility longer than 15 minutes.

4.4. Measurement Recording

Baseline CO measurements were taken at the beginning of each day, before any activity occurred; immediately after each game before the ice resurfacing equipment entered the ice surface, to determine changes in CO levels between ice resurfacings. It was assumed that the CO measurements taken from each location were a representative of that area.

The participants performed an activity in the BCIC during the time air monitoring was being conducted. Baseline measurements were taken before and after the activity to determine if there was a change in COHb between the two measurements. If a participant was scheduled to participate in more than one activity, data collection continued until their duties were completed, but each activity was considered its own monitoring set of pre and post % COHb measurement.

4.5. Statistical Testing Method

Results were recorded on an excel spread sheet and transferred into the Minitab program for hypothesis testing. Minitab is a statistics software package designed for analyzing research data (Schaefer, R, 2014).

A 1-Sample T-test was used to test hypotheses 1, 2, and 4 for statistical significance. The statistical distribution this produces is a t-distribution. A t-distribution is used when estimating the mean of a population that is normally distributed and the sample size is small. The significance level threshold used was 5% or 0.05. If the P-value is under 0.05 then the study failed to reject the null hypothesis. If the P value is greater than or equal to 0.05 then we reject the null hypothesis (Janicak, 2007).

A 2-sample T-test was used to analyze hypotheses 3 and 5 to determine the mean two random samples of independent observations, each from a normal distribution. The three assumptions for this statistical test are the following: each group is considered to be a sample from a distinct population; the responses in each group are independent of those in the other group; and the distributions of the variable of interest are normal. The significance level is 5% or

0.05. If the P-value is under the .05 then we fail to reject the null hypothesis, if it is greater than or equal to .05 then we reject the null hypothesis (Janicak, 2007).

A correlation analysis was used to analyze data for hypothesis 6. Correlation analyses are used to indicate a measure of association. When two variables are being correlated, it is referred to as a bivariate correlation. Each subject in a study is measured by two variables as displayed in the correlation coefficient. This correlation analysis can be depicted in a graph referred to as a scatter plot to depict the relationship, with the dependent variable on the vertical y-axis, and the independent variable on the x-axis. Each point on the scatter plot will represent one participant. The result of a correlation is the correlation coefficient, r. The correlation coefficient will indicate the strength of the association between the variables and the type of association that exists between the two sets of data. Correlation coefficients range from -1.00 to +1.00, with 0 as the midpoint. A correlation with a coefficient of -1.00 is referred to as a perfect inverse correlation, while a correlation coefficient of + 1.00 is referred to as a perfect positive correlation (Janicak, 2007). Percent carboxyhemoglobin monitoring results were collected from the twelve participants. These individuals were divided into two groups the off-ice officials and on-ice officials. Ten of the twelve participants were sampled more than once during this research activity. To perform the correlation analysis each individuals post activity % COHb measurement was compared to their corresponding final ambient CO concentration (ppm). For example an on-ice official had their final % COHb measurement compared to the concentration of ambient CO found at the end of their activity.

5. Results

The following results are displayed from six statistical analyses performed to prove or disprove the previous six hypotheses. One-Sample T-tests were used for hypotheses 1, 2, and 4. Two-Sample T-tests were used for hypotheses 3, and 5. A correlation analysis was used for hypothesis 6. Minitab 17 was utilized to analyze all data received during the study. Appendix A provides the CO concentrations, and Appendix B provides the COHb measurements.

5.1. Hypothesis 1

The first hypothesis was to determine whether CO concentrations in the off-ice area exceeded 50 ppm OSHA PEL. The mean concentration was 43 ppm. The One-Sample T-test yielded a p-value of 0.945 and thus the research failed to reject the null hypothesis of the mean CO concentration in the off-ice area during activities being less than or equal to the OSHA PEL of 50 ppm. The mean difference between the concentration in the off-ice area and the 50 ppm permissible exposure limit was not statistically significant. Figure 3 is a boxplot diagram of the One-Sample T-test performed of the off-ice CO concentrations against OSHA's PEL for CO.

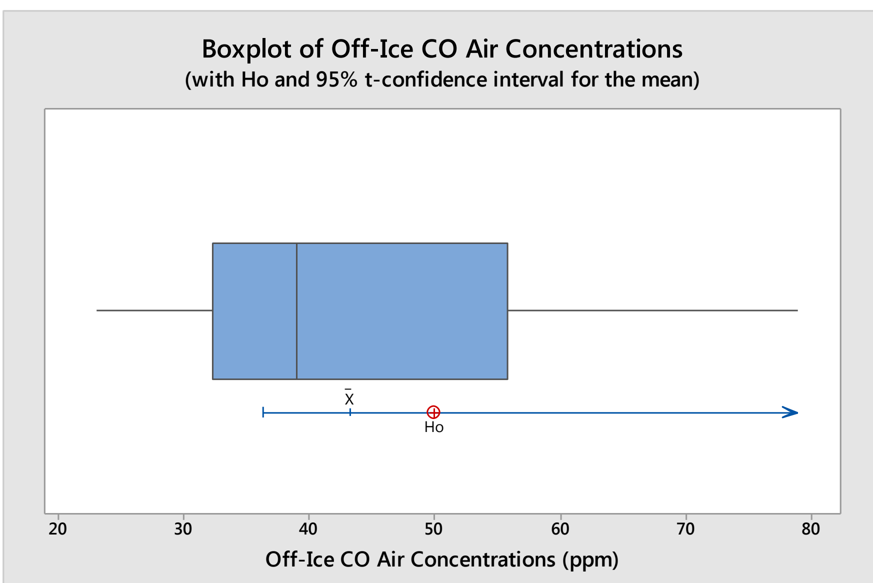

Figure 3: Off-Ice CO Air Concentration Boxplot.

Table II illustrates the results of One-Sample T-test when the 16 off-ice air concentrations are compared to the OSHA PEL of 50 ppm for CO.

Table II: Off-ice CO Concentration (ppm) One-Sample T-test Results Compared to OSHA PEL.

Variable	Number of Samples	Mean (ppm)	Standard Deviation	P-Value
Off-ice CO Concentration	16	43.25	15.92	0.945
OSHA PEL (ppm)		50		

5.2. Hypothesis 2

The second hypothesis was to determine whether CO concentrations in the on-ice area exceeded 50 ppm OSHA PEL. The mean concentration was 75.50 ppm. The One-Sample T-test yielded a p-value of 0.001 and thus rejects the null hypothesis, and accept alternative hypothesis that the mean of the on-ice CO air concentration was greater than the OSHA PEL of 50 ppm. The mean difference between the concentration in the on-ice area and the 50 ppm permissible exposure limit was statistically significant. Figure 4 is a boxplot diagram of the One-Sample T-test performed of the on-ice CO concentrations against OSHA's PEL for CO.

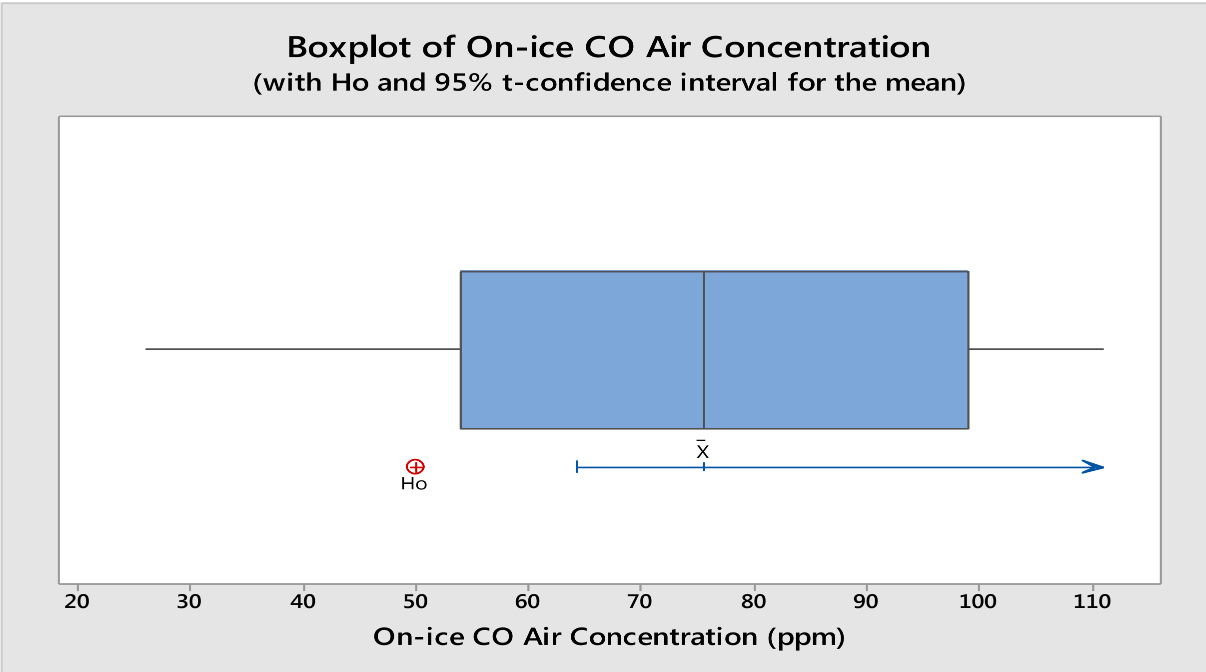

Figure 4: On-Ice CO Air Concentration Boxplot.

Table III provides the results One-Sample T-test when the 16 on-ice air concentrations are compared to the OSHA PEL of 50 ppm for CO.

Table III: On-Ice CO Concentration (ppm) One Sample T-test Results Compared to OSHA PEL.

Variable	Number of Samples	Mean (ppm)	Standard Deviation	P-Value
On-ice CO Concentration	16	75.50	25.51	0.001
OSHA PEL (ppm)		50		

5.3. Hypothesis 3

The third hypothesis stated that there is a significant difference ($p<0.05$) between mean CO levels measured from the off-ice location and the on-ice location. The Two Sample T-test revealed a P-value of 0.000. Thus, we rejected the null hypothesis, and accepted the alternative hypothesis. There is a statistically significant difference between the CO air concentrations measured at the on-ice and off-ice locations at a 95% confidence level. Figure 5 is a boxplot diagram of the Two Sample T-test performed between the off-ice location and the on-ice location.

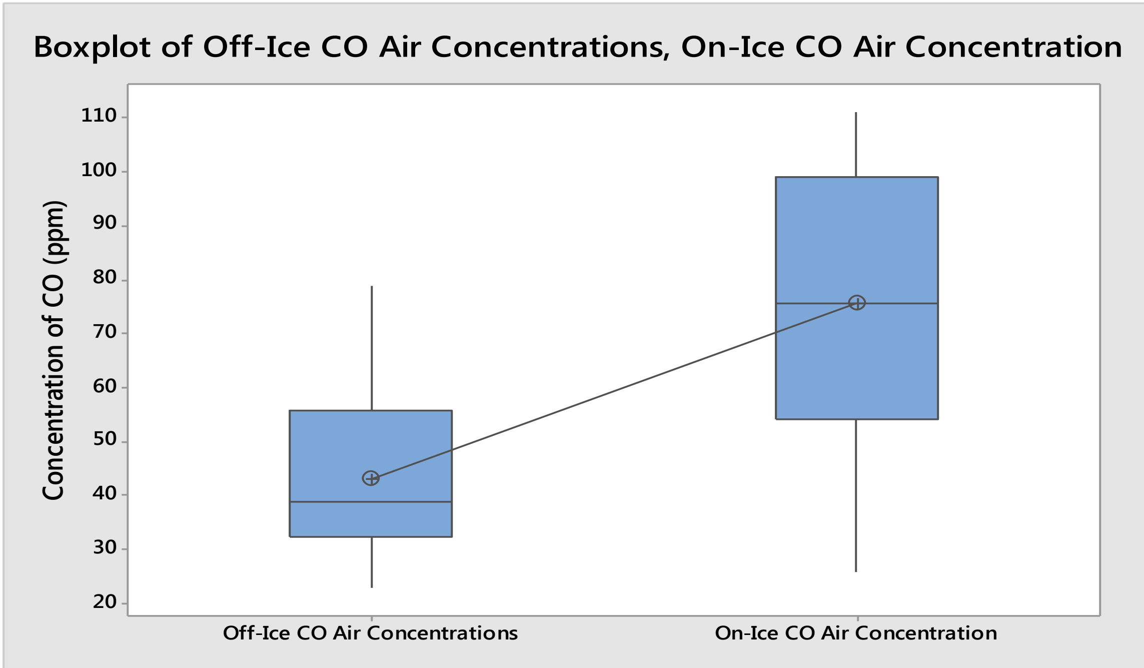

Figure 5: Off-ice and On-ice CO Air Concentrations Boxplot

Table IV presents the results of the Two Sample T-test performed between the off-ice location and the on-ice location.

Table IV: Off-ice and On-ice CO Air Concentrations Results for the Two Sample T-test

Area of Monitoring	Number of Samples	Mean (ppm)	Standard Deviation	SE Mean	P Value
Off-ice CO Concentration	16	43.3	15.9	4.0	0.000
On-ice CO Concentration	16	75.5	25.5	6.4	

5.4. Hypothesis 4

The fourth hypothesis stated that the mean % COHb levels approximately five minutes after participants have completed their activities would be greater than 10%. The mean concentration was 4.0% COHb. The One-Sample T-test yielded a p-value of 1.00 and thus the research failed to reject the null hypothesis, showing that the mean % COHb levels were below the set criteria of 10% COHb. Figure 6 is a boxplot diagram of the One-Sample T-test performed when the post-activity % COHb is compared to the 10% COHb criteria. As seen below there were two outliers seen during this study. The 11% COHb was measured at 22:00 on day two, and the other outlier was 13% measured at 12:31 on day three.

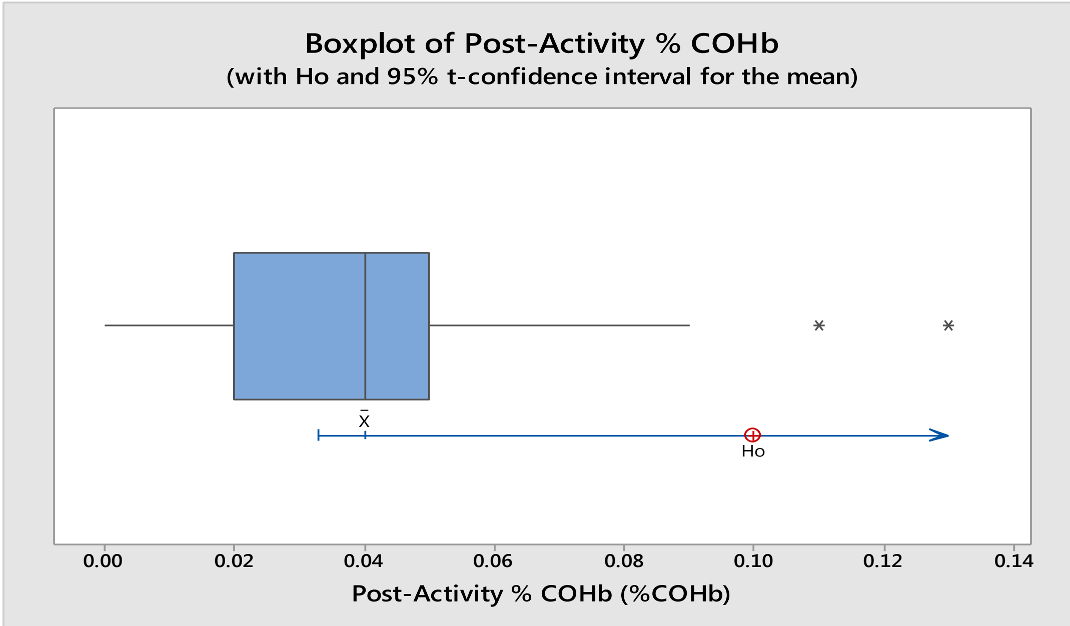

Figure 6: Post-Activity % COHb Boxplot.

Table V presents the results of the One-Sample T-test performed when the post-activity % COHb is compared to the 10% COHb criteria.

Table V: Post-activity Monitoring One Sample T-Test Results.

Variable	Number of Samples	Mean (%COHb)	Standard Deviation	P-Value
On-ice CO Concentration	46	4.022%	2.91 %	1.000

5.5. Hypothesis 5

The fifth hypothesis asked if differences in % COHb pre-activity and post-activity measurements were statically significant at a 95 % confidence level. The Two Sample T-test yielded a significance level of 0.024, below the 0.05 decision level allowing this study to reject the null hypothesis, and concludes that there is a statistically significant difference between the pre activity % COHB and the post-activity % COHb. Figure 7 is a boxplot diagram of the Two Sample T-test performed between the pre-activity and post-activity % COHb. As discussed above there were two outliers seen in the study on day two and three.

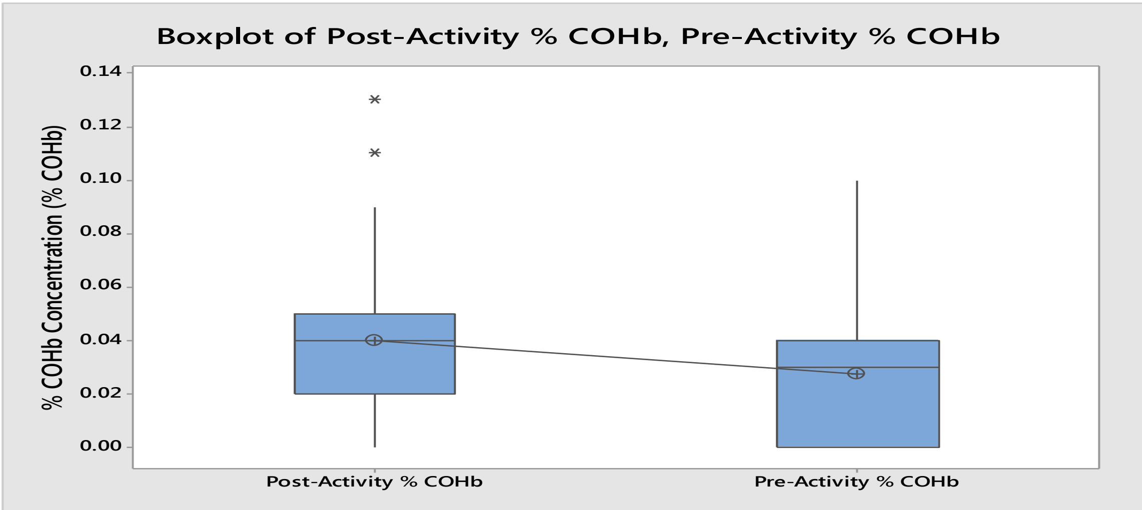

Figure 7: Pre-Activity and Post-Activity % COHb Boxplot

Table VI illustrates the results of the Two Sample T-test performed between the pre-activity and post-activity % COHb.

Table VI: % COHb Results for the Two Sample T-Test.

Monitoring Time	Number of Samples	Mean (%COHb)	Standard Deviation	SE Mean	P Value
Pre-activity Measurement	45	0.0272	0.0254	0.0037	0.024
Post-activity Measurement	45	0.0402	0.0291	0.0043	

5.6. Hypothesis 6

The sixth hypothesis was intended to determine if there was a significant correlation between CO and COHb at a 95% confidence level. To answer this question participants post activity % COHb was compared to the final ambient CO concentration found in their area (i.e. if a person was on the ice their % COHb was compared to the concentration found at the penalty box location.) After the data was sorted a Pearson correlation was performed to determine if the two data sets had a correlation coefficient greater than 0. A positive correlation coefficient was found at 0.489. Allowing the researcher to reject the null hypothesis and accept the alternative. This correlation coefficient yielded a P-value of 0.001 at a 95% confidence level. Full listing of data used can be found in appendix C, Table X. Figure 8 shows the scatter plot diagram of the data used in the Pearson correlation model, and as seen below a moderate relationship, with several outliers.

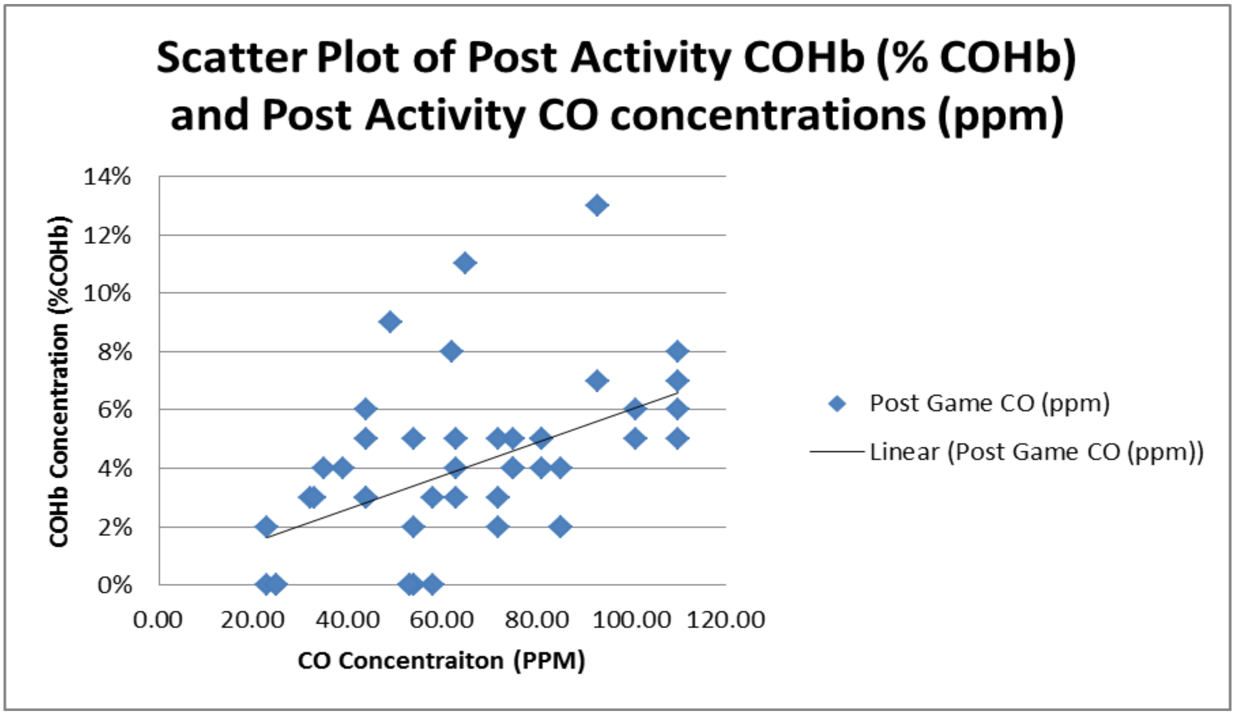

Figure 8: Correlation of Post Activity COHb (%COHb) and Post Activity CO concentrations (ppm)

Table VII provides the results of the Pearson correlation method performed between the pre-activity and post-activity.

Table VII: % CO and % COHb Correlation Results

Pearson Correlation of % COHb Concentration and Ambient CO Concentration in ppm	P-Value
(%CO) =0.489	0.001

6. Discussion

The following discussion is divided into four sections. The first discusses the results of the CO monitoring, the second section discuss COHb levels, the third section discusses the relationship between CO and COHb levels, and the fourth section discusses this study to previous research.

6.1. Carbon Monoxide Monitoring

On Day 1 an initial baseline was measured to assess the amount of CO present in the on-ice section of the building and the off-ice section of the building. The ice resurfacer had not been used since the night before. The level of CO was 25 ppm. During day 1 monitoring there had been three ice resurfacings performed, and none of the results for the off-ice location reached above the OSHA PEL of 50 ppm. The highest found was 35 ppm, a little over half of the PEL. The on ice location had two measurements above the PEL. It only took two ice resurfacings for the CO on the ice to increase above the PEL at 54 ppm

On Day 2 CO concentrations in the on-ice area measurements had not maintained over night from Day 1's last reading. When the final reading from day one was compared to the initial reading from day two from the on-ice monitoring location there was a decrease in CO of 9 ppm, and had increased 3ppm from the off-ice monitoring location. This decrease in CO could have been attributed to the dispersion of gas into the entire rink, or that the CO (which has a molecular atomic weight heavier than air) had settled closer to the ground since the instruments were elevated five feet above the ground off-ice and four feet above the ground on-ice. When the BCIC began resurfacing the ice during day two operations the CO increased throughout the day to a maximum concentration of 79 ppm at the off-ice location and 111 ppm at the on-ice location. Of the 24 measurements taken during Day 2 of sampling, 20 of the measurements exceeded OSHA's PEL. The off-ice area measurements ranged of 38 from 65 ppm. The on-ice area monitoring results ranged from 53-110 ppm. These measurements provided an early indication that there would be a significant difference in the amount of CO between inside and outside the ice surface.

On Day 3 of CO monitoring concentrations remained above the study's 50 ppm action level on the ice. When measured in the early morning, the on-ice concentration of CO had reduced from 110 ppm to 76 ppm, and the off-ice concentration had reduced from 65 ppm to 46 ppm. During this sampling period there were some inconsistent measurements taken from the stands when compared to the previous two days of monitoring. Between the first and second readings there was a drop of 13 ppm. The third measurement only increased 6 ppm from the second measurement. This deviation may have been caused by the movement of individuals and other equipment stirring up the stagnant air, or from opening up doors more frequently to start getting the facility ready for play. During that time the on-ice concentration did see a similar reduction from the initial reading to the second reading of day three. However these readings were not as large only dropping from 76 ppm on the initial reading to 72 ppm on the second reading, and then increased again to 81 ppm. Full detail of the raw CO air measurements data seen at the BCIC during this study can be found in Appendix A, Table VIII.

During each day of monitoring, CO concentrations increased in both the on-ice location and the off-ice location. This was expected as the exhaust from the ice resurfacer would introduce CO into the atmosphere, and the ice rink only possesses natural ventilation.

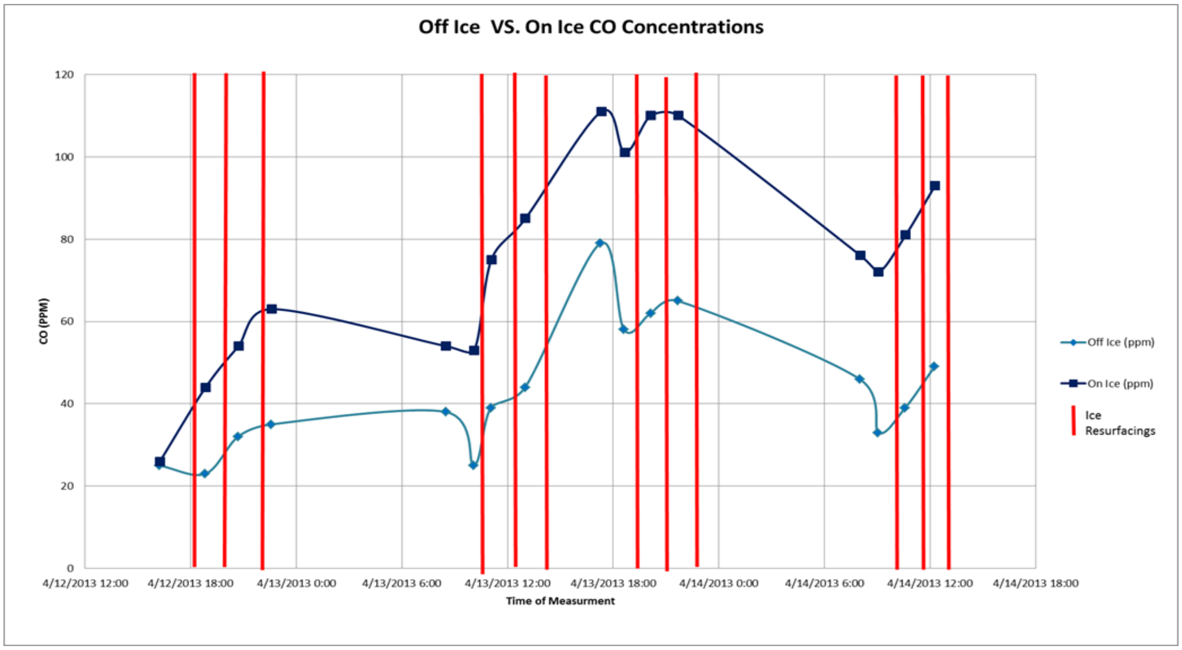

Figure 9: Off Ice VS. On Ice Concentrations

Figure 9 was created to show the increase that was seen after every ice resurfacing during the sampling period. It also presents when the drops were seen between the baseline measurements and the measurements taken prior to the first ice resurfacing. This may have been due to the having more movement being created inside the BCIC and allowing for the CO to settle in different areas. Also displayed by the graph is the increase seen during the time of sampling. During each day the amount of CO increased and never returned to the initial baseline taken prior to the start of the tournament.

Of the 32 measurements taken, 14 were below the OSHA PEL of 50 ppm CO, and 18 measurements were above. Of those 18 measurements above the PEL four were at the off-ice location and 14 were at the on-ice location. None of these measurements however reached above the 15 minute STEL established by OSHA of 200 ppm CO, this indicates that although the peaks did reach well above the established PEL the levels found in the BCIC were not immediately dangerous to life or health and that individuals could be in the area for a limited amount of time without seeing adverse health effects.

6.2. Carboxyhemoglobin

During Day 1, 22 measurements of COHb were taken from eight individuals, four of whom were involved in two activities and were sampled twice. Of individuals sampled, the highest pre-activity % COHb measurement was 5%. This high measurement could have been due to the subject participating in two activities back to back, both increasing the exposure duration and concentration, as well as decreasing the time the individual had to recover metabolically.

Pre-activity measurements ranged from 0-1% COHb, which is congruent with the known range of 0-1.5% found naturally in human blood (Light, 2007). Post-activity measurements ranged from 0-5% COHb. Most participants had an increase of 2- 4% over the course of their activity. These ranges can be seen in found in the raw data listed in Appendix B, Table IX. It was also noted that as the CO concentration inside the BCIC increased, so did the % COHb difference measured in the participants. None of the day one measurements exceeded the 10% COHb concentration at which adverse health effects due to CO exposure begin (Humphrey, 2006). No participants experienced symptoms related to overexposure to CO.

A decrease between the pre and post activity measurements occurred seven times for on-ice officials, ranging from 1 to 3%. This decrease in COHb could be due to the individual's body processing the CO more efficiently than other participants, the activity taking place in an area where there were lower concentrations of CO, or an error in measurement. The most likely cause for the decrease is a measurement error. The monitoring equipment is very sensitive, and if conditions are not adequate the monitor will not function correctly. It was noted that participant hands were very cold when participating in activities. When the body is cold it preserves more blood for internal organs, and reduces the flow of blood to other extremities such as the hands and fingers. This lack of blood flow may have contributed to the monitoring device not being able to obtain an accurate reading (Princeton, N.D.).

On Day 2, 46 measurements were taken from 8 individuals. Four subjects participated in three activities, two subjects participated in two activities, and two subjects had participated in only one activity. The pre-activity COHb measurements ranged from 0-10 % COHb (mean was 3% COHb) with the highest pre-activity measured at 10% COHb. The post-activity COHb measurements ranged from 0-11% COHb (mean= 4%). The highest measured pre-activity was taken prior to the participant’s third activity, which could be why this subject’s COHb is so high. Also this measurement was recorded at the end of day two of sampling, where the CO concentrations inside the facility were recorded at their highest.

The highest Day 2 post-activity measurement was 11% COHb, from the individual with the high pre-activity measurement of 10%. According to the monitoring results this individual only gained 1% COHb during their activity, but did maintain a high COHb level while participating in the activity. This was the only participant over the 10% COHb level considered high enough to experience adverse health effects, but this participant did not experience any symptoms associated with a COHb above 10%. This participant had been away from the facility for the previous two hours, which allowed for sufficient time for the body to remove any CO previously inhaled at the BCIC. The subject’s time away from the BCIC was not monitored. It is unknown if this participant was exposed to CO at another location that could have contributed to the elevated COHb readings seen, which could have presented a source for error.

On Day 3, 22 measurements were taken from seven participants, with four participating in two activities, and three participating in one activity. The pre-activity COHb measurements ranged from 0-9 % COHb, mean was 4% COHb, and the highest pre-activity measured at 9% COHb. The post-activity COHb measurements ranged from 2-13% COHb, the mean was 5%, and the highest post-activity measured at 13% COHb from an on-ice participant. Several factors that could have significantly increased this participant's % COHb including being in an area of high concentration of CO on the ice, instrument malfunctioned, may have had biological factors reducing the participant's ability to remove the COHb. Neither of the two participants for whom % COHb exceeded the 10% threshold, encountered any adverse health effects caused by an over exposure to CO.

Of the 90 measurements taken, 8 had increases greater than 2% COHb, with the largest being a 7% increase in COHb. Also these increases were seen later in each day of monitoring, when CO air concentration monitoring indicated as the day went on CO levels did increase. The airborne CO concentrations that participants were exposed to could have been a contributing factor to increased levels of COHb, as well as other external and lifestyle factors.

There were various possible sources of error associated with this study. Some participants had post-activity measurements of 0% COHb after an activity when they previously had a measurement above 0% COHb. This source of error can be attributed to low perfusion, or low signal quality. Low perfusion could be from a poorly chosen site; a sensor that is too tight; a disorder such as hypothermia; vasoconstriction; or damaged sensor. Low signal quality is caused by an improper sensor application, excessive motion relative to perfusion, or the sensor being again damaged (Rad-57, 2011). Normal COHb levels should be between 0 and 1.5% (Light, 2007), so it is statically possible with a plus or minus 1% source of error that a 0% COHb can be measured. However it is unlikely that an individual with a previous COHb above 0% in a pre-activity measurement would have their COHb decrease. Vasoconstriction could have been a significant factor in the 0% COHb readings. The vasoconstriction or lack of blood flow in the blood vessels of the sensor area could have been caused by the cold temperatures experienced by the participants in this facility (Rintamaki, 2007). A way to confirm this potential source of error would be to monitor CO in the participant's breath. They do produce CO monitors that detect CO gas with an electrochemical gas sensor from a participant's exhaled breath (Henderson, 1996). This commercial breath CO monitor maybe able to eliminate the effect cold has on obtaining % COHb in ice rink activity participants.

Participant activities during time away from the facility were not recorded. This information could have given an indication as to whether the exposure to CO was from the facility from another source. This lack of supplemental information made it difficult to identify a specific contributing source for increased levels of COHb. Those participants, who stayed in the facility when not participating, may be significant, because both the off-ice and on-ice areas had CO levels above the OSHA TWA exposure limit of 50 ppm. If the participants remained in the facility where concentrations of CO were present they could have been continually exposed.

6.3. Comparison of CO to COHb

Throughout the three days of sampling, both CO concentrations in the facility, and blood COHb levels increased, supporting the statistically positive correlation between CO and COHb. The data raw data used for this comparison can be seen in appendix C, Table X. While a positive correlation between CO and COHb was identified, the data did contain many outliers that can be explained by the sources of error mentioned in the previous sections. On the second day of monitoring that both CO concentrations and % COHb were at their highest during the three day sampling period. This may be attributed to an increased frequency of ice resurfacings, inadequate ventilation preventing CO from dissipating during the duration of the study, or participants could have been involved in more activities due to more activities occurring during day two. If multiple ice resurfacings occur in a short period of time, such as a tournament lasting three days, it is important to recognize the increased likelihood of increased CO and take the necessary precautions to prevent over exposure to CO.

6.4. Comparison between Current Study and Previous Studies.

Although this study had significant differences to those cited in the literature review section, many indicated similar results and causations. In the studies performed in Minnesota, Quebec City, Colorado, and by Nichols, high CO levels were found to be above the OSHA PEL. In this study levels found inside the playing surface were found to be on average above the PEL of 50 ppm, while outside of the playing surface they were not. Also the studies found attributed the main source of CO exposure to the ice resurfacing machines in their facilities. The previous studies along with this study did not focus on the source of the issue, but instead focused on the area and personal exposure gained from the participants in the study. This lack determining source concentrations of CO produced by the ice resurfacings displays a lack of foresight by the studies to not only investigate the problem, but being able to test solutions to mitigate the problem. Without knowing the source concentrations further research will be unable to identify if implementation of controls are adequate.

This study looked at %COHb levels through noninvasive means rather than through the Haldane equation or through expelled air analysis. When this studies data was compared to the Haldane equation, results were found to be on average one-third to what was found during the calculation. For this comparison the concentration of CO was used at the time the participants were in the facility, along with the duration (60) minutes in which they participated. For example the first participant was assigned an on ice activity where the post-game CO concentration was

44ppm. This along with a 60 minute participation equated to a % COHb of 7.92%. When this is compared to the real time post-game measurement of 3% COHb we find that they are not within the standard error of the instrument (=/- 1% COHb), and the studies data does not appear to be consistent with the Haldane equation. This may be attributed to the previous sources of error described above, or that my data set was not normal. When the equation was applied to the research that used the Haldane equation % COHb were found to be lower in the individuals and the rate of increase between exposures were also found to be significantly lower.

7. Conclusion

This exploratory study investigated six questions that were to be answered by completing the sampling strategy identified. First question was if the CO levels obtained from off-ice surface (stands) were above OSHA PEL of 50 ppm. While there were times where the CO concentration from the off-ice location did exceed the 50 ppm, the mean CO concentration was less than or equal to 50 ppm. This led to the conclusion that the off-ice participants and patrons who are not participating in on-ice activities are not being exposed to concentrations of CO greater than the OSHA occupational exposure limit. Although these individuals are not covered by OSHA, the standards set forth by OSHA can be applied to ensure that the exposure received is below industry standards.

The second question asked was whether the CO levels obtained from the on-ice location (penalty box) were above the OSHA PEL. Penalty box on-ice concentrations of CO exceeded the exposure limit of 50 ppm. The conclusion that can be drawn is that the individuals participating in on-ice activities are at a greater risk of being exposed to concentrations of CO greater than the OSHA PEL. As stated in the discussion many of the participants in the study participated in multiple on-ice activities, and were not able to leave area of high CO concentrations, creating an even greater risk.

The third question asked if the measurements taken from both the on-ice and off-ice locations were significantly different from one another. Data from both locations showed a difference between the CO concentrations of the on-ice and off-ice locations. It was questioned that due to the boards surrounding the ice surface, and CO's molecular weight being heavier than air the CO would settle close to the point of emission and the CO would not immediately disperse. This question has not been ruled out as a possible contributing factor with the significant difference between the two areas proven through statistical methods. Although with the increase steady in both locations throughout sampling and the continuous introduction of the CO source, some CO does migrate outside of the ice surface, but most of the CO stays within the rink boards. The information from this study indicates that the facility is a fairly closed system that does not allow the contaminants a chance to dissipate from either sampling location.

The fourth question asked whether the mean % COHb levels obtained from the participants after their designated activities were above the 10% COHb value where symptoms may begin to occur. Although there were a few instances where participants COHb were above the 10% necessary to produce CO exposure symptoms, most of participants were below this level. No participants exhibited or reported any signs or symptoms related to an over exposure to CO. Even though CO concentrations in this facility were above recommended exposure limits.

The fifth question asked if there will be a statistically significant difference between the pre-activity measurements and post-activity measurements for % COHb. Although there were some large variances that occurred, the mean increase (2 % COHb) found for the study fell within the standard percent error associated with the sampling device. Both increases and decreases in % COHb were observed. This question was based on the premise that these participants are exposed to CO concentrations in the BCIC long enough to affect the amount of COHb within the participant, but what the study found was that the BCIC may not have levels of CO great enough or participants exposed long enough to see a statistical difference in their metabolic COHb.

The sixth question asked if there is a significant correlation between the concentrations of CO in the facility and concentrations in the participant’s blood. The correlation was significant between the concentration of CO in the facility and the post-activity % COHb, leading to the conclusion that as the concentration of CO increases, the COHb levels will also increase. More ice resurfacing could cause over exposure to CO and related health effects to the participants.

In conclusion through the monitoring of the BCIC for CO his study indicates a potential risk for over exposure to CO. Even though the participants in this study did not exhibit the signs and symptoms associated with an over exposure to CO, elevated air and COHb levels indicate this is a potential outcome. In the following section recommendations designed to decrease the exposures to CO will be presented to prevent CO over exposures in volunteers, participants, and observers at the BCIC.

8. Recommendations to BCIC

The following recommendations for BCIC focus on the industrial hygiene concept of hierarchy of controls. Industrial hygienists commonly follow the hierarchy of controls: engineering, administrative, and personal protective equipment. These recommendations suggest controls and stages that will decrease and/or mitigate overexposure to CO.

1. Install ventilation system to prevent exposure to gasses created by the ice-resurfacer. Such a system should be included into the design of an ice rink facility to prevent the accumulation of CO.
2. Evaluate ice resurfacer. If this equipment has not been serviced, the equipment could be operating inefficiently or incorrectly if this ice resurfacer is operating incorrectly and cannot be repaired, a replacement is recommended. Proper maintenance of such equipment minimizes exposure to air contaminants in the exhaust.
3. Educate ice rink personnel and volunteers on how to prevent CO and other exhaust constituents from reaching dangerous levels. Plans on how to respond to emergencies, provide continuous ventilation whenever the rink is occupied, and warming up resurfacing equipment outside where ventilation is adequate (EPA, 2014). The EPA and National Fire Protection Agency (NFPA) provide literature and other training tools that could be of assistance to individuals whom volunteer at the BCIC. It is recommended that the local hockey association lead the push to train coaches and volunteers of the possible hazard with the free material that is available.
4. Participants, volunteers, and observers in the activities in this facility limit their exposure duration to an hour, after which they should take a break and more to a fresh air environment.

5. The bay doors at the north and south exits of the BCIC should be opened during breaks in operations to allow for air flow of fresh air to dilute the CO concentrations.

These suggestions would likely reduce the levels of CO, and improve the air quality for all users of the facility. If no changes are made, CO exposures will continue above with the potential to cause adverse health effects for those using the facility.

9. Recommendations for Future Studies

The following suggestions will improve on this study if repeated in the future.

1. Monitor more than two stationary locations for CO with Multi-gas devices. Such as monitoring the exhaust port of the ice resurfacer, set up compass points around the rink in off-ice locations to determine if there was a specific location in which greater concentrations of CO could be found. If feasible, attach multi-gas devices on workers/participants with data logging. This would improve statistical accuracy with the amount of CO found in both the on-ice area and off-ice areas, along with statistical significance with more data points.
2. Future researchers should determine prior to embarking on a similar study to ensure that the ice resurfacer is the only source producing CO. this would be accomplished by measuring the source amount produced by the ice resurfacer. Once they have this information they could determine if this is the only source of exposure, or if there is an unidentified source that could be producing CO in the facility. Identifying all potential sources is critical to determining participants will not be over exposed.
3. Determine when and how the ice resurfacer is serviced and maintained. The piece of equipment may have been out of specification by the manufacture and so having this information present would be beneficial to knowing if it is due to the equipment's optimal operating conditions or due to lack of service.
4. Determine whether the ice resurfacing machine is the only source of CO that a participant may be exposed to during the study. This study assumed that a participant's only source of CO exposure is from the ice resurfacer. Participants

may be exposed to other sources of CO outside their BCIC participation. Another source of CO would affect the initial and post activity measurements. Participants outside activities should be investigated to determine if there is a potential to be exposed to a secondary source other than BCIC.

5. Increase the sample size to provide more statistically significant, and strengthen the results instead of just evaluating a snapshot in time while the facility is operating. It is recommended to replicate this study over a month of operation, to not only have more data points but determine if the weekdays while practices are occurring, and weekends with fewer games cause similar levels of increase as a tournament weekend.
6. Replicate this study after the recommendations have been evaluated and implemented. If a ventilation system was installed CO measurements would provide data on the effective ness of the controls it would also be important to further studies to not any changes that have been made since the study was performed.
7. In further studies it would be prudent to have participants describe their time spend away from the facility during monitoring to identify other potential sources of CO and track COHb recovery time between activities.

References Cited

A Guide to Prevent Carbon Monoxide Poisoning. (N.D.). 24 Apr. 2014. Retrieved from http://www.carbon-monoxide-poisoning.com/sources.html

Anna, D. H. (2012). The occupational environment: Its evaluation, control and management. Fairfax, VA: American Industrial Hygiene Association.

Carbon Monoxide. (1999). World Health Organization: Environmental Health Criteria.

Carbon Monoxide | Air & Radiation | US EPA. (2014, February 23). Retrieved April 13, 2016, from https://www3.epa.gov/airquality/carbonmonoxide/

Carbon Monoxide Exposure at an Ice Skating Rink- Colorado. (1986, July 11). Retrieved March 14, 2014, from http://www.cdc.gov/mmwr/preview/mmwrhtml/00000763

Carbon Monoxide (CO). (N.D.). Retrieved May 12, 2014, from www.michigan.gov/documents/cis_wsh_cet5010_90097_7.doc

Carbon Monoxide: Health Information Summary. (2007, January 1). Retrieved March 20, 2014, from http://des.nh.gov/organization/commissioner/pip/factsheets/ard/documents/ard-ehp-20.pdf

Carbon Monoxide In Workplace Atmospheres (Direct-Reading Monitor), ID209. (1993, March). Retrieved January 31, 2014, from http://www.osha.gov/dts/sltc/methods/in

Carboxyhemoglobin. (N.D.). Retrieved April 06, 2016, from http://medical-dictionary.thefreedictionary.com/carboxyhaemoglobin

Chiew, A. L., & Buckley, N. A. (2014). Carbon monoxide poisoning in the 21st century. Critical Care Crit Care, 18(2), 221. doi:10.1186/cc13846

Cold Stress. (N.D.). Princeton University, Retrieved 13 Aug 06, 2014. <http://web.princeton.edu/sites/ehs/coldstress/coldstress.htm>.

Cruishank, W. (1801). Some observations on different hydro carbonates and combinations of carbon with oxygen, etc. in reply to some of Dr. Priestly's late objections to new system of chemistry. Journal of Natural Philosophy, Chemistry and the Arts, 1(5), 1-9.

Dugdale, D. (2012). Gas exchange - Anatomy Video: MedlinePlus Medical Encyclopedia. [Abstract]. . U.S. National Library of Medicine. Retrieved April 24, 2014, from http://www.nlm.nih.gov/medlineplus/ency/anatomyvideos/000059.htm

Ewanic, M. (2013, March 8). Personal Interview [Personal interview].

FAQ/Zamboni. (N.D.). Retrieved March 11, 2013, from http://www.zamboni.com/about/faq/

Gorman, D. (2003). The Clinical Toxicology of Carbon Monoxide. Toxicology, 25-38. Retrieved March 11, 2013.

Haldane, J. S. (2001, September 17). The Haldane Equation. Retrieved April 17, 2016, from http://www.coheadquarters.com/fighaldane.eqn1.htm

Henderson, R. E. (1996). Assessment and Management of Air Quality in the Workplace. Ergonomics Inc. Retrieved April 15, 2016.

Humphrey Ph. D., P.T., FACSM. Shortness of Breath in Exercise [Abstract]. (2006). ACSM's Health and Fitness Journal, 4. Retrieved May 13, 2014, from http://exerciseismedicine.org/pdfs/c76sobex.pdf

Indoor Ice Arenas. (N.D.) Minnesota Department of Health. MDH. Retrieved 8 Apr. 2014. http://www.health.state.mn.us/divs/eh/indoorair/arenas/icearenas.html.

Janicak, C. A. (2007). Applied statistics in occupational safety and health. Lanham, MD: Government Institutes/Scarecrow Press.

Kao LW. (2006). Toxicity associated with carbon monoxide. Clin Lab Med.; 26(1): 99-125.

Levesque, B. (1990). Carbon Monoxide in Indoor Ice Skating Rinks: Evaluation of Absorption by Adult Hockey Players. American Journal of Public Health, 594-598. Retrieved March 23, 2015.

Levesque, B. (1991). An Experiment to Evaluate Carbon Monoxide Absorption by Hockey Players in Ice Skating Rinks." Veterinary and Human Toxicology, 5-8. Retrieved March 23, 2015.

Light, A, C Grass, D Pursley, and J Krause. (2007). Carboxyhemoglobin Levels in Smokers vs. Non-Smokers in a Smoking Environment. Respir Care 52.11, 1576.

Merritt, C. (N.D.). OSHA Vs. EPA. Retrieved April 17, 2016, from http://smallbusiness.chron.com/osha-vs-epa-45018.html

Multi-Gas Monitor iTX [Instruction Manual Rev 9 ed]. (2011).

Nichols, R. (2009, April 15). E:60: Air quality at ice rinks causes concern. Retrieved April 13, 2012, from http://sports.espn.go.com/espn/e60/news/story?id=4068448

Ordway, G. (2004). Myoglobin: An Essential Hemoprotien in Striated Muscle. The Journal of Experimental Biology, 3226-3441.

OSHA Fact Sheet. (2002). Retrieved August 4, 2012, from https://www.osha.gov/OshDoc/data_General_Facts/carbonmonoxide-factsheet.pdf

Penny, D. G. (2000). Carbon Monoxide Toxicity. CRC Press. Retrieved November 27, 2015.

Prockop, L. D. (2011). Carbon Monoxide Intoxication: An updated review. Journal of Neurological Sciences, 122-130.

Rad-57 Operator's Manual. [Irvine: Masimo Rainbow]. (2011).

Raub, J. A. (2000). Carbon Monoxide Poisoning- a Public Health Perspective. Toxicology, 1-14.

Rintamaki, H. (2007). Human response to cold. Alaska Med, 49, 29-31. Retrieved January 1, 2016, from http://www.ncbi.nlm.nih.gov/pubmed/17929604

Rosen, J. (Reporter). (2011). Is the Ice Rink Making Your Child Sick? [News Report]. United States: Today Show.

Schaefer, R. L., Farber, E., & Schaefer, R. L. (2014). The student edition of Minitab [Computer software].

Theiler, J. (2011, March). The Aire We Breathe: Rink Air Quality. USA Hockey Magazine, 5-7.

Spengler, J. D., Samet, J. M., & McCarthy, J. F. (2001). Indoor air quality handbook. New York: McGraw-Hill.

Thomas, T. (2011, June 17). Raw Numbers: USA Hockey Surpasses 500,000 Registered Players in 2010-11. United States of Hockey.

ToxGuide for Carbon Monoxide. (2012, October 1). Retrieved March 7, 2013, from http://www.atsdr.cdc.gov/toxguides/toxguide-201

Weaver. LK. (Mar. 2009). Clinical practice, Carbon monoxide poisoning. The New England Journal of Medicine: 797-801.

United States. (n.d.). Retrieved April 1, 2013, from http://www.iihf.com/iihf-home/countries/united-states.html

Appendix A: CO Concentrations (ppm) found at Butte Community Ice Center

Table VIII: Raw CO Concentration Data from the BCIC

Time	Off Ice (ppm)	Time	On Ice (ppm)
4/12/2013 16:14	25	4/12/2013 16:15	26
4/12/2013 18:50	23	4/12/2013 18:51	44
4/12/2013 20:41	32	4/12/2013 20:43	54
4/12/2013 22:35	35	4/12/2013 22:37	63
4/13/2013 8:30	38	4/13/2013 8:31	54
4/13/2013 10:05	25	4/13/2013 10:06	53
4/13/2013 11:03	39	4/13/2013 11:05	75
4/13/2013 13:00	44	4/13/2013 13:01	85
4/13/2013 17:17	79	4/13/2013 17:20	111
4/13/2013 18:37	58	4/13/2013 18:40	101
4/13/2013 20:08	62	4/13/2013 20:08	110
4/13/2013 21:40	65	4/13/2013 21:42	110
4/14/2013 8:00	46	4/14/2013 8:03	76
4/14/2013 9:03	33	4/14/2013 9:05	72
4/14/2013 10:35	39	4/14/2013 10:37	81
4/14/2013 12:15	49	4/14/2013 12:17	93

Appendix B: Participants COHb Measurements (%COHb)

Table IX: Raw COHb Measurements from Study Participants

Subject ID	Day	Pre-game Measurment Time	Pre-game Measurment COHb (%COHb)	Post-game Measuement Time	Post-game Measurment COHb (% COHb)
Off-ice 1	1	17:35	0%	18:53	2%
Off-ice 2	1	17:35	0%	18:53	0%
Off-ice 2	2	9:00	0%	10:15	0%
Off-ice 2	2	11:55	6%	13:05	6%
Off-ice 2	2	17:20	3%	18:45	0%
Off-ice 2	2	18:45	0%	20:15	8%
Off-ice 2	3	11:00	9%	12:35	9%
Off-ice 3	1	19:25	0%	20:41	3%
Off-ice 3	1	21:35	1%	22:55	4%
Off-ice 3	2	10:30	3%	11:53	5%
Off-ice 4	2	9:00	0%	10:10	0%
Off-ice 4	2	12:00	3%	13:05	3%
Off-ice 4	2	17:26	3%	18:33	3%
Off-ice 4	2	20:37	10%	22:00	11%
Off-ice 5	3	8:00	4%	9:10	3%
Off-ice 5	3	9:07	3%	10:45	4%
Ref 1	1	17:25	1%	18:58	3%
Ref 1	2	10:20	5%	11:45	4%
Ref 1	2	11:45	4%	13:10	2%
Ref 2	1	18:20	1%	20:41	2%
Ref 2	1	21:25	3%	22:45	5%
Ref 2	2	10:22	3%	11:45	4%
Ref 2	2	17:25	2%	18:40	6%
Ref 2	2	20:35	8%	21:47	7%
Ref 2	3	7:50	0%	9:15	5%
Ref 2	3	9:15	5%	10:50	5%
Ref 3	1	18:36	0%	20:41	0%
Ref 3	2	8:45	0%	10:14	0%
Ref 3	2	11:49	3%	13:10	2%
Ref 3	2	18:41	0%	20:32	6%
Ref 3	2	20:32	6%	21:50	8%
Ref 3	3	7:53	0%	9:17	2%
Ref 3	3	9:17	3%	10:51	5%
Ref 4	3	10:54	6%	12:31	13%
Ref 5	3	10:55	4%	12:31	7%
Ref1	1	21:25	5%	22:46	3%
Zam 1	1	18:42	0%	19:06	0%
Zam 1	1	23:00	0%	23:15	4%
Zam 1	2	10:10	0%	10:25	0%
Zam 1	2	13:05	3%	13:20	4%
Zam 1	2	18:33	3%	18:50	5%
Zam 1	2	20:10	3%	20:25	5%
Zam 1	3	9:05	2%	9:20	3%
Zam 1	3	10:36	3%	10:47	4%
Zam 2	1	20:41	3%	20:59	5%
Zam 2	2	11:53	5%	12:05	5%

Appendix C: Data Used to Compare Post Activity COHb (%COHb) and Post Activity CO Concentrations (ppm)

Table X: Comparison Data Used for Hypothesis 6

	Post-Game Measurement COHb (% COHb)		Post-Game CO (ppm)
	2%		23.00
	0%		23.00
	3%		44.00
	2%		54.00
	0%		54.00
	0%		54.00
	3%		32.00
	5%		54.00
	5%		63.00
	3%		63.00
	4%		35.00
	4%		63.00
	0%		53.00
	0%		25.00
	0%		25.00
	0%		53.00
	4%		75.00
	4%		75.00
	5%		44.00
	5%		75.00
	2%		85.00
	2%		85.00
	6%		44.00
	3%		44.00
	4%		85.00
	0%		58.00
	3%		58.00
	6%		101.00
	5%		101.00
	8%		62.00
	6%		110.00
	5%		110.00
	7%		110.00
	8%		110.00
	11%		65.00
	3%		33.00
	5%		72.00
	2%		72.00
	3%		72.00
	4%		39.00
	5%		81.00
	5%		81.00
	4%		81.00
	13%		93.00
	7%		93.00
	9%		49.00
Maximum	13%	Maximum	110.00
Minimum	0%	Minimum	23.00
Standard Deviation	0.028697994	Standard Deviation	26.62
Mean	6%	Mean	65.16
Median	4%	Median	63.00
Mode	0.05	Mode	44.00

SIGNATURE PAGE

This is to certify that the thesis prepared by Jonathan Triner entitled "A Study of Carbon Monoxide Exposures in Ice Rink Volunteers" has been examined and approved for acceptance by the Department of Safety, Health, and Industrial Hygiene, Montana Tech of The University of Montana, on this 29th day of April, 2016.

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