The Effects of Simulated Lifeboat Motions on Carbon Dioxide Production

by

© Katie Ann Aylward

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Abstract

A Totally Enclosed Motor Propelled Survival Craft (TEMPSC) is currently the primary mode of escape during a maritime and offshore emergency situation. Although lifeboats have evolved from their original design, the interior comfort and habitability of the craft has remained virtually unchanged and is not considered during the certification process. Ambient carbon dioxide (CO_2) accumulation within TEMPSC is one factor, along with many others that may cause serious health implications for TEMPSC occupants. . Previous research has shown that with the hatches closed and the participants at rest, an international 8-hour exposure limit of 4800ppm may be reached in as little as 15 minutes. This study uses simulation as a testing methodology to determine if vessel motions in various sea-states impact the time to reach this same CO_2 exposure limit because of physical exertions of the participants to maintain stability within their seats.

Keywords: Lifeboat, TEMPSC, ambient carbon dioxide, habitability.

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List of Abbreviations and Symbols

ACGIH	American Conference of Governmental Industrial Hygienists
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BMI	Body mass index
°C	Degrees Celsius
CIS	Canadian Ice Service
CLIA	Cruise Lines International Association
CNLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CO_2	Carbon dioxide
EER	Evacuation, Escape, and Rescue
FRC	Fast Rescue Craft
HIC	Human Investigations Committee
HR	Heart Rate
HSE	Health and Safety Executive
IMO	International Maritime Organization
ISO	International Organization for Standardization
LSA	Life-saving appliance
m	Meters (distance)
MODU	Mobile offshore drilling unit
MUN	Memorial University of Newfoundland
n	Sample size
NIOSH	National Institute for Occupational Safety and Health (American)

NRC	National Research Council Canada
O_2	Oxygen
OGP	International Association of Oil and Gas Producers
OSHA	Occupational Safety and Health Administration (American)
PERD	Canadian Program of Energy Research and Development
POB	Personnel onboard
PPE	Personal protective equipment
ppm	Parts per million
REB	Research Ethics Board
RNLI	Royal National Lifeboat Institution (United Kingdom)
SA	Surface area
SAR	Search and Rescue
SD	Standard deviation
SOLAS	Safety of Life at Sea
STEL	Short-term exposure limit
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
VHF	Very high frequency

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Chapter 1 – Introduction

1.1 Background of Study

Within the past 10 years there has been a major increase of marine activity in Northern and Arctic Canadian waters. Melting ice and milder temperatures in Northern passages open new routes for vessels to pass through. This increase in activity is occurring in all maritime operations including shipping, oil and gas exploration, and tourism. As activity in the Canadian Arctic is increasing now faster than ever, the marine safety equipment and lifesaving appliances (LSA) must be able to properly function in these harsh environments. In many cases, these Arctic passageways create short cuts for shipping supplies to various locations across the globe, and can therefore potentially cause a major decrease in the overall cost to ship goods. However, there are risks associated with travelling in these geographically remote and harsh environments. While there have undoubtedly been improvements in many aspects of marine equipment design, (e.g., drilling technologies, ice breaking equipment, maneuvering capabilities, certain LSA) that are made to be able to perform in harsher environments, these designs may not fully consider the human element. Owners, operators, and manufacturers may not be aware of the safety and human element requirements of existing or newly developed equipment in the marine industry. Industry based research on the principles of human factors and ergonomics for LSA will provide the necessary background information to inform design, training and policy.

Lifesaving evacuation craft have played a crucial role in the escape, evacuation, and rescue (EER) protocols in a wide variety of maritime industries over the past 200 years

(Royal National Lifeboat Institution, RNLI, 2011).The Totally Enclosed Motor Propelled Survival Craft (TEMPSC) is the preferred method of evacuation from an offshore installation, secondary to a helicopter (HSE, 2007). A benefit TEMPSC offer over life rafts is the ability to independently navigate away from immediate or emerging danger since they are self-propelled. The current TEMPSC design has come a long way since original lifeboat designs hundreds of years ago. Changes occurred based on major accidents resulting in loss of life due to inadequate safety measures including; the Titanic in 1912, and the Alexander Kelland in 1980 (HSE, 2007). TEMPSC are now watertight, have seatbelts for all occupants, are motor propelled, and are built with more durable materials and increased capabilities. However, there are still many technical solutions required if the TEMPSC is to become fit for purpose in the Canadian North.

A disconnect often occurs during the technology development cycle between the engineering designs and the human factors needs within a system. Currently, the marine based research on LSA is mostly engineering-focused and often does not account for the humans using the equipment. Another issue is the fact that many LSA have not even been tested in realistic operating environments, which could include wind, waves, ice, poor visibility and snow. For example, marine abandonment suits are required to have a prescribed level of thermal protection when tested in "calm, circulating water" (IMO, 2010). Wind and waves will result in a significant increase in heat flow away from the body compared to calm water, which can result in reduced predicted survival times (Power J, & Simoes Ré A., 2011) Research institutions, such as the National Research Council (NRC) promote performance-based standards versus prescriptive-based standards for the approval of LSA. A prescriptive based approach is based on the fact that equipment, and

the training in the use of such equipment, should be related to the operational environment. Marine safety equipment must past testing in calm water conditions in order to get approved. However, LSA appliances including immersion suits, and lifejackets have shown deficiencies when testing includes non-benign conditions which represent harsh environments such as those to be expected in Arctic waters (Power J, & Simoes Ré A., 2011). Therefore, it is possible that LSA, which are intended to save lives in emergencies may not be adequate in the case of a marine incident.

In 2013 NRC completed a study that explored exposure time until recovery by rescue resources in in several remote Arctic locations. Exposure time in the NRC (2013) report related to the moment of initial communication of an emergency from the distressed vessel, to the arrival and successful completion of the rescue mission (Kennedy, Gallagher, & Aylward, 2013). This was the first formal research that incorporated all possible factors that may affect time to rescue including; weather and environmental conditions, multi-year ice patterns and data, bathymetry data, communication capabilities, availability of SAR resources, proximity to land, and several others. The result of this study was an estimated time (in hours) that people could possibly be waiting to be rescued in Arctic waters. The data were collected from surveys and a workshop that included representatives of Joint Rescue Coordination Centre (JRCC) Trenton and JRCC Halifax as well as other professionals with experience in marine or air based northern rescue operations. The final results indicated that the minimum exposure time values were approximately 13-27 hours if Search and Rescue (SAR) assets were deployed by helicopter and the maximum exposure times were approximately 261 hours (10.9 days) if marine vessels had to be used (Kennedy, Gallagher, & Aylward, 2013). This reality creates challenging demands upon safety

operators and equipment manufacturers because the equipment that is currently in place is expensive, difficult to replace, and not necessarily manufactured to last for up to a week.

The importance of this research is constantly growing as climate conditions and sea ice properties are changing and technology is becoming more advanced. There remain many unknown variables associated with shipping and offshore activities and routes in the Arctic. Although risk assessments are continuously performed on Arctic operations, the "minimum standards" for LSA safety, set by governing bodies such as IMO and SOLAS are not yet caught up with the increase of activity in these geographic locations.

1.2 TEMPSC Standards

The International Maritime Organization (IMO) Safety of Life at Sea (SOLAS) Convention (1974, as amended) and Life-Saving Appliance (LSA) Code (2010b) through minimum prescribed standards governs lifeboat design and operation. These standards are prescriptive regardless of the latitude in which they are operating even though vessels and installations may be operating in the Arctic. For example, vessels going north would have slightly different EER requirements (i.e. having immersion suits on board for all crew) than those operating in the warmer waters of the Gulf of Mexico. The current safety standards for TEMPSC are vague and in their conception did not anticipate the evolving usage of the TEMPSC in harsh, cold environments and how emerging technologies may be exploited to overcome these challenges.

The low minimum criteria of TEMPSC safety standards call into question the safety of the people who may have to spend any amount of time in a lifeboat. One of the most overlooked and perhaps threatening issues surrounding TEMPSC safety is the internal air quality and ambient environment inside of the lifeboat. The standard ventilation system for

most conventional TEMPSC designs is a compressed air system, which is supposed to have sufficient capacity to provide air for the maximum number of personnel and engine at full speed combustion for a minimum of 10 minutes (NORSAFE, 2000). However, after the 10-minute threshold, the compressed air is depleted and the internal environment of the lifeboat will become more hostile as regular circulations of fresh air are not available. This is compounded by the fact that the people within the lifeboat would be anxious and therefore breathing heavy, expending more oxygen which would compromise the air quality within the TEMPSC at an even faster rate. In order to provide fresh air to occupants in a conventional passive ventilation system the hatches would have to be opened, which would then compromise the water-tight integrity of the boat, expose occupants to air pollutants (fire, gases, and debris) and would take away from the overall effectiveness of the craft as a safe haven.

Carbon dioxide (CO_2) is a gas that under normal atmospheric circumstances comprises roughly 0.03% of the air humans breathe, plays a major role in metabolism within the human body and generally is not a harmful gas (Scott *et al*, 2009; Baker, 2012). However, at high concentrations, there are several known severe negative health effects on humans (Xu *et al*, 2011). Carbon dioxide accumulation within a TEMPSC is only one of the major issues surrounding human survival in lifeboats at sea; however it is a critical aspect in understanding the risks (i.e. negative consequences) associated with survival for occupants at sea.

1.3 Significance of Study

The purpose of this study was to examine whether motion rich environments, environments that a TEMPSC could likely be exposed, should be considered when

assessing the habitability requirement for human occupants. It is important to add to the existing research that has examined the internal and external habitability of TEMPSC in water, ice and harsh environments to be able to accurately provide recommendations on how to improve the design and safety of TEMPSC. Previous work has shown variables such as humidity, light, noise, airflow, air quality, passenger loading, passenger comfort, sea-sickness, temperature (Power & Simões Ré, 2013) and the ergonomics of the coxswain station as independent factors that could negatively affect occupant habitability and survivability in emergency situations (Power & Simões Ré, 2013; Taber *et al*., 2011; Baker *et al*., 2011; & Power-MacDonald *et al*., 2010). Further work on each of these variables continues to be explored in the NRC and Memorial University research cluster with an overall goal of improving maritime safety.

CO_2 accumulation is one factor that could significantly impact the health and survivability of the occupants during the time it would take for a rescue vessel, or rescue helicopter to arrive on site. Therefore, it is important to look at CO_2 independently and try to understand the impact that the accumulation of this gas could have in a realistic emergency scenario. Additionally, simulated lifeboat motions will recreate a similar situation that could be expected in the case of a stranded and distressed TEMPSC. Various simulated environmental states represented calmer and harsher ocean environments respectively using low motion and high motion conditions. The goal was to better represent the amount of CO_2 that would be produced by TEMPSC occupants.

The goal of this research was to investigate the effects that TEMPSC motions had on human CO_2 production. The results from this research will hopefully help raise questions surrounding marine safety standards and inform regulators, operators, and

manufacturers of marine safety appliances about the potential dangers to occupants associated with ambient CO_2 accumulation within TEMPSC. Previous engineering research in relation to lifeboat maneuvering through ice, proper hook release from the hatches, hull, bow, and rudder strength and flexibility has been done in realistic research environments. This research will complement the engineering, and human related work that has been completed to determine whether or not the occupants will have a good chance at survival in current TEMPSC design (Taber *et al*. (2011). Longer rescue times because of Arctic exploration, and outdated safety standards with respect to LSA create the basis for this research. Understanding the human factor within TEMPSC design will be the only way to remain confident in an emergency scenario in the maritime industry.

This study will build on previous research (Power & Simões Ré, 2013; Taber *et al*., 2011; Baker *et al*., 2011; & Power-MacDonald *et al*., 2010) that focused on habitability within a TEMPSC during a survival and recovery scenario. More specifically, this research will examine the effects of motion on CO_2 production and how this could affect TEMPSC habitability. The results of this study will hopefully help influence the future design of TEMPC ventilation systems and increase the likelihood of carrying out a successful Evacuation, Escape, and Rescue (EER) EER protocol.

1.4 Hypotheses

The current research study is a three way repeated measures design and the goal is to gain better insight into the relationship between the amounts of simulated lifeboat motions on carbon dioxide production as a result of higher ventilation rates in humans. The following hypotheses were tested in this study:

1.) Participants will have an increase in VCO_2 during the high motion and the low motion conditions compared to the baseline condition.
2.) Participants will have an increase in VO_2 during the high motion and the low motion conditions compared to the baseline condition.
3.) Participants will have an increase in heart rate during the high motion and the low motion conditions compared to the baseline condition.
4.) Simulated motions will increase CO_2 production in human's more than previous research has shown in stable non- motion conditions.

Chapter 2 – Review of Literature

Lifeboats, and more specifically, TEMPSC are evaluated, tested, and approved by resolutions developed by the International Maritime Organization – Safety of Life at Sea (IMO-SOLAS) Convention (1974, as amended) and Life Saving appliance (LSA) Code (2010b) guidance notes based on their construction, and equipment. This means there are safety standards in place for TEMPSC regarding many aspects of its design and functioning. Currently the IMO, LSA code does not specify any requirements for the interior conditions of a TEMPSC, meaning there are no performance-based standards in place for: noise; light; temperature; humidity; carbon monoxide (CO) and carbon dioxide (CO_2) levels within lifeboats (Power, & Simões Ré 2010). Having no health and safety requirements for the interior of TEMPSC may create a dangerous environment for an occupant who may need to remain enclosed for extended periods of time. Other than fire, carbon monoxide and carbon dioxide have been identified as immediate threats to survival and therefore should have specific standards and safety limits in place for risk remediation purposes.

Most of the testing that is done for any LSA, including lifejackets and immersion suits is generally conducted in a very controlled research setting, which is not representative of the setting in which it will be used. The LSA that do have regulations in place may pass all the IMO LSA code regulatory standard tests as the equipment is not actually being tested in the more extreme conditions that they could be used in. This reflects the importance of performance-based standards as opposed to prescriptive based standards; by not testing in the extreme conditions often encountered during a marine accident, the quality of construction and actual performance of the LSA in these conditions may be overlooked.

Safety standards and regulations should be specific to the situation or environment they will be used in. Currently, there is a gap between how some LSA equipment will perform in a realistic situation and how it performs in testing facilities.

Two well-known disasters, the 'Ocean Ranger' in 1982 and 'Piper Alpha' installation in 1988 caused people in the marine industry to rethink safety standards and try to create a concise set of performance standards for various aspects of EER (HSE, 2007). It seems that unfortunately sometimes it takes a major disaster with loss of lives to change or reevaluate marine safety standards. Although many aspects of the marine industry have been adjusted to adhere to updated safety regulatory standards including the ILO MLC, 2006 and several IMO codes for various spaces on marine vessels, there have been almost no changes in safety requirements for TEMPSC. TEMPSC and LSA have been essentially disregarded from the updated safety standards, indicating that more research must be done to show the need for more stringent requirements and safety standards.

2.1 Current TEMPSC standards

Apart from carbon dioxide representing a serious threat to TEMPSC occupants, there are many other issues that need to be re-evaluated by IMO and SOLAS for TEMPSC survival. One issue that has started to create momentum for change is the increasing average size of humans. Historically the weight restrictions use by IMO-SOLAS (1974, as amended) for lifeboats were based on an average human mass of 75kg. This standard is quite outdated and does not take into account the continuously changing anthropometrics of humans, and any additional cold weather PPE. However, the IMO Guidelines for Ships Operating in Polar Waters (2010a) increased the average mass to 85.2 kg, which is a closer representation of the current population. However, this document is only a guideline and

therefore is not enforced by IMO. Additionally, recent research has shown that even with the increase of approximately 10 kg, this may not be enough to accurately represent the increasing size of "offshore workers" (Kozey *et al*., 2009; C-NLOPB, 2010; & HSE, 2008). The Health and Safety Executive conducted a study and sampled 64 offshore workers (58 males and six females), which would be representative of the population who would use lifeboats in an offshore emergency (2008). The results indicated that the estimated average mass of UK offshore workers was 95kg, and this value could potentially increase based on personal protective equipment (PPE) (HSE, 2008). This information is relevant to the present study because larger people, with greater mass tend to consume more oxygen, and therefore produce more carbon dioxide (Baker *et al*., 2010). Therefore, the greater mass of the entire complement of persons on board (POB) the TEMPSC, the more CO_2 that will be trapped in the vessel.

The results of several research studies (Kozey *et al*., 2009; C-NLOPB, 2010; & HSE, 2008) examining the increasing size of humans, has in fact impacted the maximal number of POB allowed in many TEMPSC. Many survival craft have been downsized from the original manning compliment to hold less people due to the greater mass per person. The lifeboat modeled in the present study was once a 25-person lifeboat, and has since been downsized to a 20-person lifeboat, based on the published research regarding a larger mass per person. This downsize is a step in the right direction for lifeboat habitability that could have a serious impact if an EER protocol took place.

Landolt and Monaco (1992) and Taber *et al*. (2010), have previously reported issues surrounding air quality in TEMPSC. During testing trials for coxswains piloting in ice, CO and CO_2 sensors were used to measure the interior gas levels of TEMPSC (Taber *et al*,

2010). This was a precautionary measure because it was believed that due to the SOLAS design requirements of waterproofing the vessel; gas concentrations could rise to unacceptable levels according to the Canadian National Health and Safety Standards (Taber *et al*, 2010). The results of this study showed that with only three people in the 20-person TEMPSC and the hatches closed, CO_2 levels reached maximum limits and the CO2 sensor alarms sounded at the 10-minute mark of data collection. Conclusions from this study indicated that if the hatches were required to stay closed due to environmental conditions such as rain, snow, high wind or waves, freezing spray or any airborne toxins, the people within the TEMPSC would suffer from very poor air quality and complications of CO_2 accumulation (Taber *et al*, 2011). The study by Taber *et al*. (2011) and later work done by Baker *et al*. (2011) are the only known research studies that have found and reported the possibility of a major flaw in the current air quality systems of TEMPSC, and the detrimental effects this could have on the human occupants.

2.2 Historical CO_2 incidents

One of the most historically recognized events that involved death due to CO_2 exposure was in Cameroon during the Lake Nyos disaster of 1986. This incident killed close to 2,000 people when a cloud of CO_2 gas shot up from the depths of Lake Nyos and the people sleeping in the village were killed during the night (Beagle, *et al*. 2015). This incident, along with several other smaller scale events highlighted the threat of CO_2, and people became more aware of the potentially deadly side effects. Although industrial incidents are well reported and documented in safety literature for CO_2 exposure, it is not as common to read about clinical side effects of smaller CO_2 exposure events that do not cause death (Halperin, Raskin, Sorkine, & Oganezov, 2004).

Previous work by Halperin et al. (2004) examined a group of people who survived CO_2 exposure over a short amount of time. This particular work looked at the physiological changes in respiratory and cardiovascular functioning after CO_2 exposure. Specific symptoms of the 25 casualties involved in this incident included less serious issues including; dyspnea, cough, dizziness, chest pain, and headache, and more serious symptoms including; atrial fibrillation, patchy alveolar patterns, pulmonary edema, and non Q-wave myocardial infarction. The findings of this study suggest that cardiac complications are a direct side effect of exposure to unnatural levels of CO_2 in a confined space, but full recovery is possible with prompt evacuation and supportive therapy. Quick reaction time and prompt medical attention could increase the likelihood of a favorable prognosis in relation to CO_2 exposure (Halperin, Raskin, Sorkine, & Oganezov, 2004; &. Langford, 2005).

2.3 Experimental Indoor Air Quality (IAQ) Studies

Seppanen, Fisk, and Mendell (1999) undertook a literature review that investigated the association of ventilation rates and carbon dioxide concentrations with health in non-industrial buildings. Sick Building Syndrome (SBS) is a term coined by the World Health Organization (WHO, 1983) and is characterized by eye, nose and throat irritation; a sensation of dry mucous membranes and skin; erythema; mental fatigue; headache; wheezing, itching and non-specific hypersensitivity; nausea and dizziness (Seppanen et al., 1999). These SBS symptoms are generally only present when a person occupies the building and symptoms subside when away from the building. Normal indoor environments tend to have a CO_2 range between 350-2500ppm and this range seems to have no effect on human health. Results of this review indicate that an increase in CO_2 concentration will

decrease Perceived Air Quality (PAQ), however the results were sometimes inconsistent and this could be because of the temporal variation in indoor CO_2 concentrations, and the many factors that affect CO_2 measurements. Some of these include; lack of standardization of measurement locations, and lack of reporting of the outdoor carbon dioxide levels, and some reports of CO_2 could have an error on the order of 100 ppm (Seppanen et al., 1999). Overall, this study concluded that many studies report that there is a relationship between ventilation rates and health outcomes and CO_2 accumulation and health outcomes; however it is difficult to report a recommended limit for CO_2 levels or a recommended building ventilation rate (Seppanen et al., 1999).

Chung, Tang, and Wan (2011) explored the linear relationship of people in a medical operating room to the increasing levels of carbon dioxide. Indoor air quality is cited as an important factor in hospitals and medical facilities for preventing and reducing the chance of infection. Poor air quality in hospitals could lead to serious health risks and occupational hazards. In Taiwan there are currently no standards for air quality in operating rooms (Chung et al., 2011). This lack of standardization is relevant to the lack of internal environmental regulations within TEMPSC. The results of this study indicate a positive relationship between the number of people in the operating room and CO_2 concentrations. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) suggests that in settings where the air quality is important, there must be a limit to the number of occupants in the room to have adequate and safe air quality (2006). The suggestion provided by ASHRAE to limit the number of people in the operating room at one time is applicable to a TEMPSC as well through a POB requirement. A POB restriction in TEMPSC is a measure that is already in place, however its purpose is for seating capacity

and shoulder and hip breadth weight restrictions and not based on air quality. It could also be argued that the POB requirement should be made based on air quality standards.

Mahyuddin and Awbi (2010) looked at the spatial distribution of carbon dioxide in a classroom setting, which represented an environmental test chamber. The goal was to monitor and understand the how the classroom air quality deteriorated over time. Previous research has shown variations in CO_2 accumulation within a classroom space, at different sampling points or sensor locations (Ferng & Le, 2002). Similar to the internal modeling of a TEMPSC, the goal of this work was to examine the CO_2 distribution within a confined classroom setting. One of the significant findings of the study was the ventilation strategy for any space is related to CO_2 accumulation (Mahyuddin & Awbi, 2010). Moreover, there are many factors that will influence the dispersion of CO_2 including: occupancy level of the room; occupant sitting position; air flow rate; location of the inlet and outlet air terminals; and external and internal environmental conditions (Mahyuddin & Awbi, 2010). It may be hypothesized that the same or similar factors would affect the environmental conditions within a confined TEMPSC.

Additionally, Ferng and Le (2002) investigated IAQ in daycare facilities across the United States. Air quality is known as an important factor to human health and is especially essential to the health of small children or infants. This study specifically examined carbon dioxide during naptime and playtime in children. The results indicated that over 50% of the daycares in this study had CO_2 levels above the recommended levels set by the ASHRAE. The naptime average CO_2 level was significantly higher ($p < 0.05$) (about 117ppm) than the non-nap time level. The reason for the higher levels of CO_2 within the naptime room was not because the children were not moving; it was because the room was completely

isolated, acting as an entirely closed system. This research provides evidence that more stringent standards for IAQ should be available and should be monitored more frequently when people are spending extended amounts of time in an enclosed space. If there are CO_2 levels above the ASHRAE limits, then alternative ventilation options should be explored to ensure adequate air circulation is provided in daycares, offices, or any other isolated room with lots of occupants. Alarms should also be in place to sound when the exposure limit has been reached, which has been implemented in newer TEMPSC designs.

2.4 Ambient Carbon Dioxide Testing Threshold

Several occupational health and safety regulatory agencies recognize an ambient CO_2 exposure limit of 5000ppm as posing no immediate threat to human health for exposures of up to eight hours per day (Table 2.1).

Table 2. 1 Ambient CO_2 exposure limits

Source (year)	Value (ppm)	Application
NIOSH (2011)	5000	Permissible exposure limit (8 hours)
HSE* (2007)	5000	Workplace long-term exposure limit (8 hours)
ACGIH** (2005)	5000	Threshold limit value (8 hours)
OSHA (2001)	5000	General industry exposure limit (8 hours)
NIOSH (2011)	30000	Short-term exposure limit (10 minutes)
HSE (2007)	15000	Workplace short-term exposure limit (10 hours)
ACGIH (2005)	30000	Threshold value limit (15 minutes)

*United Kingdom Health and Safety Executive
**American Conference of Governmental Industrial Hygienists

In addition to the Health and Safety Executive (HSE) Workplace short-term exposure limit in Table 2.1, there was more work done by members of the HSE, which is

known as an assessment of Dangerous Toxic Load (DTL) (Harper, Wilday, & Bilio, 2011). This assessment is used to calculate CO_2 exposure conditions in terms of the concentration and the duration of exposure. The terms Specified Level of Toxicity (SLOT) and the Significant Likelihood of Death (SLOD) are used to categorize CO_2 exposure. HSE defines SLOT as causing: "severe distress to almost everyone in the area; substantial fraction of exposed population requiring medical attention; some people seriously injured, requiring prolonged treatment; highly susceptible people possibly being killed, likely to cause 1-5% lethality rate from a single exposure to a certain concentration over a known amount of time" (Harper et al., pg. 3, 2011). SLOD is defined as "causing 50% lethality from a single exposure over a known amount of time. Data for this calculation is collected from routine toxicity testing on animals, using cautious results" (Harper et al., pg. 3, 2011). Table 2.2 presents the output of this assessment for CO_2 and the significant threats to humans in an environment of increased CO_2 accumulation.

Table 2. 2 HSE assessment of CO_2 for SLOT and SLOD

Inhalation exposure time	**SLOT: 1-5% Fatalities CO_2 concentration in air**		**SLOD: 50% Fatalities CO_2 concentration in air**	
	%	**ppm**	**%**	**ppm**
60 min	6.3%	63 000	8.4%	84 000
30 min	6.9%	69 000	9.2%	92 000
20 min	7.2%	72 000	9.6%	96 000
10min	7.9%	79 000	10.5%	105 000
5 min	8.6%	86 000	11.5%	115 000
1 min	10.5%	105 000	14%	140 000

2.5 Detrimental health effects of increased CO_2 exposure

According to the National Institute for Occupational Safety and Health (NIOSH) CO_2 exposure creates a range of symptoms such as headache, dizziness, restlessness, breathing difficulty, sweating, malaise, increased heart rate, cardiac output, blood pressure, coma asphyxia convulsions and possibly death (2010). The NIOSH chemical hazard guide also indicates that the CO_2 gas targets the respiratory and cardiovascular systems. Carbon dioxide is well studied as a stress stimulus and the human response to minimal elevated levels of CO_2 is well documented (Kaye *et al.,* 2004; NIOSH 2010; Harper et al., 2011). Previous work by Kaye et al. (2004) investigated the behavioral and cardiovascular effects of elevated CO_2 at 7.5% on a healthy group of subjects as a test group. The goal was to further investigate anxiety provocation in individuals who do not suffer from an anxiety disorder. The results indicate that the 7.5% CO_2 inhalation significantly increased heart rate and systolic blood pressure compared to a control group who inhaled normal room air (Bailey, Argyropoulos, Kendrick, & Nutt, 2005). Moreover, the results show that the effects seem to occur very rapidly after exposure to the CO_2, and it was evident that subject fear and anxiety is increased in the elevated CO_2 group. One of the limitations of this work was that there was no definitive/objective measure of the severity of a headache, even though most of the participants complained of a headache after exposure to CO_2. This is one of the known side effects of CO_2 in elevated concentrations, therefore in future studies it should be measured using a wellness scale (Kaye *et al.,* 2004). Overall, this study shows the onset of negative health events after a short exposure (20 minutes) to 7.5% CO_2.

Inhalation of increased CO_2 is also known to cause several vascular changes in the brain such as increased cerebral blood flow, increased cerebral blood volume, and higher

O_2 and CO_2 concentrations in the blood (Kastrup *et al*, 1999; Rostrup *et al*, 2000; Sicard & Duong, 2005). However, there is a gap in literature surrounding the influence of CO_2 on cognitive brain function and the exact neural effect that it could have. The work that has been done in this area has shown that CO_2 can cause a suppressive effect on brain activity in the effect of a reduction of metabolic activity and a decrease in spontaneous brain connectivity (Xu *et al*, 2011).

Although it has been briefly studied before, prolonged exposure to CO_2 at concentrations greater that 6% in confined spaces is not well researched with respect to the effects on mental performance, as it is dangerous to human health and functioning. Sayers, Smith, Holland, & Keatinge, (1987) found that exposure to 6.5% CO_2 produced an increase in irritability and discomfort with no significant change in long-term memory. Several other side effects of CO_2 exposure are anxiety (Bailey *et al*, 2005), fear (Colasanti *et al*, 2008), and panic (Griez *et al*, 2007). Baker et al. (2011) created a summary table (Table 2.3), which shows symptoms associated with increased CO_2 exposure and the accompanying references for this information.

Table 2. 3 Summarized CO2 exposure symptom literature (*NP = Not provided **PE ="Prolonged exposure") Source: Baker et al., 2011

Symptom	[CO_2] Range (ppm)	Exposure Time	Source (year)
Increased Respiration	10000-40000	NP*	Scott *et al* (2009)[1]; OSHA (1978)[1]
Headache, Sweating	30000-76000	1 hour, NP, or PE**	Harper *et al* (2011)[1]; US Department of the Interior (2006)[1]; OSHA (1978)[1]
Increased Heart Rate and Blood Pressure	50000-150000	1 min, NP, or 20 min	Bailey *et al* (2005)[2]; Scott *et al* (2009)[1]; OSHA (1978)1; US Department of the Interior (2006)[1]; Harper *et al* (2011)[1]
Breathlessness, Hyperventilation	75000-80000	NP	Scott *et al* (2009)[1]; US Department of the Interior (2006)[1]
Nausea	76000-100000	NP, PE	OSHA (1978)[1]; US Department of the Interior (2006)[1]
Impaired Hearing and Vision, Unconsciousness	100000-300000	1 min, 2min, NP, or 10 min	Harper *et al* (2011)[1]; US Department of the Interior (2006)[1]; Scott *et al* (2009)[1]; OSHA (1978)[1]
Convulsions, Coma	150000-300000	1 min, NP, or seconds	Harper *et al* (2011)[1]; US Department of the Interior (2006)[1]; OSHA (1978)[1]; Scott *et al* (2009)[1]
Death	170000-500000	1 min, NP, or seconds	Scott *et al* (2009)[1]; Harper *et al* (2011)[1]; US Department of the Interior (2006)[1]

[1]Review of existing standards and reported effects
[2]Results of specific experimental research

There are few studies looking at CO_2 exposure at extremely high levels, due to the obvious risk to participant's health and well-being. It is possible that dangerous levels could be reached in a confined TEMPSC with a poor ventilation system. The limited information available on the ambient environment of TEMPSC makes it necessary to use information that is available from industrial, home or research settings. The types of ventilation systems vary significantly in industrial and home settings and it cannot be known how much CO_2 is building up without collecting data from a specific location. Table 2.3 provides a good

summary of the progression of symptoms to expect starting with smaller health issues, and progressing toward coma, convulsions, and death at high CO_2 levels. It is difficult to determine an allowable threshold limit for CO_2 exposure, especially within TEMPSC as Charles *et al*. (2005) concluded that there are differences between standards and guidelines even within major air quality standards organizations including NIOSH, NOSHA, and ASHRAE

2.6 Confined spaces and CO_2

In confined spaces there is a different relationship between the amount of O_2 breathed in and the amount of CO_2 produced. With each inhalation there will be lower levels of O_2, and on expiration, greater levels of CO_2. This pattern will continue to increase levels of CO_2 as long as the number of occupants within a confined space increases, or as long as the occupants keep breathing (Baker *et al*, 2011, Scott et al, 2009). This would be the case in a TEMPSC, as there would be a large group of people in a small volume of space, which would elevate levels of CO_2 at a fast rate. Additionally, it is known that the level of toxicity from CO_2 is directly related to the amount and exposure time to this gas (Scott *et al*, 2009; Harper *et al*, 2011). Therefore, the length of time spent within an enclosed TEMPSC is an important factor to consider regarding the survival of occupants.

Because of the watertight design of the TEMPSC, accumulation of CO_2 is inevitable. Recognized first by Landolt and Monaco (1992) that poor ventilation and CO_2 accumulation could be life threatening to TEMPSC occupants over longer exposure periods. Due to the negative effects brought on by CO_2 accumulation (Baker, *et al*., 2011 & Taber *et al*., 2010) suggest that the IMO-SOLAS guidelines regarding the waterproofing

and internal air-tightness could contribute to the increased CO_2 gas concentrations. The confined space of a TEMPSC does not only increase the chances of CO_2 accumulation above allowable limits, there will also likely be an increase in the concentration of other pollutants (Baker *et al*. 2011). Any increase in other pollutants could lead to the deterioration of health and overall wellness affecting: reaction times, cognitive functioning, physical harm, and panic or anxiety in the occupants and the designated coxswain (Taber *et al*., 2010; Power & Simões Ré., 2010; Power & Simões Ré., 2013). Any deterioration in performance of the TEMPSC coxswain or occupants such as decision-making and navigation abilities could impede with successful EER operations. This could be further complicated in Arctic environments which would require longer waiting times, harsher conditions, and additional exposure to health hazards.

2.7 Occupant habitability within TEMPSC

The overall internal habitability within a TEMPSC has been a recent area of research at the NRC and Memorial University of Newfoundland (MUN). There have been several studies that specifically examined the internal environment of several designs of TEMPSC and if they have the capacity to keep occupants safe until help arrives (Power & Simões Ré., 2010; Power & Simões Ré., 2013). This is a challenging area of research because it is difficult to test LSA in realistic conditions that replicate reality. For example, it would be very difficult to measure the CO_2 production and O_2 consumption of 25 people in a confined TEMPSC in the middle of a storm with high sea states. There is significant danger associated with carrying out this type of emergency protocol when there is no real emergency. This makes it difficult to know whether or not the current LSA are adequate to withstand the harsh environments in which they will be used. However, simulation

technologies such as replicating the wave motions and recreating the internal environment of a TEMPSC can create a scenario that is a much closer representation of reality than current physical training practices that occur under rather benign conditions.

2.8 Design of the present study

The present study builds upon the limited research that is currently available on the effects of ambient CO_2 on humans within a TEMPSC. This study was primarily designed to help prove and further explore the dangers of CO_2 accumulation within a TEMPSC operating at sea. The present study supplements previous and ongoing work at NRC researching lifeboat habitability and thesis work done by Andrew Baker titled "Occupant Habitability within a Totally Enclosed Motor Propelled Survival Craft" (2011). This specific research looked at carbon dioxide, relative humidity, and temperature levels inside a 20-person TEMPSC with different occupant loading complements. The goal of Baker's work was to determine if the ambient conditions of the TEMPSC would deteriorate more quickly with the prescribed amount of people on board and the type of clothing worn by occupants (PPE versus everyday clothing). Baker *et al*, 2011 used carbon dioxide sensors placed around the interior of the TEMPSC that sounded if the CO_2 levels reached the 8-hour exposure limit of 5000ppm. The final result was that the 8-hour exposure limit was reached within 12 minutes with 15 people inside the boat. The test was stopped and the occupants were unloaded right away. With three occupants loaded into the TEMPSC it took about 60 minutes to reach the 8-hour exposure limit (Figure 2.1). The carbon dioxide levels were not measured on a breath-by-breath basis but rather as a total accumulated amount of CO_2 (ppm), therefore regression calculations were performed to predict how much CO_2 each occupant was producing. A limitation of this study and essentially the goal of the

present study is the fact that the TEMPSC was stationary and located in an interior building-loading bay. In a realistic situation, the TEMPSC would be located in a moving environment (i.e. the water). This is one of the challenges with this type of research; it is difficult to recreate an emergency scenario while ensuring safety of the participants in the trials. Baker's 2011 work produced preliminary evidence to suggest that the ventilation systems within this particular TEMPSC design are seriously lacking suitability for any prolonged time in a lifeboat. This is supported by previous literature indicating the possible complications with the current passive ventilation systems in certain lifeboats (Taber *et al*, 2011).

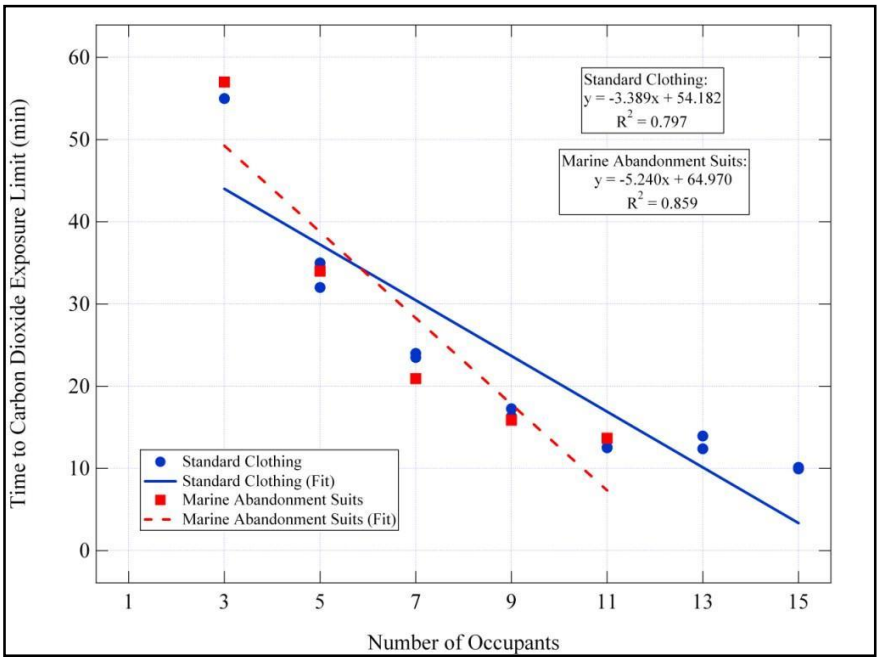

Figure 2. 1 Findings from Baker et al study (2011), which represent time to ambient CO_2 threshold relative to the number of occupants in standard clothing and marine abandonment suits

The findings of Baker et al (2011) research created a foundation for the present study, which used simulation to create the effect of a realistic ocean environment. The goal

was to validate Baker's research in calm conditions, and then determine if the movement of a rough sea (high wind and waves) would have an effect on the carbon dioxide production in occupants, and also the time to reach the 8-hour exposure limit. This research built on the small pool of existing literature that highlights the threat of CO_2 in TEMPSC.

Chapter 3 – Methodology

3.1 Participants

The study involved a sample size (*n*) of 21 healthy participants, consisting of 10 male and 11 female participants. Participants recruited for this study were between 19 and 45 years. The mean age was 23.76 years (standard deviation *SD* = 1.73), the mean stature was 1.74m (*SD* = 1.16m), and the mean mass was 77.28kg (*SD* = 15.63kg) (Table 3.1). Recruitment began on September 4th, 2013 and continued until testing began in mid-September 2013. Body fat percentage was calculated using a Tanita bioelectrical impedance scale (Figure 3.3), and the mean body fat percentage was 24.4% (*SD* = 3.15). Lean body mass (LBM) was calculated to normalize between females and males and eliminate any sex differences, as females generally tend to carry a higher body fat percentage (Wu & O'Sullivan, 2011). The mean LBM was 58.73kg (*SD* = 15.0 kg). All participants were asked to fill out a physical activity readiness questionnaire (PARQ) (Appendix F) form and a Motion Sickness Susceptibility Questionnaire (MSSQ) (Appendix D) to determine the eligibility to participate. The NRC Research Ethics Board (REB), the Memorial University Interdisciplinary Committee on Ethics in Human Research (ICEHR), and the Health Research Ethics Authority (HREA) approved the study protocol (NRC REB #2013-20). All participants gave their verbal and written informed consent prior to testing. The ethics applications, example consent form and recruitment poster are included in Appendices A, B, and C respectively.

Table 3. 1 Participant demographic data

***n* = 21**	**Age (years)**	**Stature (m)**	**Mass (kg)**	**Lean Body Mass (kg)**	**Body Fat (%)**
Mean	23.76	1.74	77.28	58.73	24.4
SD	1.73	1.16	15.63	15.0	3.15

3.2 Simulator Characteristics and Test Conditions

Testing took place at the Faculty of Engineering and Applied Science building at Memorial University (FEAS) in St. John's, Newfoundland and Labrador, Canada. The simulator that was used is a newly developed system that has advanced capabilities in relation to marine simulation. The 360 degree visual screens in the simulator were not used, only the motion platform necessary for this study. The screens were not used because the goal was to replicate the interior environment of a TEMPSC and the occupants in a TEMPSC would not be able to clearly view the external environment from their seats. Generally, sightlines would be limited to the interior of the lifeboat.

The simulator was set up as a fast rescue craft (FRC) as this was the intended use when it was originally built. As shown in Figure 3.1 there are two seats side by side: the coxswain seat and console to the right and the navigator seat and console to the left. Although this is not an exact replication of TEMPSC occupant arrangement, it is a similar seating arrangement. The participants were randomly chosen to sit in either the coxswain seat or the navigator seat. The main laboratory lights were turned off in all conditions, including baseline, mimicking the lighting levels in the interior of a

TEMPSC. The seats on the motion bed were equipped with 4-point harnesses which is similar to the restraining system in a newly fitted TEMPSC, although TEMPSC harnesses are not as padded and comfortable (Figure 3.2)..

Figure 3. 1 Participants during testing on the motion platform

Figure 3. 2 Four-point seatbelt system in simulator

The motion bed is capable of moving in six degrees of freedom and has been programmed to replicate hydrodynamic patterns collected in-situ. The angular motions (roll, pitch and yaw) and linear accelerations (surge, sway and heave) were chosen for this experiment were based on those of a 25-person TEMPSC recorded during prior TEMPSC trials at NRC. A trained coxswain reviewed all possible simulator motions and chose the motion profiles for low motion and high motion (Table 3.2) for this study.

Table 3. 2 Absolute Displacement of Motion Bed in Six Degrees of Freedom

	Roll (degrees)	Pitch (degrees)	Yaw (degrees)	Surge (cm)	Sway (cm)	Heave (cm)
Angular and Linear Displacement Range in **Low Motion**	0.10	2.43	0.01	0.49	0.45	6.19
Angular and Linear Displacement Range in **High Motion**	16.89	12.57	0.74	4.36	10.2	18.75

The goal of these motion profiles was to replicate a TEMPSC stationary (i.e. not motoring) in ice, in a lower, and a higher sea state. This represented a realistic scenario if the boat was out of fuel, stuck in ice, or waiting for a rescue vessel. Since this study used simulation, there was no real TEMPSC and the participants were not actually driving the boat, therefore it was not necessary to recruit participants who had previous experience piloting lifeboats. A no motion condition was included for baseline data collection.

3.3 Dependent Variables and Instrumentation

3.3.1 Body fat estimations and Stature Determination using tape measure for height

A Tanita BF-350 Body Composition Analyzer bioelectrical impedance scale, (Figure 3.3) was used to measure body fat percentage. To measure stature a tape measure was secured to the wall and participants were asked to stand bare foot with their heels against the wall. Participants took a deep breath, and two consecutive measurements were taken, an average of the two was recorded as stature.

Figure 3. 3 Bioelectrical Impedance Scale used for body fat percentage

3.3.2 Oxygen Consumption and Carbon Dioxide Production

Oxygen consumptions and carbon dioxide production throughout each trial were collected. Two KORR CardioCoach™ metabolic carts were used to collect the oxygen consumption and carbon dioxide production data (Figure 3.4). Long tubing was used to reach from the participant's seat to the cardio coach systems. Re-useable face masks were used and soaked in soapy water for 10 minutes after each trial. The Cardio Coach systems were re-calibrated before every condition and/or after every 25 minutes. These data were recorded on two laptops that were located behind the motion platform on the data collection desk, and each trial was saved and backed up after every data collection session.

Figure 3. 4 KORR CardioCoach™ (Korr Medical Technologies, 2015) system used to measure VCO_2, and VO_2.

3.3.3 Heart Rate

A polar heart rate monitor was used to measure heart rate during all conditions. These data were transmitted and stored on the watch, which was placed near the participant during data collection. The heart rate data were downloaded after every trial and backed up to an external hard drive.

3.3. 4 Body volume calculations

Body volume was determined as an important parameter to calculate, to understand the overall interior breakdown of CO_2 within TEMPSC. When people are in the lifeboat, the volume and quality of air will change, and body volume also varies from person to person based on height, weight, and fat content. There are several available calculations for body volume, and it is still a highly disputed area as it is argued that it is impossible to get an exact value of human body volume without using complicated methods including; specific gravity, density and hydrostatic weighing techniques (Sendroy & Collision, 1996). These techniques are quite expensive and require additional time and resources, therefore equations identified in the paragraph have been developed based on regression analysis to determine human body volume for males and females.

The method for determining Body Volume (BV) is based on another calculation of Body Surface Area (BSA) (Lee, Choi, & Kim, 2008). The equation that was chosen had smaller margins of error than some of the well-known body volume equations papers including; Du Bois and Du Bois (1916), Gehan & George's (1970), and Mosteller's (1987) formulas when applied to several datasets. The mean error of the formula was -0.1% and did not show significant differences based on gender or body shape (Lee, Choi, & Kim, 2008). The calculation for BSA is as follows ($r^2 = 0.999$):

$$BSA\ (cm^2) = 73.31\ [Height\ (cm)^{0.725} \times Weight\ (kg)^{0.425}]$$

The equations used to calculate Body Volume Index (BVI) were from Sendroy & Collision (1966), for females and males. The final body volume calculation is from Bihari *et al*. (2013) and is a product of BVI and BSA, which is represented in liters (L).

$$Female\ BVI\ (V/S) = 62.90\ (Weight/Height)^{0.578}$$

$$Male\ BVI\ (V/S) = 60.20\ (Weight/Height)^{0.562}$$

$$Body\ Volume\ (L) = BSA\ (m^2) \times BVI$$

The results of these equations are presented in Chapter 4, the results section and the mean body volumes of each occupant are used in the assessment of the CO_2 percentage within the TEMPSC. This is used to determine how much space the occupants are taking up in relation to the remaining free space in TEMSPC.

3.4 Experimental Design

Prior to data collection, participants were instructed to wear standardized clothing: cotton socks, t-shirt, jeans, and females were required to wear a sports bra. The participants were instructed to avoid caffeine for three hours before the experiment and alcohol for 24 hours before the experiment. After the participant was instrumented with the polar heart rate strap, they were required to don a Transport Canada approved insulated marine abandonment suit over their clothing (Whites Marine, Victoria, British Columbia, Canada) (Figure 3.5) which was zipped all the way, with the exception of the zipper across the chest. The suit was donned for the entire duration of the test. The hood and the gloves provided with the suits were not worn, because temperature was not a variable in this study.

Figure 3. 5 Transport Canada approved insulated marine abandonment suit

Once the participant was instrumented and had donned the marine abandonment suit, they entered the motion bed platform using a small ladder. The participant was randomly assigned to sit in either the coxswain or navigator seat. There was no difference in either seat, except for the console design in front of the participant. Before any motion occurred from the simulator, the participant was told about the emergency stop button that was located on each console of the simulator. This button would automatically shut down the simulator during motion conditions if the participants felt motion sickness or uneasy at any point. There was also an emergency stop button located at the instructor station. Fortunately, the emergency stop procedure was never

implemented during this study. The participant was also told to limit body movement as much as possible and to avoid talking to the researcher or other participants.

This was a one way repeated measures study design (ANOVA) in which all participants were measured in each condition: baseline, low motion and high motion. The dependent variables in this study are the volume of carbon dioxide produced ($\dot{V}CO_2$), the amount of oxygen consumed ($\dot{V}O_2$), and heart rate, which was measured in beats per minute. The dependent measures $\dot{V}O_2$ and $\dot{V}CO_2$ were normalized to lean body mass for comparison between individuals. The motion conditions were as follows:

1. No motion at all, this was the baseline condition.
2. A low motion profile that replicated the motions of a TEMPSC that would be idle in the open ocean. This condition had pronounced heave, pitch, and roll motions (similar to a ship riding in the waves)
3. A high motion profile that replicated the motions of a TEMPSC that would be idle in a field of pack ice. This condition had reduced have, pitch and roll motions due to the dampening wave action, but shuddered and jolted to replicate a TEMPSC hitting ice.

The first measure in each participant trial was the baseline, which was collected on the motion bed in the exact seat that the rest of the trials were conducted. The baseline was 10-15 minutes long and ended when the participants reached steady state as indicated by their $\dot{V}O_2$ and $\dot{V}CO_2$ measurements. The order of the low motion and high motion conditions were randomly selected for each participant, to avoid any possible order effects. Ten participants were tested first in the low motion condition, and 11

participants were tested in the high motion condition first. Each motion condition lasted 20-25 minutes with the last, or first fine (5) minutes used for extra data to account for any delay in start-up time of the simulator at the beginning of the trial. Only 20 minutes of data from each participant was used in the data analyses. A 10-minute break was given in between each condition. Each participant was required to be in the experimental lab for 2 - 2.5 hours and the breakdown of the experiment is represented in Table 3.3.

Table 3. 3 Experiment breakdown over 2.5 hours

Time breakdown	Task Breakdown
1 hour	Introduction to experiment, signing of consent forms and questionnaires, anthropometric data collection, and donning of the immersion suit and instrumentation equipment.
10-15 minutes	Baseline measurement using the cardio coach and the polar heart rate monitor
20-25 minutes	Condition 1 (Randomized between high motion and low motion conditions)
10 minutes	Break for participants to rest
20-25 minutes	Condition 2 (Randomized between high motion and low motion conditions)
15 minutes	Exit motion bed and de-instrument the participant

3.5 Data Organization and Analysis

Upon completion of each day of testing the data was backed-up and uploaded to the NRC-OCRE computer system. Each day after securing the data, it was organized by participant number, motion condition and the date. The raw data was then normalized

to the lean body mass of each participant. All statistical and graphical analyses were done using Microsoft Excel and the PASW Statistics 18 Software package.

Data from three (3) participants out of the total group of 21 participants were eliminated based on unusual $\dot{V}O_2$ and $\dot{V}CO_2$ data recordings, likely due to instrumentation error. Therefore the final number of subjects in the data analysis is 18 for $\dot{V}O_2$ and $\dot{V}CO_2$. Additionally, there was a malfunction with the polar heart rate monitors when two subjects were tested at once. Although the polar heart rate monitors are not supposed to affect each other in close proximity, there was a sudden and inexplicable increase in one of the participant's heart rate data when two participants were tested at once. Overall data from six (6) people were eliminated from the heart rate analysis.

Chapter 4 – Results

Previous work has suggested that levels of ambient carbon dioxide (CO_2) within a confined space, such as a TEMPSC could impact occupant health and safety (Baker *et al*., 2011; Taber et al., 2011; Power & Simões Ré, 2013; Power-MacDonald et al., 2010). The present study suggests that simulated TEMPSC motions have an influence on occupant CO_2 production.

The metrics analyzed for each experimental condition were: carbon dioxide produced, oxygen consumed, and heart rate. The participants were not negatively affected by the high levels of CO_2 produced during any of the testing conditions, as this research was not conducted in an enclosed space. All volume equations and calculations for the TEMPSC and participants used to model the expected rates of accumulation of expired CO_2 are provided in Appendix D.

4.1 Motion Effects on CO_2

Results show that there was a significant motion condition effect on CO_2 produced ($F_{(1.30, 22.08)} = 32.42$, $p < .001$). The ANOVA revealed that in terms of the volume of carbon dioxide produced; the low motion condition had the lowest amount (3.12 +/- 0.44 $ml.kg^{-1}.min^{-1}$), followed by the baseline (no motion condition) (3.16 +/- 0.43 $ml.kg^{-1}.min^{-1}$), and the participants produced the most CO_2 during the high motion condition (3.56 +/- 0.44 $ml.kg^{-1}.min^{-1}$).

4.1.1 CO_2 Pre and Post Hoc Analyses

Tests for normality were performed. $\dot{V}CO_2$ produced was not skewed or kurtosed in any of the conditions: baseline ($z_{skewness} = -0.44$) ($z_{kurtosis} = 0.158$); low motion ($z_{skewness}$

= 0.619) ($z_{kurtosis}$ = 1.845) or high motion ($z_{skewness}$ = 0.782) ($z_{kurtosis}$ = 1.087). The $\dot{V}O_2$ data were normally distributed according to the Kolmogorov-Smirnov normality test in baseline ($D_{(18)}$ = .152, p < .200), low motion ($D_{(18)}$ = .191, p < .200), and high motion ($D_{(18)}$ = .137, p < .200). There were no outliers in $\dot{V}CO_2$ in any of the experimental conditions. Mauchly's test indicated that the assumption of sphericity had been violated for $\dot{V}CO_2$ ($X^2_{(2)}$ = 12.43. p < .05), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .65). Bonferroni adjusted post hoc tests were used since sphericity was violated in the $\dot{V}CO_2$ measure (Field, 2009): comparisons revealed that participants produced significantly more CO_2 in the high motion condition (3.56 +/- 0.44 ml.kg^{-1}.min^{-1}) compared to the baseline condition (p < .001), and low motion condition (p < .001), and no significant difference between the baseline and no motion conditions.

4.2 Motion Effects on $\dot{V}O_2$

Results show that there was a significant motion condition effect on O_2 produced ($F_{(1.62, 27.48)}$ = 27.83, p < .001). In terms of the volume of oxygen consumed, the low motion condition had the lowest amount (3.13 +/- 0.48 ml.kg^{-1}.min), followed by the baseline (no motion condition) (3.18 +/- 0.52 ml.kg^{-1}.min^{-1}), and the participants consumed the most oxygen during the high motion condition (3.58 +/- 0.45 ml.kg^{-1}.min^{-1}).

4.2.2 O_2 Pre and Post hoc Analyses

Tests for normality were performed. $\dot{V}O_2$ consumed was not skewed or kurtosed in any of the conditions: baseline ($z_{skewness}$ = -0.215) ($z_{kurtosis}$ = 1.077); low motion ($z_{skewness}$ = 0.599) ($z_{kurtosis}$ = 0.034) or high motion ($z_{skewness}$ = 0.004) ($z_{kurtosis}$ = -0.628). The $\dot{V}O_2$ data were normally distributed according to the Kolmogorov-Smirnov normality test in baseline

($D_{(18)} = .109$, $p < .200$), low motion ($D_{(18)} = .080$, $p < .200$), and high motion ($D_{(18)} = .105$, $p < .200$). There were no outliers in $\dot{V}O_2$ in any of the experimental conditions. Further statistical testing included Mauchly's test of sphericity, which indicated that the assumption of sphericity has not been violated for $\dot{V}O_2$ ($X^2_{(2)} = 4.33$. $p > .05$). Bonferroni adjusted post hoc tests were are used for $\dot{V}O_2$ to guarantee control over the Type 1 error rate (Field, 2009). Comparisons revealed that the high motion condition (3.58 +/- 0.45 $ml.kg^{-1}.min^{-1}$) caused participants to significantly consume more oxygen than in the baseline ($p < .001$) and low motion ($p < .001$) conditions. However, there was no significant difference between the baseline and low motion conditions.

4.3 Motion Effects on Heart Rate

Results show that there was a significant motion condition effect on heart rate ($F_{(1.91, 20.95)} = 9.49$, $p < .01$). However, the heart rate data showed a different trend than $\dot{V}O_2$ and $\dot{V}CO_2$. The baseline condition had the lowest average beats per minute (76.45 +/- 10.07 $beats.min^{-1}$), followed by the low motion condition (80.36 +/- 9.86 $beats.min^{-1}$), and the participants had the highest heart rate average during the high motion condition (81.90 +/ - 6.83 $beats.min^{-1}$).

4.3.1 Heart Rate Pre and Post Hoc Analyses

Tests for normality were performed. Heart rate was not skewed or kurtosed in the baseline condition ($z_{skewness} = -0.753$) ($z_{kurtosis} = -0.135$); or the low motion condition ($z_{skewness} = -1.70$) ($z_{kurtosis} = 1.060$). However the high motion condition was both skewed ($z_{skewness} = -2.73$) and kurtosed ($z_{kurtosis} = 2.20$). The heart rate data were normally distributed according to the Kolmogorov-Smirnov normality test in baseline ($D_{(15)} = .161$, $p < .200$), and low motion ($D_{(15)} = .144$, $p < .200$). However the high motion ($D_{(15)} = .252$,

p > .200) was not normally distributed. There were outliers in heart rate data in the experimental conditions. Further statistical testing included Mauchly's test of sphericity, which indicated that the assumption of sphericity has not been violated for heart rate ($X^2_{(2)}$ = 1.262. p > .05). Bonferroni adjusted post hoc tests were used for heart rate to guarantee control over the Type 1 error rate (Field, 2009). Comparisons for heart rate data revealed that the high motion condition (M = 81.9, SD = 6.83) was significantly higher than the baseline condition (76.45 +/- 10.07 beats.min^{-1}) (p = .015), and the differences were not significant between the low motion and baseline conditions.

Heart rate data were collected for every participant; however halfway through the trials it was evident that in the trials that involved collection of two participants at the same time, the heart rate values seemed unrealistic for one of the two participants. This was likely due to crosstalk between the telemetered heart rate collection devices. Therefore, the heart rate data for six participants during the trials was excluded from further analysis.

These results of all the descriptive statistical tests are summarized in Table 4.1, and post hoc test results are provided in Table 4.2. In summary the results indicate that the high motion condition produced the most physiological changes in participants in comparison to the baseline and low motion conditions.

Table 4. 1 Descriptive Statistics for $\dot{V}O_2$, $\dot{V}CO_2$, and heart rate in baseline, low motion and high motion conditions

		Mean	Standard Deviation	Standard Error	Z_{skew}	Z_{kurt}	K-S[a] Test *D* (df)
$\dot{V}O_2$ ($ml.kg^{-1}.min^{-1}$)	B [b]	3.18	0.517	0.122	-0.215	1.077	$.109_{(18)}$
	L [b]	3.13	0.480	0.113	0.599	0.034	$.080_{(18)}$
	H [b]	3.58	0.450	0.118	0.004	-0.628	$.105_{(18)}$
$\dot{V}CO_2$ ($ml.kg^{-1}.min^{-1}$)	B [b]	3.16	0.434	0.102	-0.44	0.158	$.152_{(18)}$
	L [b]	3.12	0.438	0.103	0.619	1.845	$.191_{(18)}$
	H [b]	3.56	0.436	0.103	0.782	1.087	$.137_{(18)}$
HR ($beats.min^{-1}$)	B [b]	76.45	10.07	2.60	-0.753	-0.135	$.161_{(15)}$
	L [b]	80.36	9.86	2.55	-1.70	1.060	$.144_{(15)}$
	H [b]	81.9	6.83	1.76	-2.73	2.20	$.252_{(15)}$

[a] Kolmogorov-Smirnov normality test

[b] B = baseline, L = low motion, H = high motion

Post hoc testing Summary Table

Table 4. 2 Results of paired post hoc comparisons

Condition	Condition	Significance level
$\dot{V}O_2$ baseline	$\dot{V}$**O₂** low motion	1.0
$\dot{V}O_2$ baseline	**$\dot{V}O_2$ high motion**	**< .001***
$\dot{V}O_2$ low motion	**$\dot{V}O_2$ high motion**	**< .001***
$\dot{V}CO_2$ baseline	$\dot{V}$**CO₂** low motion	1.0
$\dot{V}CO_2$ baseline	**$\dot{V}CO_2$ high motion**	**< .001***
$\dot{V}CO_2$ low motion	**$\dot{V}CO_2$ high motion**	**< .001***
HR baseline	HR low motion	.066
HR baseline	**HR high motion**	**< .015***
HR low motion	HR high motion	.714

*= Significant value

4.4 Predictive CO_2 Data

Additional data analysis was performed to expand on work by Baker *et al.* (2011). Baker *et al.* (2011) measured the time for CO_2 to accumulate to harmful levels in an enclosed TEMPSC system as a function of occupancy. From these data he used a linear regression approach to predict CO_2 to accumulation based on average body mass, PPE clothing ensemble, and number of occupants in TEMPSC. CO_2 was collected indirectly, via sensors located throughout the modified TEMPSC.

The current study examined whether motion perturbations upon an occupant, typical of a TEMPSC afloat, would increase the energy costs and thus CO_2 output. If there

were motion effects, then the Baker *et al.* (2011) predictions would likely be underestimations of the time to noxious cabin CO_2 level accumulation.

This study collected the oxygen consumption and the carbon dioxide production under three motion states (no motion, low motion and high motion). Metabolic energetics were expressed as relative values, minimizing the effects of morphology on the proposed comparisons with Baker *et al.* (2011). Appendix D describes how individual data could be extrapolated to reflect interior cabin values of CO_2 production.

Table 4.3 provides an overview of the variables that were used in the prediction equations and the standard mean values for CO_2 accumulation.

Table 4. 3 Variables and values included in prediction equations based on 15- person occupancy

Variable	Mean constant values
Number of occupants	15
Mean mass of occupants (kg)	77.28
Mean $\dot{V}CO_2$ of occupants ($ml.kg\text{-}^{1}.min^{-1}$)	Base:3.16 Low:3.10 High:3.56
Mean $\dot{V}O_2$ of occupants ($ml.\ kg\text{-}^{1}.min^{-1}$)	Base: 3.18 Low: 3.13 High: 3.58
Mean stature of occupants (m)	1.74
Volume of lifeboat empty (m^3)	14
Surface Area (SA) of mean occupant (cm^2):	21094.6
Body Volume Index (BVI) of mean occupant (V/S):	42.078
Volume of mean occupant (L):	88.76
Volume of mean occupant (m^3):	0.089
Volume of free space in lifeboat with people (m^3):	12.67
All occupants $\dot{V}CO_2$ Production ($ml.min^{-1}$):	4278
Total Volume of lifeboat with people (L)	12668.57

For comparison purposes, the values in Table 4.3 are used to calculate the expected values for 15 occupants, as this was one of the occupancy loads trialed and reported by Baker *et al.* (2011). However, the estimations to predict the CO_2 accumulation can be done for any complement of people up to the limit that can fit in this particular TEMPSC (25 person limit) with the exact same data. These predictive equations may also be applied to other TEMPSC by adjusting the values for the TEMPSC volume. Additionally, it is possible to input any mean mass (kg) or stature (m) into the equation to determine approximately how quickly CO_2 would accumulate within this particular lifeboat design.

4.5 Predictive $\dot{V}CO_2$ Results

Direct comparison with Baker *et al.* (2011) should be done with caution, given that methodology to predict time to noxious levels was different from the one used in this study. However, it is important to look at the CO_2 production as a total value based on the number of occupants within the TEMPSC and duration of exposure. Baker *et al.* (2011) did not measure the O_2 intake and CO_2 production of each participant individually. Ambient measurements (i.e. the cumulative effect) were recorded at described locations within the TEMPSC interior. These data were used to calculate values such as CO_2 ($ppm.min^{-1}$) and ($ppm.min^{-1}.kg^{-1}$).

Table 4.4 provides the results for the present study predicting the mean and relative rates of CO_2 production for various motion and occupant number states.

Table 4. 4 Predictions of the relative rate of $\dot{V}CO_2$

Number of Occupants	Condition	Mean Rate of CO_2 production ($ppm.min^{-1}$) Present Study	Total Group Mass (kg)*	Relative Rate of CO_2 production ($ppm.kg^{-1}.min^{-1}$)
1	Baseline	17.5	77.3	0.22
3		53.2	231.9	0.23
5		89.6	386.5	0.23
7		126.9	541.1	0.23
9		164.9	695.7	0.24
11		203.9	850.3	0.24
13		243.7	1004.9	0.24
15		284.5	1159.5	0.25
1	Low Motion	17.2	77.3	0.22
3		51.2	231.9	0.23
5		87.9	386.5	0.23
7		124.5	541.1	0.23
9		161.8	695.7	0.23
11		200.0	850.3	0.23
13		239.1	1004.9	0.24
15		279.1	1159.5	0.24
1	High Motion	19.8	77.3	**0.26**
3		60.0	231.9	**0.26**
5		101.0	386.5	**0.26**
7		142.9	541.1	**0.26**
9		185.8	695.7	**0.27**
11		229.7	850.3	**0.27**
13		274.6	1004.9	**0.27**
15		320.5	1159.5	**0.28**
		Relative Rate Average:		0.27

*Note: Occupant mean mass of 77.3kg and stature of 1.74m were used in all calculations

Results reported in Table 4.4 were used to estimate the time histories to reach a critical CO_2 accumulation within the TEMPSC. Similar to Baker *et al.* (2011) results, Table 4.5, and Figure 4.1 shows that with 15 people in the TEMPSC, the 4800ppm 8-hour

threshold is reached in fifteen minutes in the high motion condition, and seventeen minutes in the low motion and baseline conditions.

Table 4.5 Results of CO_2 production using the prediction equations, based on the lifeboat volume and a 15-person occupancy

Time (minutes)	Total CO_2 production (Baseline) ppm	Total CO_2 production (Low Motion) ppm	Total CO_2 production (High Motion) ppm
1	284.5	280.9	320.5
2	589.0	561.8	641.0
3	853.5	842.7	961.5
4	1138.0	1123.6	1282.1
5	1422.5	1404.5	1602.6
6	1707.0	1685.4	1923.1
7	1991.5	1966.3	2243.6
8	2276.0	2247.2	2564.1
9	2560.5	2528.1	2884.6
10	2845.0	2808.9	3205.1
11	3129.5	3089.9	3525.6
12	3414.0	3370.8	3846.2
13	3698.5	3651.7	4166.7
14	3983.0	3932.6	4487.2
15	4267.5	4213.5	4807.0
16	4552.0	4494.4	5128.2
17	4836.5	4775.3	5448.7
18	5121.0	5056.2	5769.2
19	5405.5	5337.1	6089.8
20	5690.0	5617.9	6410.3

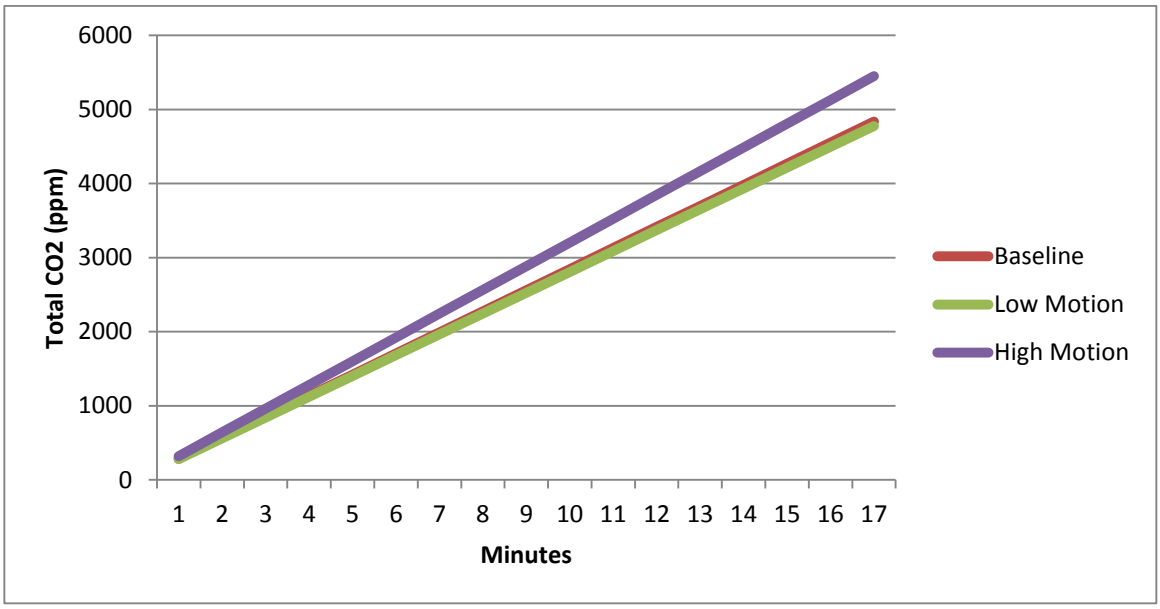

Figure 4. 1 Time to reach the 4800ppm 8-hour threshold in each testing condition (baseline, low motion, and high motion)

The baseline (no motion) condition shows an increase in CO_2 at a rate of 284.5 ppm.min^{-1}, the low motion condition is increasing at 280.9 ppm.min^{-1}, and the high motion condition is increasing at 320.5 ppm.min^{-1} (Figure 4.2). Based on these values it is possible to calculate the relative rate of CO_2 production based on any group mass from any database.

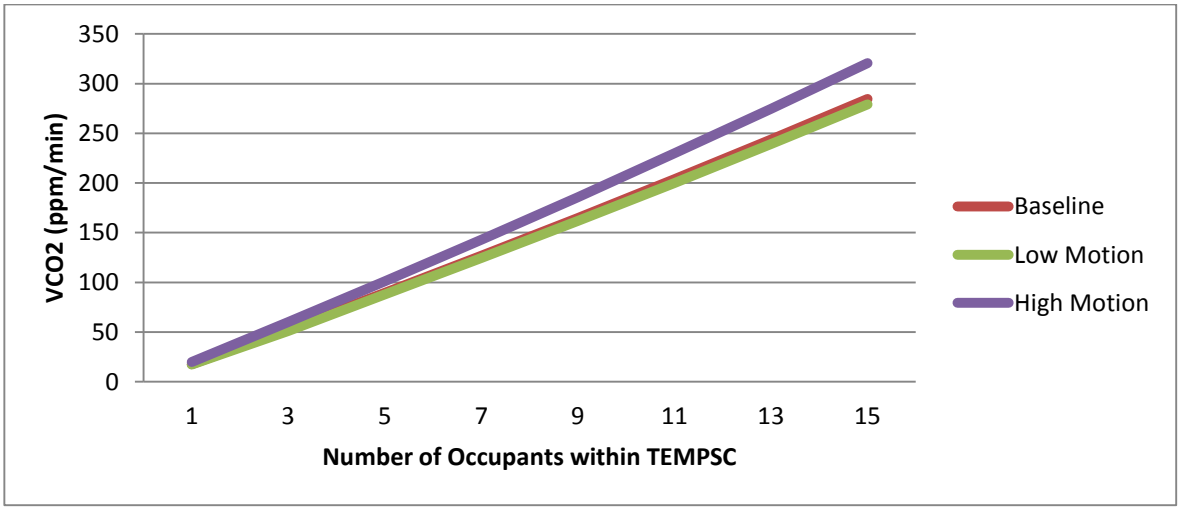

Figure 4. 2 Rate of Carbon dioxide accumulation (ppm.min-1) over time as the total mass/ number of occupant's increases.

Larger individuals tend to produce more CO_2 than smaller ones (Foss & Keteyian, 1998) and since almost all body tissues consume oxygen, a person with a larger total body mass will be much more likely to consume more oxygen than a person with a lower total body mass, and therefore produce more CO_2 (Baker *et al.,* 2011). Thus, the mean mass of the occupant complements (i.e. anthropometric variability) is an important factor to consider when determining how long it will take ambient CO_2 to accumulate in an enclosed space. When normalized by body mass, it becomes apparent that the relative rates of CO_2 production were similar regardless of complement size or motion condition (Table 4.6). The rate of CO_2 accumulation within the TEMPSC using the largest group of participants in the study in relation to body mass (1272.5kg for 15 occupants) is shown in Table 4.6.

Table 4. 6 Results of constant variables used to calculate the relative rate of CO_2 - production for largest group of participants in present study

Number of Occupants	Condition	Mean Rate (ppm.min-^{1}) Present Study	Total Group Mass (kg)	Relative Rate (ppm.kg-^{1}.min-^{1})
1	Baseline	24.4	107.2	0.23
3		69.9	303.3	0.23
5		113.6	486.7	0.24
7		156.0	660.1	0.24
9		197.3	825.5	0.24
11		238.2	985.3	0.24
13		277.3	1135.1	0.24
15		314.0	1272.5	0.25
1	Low Motion	23.9	107.2	0.23
3		68.6	303.3	0.23
5		111.5	486.7	0.23
7		153.0	660.1	0.24
9		193.6	825.5	0.24
11		233.6	985.3	0.24
13		272.1	1135.1	0.24
15		308.0	1272.5	0.24
1	High Motion	27.5	107.2	0.26
3		78.8	303.3	0.26
5		128.0	486.7	0.26
7		175.7	660.1	0.26
9		222.3	825.5	0.27
11		268.3	985.3	0.27
13		312.4	1135.1	0.28
15		353.7	1272.5	0.28

*The stature used to calculate this data is the average stature of the largest group of occupants (1.802m).

Even the largest group of participants in the present study did not meet the mean mass proposed by IMO (1974, as amended) & Kozey *et al.* (2009). However, participants in the IMO & Kozey research were offshore oil workers and likely to be more obese than the volunteer student population used in the present study.

4.6 Predictive CO_2 exposure values for various populations

It is possible to predict time to 8-hour exposure limits, and short-term exposure limits based on relative rate of CO_2 production using international standards based on mean mass assumptions. The results of the predictive equations based on 20-person occupancy and the relative rates of CO_2 are presented in Table 4.7.

Table 4. 7 Predicted times to the adjusted 8-hour (4800ppm) and short-term (30000ppm) CO_2 exposure limits based on 20-person occupancy.

Source	Total Mass (kg)	Rate Per Occupant ($ppm.kg^{-1}.min^{-1}$)	Overall Rate ($ppm.min^{-1}$)[1]	Time to 8-Hour Limit (min:sec)[2]	Time to Short-Term Limit (min:sec)[3]
Current Study (High Motion)	1570.6	0.28	439.8	10:09	68:21
Baker *et al*, (2011)	1524	0.355	541.0	9:14	55:27
Kozey *et al*, (2009)	1764	0.355	626.2	7:59	47:55
IMO (1974, as amended)	1650	0.355	585.8	8:32	51:13

[1]Overall Rate ($ppm.min^{-1}$) = Total Mass (kg) • Rate Per Occupant ($ppm.kg.^{-1}min^{-1}$)
[2]Time to 8-Hour Limit (min) = 4800ppm / Overall Rate ($ppm.min^{-1}$)
[3]Time to Short-Term Limit (min) = 30000ppm / Overall Rate ($ppm.min^{-1}$)

Another option is to input the various group masses: current study (77.3kg), Baker et al, (2011) study (76.2 kg), Kozey's study (2009) (88.2kg), and IMO (1974, as amended) (82.5kg) into the predictive equation for high motion and determine the time to threshold based on these equations for a group of 20 people.

Chapter 5 – Discussion

The findings of this study are critical to the health and safety of persons onboard a TEMPSC during EER events. The fact that vessels are venturing into more challenging and remote operating environments means there should be an update to LSA safety standards, which reflect these working conditions. An example of the general guidelines applied to environmental hazards encountered by vessels includes the IMO Guidelines for Ships Operating in Polar waters which vaguely states that a TEMPSC must "provide adequate shelter from the anticipated operating environment" (2010, Section 11.5.1). These current standards are not fit-for-purpose, lack specificity and do not provide adequate regulatory guidance for interior habitability of a TEMPSC.

Additionally, the chances of a TEMPSC ending up in a scenario that it cannot open the hatches, but still must have the motor running may not be very likely. However, TEMPSC are only required to carry enough diesel fuel for 24 hours of operation at a speed of six knots (IMO, 2010, Chapter 4, Code 4.4.6.8), and, recent research has shown that rescue times may vary from hours to days (Kennedy, Gallagher, & Aylward, 2012). Although this situation is unlikely, this amount of fuel would likely not be adequate for a TEMPSC stranded in any sort of northern location and would therefore leave the craft and those onboard stranded without a running engine to draw in fresh air from the surrounding external environment.

The findings of this study looked specifically at CO_2 accumulation, which is only one aspect of interior habitability. CO_2 in large concentrations and confined spaces can be

a dangerous gas and may impact occupant well-being or even survival time for occupants in less than 20 minutes.

5.1 Increase Vessel Motion Will Increase CO_2 Production

The primary finding of this study was that the high motion condition caused the most physiological changes in participants for CO_2 production, O_2 consumption and heart rate (Chapter 4 - Sections 4.1 - 4.3). The high motion condition caused participants to produce more CO_2, than during the low motion condition ($p < .001$) or the baseline condition ($p < .001$). This trend was similar for the O_2 consumption. This was to be expected because although the participants were fully strapped in during each trial, they still demonstrated some physical movements to stabilize themselves against the motions of the motion bed. The participants were constantly expending energy through a muscular effort to try and stabilize themselves within the seats. In a realistic EER scenario the occupants would be anxious and there would be much more physical exertion causing the O_2 consumed and CO_2 produced to be even greater, as motion intensity in open seas may be greater than in this test series. This would lead to a greater rate of CO_2 accumulation in the internal environment of the TEMPSC. However, the low motion trial results are surprising as they caused less energy expenditure than the baseline (no motion) condition. This could be explained by the fact that the low motion condition may not have been significant enough to require participants to stabilize themselves, which would require more energy expenditure. Furthermore, the baseline trial was always collected first, and the participant may have been demonstrating some effects due to anxiety of beginning the test protocol, which would increase energy expenditure.

Although the high motion condition had a significant influence on CO_2 production, when entered into the predictive VCO_2 equations (Chapter 4 - Section 4.4) there was not a practical difference in the time to the 8-hour exposure limit value (4800ppm) compared to Baker's *et al.* (2011) work in a stationary environment. Even though there is a need to shift toward fit-for-purpose testing, in this case the final CO_2 accumulation values did not change enough to warrant a totally different testing protocol than the original stationary lifeboat methodology. Additionally, through a combination of data from the Baker *et al.* (2011) study and the present study it would be possible to extrapolate air quality results for virtually any size lifeboat (e.g. 50 person lifeboat).

5.2 Validation of CO_2 exposure time values

One important finding of this study is that it supports results found by Baker *et al.* (2011) in relation to CO_2 accumulation within TEMPSC. Although the data collection methodology was different, the results were similar and supported the fact that ambient CO_2 within TEMPSC is a serious safety concern for occupants. This is important information as there is limited work done on CO_2 accumulation within TEMPSC and replicating this work is critical to be able to ensure consistent results. Baker *et al.* (2011) found that with a complement of 15 occupants and group mass of (1143kg) within a TEMPSC, the 4800ppm threshold value was reached within 15 minutes. The present study found that using the same group mass but predictive equations based on the breath-by breath method and complement of 15 occupants the 4800ppm threshold was met after 18 minutes in no motion, 18 minutes in low motion, and 16 minutes in high motion.

These results, which have now been shown in two independent studies, provide a specific time frame that occupants have within a TEMPSC before they would experience

the initial negative health effects of carbon dioxide overexposure including; physiological and neurological symptoms ranging from headache and rapid breathing, to unconsciousness and death (United States Department of the Interior, 2006; OSHA, 1978). This creates a dangerous internal TEMPSC environment, which can be hazardous to human health (Power & Simões Ré, 2010; Taber *et al*. 2010). Organizations responsible for legislation and standardization of LSA rules should have this information available when updating existing TEMPSC designs. Knowing a specific number of minutes (i.e. 15 minutes) before occupants would start to feel the effects of CO_2 should prove helpful in the development of an alternative ventilation system design. This could include a certain number of fresh air exchanges every 10 minutes, or some specific criteria to allow proper airflow throughout the craft.

5.3 Predictive testing equations

A benefit of the present study was the development of predictive equations that can be used to determine the amount of ambient CO_2 within a 25-person (modified) lifeboat. These equations and all the formulas used in this study can be adapted to other TEMPSC sizes (more specifically their internal free-space volumes), and other group means of stature and mass (Appendix E). This is a valuable tool for SAR coordinators or joint rescue centers, as it allows the user to have a rough estimate of safe exposure time within a TEMPSC, which may aid in planning rescue missions.

CO_2 accumulation varies greatly based on total mass of occupants within the TEMPSC. This is an important finding in this study, as the time to ppm threshold was within minutes of Baker *et al*., 2011 findings even though the participants in this study were exposed to wave motions in two of the conditions.

This is relevant to the results of the predictive equations, as the final ppm value, as calculated, is linearly related to the mean occupant mass. A group of heavier individuals will reach the threshold for CO_2 faster than a group of lighter individuals. Thus, the universal trend of increasing obesity becomes an issue (Gregg, *et al*., 2004). The participants in the current study were a young, relatively fit (based on the PAR-Q & You Questionnaire) group of university students and therefore the average mass was less than what would be expected of the general population. The anthropometric data collected from Kozey *et al*. (2009) of the offshore population and also the International Maritime Organization (IMO, 2010) standard for human body mass support this notion. The values reported for average human body mass are 88.2kg and 82.5kg respectively. This demonstrates an excellent use for the predictive equation, as it is possible to predict CO_2 based on these average mass values for a more likely group of people to be in an emergency TEMPSC scenario (Table 4.7).

The present data were a direct measurement using a breath-by-breath system, and can be converted to $ppm.min^{-1}$ to understand the ambient CO_2 levels in units that can be compared to other studies. This information is critical to the maritime industry, specifically manufacturers and maritime safety regulators as it demonstrates quantitative evidence that the current TEMPSC ventilation systems in this type of lifeboat design do not allow adequate airflow. Additionally, occupants will experience symptoms including; nausea, increased heart rate, confusion, and an overall progressive degradation in health within anywhere between 15-20 minutes. It's also important to keep in mind that the equations developed for the TEMPSC modeled in this study was originally rated for 20 occupants.

Inputting a 20-person complement and a high motion sea state into the predictive equations, the time to the 4800ppm threshold is only 11 minutes. Therefore we see an increase in the rate of accumulation and a decrease in the time required to exceed safety thresholds.

5.4 Impact of the Results

The results of this study support existing research regarding CO_2 accumulation within TEMPSC. Due to the measurement technologies used in this study, the predictive equations are likely more accurate than those reported by Baker *et al.* (2011). Fit-for-purpose testing is still important to be able to account for the physiological changes that occur in humans when they are in a scenario that closely replicates reality (i.e. testing in higher sea states as opposed to stationary conditions). For example in this study the high motion condition caused increased heart rate, increased oxygen consumption, and increased CO_2 production. However, the reality of testing in an environment more similar to a real emergency is unlikely, as it could pose health threats to the participants. There is such little information available on this topic that any knowledge reinforcing the dangers associated with internal environment of TEMPSC is important.

5. 5 Limitations

This study has several limitations because of the fact that performing this type of study in a realistic environment could potentially cause harm to participants. The following limitations have been identified.

1.) The ability to exactly replicate wave motions for “high” and “low” sea states through simulation is challenging due to the physical limitations of commercially available motion beds. However, an experienced coxswain (30 years of experience) did confirm that the sea sates used in this study were a close replication of those

previously experienced. Therefore a limitation would be that this study used simulation and not real wave motions. Future research will benefit from improved hydrodynamic models incorporated into available simulators.

2.) In a more realistic scenario the occupants of TEMPSC could be experiencing a great deal of fear, perhaps hyperventilation, increased heart rate, increased perspiration, anxiety, and other excitatory physiological and psychological changes associated with experiencing an emergency. This would theoretically increase the amount of expired CO_2 and therefore decrease the time to reach the CO_2 exposure limits. Therefore, occupants would most likely experience the negative health effects of CO_2 exposure earlier than the reported values in this paper in a real emergency scenario.

3.) The sample population examined in this study was a relatively fit group of university students according to the PAR-Q & YOU pre-study questionnaire, who participate in regular physical activity. This sample may not be representative of the offshore population or end user of a TEMPSC. It's important to consider other group means for mass and stature as well as that of the current study to interpret the results.

4.) This TEMPSC calculations and assumptions for CO_2 accumulation in the present study are based on one particular model of lifeboat. There are many different designs of lifeboats that may not yield the same results. Other models and designs of lifeboats should have been explored in the design of this study. Further testing should be completed in the future looking at alternative designs.

5.) There was no actual lifeboat used in this study, as the motion platform was not enclosed. This may have impacted the assumptions in the calculations that the TEMPSC is completed airtight.

Chapter 6 - Conclusion and Recommendations

6.1 Conclusion

The human factor is an extremely important aspect in the design of a system and is often overlooked. In this study, the design of TEMPSCs was questioned in relation to its ventilation systems. The purpose of a TEMPSC is to provide a temporary refuge for people in an emergency scenario at sea to be able to survive until rescue services arrive. Within the past few years, EER research has identified that the internal habitability of a TEMPSC may be compromised by ambient environmental issues including; temperature, humidity, and CO_2 accumulation (Baker *et al.*, 2011; Baker *et al.*, 2011a; Power & Simões Ré, 2010; Power & Simões Ré, 2013; Taber *et al*, 2011) This is relevant, as rescue times appear to be getting longer as operators push vessels further north to more remote locations (Kennedy, Gallagher, & Aylward, 2012). Although there are many aspects of TEMPSC design that should be addressed, this study looked specifically at the production of CO_2, the consumption of O_2, and heart rate during various sea states within a TEMPSC.

This work has supported existing research that shows that CO_2 levels accumulate to international standard threshold limits of 4800ppm within 15-18 minutes with a complement of 15 people (Baker *et al.*, 2011). The passive ventilation systems currently in place in typical TEMPSCs are not adequate to circulate air to the occupants during situations in which the craft may be stationary with the motor still running. This study showed that a TEMPSC in motion conditions (i.e. higher sea states) would reduce the time to the 4800ppm threshold compared to calm or lower sea states as the participants expend more energy trying to stabilize themselves in their seats during motion. Additionally, it is

evident that the number and overall mass of the occupants is a significant factor in determining the time to reach the CO_2 threshold after the internal compressed air system has been depleted. The predictive equations developed in this study may be used to estimate this time to reach threshold based on any group mass, or number of people.

As for a solution to ambient CO_2 accumulation, the ability to simply open the hatches and circulate fresh air from the external environment is not always an option depending on the environment in which the craft is operating. If there is any type of debris, large waves, smoke, fire, or any type of airborne pollutant in the immediate surroundings of the TEMPSC, this will impact the internal integrity of the boat compromising the safety of the occupants. Therefore, it is recommended to adapt an alternative design (i.e. active ventilation system) for TEMPSC that would allow an exchange of fresh air at regular intervals. This alternative design of ventilation systems would be a step in the right direction in the overall improvement of TEMPSC design with a goal of occupant safety and survivability.

Any type of EER event is physiologically and psychologically straining for the people involved at a time in which they are expected to be able to perform critical tasks that will impact safety of not only themselves but also fellow crew members. Improving the ventilation systems in existing and future TEMPSC is important for the survival of occupants until rescue services arrive. The information from this study should be available to owners, manufacturers, standards boards and safety organizations to promote a change in ventilation designs to allow for adequate airflow into the interior of the TEMPSC.

6.2 Recommendations

Based on the results of the current study, it is recommended that:

1) Alternative ventilation systems (for example active ventilation systems) should be implemented onboard future models of TEMPSC. International maritime regulatory bodies including the IMO-SOLAS must recognize its necessity and mandate its inclusion in TEMPSC in order for this change to take place.
2) Further research should be done to investigate the accumulation of environmental variables during TEMPSC operation in realistic testing situations such as open-water and ice field conditions, as well as various weather and sea states. This could include the implications of temperature, possible seasickness among occupants, and other effects that were beyond the scope of this study.
3) Further research should be conducted to examine the accumulation of CO_2 within other models of TEMPSC. TEMPSC are designed and manufactured internationally by different companies, and there are many different types and models. This could be accomplished using the predictive equations available from this study and information available from the manufacturers on physical dimensions of the craft. This would allow testing of all different TEMPSC models, and numerous ventilation strategies and scenarios could be applied and investigated. Additionally, this predictive model supports recommendations put forward by Det Norse Veritas (DNV) for the certification of lifeboat ventilation systems (DNV Cert. No. 2.20, 2007).
4) If the current ventilation system remains the standard for TEMPSC, there should be further research to understand how often these TEMPSC should be manually ventilated if air exchange between the interior and exterior of the craft is limited. Perhaps a guideline document for mariners and anyone who may need to use a

TEMPSC could be developed to inform them of a protocol if this were to happen. This guideline should be designed using a performance-based approach, meaning it should be adaptable to various situations as occupant complements and external environmental factors may be unpredictable.

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APPENDIX

APPENDIX A: ETHICS APPLICATION

To be used by ICEHR administration

ICEHR Ref. #: 20140454-HK **Date Received:**

INTERDISCIPLINARY COMMITTEE ON ETHICS IN HUMAN RESEARCH

Application for Ethics Review **[Review Process 4 weeks, 6 weeks during peak periods]**

Revised: June 2013

Form 1B: Student and Post Doctoral Fellow Research

Application Guidelines

Submit an electronic copy with all attachments to icehr@mun.ca. We do not accept hard copy. **For MUN researchers, electronic submissions must originate from a MUN email address**. ICEHR is not obliged to accept email that is not from a valid MUN email address.

"Section D Signature" page containing original signature(s) must be forwarded to the ICEHR before processing of application.

If the proposed research is health related, please complete the **HREA Notification Form** for the Health Research Ethics Authority (HREA) along with original signatures and submit it with "Section D Signature" page to the ICEHR.

Submit original signatures to: ICEHR
Bruneau Centre for Research and Innovation, Room 2010C
Memorial University of Newfoundland
St. John's, NL A1C 5S7

Please refer to our web page at for information on preparing your application.

Checklist - Please complete the checklist provided near the end of the application to ensure that the application includes all necessary documents related to the project.

Form 1B: Student and Post-doctoral Fellow Research

(It is the responsibility of researchers to read the ICEHR "Information for Researchers" found on our website: http://www.mun.ca/research/ethics/humans/

Access to Information and Protection of Privacy

The information on this form is collected under the authority of the Memorial University Act (RSNL 1990 Chapter M-7) and will be used by the Interdisciplinary Committee on Ethics in Human Research (ICEHR) to assess your application for ethics review and to administer ethics clearance. If you have any questions about the collection and use of this information contact the ICEHR at icehr@mun.ca or at 709 864-2561/2861.

SECTION A – GENERAL INFORMATION

General instructions: This application form has been revised to facilitate the application and review process. It is designed to be completed and submitted electronically. Use the space inside the expandable textbox to provide the information requested. Please do not skip items. **Answer "n/a" if it does not apply to your proposed research**. **Click or double - click on the "yes/no" box to select**.

1. TITLE OF PROPOSED RESEARCH PROJECT

The effects of simulated lifeboat motions on carbon dioxide production.

2. PREVIOUS OR OTHER RESEARCH ETHICS BOARD APPROVAL(S)

Has this research project been reviewed by another institution's ethics board or another ethics board within your institution?

☐ Yes [Attach a copy of the application you submitted and the approval letter.]

☐ Pending application ☐ Animal Care ☐ BioSafety [please attach copies of approvals]

☒ No

Note: ***Research that has been reviewed and approved by another REB, please refer to Guidelines for completing the proposal.***.

3. ORGANIZATIONAL OR COMMUNITY CONSENT

If the research is taking place within a recognized organization or community (e.g. School Boards, Band Councils, etc.) which requires that formal consent be sought prior to the involvement of individual participants, explain whether consent from that organization/community will be sought. Describe this consent process and attach a copy of the approval document. If consent will not be sought, please provide a justification and describe any alternative forms of consultation that may take place.

N/A

4. STUDENT OR POST DOCTORAL FELLOW PRINCIPAL INVESTIGATOR INFORMATION

Title: (Dr./Mr./Ms./etc)	Last Name:	First Name:	Middle Initial:
Ms.	Aylward	Katie	A

Department/Faculty/School (or Institution if not MUN):
School of Human Kinetics & Recreation

Mailing address for correspondence, if different from department/faculty/school:	MUN email address mandatory: Kaa257@mun.ca
	Telephone: 709-764-7413
	MUN Student No. 200839512

Positions:

☐ MUN Undergraduate Student ☒ MUN Master's Student ☐ MUN PhD Student

☐ MUN Post-Doctoral Fellow ☐ Other (specify): Click here to enter text.

5. PROJECT PROGRAM

☐ Undergraduate Honours Thesis ☒ Master's Thesis ☐ Doctoral Dissertation

☐ Other: Click here to enter text.

6. CO-PRINCIPAL INVESTIGATOR INFORMATION (to be completed if the project is being conducted by a group of students doing a group paper or report)

Title: (Dr./Mr./Ms./etc) Click here to enter text.	Last Name: Click here to enter text.	First Name: Click here to enter text.	Middle Initial: Click here to enter text.
Department/Faculty/School (or Institution if not MUN): Click here to enter text.			
MUN/Institutional email address mandatory Click here to enter text.	Other email address: Click here to enter text.	Telephone: Click here to enter text.	
Positions: ☐ MUN Faculty ☐ MUN Staff ☐ Other (specify): Click here to enter text.			
Title: (Dr./Mr./Ms./etc) Click here to enter text.	Last Name: Click here to enter text.	First Name: Click here to enter text.	Middle Initial: Click here to enter text.
Department/Faculty/School (or Institution if not MUN): Click here to enter text.			
MUN/Institutional email address mandatory Click here to enter text.	Other email address: Click here to enter text.	Telephone: Click here to enter text.	
Positions: ☐ MUN Faculty ☐ MUN Staff ☐ Other (specify): Click here to enter text.			
Title: (Dr./Mr./Ms./etc) Click here to enter text.	Last Name: Click here to enter text.	First Name: Click here to enter text.	Middle Initial: Click here to enter text.
Department/Faculty/School (or Institution if not MUN): Click here to enter text.			
MUN/Institutional email address mandatory Click here to enter text.	Other email address: Click here to enter text.	Telephone: Click here to enter text.	
Positions: ☐ MUN Faculty ☐ MUN Staff ☐ Other (specify): Click here to enter text.			
Title: (Dr./Mr./Ms./etc) Click here to enter text.	Last Name: Click here to enter text.	First Name: Click here to enter text.	Middle Initial: Click here to enter text.
Department/Faculty/School (or Institution if not MUN): Click here to enter text.			
MUN/Institutional email address mandatory Click here to enter text.	Other email address: Click here to enter text.	Telephone: Click here to enter text.	
Positions: ☐ MUN Faculty ☐ MUN Staff ☐ Other (specify): Click here to enter text.			

7. CO-INVESTIGATOR(S): *[Do not include supervisor's information here – see item 6]*

Name	Position	Faculty/Department	Email
Antonio Simoes Re	Senior Research Officer	National Research Council	Antonio.Simoes_re@nrc.ca
Jonathan Power	Research Council Officer	National Research Council	Jonathan.Power@nrc.ca
Andrew Baker	Research Council Officer	National Research Council	Andrew.baker@nrc.ca

8. SUPERVISOR(S)

Name	Department/Faculty/School (or Institution if not MUN)	Email
Principal Supervisor: Dr. Scott MacKinnon	School of Human Kinetics and Recreation	smackinn@mun.ca
Co-supervisor: Antonio Simoes Re	National Research Council	Antonio.simoes_re@nrc.ca

9. DATA COLLECTION START AND END DATES

Beginning of formal recruitment or informed consent process normally constitutes the start date of data collection.

Estimated project start date: September 10, 2013

Estimated start date of data collection involving human participants: September 10, 2013
Note – Please allow 4 weeks for review process, 6 weeks during peak periods.

End date of involvement of human participants is when all data has been collected from participants, no further contact with them will be made, and all data are recorded and stored in accordance with the provisions of the approved application.

Estimated end date of involvement of human participants for this project: October 30, 2013

Estimated project end date: May 2014

10. USE OF SECONDARY DATA

Does your project involve secondary use of data collected for other purposes? If it involves the use of secondary data that is not in the public domain, provide letter of approval from the data holder.

☐ Only secondary data
☐ Both human participants and secondary data
☒ Only human participants

11. FUNDING OF PROJECT

Is this project funded? ☐ No

☒ Yes, funding agent/sponsor: National Research Council

If **no**, is funding being sought? ☐ No

☐ Yes, funding agent/sponsor: Click here to enter text.

Will funds be administered through MUN? ☐ Yes ☒ No ☐ N/A

Funded research title if different from this application:
N/A.

Principal Investigator of above funded research: N/A

12. CONTRACTS

Is there a MUN funding or non-funded contract/agreement associated with the research? ☐ Yes
☒ No

If **Yes**, please include one (1) copy of the contract/agreement with this application

Is there any aspect of the contract/agreement that could put any member of the research team in a potential conflict of interest? ☐ Yes ☒ No

If **Yes**, please **elaborate under Section C, item #5**.

13. SCHOLARLY REVIEW

The ICEHR will assume that research proposals prepared for presentation to the three national granting councils (CIHR, NSERC and SSHRC), as well as other funding agencies, will be subjected to scholarly review before funding is granted. The ethics review process for research that is beyond minimal risk will incorporate a determination of the project's scholarly merit and may request the researcher to provide full documentation of such scholarly review.

Please check one:

☐ The research project has undergone scholarly review prior to this application for ethics review by (**specify review committee** – e.g. departmental research committee, peer-review committee, etc):

Click here to enter text.

☐ The research project will undergo scholarly review prior to funding by (**specify review committee** – e.g. departmental research committee, peer-review committee, etc):

Click here to enter text.

☒ The research project will not undergo scholarly review.

☒ The research project has been reviewed the supervisor(s).

SECTION B – SUMMARY OF PROPOSED RESEARCH

1. RATIONALE AND PURPOSE/RESEARCH QUESTION

Explain in non-technical, plain and clear language the purpose and objectives of the proposed project. Include hypothesis or research question if applicable. The rationale for doing the study must be clear.

Maximum 1 page

Totally enclosed motor propelled survival crafts (TEMPSC) are a life saving appliance (LSA) that are used throughout the marine and offshore petroleum industry. Many regulations require that both ships and offshore installations carry a sufficient number of TEMPSC on board to provide a safe means of evacuation for personnel. Once on board the TEMPSC, personnel may be inside these craft for prolonged periods of time possibly up to 24 hours or more (IMO, 2010). The conditions inside these craft can become very uncomfortable after only a short amount of time due to their enclosed nature and confined conditions.

These cramped, confined conditions will result in the creation of environmental conditions that can have detrimental effects on the TEMPSC occupants. Previous work done by the National Research Council (NRC) investigated the rate of carbon dioxide (CO_2) accumulation in a TEMPSC with a varying number of people inside it. The results from this work found that CO_2 levels quickly rose to unsafe values after only a few minutes when the TEMPSC was filled to capacity.

In the NRC study, the participants were sitting passively in the lifeboat while the CO_2 levels rose. During actual operation of a TEMPSC in the open ocean, wave action and motions of the craft will cause movement of the occupants, which they would have to compensate for in order to remain upright. It is hypothesized that the extra energy that will have to be expended on part of the occupants to maintain their posture could result in more CO_2 being produced. If this is true, then the rate of CO_2 accumulation in lifeboats could be higher than originally thought which could put the occupants at risk in a shorter amount of time then previously estimated.

2. PROPOSED STUDY DESIGN/METHOD

Describe in some detail all procedures and methods to be used. Explain what the participants will be doing in the study, types of information to be gathered from participants, where and how it will be obtained and analyzed. If research includes intentions to publish, please indicate publication venues.

Attach a copy of all materials (survey questionnaires, interview questions, or other non-standard test instruments) to be used in the study.

Maximum 3 pages

Participants will perform a series of seated experiments on a motion platform in order to replicate the effects of being in a TEMPSC operating in waves and ice covered water.

The motion platform, which allows for five degrees of freedom motion, is located in the Faculty of Engineering and Applied Science at Memorial University. The motion platform will be outfitted with a seat and console style arrangement, which will replicate the interior seating of a TEMPSC.

Oxygen consumption (VO_2) and carbon dioxide production (VCO_2) will be measured using a Cardio Coach CO_2 metabolic cart. Participants will wear a reusable facemask for

the duration of each tests which will be connected to the Cardio Coach via a length of flexible hose. The masks will be sanitized after each test.

Skin temperature (Tsk) will be measured using a series of heat flux transducers, which will be connected to self-contained data loggers. The heat flux transducers will be affixed to the participants using a piece of porous, adhesive tape to the following locations: right foot, left shin, right quadriceps, left abdominal, right pectoral, left overarm, right calve, left hamstring, right lower back, left shoulder blade, right underarm, and the forehead.

Heart rate (HR) will be measured using a Polar Heart Rate monitor. The Polar Heart Rate monitor is a small black band worn around the torso of the participant, at the bottom of the rib cage. The measurements from the Polar Heart Rate monitor will be recorded by another self contained data logger, which will be placed on the participant.

Skin fold calipers will be used to measure skin fold thickness at the following sites: biceps; triceps; sub-scapular (should blade); and iliac crest (top of the hip).

Participants will be instructed to wear the following clothing ensemble: cotton socks, cotton pants, cotton undershirt, and a long sleeved cotton shirt. Participants will wear a certified marine abandonment immersion suit, fully zipped, over the prescribed clothing ensemble.

Participants will perform two separate data collection sessions in two different conditions:

Condition 1: A motion profile (the movements of the motion platform) will be used that will replicate the motions of a TEMPSC that is running in the open ocean. This condition will have pronounced heave, pitch and roll motions (similar to a ship riding a wave).

Condition 2: A motion profile will be used that will replicate the motions of a TEMPSC that is running through pack ice. This condition will have reduced heave, pitch and roll motions due to ice dampening wave action, but will shudder and jolt to replicate a TEMPSC hitting ice.

On the day of the test, participants will arrive at the Faculty of Engineering and Applied Science at a time prearranged with the study team. The participant will change out of their street clothing and a team member will attach the heat flux transducers in the indicated spots with a piece of porous adhesive tape. Once the transducers are secured, the heart rate monitor will be attached and the participant will change into the prescribed test clothing. The participant will then make their way to the motion bed and don the immersion suit. The reusable facemask will then be secured to the participant and the test will begin. The participant will sit quietly for 10-15 minutes on the motion bed and then experience either Condition 1 or 2 for approximately 20-30 minutes. After Condition 1 or 2 is finished, the test will end and the participant will exit the motion platform. The participant will be given a rest period of approximately 20-30 minutes and will then enter the motion platform once again to perform the remaining condition (1 or 2). After the remaining condition has been tested, the participant will be deinstrumented and will be free to leave the facility once their well being is ensured.

It is expected that the total time commitment to this experiment is approximately 2.5 hours for each participant.

3. PARTICIPANTS INVOLVED IN THE STUDY

a. Indicate who will be recruited as potential participants in this study

☒ Undergraduate students	☒ Graduate students	☐ Faculty or staff
☒ General population	☐ Children	☐ Adolescents
☐ Senior citizens	☐ Aboriginal people	☐ Other (specify): Click here to enter text.

b. Specify the expected number of participants and exclusion criteria. Provide justification if participation is dependent on attributes such as culture, language, religion, mental or physical disability, sexual orientation, ethnicity, gender or age.

It is expected that 20 participants will be required for this experiment. To account for the inevitable participant dropout 23 participants will be recruited.

c. If your research involves Aboriginal peoples, please describe in detail the ethical issues relevant to the proposed project and how you plan to comply with the TCPS2 guidelines Chapter 9.

N/A

d. Is there any pre-existing relationship between you (or any member of your research team) and the participants (e.g. instructor-student; manager-employee)?

☐ Yes ☒ No ☐ N/A

If **yes**, please explain:
Click here to enter text.

e. Are you or any member of your research team in a direct position of power to the participants outside the scope of the research study?

☐ Yes ☒ No ☐ N/A

If **yes**, please explain:
Click here to enter text.

f. Will you or any member of your research team be collecting research data from your/their own students?

☐ Yes ☒ No ☐ N/A

If **yes**, please explain: Click here to enter text.

g. Will the targeted research population consist of any vulnerable group that will have difficulty understanding or will not be able to give free and informed consent e.g. the mentally disabled, minors (under 19), or any institutionalized individuals such as prisoners, etc?

☐ Yes ☒ No

If **yes**, please explain:
Click here to enter text.

4. RECRUITMENT PROCESS AND STUDY LOCATION

a. Describe how, by whom, and from where the potential participants will be recruited. Where participant observation is to be used, please explain the form of your (or members of your team) insertion into the research setting (e.g. living in a community, visiting, attending organized

functions). Please make it explicit where it is reasonable to anticipate that all or some of the participants who will be recruited will not speak English or will speak English as a second language. Describe any translation of recruitment materials, how this will occur and whether or not those people responsible for recruitment will speak the language of the participants. **Attach a copy of any materials to be used for recruitment [e.g., emails, posters, advertisements, letters, and telephone scripts]**.

Maximum 2 pages

Potential participants will be recruited from the local university (Memorial) and surrounding areas in St. John's, NL.

Posters (separate document) and word of mouth will be used to advertise information about this study and attract potential participants.

Healthy males and females between the ages of 19 and 45 years who are able to make decisions on their own behalf will be recruited. All potential participants will be asked to fill out a physical activity readiness questionnaire (PARQ) form and a Motion Sickness Susceptibility Questionnaire (MSSQ) to determine the eligibility to participate.

b. Identify where the study will take place.

☒ On campus (e.g. university classroom, university lab, etc.) Please specify below.
☐ Off campus (e.g. aboriginal community, schools, etc.) Please specify below.

Click here to enter text.

5. EXPERIENCE

For projects that involve collection of sensitive data, methods that pose greater than minimal risk to participants, or involve a vulnerable population, please provide a brief description of your (or your research team) experience with this type of research (including people who will have contact with the participants).

N/A

6. COMPENSATION

If compensation is offered, it should not impose undue influence on a participant's decision to participate in the research. Justification for the amount of compensation to be offered should be provided.

a. Will participants receive compensation for participating in the research?

☐ Yes ☒ No

If **yes**, please provide details and justification for the amount or value of the compensation offered.

b. If participants choose to withdraw, how will you deal with the compensation offered?

N/A

7. SHARING OF RESEARCH RESULTS WITH PARTICIPANTS

Explain what and how information/feedback will be provided to participants and/or communities after their participation in the project is complete. (e.g., report, poster presentation, pamphlet, etc.)

The data collected from this study will be published in reports and/or peer reviewed papers. If participants wish to see the results from this study, they can contact a member of the research team who will let them know when they have become available in the public domain.

SECTION C – STATEMENT OF ETHICAL ISSUES

1. BENEFITS

a. Identify and describe any known or anticipated *direct benefits* to the participants (or to the community) from their involvement in the project. Please do not list compensation as a benefit.

There are no known direct benefits to the participants.

b. Identify and describe any known or anticipated *benefits to the scientific/scholarly community or society* that would justify involvement of participants in the research.

The results from this study will help improve the safety of the end users of TEMPSC as it will determine the rate at which the interior environments can become unsafe.

2. HARMS

In explaining the risks involved in participating in a project, it is important to provide potential participants with a clear understanding of the potential for harm. Research risks are those that reflect the likelihood and magnitude of harms that participants may experience as a direct result of taking part in this research (e.g., stress or anxiety during data collection, stigma, loss of job, injury, etc.).

Please indicate if the participants as individuals or as part of an identifiable group or community might experience any of the following risks by being part of this research project. In particular, consider any factors that pose potential harm to at-risk groups.

a.	Physical risks *(including any bodily contact, administration of any substance or in dangerous location such as politically unstable countries)*?	☒ Yes	☐ No
b.	Psychological/emotional risks *(feeling uncomfortable, embarrassed, anxious or upset)*?	☒ Yes	☐ No
c.	Social risks *(including possible loss of status, privacy or reputation)*?	☐ Yes	☒ No
d.	Is there any deception involved?	☐ Yes	☒ No
e.	Will your methods induce participants to act against their wishes?	☐ Yes	☒ No
f.	Will participants be asked to disclose information of an intimate nature or otherwise sensitive nature?	☐ Yes	☒ No
g.	Financial risks to participants *(e.g. loss of job, promotion opportunities, etc.)*?	☐ Yes	☒ No
h.	Financial risks to organization/company *(decrease in demand for goods/services, loss of funding opportunities, etc.)*?	☐ Yes	☒ No

If **yes** to any of the above, please explain the risks and describe how they will be managed or minimized. In the case of an adverse event (if any), provide information on how you plan to manage the risks inherent in your research and provide information or resources to participants who might experience adverse effects stemming from participation in your research.

There is a small risk of physical injury during the test program. The motion bed will be moving in five degrees of freedom and may move enough to cause a motion induced interruption in the participant. This motion-induced interruption may result in slight physical injury to the participant (e.g. their hand striking against a solid object). Given that the participants will be secured in a seated position, it is expected that this risk is very minimal.

There may be some psychological discomfort due to the motion of the platform (i.e. motion sickness). However, participants who are prone to motion sickness will be screened out of the study based on results of the Motion Sickness Susceptibility Questionnaire (MSSQ).

3. FREE AND INFORMED CONSENT

You are encouraged to examine our informed consent form template for information on the required minimum elements that should be included in the information letter and consent form, and follow a similar format.

a. What process will you use to inform the potential participants about the study's details and to obtain the participants' consent for participation? If the research involves extraction or collection of personally identifiable information from a participant, please describe how consent from the individuals or authorization from the data custodian will be obtained.

Potential participants will initially make contact with a member of the research team to inquire about the study. The research team member will provide them with a copy of the consent form and ask for them to review it. After reviewing the consent form, the potential participant can get back in contact with the research team member and agree to participate in the study by providing signed, written consent. At any time in the process the potential participant will be able to ask any and all questions about the study.

b. If you will not be obtaining written consent, please provide the rationale for oral or implied consent (e.g. discipline, cultural appropriateness, etc.) and explain how consent will be recorded. Also, explain how you will ensure that participants understand that their participation is voluntary.

N/A

c. If the target population is not competent by reason of age or mental ability to provide free and informed consent *(the age of legal consent in this province is 19 years of age)*, describe and justify the process you will use to obtain parental or third-party consent. *[Note: If the participants are capable of understanding the objectives and consequences of the research, their assent should be obtained in addition to the consent of the parent or guardian.]*

N/A

4. ANONYMITY OF PARTICIPANTS AND CONFIDENTIALITY OF DATA

a. Describe the procedures you will use to protect anonymity of participants or informants, where applicable, and the confidentiality of data during the conduct of the research and in the release of the findings.

Access to the personal information of the participants (names, contact details, etc.) will be limited to members of the project team (Scott MacKinnon, Katie Aylward, Jonathan Power). Data collected from that participants will be anonymous during the analysis process, and only aggregated data will be reported in public communications.

b. Explain how written records, video/audio recordings, photographs, artifacts and questionnaires will be securely stored, how long they will be retained, who will have access, and provide details of their storage location and final disposal. Provide a justification if you intend to store your data for an indefinite length of time. If the data may have archival value, discuss this and whether participants will be informed of this possibility during the consent process. Data security measures should be consistent with Memorial University's *Policy on Integrity on Scholarly Research* .

Written records will be kept in locked storage at the Memorial University of Newfoundland campus in St. John's, NL. Access to the written records will be limited to members of the project team. All electronic data will be kept on a secured project drive on a server at MUN, and members of the project team can only assign access to the drive. All identifiable data will be retained for a period of 5 years, after which it will be destroyed.

c. Describe any limitations to protecting the confidentiality of participants' data (eg. access to or disclosure of information during or at the end of the study) whether due to the law, the methods used or other reasons (e.g. duty to report).

There are no anticipated limitations in protecting the confidentiality of the data collected from the participants. The actions listed for protecting the participant's data have been used by MUN in many studies in the past and there have been no complications in protecting the anonymity of the participants.

d. If participants' anonymity is difficult or impossible to achieve (e.g. in focus groups), please explain the limits to anonymity.

N/A

5. CONFLICT OF INTEREST

If any member of the ICEHR is ineligible to review your application because of a conflict of interest, please notify the ICEHR administrative staff.

If the proposed research involves real or apparent conflict of interest (e.g., yours or your team's judgement may be influenced or appear to be influenced by private or personal interests such as remuneration, intellectual property rights, rights of employment, consultancies, board membership, stock options, etc.), please identify and explain how you will inform research participants of these conflicts.

No members of the research team have a conflict of interest with this study

6. PARTICIPANT WITHDRAWAL

a. Please describe how participants will be informed of their right to withdraw from the project. Outline the procedures which will be followed to allow them to exercise this right.

Participants are free to withdraw from the study at any time. If a participant wishes to withdraw, they can get in contact with a member of the research team and tell them that they wish to no longer participate in the study.

c. Indicate what will be done with the participant's data and any consequences that withdrawal may have on the participant.

If a participant chooses to withdraw from the study, then their data will be destroyed.

d. If participants will not have the right to withdraw from the project at all, or beyond a certain point, please explain.

N/A

7. DECEPTION

a. Describe and justify the use of deception or intentional non-disclosure in this study.

N/A

b. Explain and justify if information will be withheld from participants that might reasonably lead them to decline to participate in the study.

N/A

c. Explain and justify if participants will be photographed or video- or audio-taped without their knowledge or consent.

N/A

d. Debriefing (***Attach a copy of written debriefing sheet or script)***
Outline the process to be used to debrief participants. Explain and justify whether participants will be given the option of withdrawing their data following the debriefing.

N/A

Recruitment Documents and Consent Forms

A template of an Informed Consent Form is available on the ICEHR Website. The Committee encourages you to examine the template and follow a similar format. Note that the template outlines only the minimum information that should be included in an informed consent form. Please consult the **ICEHR guidelines** for additional information that may be required.

Note:

- **The ICEHR approval statement must be included on all recruiting information and consent forms given to participants, and should be in a paragraph separated from all other text or contact information**.

- **A *consent form checklist* is provided to assist you to ensure you that you have covered everything necessary for your project.**

Application Checklist (This checklist must be completed and included with your electronic application)

☒ New application
☐ HREA Notification Form (only for health related research)
☒ Resubmission as requested
☒ **Forwarded e-copy** of electronic application and attachments to icehr@mun.ca
☒ Answered all questions on the application form
☒ **Section D of Form 1B completed and signed by PI and supervisor and forwarded to ICEHR**
☒ The ICEHR Approval Statement included on Informed Consent Form and Recruitment Documents

Where Applicable, Attachments Included with Application:

☒ Proposed Recruitment letter, Advertisement, Poster
☒ Proposed Questionnaire, Survey, or Other Instrument
☐ Proposed Interview Questions
☐ Proposed Oral Script for Recruitment (e.g., in-class and telephone invitation/information script)
☐ Proposed Information Letter for Participants
☒ Proposed Informed Consent Form for Participants
☐ Proposed Information Letter for Parents, Guardians, Proxy
☐ Proposed Consent Form for Parents, Guardians, Proxy
☐ Proposed Debriefing Statement (if using deception)

☐ Other, please specify: Click here to enter text.

SECTION D – SIGNATURE

The effects of simulated lifeboat motions on carbon dioxide production

PRINCIPAL INVESTIGATOR:

As the **Principal Investigator** on this project, my signature confirms that I have read *Memorial University's Policy on Ethics of Research Involving Human Participants* and the *Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans (TCPS2)*. I will ensure that all procedures performed under the project will be conducted in accordance with the TCPS2 and all relevant university, provincial, national and international policies and regulations that govern the collection and use of personally identifiable information in research involving human participants. I agree to conduct the research subject to Section 3 (Guiding Ethical Principles) and accept the responsibilities as outlined in Section 18 (Responsibilities of Researchers) of Memorial University's *Policy on Ethics of Research Involving Human Participants*.

Any deviation from the project as originally approved will be submitted to ICEHR for approval prior to its implementation. I understand that deviations from the project that alter the risks to participants and that are implemented without ethics approval constitute a violation of the TCPS2 and Memorial University's policy.

If there is any occurrence of an adverse event(s), I will complete and submit *Form 5 – Adverse Event(s) Report* to the Chair of ICEHR immediately.

My signature confirms that my project has been reviewed and approved by my supervisor(s) and advisory committee (where applicable). If my status as a post-doctoral fellow/student changes, I will inform the ICEHR.

Katie Aylward	July 16, 2013
Name and Signature of Principal Investigator	Date

PRINCIPAL SUPERVISOR:

As the **Principal Supervisor** of this project, my signature confirms that I have reviewed and approved the scholarly and/or scientific merit of the research project and this ethics protocol submission.

I understand that as the Principal Supervisor, I have ultimate responsibility for the conduct of the study, the ethical performance of the project and the protection of the rights and welfare of human participants. I will provide the necessary training and supervision to the researcher throughout the project to ensure that all procedures performed under the research project will be conducted in accordance with the TCPS2 and all relevant University, provincial, national or international policies and regulations that govern research involving human participants.

I will ensure that any deviation from the project as originally approved will be submitted to the ICEHR for approval prior to its implementation, and any occurrence of adverse event(s) will be reported to the ICEHR immediately.

Dr. Scott MacKinnon	July 16, 2013
Name and Signature of Principal Supervisor	Date

APPENDIX B: CONSENT FORM

Informed Consent Form

Title: **The effects of simulated lifeboat motions on carbon dioxide production**

Researcher(s):

Katie Aylward
National Research Council of Canada
Memorial University
Katie.aylward@nrc.ca

Dr. Scott MacKinnon
School of Human Kinetics and Recreation
Memorial University
Smackinn@mun.ca

Dr. Jonathan Power
National Research Council of Canada
Jonathan.power@nrc.ca

Antonio Simoes Ré
National Research Council of Canada
Antonio.simoes_re@nrc.ca

You are invited to take part in a research project entitled "The effects of simulated lifeboat motions on carbon dioxide production".

This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw from the study at any time. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researcher, Katie Aylward, if you have any questions about the study or for more information not included here before you consent.

It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or in the future.

Introduction

My name is Katie Aylward and I am a graduate student at Memorial University and also Principal Investigator of this research project. I will be completing this research as a component of my Master's thesis. Dr. Scott MacKinnon is my supervisor and also a professor at Memorial University of Newfoundland. The research project is examining the effects of simulated lifeboat motions on carbon dioxide production. This research has important implications for marine safety as lifeboats are relied on during emergencies, but there may be issues with the build-up of dangerous gases insides of them that may threaten the health of the people.

Purpose of study:

The purpose of this study is to investigate the effects that simulated lifeboat motions have on carbon dioxide production in humans. Carbon dioxide is a by-product of energy production in humans that we breathe out. In sufficient quantities, carbon dioxide can become hazardous to our health and even potentially lethal. In our day to day lives there is little risk of carbon dioxide building up to the levels where it can become a hazard; it is only when there is very little circulation with fresh air that carbon dioxide can build up. By requirement, a lifeboat must be water tight when it is operating, which also means it is air tight. Due to the lack of fresh air being circulated inside a lifeboat, carbon dioxide build up can be a problem. The National Research Council of Canada (NRC) has done studies that investigated how long it takes for carbon dioxide to build up to dangerous levels inside a lifeboat, but all the people involved in that study were sitting quietly. In an actual marine accident (when a lifeboat would be used) the lifeboat would be moving, which would mean the people inside would be moving as well. We wish to investigate if this movement increases carbon dioxide production compared to when there is no motion.

What you will do in this study:

Before starting the test conditions, you will be asked to complete a Physical Activity Readiness Questionnaire (PAR-Q), and a Motion Sickness Questionnaire to determine your eligibility for this study. Pre-existing medical conditions or previous episodes of sea-sickness may result in some people not being eligible for this study.

You will be asked to perform a series of seated experiments on a platform that will move (called a motion platform) in order to recreate the effects of being in a lifeboat operating in waves and ice covered water. All tests will take place at the Faculty of Engineering and Applied Science (FEAS) at a time agreed upon between you and the research team.

There will be two separate test conditions:

Condition 1: Movements similar to a lifeboat running in the open ocean. This condition will have the motion platform moving up and down, similar to riding a wave.

Condition 2: Movements similar to a lifeboat running through water covered in pans of ice. This condition will have less movement up and down compared to Condition 1, but will shudder and jolt similar to a lifeboat hitting a piece of ice.

On the day of the test, you will arrive at the Faculty of Engineering and Applied Science building and change out of your street clothes and a research team member will apply temperature sensors to your skin using a piece of porous, adhesive tape. After these sensors are secured, you will put on a heart rate monitor that is a band that is secured around your chest. Once all the instrumentation is secured, you will change into the following clothing: cotton socks, cotton pants, cotton undershirt, and a long sleeved cotton shirt and then put on an immersion suit.

You will make your way to the motion platform, sit down, and have a mask secured to your face. This mask allows the research team to measure the amount of carbon dioxide you produce. You will sit quietly for 10-15 minutes on the motion platform and then experience either Condition 1 or 2 for approximately 20-30 minutes. After the condition is finished, the test will end and you will exit the motion platform. You will be given a rest period of approximately 20-30 minutes and will enter the motion platform once again to perform the remaining condition. After the remaining condition has been tested, you will be have the sensors removed and will be free to leave the facility once your well-being is ensured.

Length of time:
It is expected that the total time commitment to this study will be approximately 2.5 hours.

Withdrawal from the study:

You are free to withdraw from this study at any time without any negative impact. If at any time you wish to withdraw from the study, let one of the research team members know. Any data collected from you personally will be destroyed.

Possible benefits:

You will not benefit directly from participating in this study.

It is expected that the data from this study will benefit the area of marine safety by determining how long until the interior environment of lifeboats become hazardous.

Possible risks:

There is a small risk of physical injury during the test program. The motion platform will be moving and may move enough to cause you to move involuntarily. This movement may result in a slight physical injury (e.g. striking your hand against a solid object). Given that you will be secured in a seated position, it is expected this risk is very minimal.

There may be some psychological discomfort due to the motion of the platform such as motion sickness. If you are prone to motion sickness you should not participate in this study.

Confidentiality vs. Anonymity

There is a difference between confidentiality and anonymity: Confidentiality is ensuring that your identity is accessible only to those authorized to have access. Anonymity is a result of not disclosing your identifying characteristics (such as name or description of physical appearance).

Confidentiality and Storage of Data:

The following procedures will be implemented to ensure the confidentiality and utmost privacy of any personal information we obtain from you:

- Locked storage of all data recorded on paper.
- Password protection on all electronic data.
- Only Katie Aylward and Dr. Scott MacKinnon will have access to the data.

The information collected during this study will be kept for a minimum of five years, as per Memorial University policy on Integrity in Scholarly Research.

Anonymity:

Every reasonable effort will be made to ensure that you remain anonymous throughout all aspects of this study. You will not be identified in any reports or publications unless we seek your express permission to do so. However, due to the small number of people recruited in this study, complete anonymity cannot be guaranteed.

Reporting of Results:

All results collected from this study will be reported in a Master of Kinesiology thesis, journal articles, and technical reports. All information will be reported as group averages, and if individual data is presented, it will be anonymous.

Sharing of Results with Participants:

If you would like to obtain a copy of the results in a published format, please contact a member of the research team who will let you know when it is available and how to obtain a copy.

Questions:
You are welcome to ask questions at any time during your participation in this research. If you would like more information about this study, please contact:

Katie Aylward
E-mail: Katie.aylward@nrc.ca
Phone: 709-772-7774

ICEHR Approval Statement:

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. This research has also been reviewed by the National Research Council of Canada's Research Ethics Board which has granted ethical approval for this study. If you have ethical concerns about the research (such as the way you have been treated or your rights as a participant), you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

Consent:
Your signature on this form means that:

- You have read the information about the research.
- You have been able to ask questions about this study.
- You are satisfied with the answers to all your questions.
- You understand what the study is about and what you will be doing.
- You understand that you are free to withdraw from the study at any time, without having to give a reason, and that doing so will not affect you now or in the future.
- You understand that any data collected from you up to the point of your withdrawal will be destroyed.

If you sign this form, you do not give up your legal rights and do not release the researchers from their professional responsibilities.

Your signature:
I have read what this study is about and understood the risks and benefits. I have had adequate time to think about this and had the opportunity to ask questions and my questions have been answered.

☐ I agree to participate in the research project understanding the risks and contributions of my participation, that my participation is voluntary, and that I may end my participation at any time.

A copy of this Informed Consent Form has been given to me for my records.

_____ _____

Signature of participant Date

Researcher's Signature:

I have explained this study to the best of my ability. I invited questions and gave answers. I believe that the participant fully understands what is involved in being in the study, any potential risks of the study and that he or she has freely chosen to be in the study.

_____ _____

Signature of Principal Investigator Date

APPENDIX C: Recruitment Poster

NRC·CNRC

MEMORIAL UNIVERSITY

RECRUITMENT FOR SCIENTIFIC RESEARCH PROJECT

"The effects of simulated lifeboat motions on carbon dioxide production"

My name is Katie Aylward and I am a second year graduate student at Memorial University of Newfoundland (MUN) and the National Research Council (NRC). I am conducting research as a part of my Master's thesis requirements, and this research project is looking at the effects of simulated lifeboat motions on carbon dioxide production. This research could contribute to a better understanding of how long it takes until the interior environment of lifeboats become hazardous.

Who can participate?

- Healthy male and female individuals who are **19 - 45** years old

Who cannot participate?

Anyone who has:

- Any heart or respiratory illnesses
- Susceptibility to sea-sickness

What will be done: You will be asked to perform a series of seated experiments on a platform that will move (called a motion platform) in order to recreate the effects of being in a lifeboat operating in waves and ice covered water. Your heart rate, and carbon dioxide production will be measured.

Duration: You will be required to participate in one 2.5 hour testing session.

Where: Faculty of Engineering and Applied Science (FEAS) building, on the Memorial University campus, St. John's, NL.

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research (such as the way you have been treated or your rights as a participant), you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

If you are interested in volunteering, please contact Katie Aylward:

772-7774 (M-F 8:00-13:00), kaa257@mun.ca or Katie.Aylward@nrc.gc.ca

APPENDIX D: TEMPSC Volume Calculations

Values that remained constant:

Variable	Mean constant values
Number of occupants	1-15
Mean mass of occupants (kg)	77.28
Mean VCO_2 of occupants ($ml.kg^{-1}.min^{-1}$)	Base:3.16 Low:3.10 High:3.56
Mean VO_2 of occupants ($ml.\ kg^{-1}.min^{-1}$)	Base: 3.18 Low: 3.13 High: 3.58
Mean height of occupants (m)	1.74
Freespace of Internal TEMPSC (m^3)	14
Mean Lean Body Mass (LBM) of occupants (kg)	58
Air in lifeboat (%)	N_2: 79.04 O_2: 20.93 CO_2: 0.03

Surface Area (SA) of mean occupant (cm^2) = 73.31*((Stature*100)^(Mass^0.425)
Body Volume Index (BVI) of mean occupant = 60.2*((Mass/(Stature*100))^0.562)
Volume of Mean Occupant (L) = (SA of occupant/10000)*BVI
Volume of Mean Occupant (m^3) = Volume of Mean Occupant*0.001
Volume of free space in lifeboat with people (m^3) = Volume of lifeboat empty (m^3)-(Volume of mean occupant (L)*Number of occupants)
All occupants VCO_2 Production ($ml.min^{-1}$) = Number of occupants*Mass of occupants (kg)*Mean VCO_2 of occupants ($ml.kg^{-1}.min^{-1}$)
Volume of lifeboat with people (L) = Volume of free space in lifeboat with people (m^3)*1000
Gas volume in lifeboat with occupants (m^3):
N_2 = (79.04/100)*Volume of free space in lifeboat with people (m^3)
O_2 = (20.93/100)* Volume of free space in lifeboat with people (m^3)
CO_2 = (0.03/100)* Volume of free space in lifeboat with people (m^3)
CO2 calculations:
Volume of CO_2 (L) = All occupants VCO_2 production ($mL.min^{-1}$)/1000)*Time (minutes)

Volume of CO_2 (L) / Lifeboat Volume (L) = Volume of CO2/Volume of Lifeboat with people (m^3)
Volume of CO_2 (m^3) = Volume of CO2 (L)*0.001
Percent CO2 (%) = (Volume of CO2 (m3)/ Volume of free space in lifeboat with people (m3))*100
Total CO2 (ppm) = Percent CO_2 (%)*10000

APPENDIX E: Motion Sickness Questionnaire

Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short)

1. Please State Your **Age** ..... Years. *2.* Please State Your Sex (tick box) **Male** [1] **Female** [2]

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

Your CHILDHOOD Experience Only (before 12 years of age), for each of the following types of transport or entertainment please indicate:

3. **As a CHILD (before age 12),** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Your Experience over the LAST 10 YEARS (approximately), for each of the following types of transport or entertainment please indicate:

4. **Over the LAST 10 YEARS,** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Scoring the MSSQ- Short

Section A (Child) (Question 3)

Score the number of types of transportation not experienced (i.e., total the number of ticks in the 't' column, maximum is 9).

Total the sickness scores for each mode of transportation, i.e. the nine types from 'cars' to 'big dippers' (use the 0-3 number score key at bottom, those scores in the 't' column count as zeroes).

MSA = (total sickness score child) x (9) / (9 - number of types not experienced as a child)

Note 1. Where a subject has not experienced any forms of transport a division by zero error occurs. It is not possible to estimate this subject's motion sickness susceptibility in the absence of any relevant motion exposure.
Note 2. The Section A (Child) score can be used as a pre-morbid indicator of motion sickness susceptibility in patients with vestibular disease.

Section B (Adult) (Question 4)

Repeat as for section A but using the data from section B.

MSB = (total sickness score adult) x (9) / (9 - number of types not experienced as an adult)

Raw Score MSSQ-Short

Total the section A (Child) MSA score and the section B (Adult) MSB score to give the MSSQ-Short raw score (possible range from minimum 0 to maximum 54, the maximum being unlikely)

MSSQ raw score = MSA + MSB

Percentile Score MSSQ-Short

The raw to percentile conversions are given below in the Table of Statistics & Figure, use interpolation where necessary.

Alternatively a close approximation is given by the fitted polynomial where y is percentile; x is raw score
$y = a.x + b.x^2 + c.x^3 + d.x^4$
a = 5.1160923 b = -0.055169904
c = -0.00067784495 d = 1.0714752e-005

Table of Means and Percentile Conversion Statistics for the MSSQ-Short (n=257)

Percentiles Conversion	Raw Scores MSSQ-Short		
	Child Section A	Adult Section B	Total A+B
0	0	0	0
10	.0	.0	.8
20	2.0	1.0	3.0
30	4.0	1.3	7.0
40	5.6	2.6	9.0
50	7.0	3.7	11.3
60	9.0	6.0	14.1
70	11.0	7.0	17.9
80	13.0	9.0	21.6
90	16.0	12.0	25.9
95	20.0	15.0	30.4
100	23.6	21.0	44.6
Mean	7.75	5.11	12.90
Std. Deviation	5.94	4.84	9.90

Table note: numbers are rounded

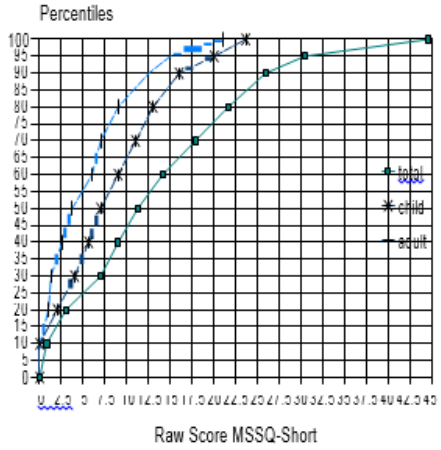

Figure: Cumulative distribution Percentiles of the Raw Scores of the MSSQ-Short (n=257 subjects).

Reference Note

For more background information and references to the original Reason & Brand MSSQ and to its revised version the 'MSSQ-Long', see:
Golding JF. Motion sickness susceptibility questionnaire revised and its relationship to other forms of sickness. **Brain Research Bulletin**, 1998; 47: 507-516.
Golding JF. (2006) Predicting Individual Differences in Motion Sickness Susceptibility by Questionnaire. **Personality and Individual differences, 41:** 237-248.

APPENDIX F: PAR-Q & You Questionnaire

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	2.	Do you feel pain in your chest when you do physical activity?
☐	☐	3.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5.	Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
☐	☐	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7.	Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

→ DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____ DATE _____

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) _____ WITNESS _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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