Effects of water temperature and skin exposure on underwater breath-holding and subsequent minute ventilation by

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A Thesis submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

Faculty of Kinesiology and Recreational Management

University of Manitoba

Winnipeg

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ABSTRACT

Helicopter crashes in cold water present a survival challenge to passengers especially if they are trapped underwater. We tested the effect of varying skin exposure and water temperature on underwater breath-hold time and subsequent minute ventilation.

Twelve subjects (2 female) were studied in 8 and 20°C water while wearing a helicopter transport suit with a dive mask. At each temperature, subjects performed a maximum breath-hold and then breathed for 90 s (through a mouth piece connected to room air) in five skin-exposure conditions. The first trial was out of water for Control (suit zipped up, hood on, mask off). Four submersion trials were then conducted with exposure of the: Partial Face (hood and mask on); Face (hood on, mask off); Head (hood and mask off); and Whole Body (suit unzipped, hood and mask off).

Decreasing temperature and increasing skin exposure reduced breath-hold time (to as low as 10 ± 4 s), generally increased minute ventilation (up to 40 ± 15 L·min⁻¹), and decreased predicted endurance time (PET) of a 55-L Helicopter Underwater Emergency Breathing Apparatus (HUEBA); for example, in 8°C water, PET was 2 min 39 s (Partial Face) and decreased to 1 min 11 s (Whole Body) (P<0.05).

Results have significant applications for education and preparation of helicopter occupants. Thermal protective suits and dive masks should be provided and occupants must wear the suits zipped up with hoods on, and don the dive mask prior to crashing if possible. This will greatly increase survivability.
ACKNOWLEDGEMENTS

First, I will like to thank my advisor, Dr Gordon Giesbrecht for giving me the opportunity to work in his lab. His guidance, support and constant encouragements have helped me gain critical skills and the ability to carry out good research.

I also would like to express my gratitude towards my other committee members: Dr. Heather Carnahan and Dr. Stephen Cornish for their profound contribution and support throughout the study.

My appreciation goes to Keri-Ann Everly and Robert Brown. Their collaboration and support contributed to the success of this study.

A special thanks to my colleagues: Kaitlyn Tymko, Gerren MacDonald and Daryl Hurrie for their enormous contribution in data collection and analysis. I wish you all the best in your future endeavours.

I also want to thank all the 12 subjects that were involved in this study. Despite their busy schedule, they were able to complete all the trials within the desired time frame.

Much appreciation goes to my family, who regardless of the long distance never ceased to show their love and support. And more especially to my husband, Victor, who has been a strong pillar. His constant words of encouragement helped me pull through difficult times.

Finally, all thanks to God almighty for seeing me through to the completion of this project.
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CHAPTER 1: INTRODUCTION
With the ongoing development of offshore oil exploration in the North, the frequency at which oil platform workers fly across cold water has increased (Brooks 1989). Helicopters are the primary means of flying to ocean-based oil platforms. Occasionally, helicopters experience an emergency landing, ditching or outright crash into water (Cheung, D'Eon et al. 2001, Taber and McCabe 2007, Brooks and MacDonald 2017). The fatality rate of passengers following a helicopter ditching or water accident is quite high. Taber and McCabe reviewed a total of 511 helicopter crashes between 1971 to 2005 (Taber and McCabe 2007). These accidents involved 1643 crew and passengers, and the fatality rate was 34%. Similarly, Brooks reported fatality rates for helicopter crashes in water as 23% during the day and 35% at night (Brooks 1989). Sadly, up until now, there has not been significant improvement in survival rates.

Occupants of a crashed helicopter experience several challenges to survival. First, injury on impact may cause death, or incapacitation leading to death due to drowning. Second, since helicopters are inherently stable upside down (due to the location of the engine on top of the passenger compartment), they often roll into an inverted position resulting in total submersion of the occupants (necessitating breath-holding in order to escape), and spatial disorientation. Third, for most of North America and Europe, ocean waters are cold for much of the year (Giesbrecht and Steinman 2017).

Given these challenges, several factors contribute to the high fatality rates of helicopter crashes. One of the reasons for the low survival rate can be attributed to the low altitude from which many helicopter crashes occur (Brooks and MacDonald 2017). As a result, the passengers have little or no time to prepare for landing. Before they realize it, they are submerged in water, often upside down.
The second major reason for the low survival rate is the lack of knowledge of the right procedure for underwater escape following a crash. When the helicopter crashes in water, it usually becomes inverted. Brooks and Macdonald showed that many helicopter occupants are not informed of what to do in the event of a helicopter ditching. Hence, most people remain trapped in an inverted helicopter cabin, and that can lead to death by drowning. The procedure for escaping is first to forcefully open the window and jettison it, hold onto the window sill, undo the seat belt, and then exit through the window (Brooks and MacDonald 2017).

The final and most important reason for low survival rates is limited breath-hold time under water. When a helicopter becomes inverted after a crash, breath-holding is needed to escape successfully. However, breath-hold time is reduced by the cold shock response (Hayward, Matthews et al. 1984, Tipton, Stubbs et al. 1991, Cheung, D'Eon et al. 2001). The cold shock response includes an inspiratory gasp, hyperventilation, tachycardia, increase in blood pressure, increase in minute ventilation and is evoked immediately during cold water submersion and lasts up to one min (Hayward, Matthews et al. 1984, Tipton, Stubbs et al. 1991, Cheung, D'Eon et al. 2001). The cold shock response depends on water temperature, rate of skin cooling and amount of skin exposed (Keatinge and Nadel 1965, Mekjavic, La Prairie et al. 1987). Since most ocean waters in North America and Europe have temperatures <10°C for much of the year (Giesbrecht and Steinman 2017), limited breath-hold ability is a significant risk for occupants of helicopter water landings.

Given that breath-hold reduction by cold water decreases underwater survival time, emergency breathing systems have been developed to solve this problem (Tipton, Balmi et al. 1995). These breathing systems can extend survival time considerably through breathing in of compressed gas from the apparatus (Tipton, Balmi et al. 1995). One example of such a breathing
system is the Helicopter Underwater Emergency Breathing Apparatus (HUEBA). However, the air supply in the apparatus is limited (~55 L) and the length of time it lasts (e.g., endurance time) is inversely related to the rate of minute ventilation ($\dot{V}_E$). Air supply from a HUEBA system needs to be inhaled judiciously in order to maximize survival time. Minute ventilation can be affected by the rate of work and oxygen consumption, excitement, panic (Barwood, Datta et al. 2007), hyperventilation and the cold shock response (Mekjavic and Bligh 1989).

Since the cold shock response decreases breath-hold time and increases minute ventilation, any factors that attenuate this response (e.g., thermal insulation) would favour a longer endurance time for a HUEBA. Thermal protective clothing, such as a helicopter transport suit, minimizes the fall in skin temperature, attenuates the cold shock response, increases breath-hold time and decreases minute ventilation (Tipton, Stubbs et al. 1990).

Currently, there are several models of hooded helicopter transport suits that provide high insulation to the body and head. A dive mask can also be worn on the arm during flight so it can be donned prior to an imminent crash. Thus, it is possible to have full body and head insulation except for the lips and chin. One limitation is that the suits can be very hot and uncomfortable during flight (Light, Gibson et al. 1987). Occupants often “cheat” by leaving the hood off and/or even unzipping the suit in order to cool the body. Unfortunately, any crash scenario with limited preparation time, would prevent doing the zipper up and putting the hood on before impact. This would result in increased skin cooling after the crash and likely decrease breath-hold ability and thus, the chance of survival.

We are unaware of any comprehensive study quantifying the effects of cold water and the amount of exposed skin on both breath-hold time and subsequent minute ventilation with the head completely submersed under water.
Purpose

The purpose of the study was to examine the effect of water temperature and skin exposure on breath-hold time and subsequent minute ventilation, and to predict endurance time of a compressed air source (e.g., HUEBA).

Hypothesis

We hypothesized that more skin exposure and colder water temperature would decrease breath-hold time, increase subsequent minute ventilation and decrease predicted endurance time of a HUEBA device.
CHAPTER 2: REVIEW OF LITERATURE
This review of literature will focus on the cold shock response as a major factor that leads to low survival rate in cold water submersion. It will provide a summary of current and relevant studies that have discussed ways of attenuating this response in order to extend underwater survival time. For the purpose of this project, “immersion” refers to the airways being above water, and “submersion” refers to the airways being below water.

**Helicopter Ditching**

The Civil Aviation Authority (CAA) and the Federal Aviation Administration (FAA) defined helicopter ditching as a controlled emergency water-landing of a helicopter which has functional control systems but failed engine(s) (Authority 1995, Administration 2002). Engine failures can be due to mechanical errors (Brooks 1989, Taber and McCabe 2007). Brooks reported that helicopter ditchings have higher chances of occurring during critical phases of the flight such as during take offs and landing with little or no warning time (Brooks 1989). Furthermore, Taber and McCabe reviewed 511 helicopter ditchings which occurred between 1971 to 2005 (Taber and McCabe 2007). They reported that when helicopters get inverted and sink, survivability is significantly reduced.

The main problem with helicopter ditching is that the helicopter often becomes inverted when it crashes into the water (Brooks 1989, Taber and McCabe 2007). As a result, the passengers are likely to be trapped, and faced with very low chances of survival. Brooks further reported that when a helicopter accident happens during the day, 23% will not survive, and if it occurs at night the fatality rate increases to 35% (Brooks 1989). This increased fatality rate is compounded by the fact that the accident rate (per 100,000 hours of flight) is more than five times higher at night than during the day (Brooks and MacDonald 2017).
**Immersion in Water**

In order to better understand reasons for the low survival rate, it is essential to know the physiological responses that occur when a person is suddenly submerged in water. Submersion into both cold and thermoneutral water poses a threat to the cardiovascular and respiratory systems. Studies have shown that patients who suffer from cardiovascular or respiratory diseases are at a higher risk during water immersion (Brooks and MacDonald 2017). Immersion in water leads to redistribution of blood to the thoracic region as a result of external hydrostatic pressure on the limbs (Lin 1984, Mekjavic and Bligh 1989). Datta and Tipton reported that this increase in thoracic blood volume competes with air for space, reducing functional residual capacity and further results to 65% increase in work of breathing (Datta and Tipton 2006). These changes in lung functions pose more threat to individuals with respiratory and cardiovascular diseases.

**The Cold Shock Response**

Most accidental immersions occur in cold water because water bodies, especially northern oceans, have temperatures lower than 10°C (Giesbrecht and Steinman 2017). Previously, most drowning incidents were attributed to hypothermia. However, recent studies have shown that the cold shock response is a major precursor to ingesting water and drowning (Tipton 1989, Tipton, Stubbs et al. 1991). The cold shock response is responsible for the 400-1000 open-water immersion deaths that occur in the UK yearly (Tipton 1989). The threat is greatest during the first 20 to 30 s of immersion but can last up to 2-3 min (Tipton, Stubbs et al. 1991). It is characterized by an inspiratory gasp, hyperventilation, tachycardia, increase in cardiac output, and increase in blood pressure (Keatinge and Nadel 1965, Cooper, Martin et al. 1976, Tipton and Golden 1987, Tipton and Vincent 1989) and is controlled by the sympathetic nervous system (Tipton, Gibbs et al. 2010, Shattock and Tipton 2012). These studies suggest
that this response may be evoked by the reflex stimulation of the cutaneous cold receptors in response to rapid skin cooling.

**Physiological Effects of the Cold Shock Response**

**Reduction in Breath-hold Time**

Breath-hold is very necessary for underwater survival from an inverted helicopter cabin. Barwood et al. described breath-hold as the ability of consciously suppressing one's respiratory drive (Barwood, Datta et al. 2007). During breath-holding, the body reaches a state of hypoxia and hypercapnia; the breaking point occurs when the body can no longer tolerate hypercapnia (Jay and White 2006). However, studies have shown that the cold shock response decreases breath-hold time long before the victim reaches the breath-hold breaking point. Due to the inspiratory gasp and the increase in respiratory drive, breath-hold time decreases during cold water submersion, hence decreasing the survival time (Cheung, D'Eon et al. 2001). Hayward et al. demonstrated that decreasing water temperature from 15 to 0°C reduced breath-hold duration in uninsulated subjects during whole body and head submersion (Hayward, Matthews et al. 1984). A study by Tipton and Vincent reported the adverse effect of the cold shock response on breath-hold as they compared breath hold duration in the air and during head-out immersion in cold water. The maximum breath-hold time observed in 18 normally clothed subjects fell from 45 s in the air to 9.5 s in 5°C cold water (Tipton and Vincent 1989). Furthermore, Cheung et al. demonstrated an attenuation in breath-hold time in colder water temperatures. They noted that breath-hold in cold water is decreased by up to 80% especially when the temperature is less than 15°C (Cheung, D'Eon et al. 2001). They further reported that 34% of the subjects were unable to hold their breath for up to 28 s in water, which they estimated as a minimum time required to survive an underwater escape.
Increase in Minute Ventilation

The inspiratory gasp evoked by the cold shock response increases minute ventilation during cold water submersion (Datta and Tipton 2006). Keatinge and Evans found that minute ventilation increased by a factor of 4 during the first min of exposure in a head-out immersion in 2°C water (Keatinge and Evans 1961). A study conducted by Tipton and Golden (1987) also observed that the inspiratory gasp led to inhaling about 2-3 liters of air within the initial seconds of immersion followed by a 10-fold increase in minute ventilation (Tipton and Golden 1987). This increase in minute ventilation is also thought to be as result of the increase in the rate of skin cooling and respiratory drive (Keatinge and Nadel 1965, Mekjavic, La Prairie et al. 1987) and believed to be a reflex initiated by the cold receptors in the skin and mediated at the midbrain (Keatinge and Nadel 1965).

Water temperature has been found to have an effect in the increase in minute ventilation during the first few min of immersion. Tipton examined minute ventilation in five male subjects immersed to the neck at water temperatures of 10, 15 and 20°C. Results from the study showed an inverse relationship between water temperature and minute ventilation; minute ventilation was found to be lowest in 20°C water (Tipton 1992). This observation is consistent with another study by Tipton et al. which reported a lower breathing rate in water temperature of 15°C in comparison to water temperatures of 5 and 10°C (Tipton, Stubbs et al. 1991). The observed rate of breathing in 15°C suggests that it is easier to suppress respiratory drive in warmer temperatures and consequently decrease minute ventilation.
Tachycardia

Cooper et al. recorded an increase in heart rate when 15 naked subjects breathing normally performed a head-out immersion in 10 and 27°C water. They recorded a greater increase in heart rate of 20 bpm in 10°C water (Cooper, Martin et al. 1976). This suggests that greater cold exposure increases heart rate. This increase is also believed to be due to the reflex stimulation of the sympathetic nervous system as a result of rapid falls in skin temperature. This finding is consistent with results from other studies (Goode, Romet et al. 1975, Tipton and Golden 1987, Tipton and Vincent 1989). Conversely, Hayward et al. observed that heart rate was unaffected by water temperature or cold exposure when 160 subjects holding their breath were submerged in water temperatures from 0 to 35°C (Hayward, Matthews et al. 1984). The presence of breath-hold led to diving bradycardia (slower than normal heart rate) and attenuated the effect of the cold shock response.

The Effect of Sex

The increase in minute ventilation has been found to be sex dependent. There is evidence that demonstrates a difference in minute ventilation between men and women. Malkinson et al. reported a 35% smaller increase in minute ventilation in women than men in cold water during the first 0.5 minutes of a head-out immersion (Malkinson, Martin et al. 1981). They found that the difference observed could be as a result of differences in some pulmonary functions between male and female and could also be due to the type of swimming wear that was worn. The females wore either two-piece or one-piece full-length swim suits, while the males mainly wore boxers. On the other hand, it has been observed that sex does not influence the cold shock response and breath-hold during cold water immersion. Jay and White compared the breath-hold times between male and female subjects of similar pulmonary capacities, body mass,
height and age, during a sudden face only immersion in a wide range of water temperatures from 0 to 33°C. Results showed that sex did not affect breath-hold capabilities (Jay and White 2006). The breath-hold times were similar in both groups and generally dropped as the temperature decreased.

**The Dive Response**

The dive response is an initial response that prolongs survival time under water. It achieves this by conserving oxygen for the brain through reducing blood flow to cutaneous, muscular and splanchnic circulations (Panneton 2013). It is more pronounced in diving mammals and birds. This response is mediated by the parasympathetic nervous system and characterized by decreased heart rate (bradycardia), decreased cardiac output and vasoconstriction which redirects blood flow to the central nervous system and the heart (Panneton 2013). It is a reflex stimulation of the ophthalmic division of the trigeminal nerve during face immersion and also evoked during breath-holding (Mukhtar and Patrick 1986, Tipton, Gibbs et al. 2010, Panneton 2013). Mukhtar and Patrick found that breath-hold times of 14 subjects, who lay prone and performed face immersion in 13°C water, were increased by 14% (Mukhtar and Patrick 1986). It was then concluded that face immersion which is a component of the dive response reduces ventilatory drive, therefore increasing breath-hold times. A study by Tipton found that the dive response is likely not to be evoked during the first few min of head-out immersion in cold water because the cold shock response decreases the ability to breath-hold, thus the dive response is less pronounced during rapid cooling of the cutaneous cold receptors (Tipton 1989). Furthermore, studies have also shown that oxygen sparing during the dive response is stronger when breath-holding is in water compared to air (Marabotti, Piaggi et al. 2013). It is important to note that during naked submersion, the cold shock response
predominates and during submersion with immersion suits the dive response predominates 
(Tipton, Gibbs et al. 2010).

Cardiac Arrythmias

Tipton et al. observed cardiac arrhythmias in 26 male volunteers who partook in five Helicopter Under Water Escape Training submersions in 29.5°C water (Tipton, Gibbs et al. 2010). They found that the combined actions of the dive response and the cold shock response could be detrimental in some vulnerable individuals. This finding suggests that the cold shock response might not be the only response that contributes to drowning. The speed at which the cold shock and dive responses are evoked within a short period of immersion suggests they are controlled by the autonomic nervous system (Tipton, Gibbs et al. 2010, Shattock and Tipton 2012), and have been categorized as antagonistic in nature. The sympathetic nervous system controls the cold shock response while the parasympathetic nervous system controls the dive response (Tipton, Gibbs et al. 2010, Shattock and Tipton 2012). It was found that the simultaneous activation of both arms of the autonomic nervous system causes cardiac arrhythmias which may be a precursor to death during immersion (Tipton, Gibbs et al. 2010).

Factors that Modify the Cold Shock Response

As has been stated earlier, breath-hold is essential for survival, and there is evidence to show that cold water reduces its duration. However recent studies have discovered ways of attenuating the cold shock response; thereby, potentially extending under water breath-hold time.

Habituation

A few studies have shown that habituation reduces the cold shock response and improves breath-hold time (Hayward, Matthews et al. 1984, Tipton, Eglin et al. 1998, Barwood,
Datta et al. 2007). Hayward et al. found that habituation (2-3 min of immersion to the neck) and mild voluntary hyperventilation, more than doubled breath-hold time for all water temperatures ranging from 0 to 35°C (Hayward, Matthews et al. 1984). Barwood et al. further demonstrated the positive effects of habituation on breath-hold time in 20 male subjects during two 2.5-min head-out cold water immersions. Breath-hold time increased by 73% during the second cold water immersion (Barwood, Datta et al. 2007). These results confirm that repeated cold exposure reduces the respiratory drive thereby prolonging breath-hold time. Tipton et al. during a three min head-out immersion in 10°C water reported that the mechanisms governing habituation are centrally located (Tipton, Eglin et al. 1998)

Psychological Training

Psychological training has also been found to increase breath-hold time. Barwood et al. conducted two 2.5-min head-out immersions in 11°C water and found that breath-hold time was increased by 80% when subjects were exposed to psychological training before immersion (Barwood, Dalzell et al. 2006). The effects of psychological training and habituation are additive. Barwood et al. observed that habituation increased breath-hold time by 73% and the addition of psychological training to habituation further increased breath-hold time by 47% (Barwood, Datta et al. 2007).

Clothing and Thermal Protection

Protective clothing worn by helicopter occupants on flights over cold water is essential for survival in the event of helicopter ditching. Most studies have shown that protective clothing can extend the breath-hold time by attenuating the cold shock response and the fall in skin temperature (Tipton and Vincent 1989, Tipton, Stubbs et al. 1990). Earlier studies have focused
on establishing proper clothing that can prevent a decrease in core temperature and by extension hypothermia (Hayward 1984, Tipton 1991). However, the cold shock response occurs immediately and long before a drop-in core temperature and hypothermia, which generally sets in during immersion longer than 30 min (Hayward 1984, Tipton 1991). Hence, to increase survivability, attention has been shifted to clothing that provides thermal protection against the cold shock response rather than hypothermia.

A few studies have compared the effect of exposing certain areas of the body to cold (Tipton and Golden 1987, Burke and Mekjavic 1991) and found that respiratory drive and minute ventilation during the first min of a head-out immersion were highest in the whole body exposure condition compared to the torso and limb exposure conditions (Tipton and Golden 1987, Burke and Mekjavic 1991). Some studies have also compared the minute ventilation of subjects in whole body exposure and regular clothing conditions during a head-out immersion in 10 and 14°C water and found that minute ventilation was lower in the clothing condition (Martin, Diewold et al. 1978, Mekjavic, La Prairie et al. 1987). This confirms that clothing attenuates the cold shock response by reducing the amount of skin cooling.

It is also important to note that different clothing ensembles provide different levels of thermal protection. Tipton and Vincent compared the protection provided by cotton overall, trunk-and-arm wet suit and a full dry suit during a 2-minute head-out immersion in 5°C water (Tipton and Vincent 1989). They observed increased breath-hold time and lower minute ventilation in the dry suit during the first 2 minutes of immersion. This observation is consistent with another study which compared the effects of different clothing and skin exposure to initial responses to cold water immersion. The authors conducted three 2-min head-out immersions in 10°C water and examined the effect of swimming trunks, conventional clothing, and windproof
clothing (Tipton, Stubbs et al. 1990). Lower skin temperature, higher respiratory frequency and minute ventilation were recorded in the swimming trunk group compared to the other clothing ensembles because there was more skin exposure in that condition.

Whereas dry immersion suits provide more thermal protection than wet suits and regular clothing and thus are more likely to increase survivability, (Stewart, Ledingham et al. 2017) identified buoyancy to be a factor that can limit the ease of movement in water and by extension underwater escape. Air trapped inside the suit increases buoyancy and needs to be expelled in order to enhance movement. They found that the ease at which the air is expelled depends on the design of the suit, tightness of fit, location of air pockets and body orientation inside the suit. To enhance the usefulness of a survival suit under water, it is important to design the suit to be well vented, in order to minimize the amount of trapped air, and at the same time provide thermal protection from the cold shock response (Stewart, Ledingham et al. 2017).

**Emergency Underwater Breathing Apparatus**

Apart from breath-holding in cold water, using an emergency underwater breathing apparatus is another way of increasing survival time. Earlier studies have confirmed that breath-hold is often not sufficient enough to enable successful underwater escape (Tipton et al. 1995; Tipton et al. 1997). Tipton and Vincent and Cheung et al. estimated successful evacuation time to be between 28 to 60 s (Tipton and Vincent 1989, Cheung, D'Eon et al. 2001). However, the average breath-hold time of a resting individual submerged in water at 5°C can be as low as 9 s and hence not sufficient to make an underwater escape (Tipton and Vincent 1989). For this reason, Emergency Underwater Breathing Apparatus (EUBA), also referred to as HUEBA, has been introduced to extend the underwater escape time from an inverted helicopter (Tipton, Balmi et al. 1995). There are two types of EUBA: an air pocket rebreather; and a Self-Contained
Underwater Breathing Apparatus (SCUBA). It has been established that these two types of EUBA extend survival time. Two studies by Tipton et al. reported that introducing an air pocket rebreather can increase survival time by 2-3 times, while a compressed gas system increases survival time considerably more (Tipton, Balmi et al. 1995, Tipton, Franks et al. 1997).

Moreover, it is also important to note that the cold shock response reduces the length of time a HUEBA can last (also known as the endurance time). There is an inverse relationship between the cold-induced increase in minute ventilation and the endurance time of a HUEBA. Therefore, factors that decrease the cold shock response should increase the endurance time of a HUEBA.

Summary

Literature about initial responses during immersion in cold water is vast and this topic has been well-studied. Studies indicate that breath-hold time is reduced as water temperature decreases. Many studies have addressed the problem of breath-hold reduction and increase in average minute ventilation by demonstrating ways in which it can be improved. Protective clothing, such as a helicopter transport suit, attenuates the cold shock response thereby increasing breath-hold time (Tipton and Vincent 1989, Cheung, D'Eon et al. 2001). However, due to the warm helicopter environment and the possibility of these suits being impermeable to sweat vapor, many passengers during flight wear the suit with the hood off, or with the chest zipper partially or fully unzipped (Light, Gibson et al. 1987). Under these conditions, if an accident occurs, the skin becomes exposed to cold water and would therefore stimulate an intense cold shock response, reducing breath-hold time and increasing subsequent minute ventilation; and will ultimately decrease the endurance time of a HUEBA.
On the other hand, there is paucity of studies measuring subsequent peak minute ventilation following breath-hold during a whole body submersion while varying skin exposure and water temperature. The majority of previous studies (Tipton and Golden 1987, Tipton and Vincent 1989, Tipton, Stubbs et al. 1990) measured average minute ventilation without prior breath-holding by the subjects. As well, these studies were mostly done in a head-out immersion while varying either water temperature or skin exposure.

The present study focuses on how different skin exposure conditions and water temperature can affect underwater breath-hold time and subsequent minute ventilation; the latter factor directly affects the endurance time of a HUEBA device. The knowledge acquired from this present study will demonstrate how progressive skin exposure affects underwater breath-hold time, subsequent minute ventilation and the endurance time of a HUEBA device.

**Research Questions**

1. In 8°C water, what effects do the following suit conditions have on underwater breath-hold time and subsequent minute ventilation?
   a. Suit zipped, hood on, mask on (partial-face exposed; PF)
   b. Suit zipped, hood on, mask off (face exposed; F)
   c. Suit zipped, hood off, mask off (head exposed; H)
   d. Suit unzipped, hood off, mask off (whole body exposed; WB)

2. How does this change in warm 20°C water?
CHAPTER 3: STUDY MANUSCRIPT

(submitted for publication, February 11, 2019)
Abstract

**Purpose** Helicopter crashes in cold water present a survival challenge to passengers especially if they are trapped underwater. We tested the effect of varying skin exposure and water temperature on underwater breath-hold time and subsequent minute ventilation.

**Methods** Twelve subjects (2 female) were studied in 8 and 20°C water while wearing a helicopter transport suit with a dive mask. At each temperature, subjects performed a maximum breath-hold and then breathed for 90 s (through a mouth piece connected to room air) in five skin-exposure conditions. The first trial was out of water for Control (suit zipped up, hood on, mask off). Four submersion trials were then conducted with exposure of the: Partial Face (hood and mask on); Face (hood on, mask off); Head (hood and mask off); and Whole Body (suit unzipped, hood and mask off).

**Results** Decreasing temperature and increasing skin exposure reduced breath-hold time (to as low as 10 ± 4 s), generally increased minute ventilation (up to 40 ± 15 L·min⁻¹), and decreased predicted endurance time (PET) of a 55-L Helicopter Underwater Emergency Breathing Apparatus (HUEBA); for example, in 8°C water, PET was 2 min 39 s (Partial Face) and decreased to 1 min 11 s (Whole Body) (P<0.05).

**Conclusion** Results have significant applications for education and preparation of helicopter occupants. Thermal protective suits and dive masks should be provided and occupants must wear the suits zipped up with hoods on, and don the dive mask prior to crashing if possible. This will greatly increase survivability.
Keywords

Helicopter underwater emergency breathing apparatus; HUEBA; helicopter crash; cold water submersion; drowning; cold shock response
### Abbreviations

<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
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<td>BHT</td>
<td>Breath-hold time</td>
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<td>F</td>
<td>Face</td>
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<td>H</td>
<td>Head</td>
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<td>HUEBA</td>
<td>Helicopter Underwater Emergency Breathing Apparatus</td>
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<tr>
<td>MSS $\dot{V}_E$</td>
<td>Mean Steady State Minute Ventilation</td>
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Introduction

With the ongoing development of offshore oil exploration in the North, the frequency at which oil platform workers fly across cold water has increased (Brooks 1989). Helicopters are the primary means of flying to ocean-based oil platforms. Occasionally, helicopters experience an emergency landing, ditching or outright crash into water (Cheung, D'Eon et al. 2001, Taber and McCabe 2007, Brooks and MacDonald 2017). The fatality rate of passengers following a helicopter ditching or water accident is quite high. Taber and McCabe reviewed a total of 511 helicopter crashes between 1971 to 2005 (Taber and McCabe 2007). These accidents involved 1643 crew and passengers, and the fatality rate was 34%. Similarly, Brooks reported fatality rates for helicopter crashes in water as 23% during the day and 35% at night (Brooks 1989). Sadly, up until now, there has not been significant improvement in survival rates.

Occupants of a crashed helicopter experience several challenges to survival. First, injury on impact may cause death, or incapacitation leading to death due to drowning. Second, since helicopters are inherently stable upside down (due to the location of the engine on top of the passenger compartment), they often roll into an inverted position resulting in total submersion of the occupants (necessitating breath-holding in order to escape), and spatial disorientation. Third, for most of North America and Europe, ocean waters are cold for much of the year (Giesbrecht and Steinman 2017).

Given these challenges, several factors contribute to the high fatality rates of helicopter crashes. First, many crashes occur from a low altitude (Brooks and MacDonald 2017). As a result, occupants have little or no time to prepare for landing or subsequent survival actions. Before they realize it, they have impacted the water and are submerged, often upside down.
Second, many helicopter occupants lack knowledge of, or training in, the correct procedure for underwater escape following a crash. The correct action sequence is to remain in the seat restraints, forcefully open the window and jettison it, hold onto the window sill, then unfasten the seat restraints, and exit through the window. Brooks and MacDonald showed that many helicopter occupants are not informed of what to do in the event of a helicopter ditching (Brooks and MacDonald 2017). Hence, many occupants remain trapped in the inverted helicopter cabin and drown.

The final significant factor is limited breath-hold time under water. If a helicopter is inverted after a crash, breath-holding is required to escape successfully. Normally breath-hold time is limited, but it is reduced significantly in cold water by the cold shock response (Hayward, Matthews et al. 1984, Tipton, Stubbs et al. 1991, Cheung, D'Eon et al. 2001). The cold shock response includes an inspiratory gasp (the gasp reflex), hyperventilation, tachycardia, increase in blood pressure and increase in minute ventilation. It is evoked immediately during cold water submersion and lasts up to one minute (Hayward, Matthews et al. 1984, Tipton, Stubbs et al. 1991, Cheung, D'Eon et al. 2001). The cold shock response depends on water temperature, rate of skin cooling and amount of skin exposed (Keatinge and Nadel 1965, Mekjavic, La Prairie et al. 1987). Since most ocean waters in North America and Europe have temperatures <10°C for much of the year (Giesbrecht and Steinman 2017), limited breath-hold ability is a significant risk for occupants of helicopter water landings.

Given that breath-hold reduction by cold water decreases underwater survival time, underwater emergency breathing systems have been developed to help solve this problem (Tipton, Balmi et al. 1995, Tipton, Franks et al. 1997). These systems can extend survival time considerably by providing a compressed air source for breathing while submersed. One example
of such a breathing system is the Helicopter Underwater Emergency Breathing Apparatus (HUEBA). The air supply in this apparatus is limited (~55 L) and the length of time it lasts (e.g., endurance time) is inversely related to the rate of minute ventilation ($\dot{V}_E$). Minute ventilation depends on factors such as physical exertion (increase in oxygen consumption), psychological factors (panic, excitement) (Barwood, Corbett et al. 2017) and the cold shock response (Mekjavic and Bligh 1989).

Since the cold shock response decreases breath-hold time and increases minute ventilation, any factors that attenuate this response (e.g., thermal insulation) would favour a longer endurance time for a HUEBA. Thermal protective clothing, such as a helicopter transport suit, minimizes the fall in skin temperature, attenuates the cold shock response, increases breath-hold time and decreases minute ventilation (Martin, Diewold et al. 1978, Tipton, Stubbs et al. 1990).

Currently, there are several models of hooded helicopter transport suits that provide high insulation to the body and head. A dive mask can also be worn on the arm during flight so it can be donned prior to an imminent crash. Thus, it is possible to have full body and head insulation except for the lips and chin. One limitation is that the suits can be very hot and uncomfortable during flight (Light, Gibson et al. 1987). Occupants often “cheat” by leaving the hood off and/or even unzipping the suit in order to cool the body. Unfortunately, any crash scenario with limited preparation time, would prevent doing the zipper up and putting the hood on before impact. This would result in increased skin cooling after the crash and likely decrease breath-hold ability and thus, the chance of survival.

We are unaware of any comprehensive study quantifying the effects of cold water and the amount of exposed skin on both breath-hold time and subsequent minute ventilation with the
head completely submerged under water. The purpose of the study was to examine the effect of water temperature and skin exposure on breath-hold and subsequent minute ventilation, and to predict endurance time of a compressed air source (e.g., HUEBA). We hypothesized that more skin exposure and colder water temperature would decrease breath-hold time, increase subsequent minute ventilation and decrease predicted endurance time of a HUEBA device.

**Methods**

Subjects wore a helicopter transport suit and had a dive mask. After conducting a control breath-hold trial, they then entered either cold (8°C) or warm (20°C) water. At each water temperature, they submerged themselves and conducted breath-hold trials under each of four conditions with different amounts of skin exposure.

**Subjects**

Twelve healthy subjects (2 female) participated after providing written consent. The protocol was approved by the Education, Nursing, Research Ethics Board at the University of Manitoba.

**Instrumentation and Materiel**

Subjects were fitted with a helicopter transport suit (Survitec Group, Birkenhead, UK) and a dive mask (see Figure. 1). The dry suit has an inner and outer layer with an inflatable collar which remained uninflated throughout the experiment. They wore regular socks, pants and shirt as well as two sets of gloves; one knit glove was covered by a rubber glove which did not provide a waterproof seal for the hand.
Figure 1. The Helicopter Transport Suit: (Left) Inner layer, (Middle) Outer layer, (Right) Inflatable collar

Minute ventilation was measured using a metabolic cart (Parvo Medics, Utah). Throughout each breath-hold trial, subjects breathed through a mouthpiece attached to a Hans Rudolph two-way non-rebreathable T-shaped valve which was connected via tubing to room air (inspiratory) and the metabolic cart (expiratory). This configuration allowed underwater, post breath-hold breathing. Each session lasted for a total of ~40 min. Since it was difficult to use the mouthpiece for this entire period, a system was designed to rapidly switch from the mouthpiece to a facemask when subjects exited the water between breath-hold trials. The facemask was connected to a similar two-way valve, thus airflow could be directed through either the mouthpiece or facemask.

Heart rate was collected throughout with a transmitter (Polar H7 Bluetooth) and recorded on a smart phone (Wahoo Fitness app) which was placed in a waterproof bag under the transport suit.
After donning the transport suit, subjects were asked to climb into a tank of either 8 or 20°C water. The water level was 1.2 m high. A platform was placed 0.4 m above the water surface for subjects to sit on between breath-hold trials. A ladder was used to climb in and out of the tank. Appropriate weights were added (on a weight belt and in a thigh pocket) to allow subjects to fully submerge without effort.

At the end of each breath-hold trial, subjects sat on the platform and were asked to rate how cold they felt, during the previous submersion using a Whole Body Cold Discomfort Scale (e.g., 0 = no cold sensation, to 10 = unbearably cold; responses were not limited to whole number values but could be given to a precision of 0.5).

**Protocol**

Familiarization Session

During the first laboratory visit each subject was fitted with the right sized suit, dive mask and facemask for the metabolic cart. They stood in the tank of 20°C water and were given the mouthpiece. Then they submerged their head completely under water and breathed through the mouthpiece until they became comfortable. Next, they took a deep breath and submerged, this time while holding their breath. Once they could no longer hold their breath, they breathed through the mouthpiece while still underwater. They repeated this until there was a constant breath-hold time (to eliminate any learning/practice effect).

Experimental Sessions

During sessions two and three (separated by a minimum of 48 h), the subjects were submerged in either cold (8°C) or warm (20°C) water. The order of water temperatures was balanced. In each trial, there were five exposure conditions which varied the amount of skin
contacting the water. The first condition required sitting on the platform above the water with suit zipped and hood on (no exposure, Control). The remaining trials required submersion in four exposure conditions: suit zipped, hood and mask on (partial-face exposed; PF); suit zipped, hood on, mask off (face exposed; F); suit zipped, hood and mask off (head exposed; H); suit unzipped, hood and mask off (whole body exposed; WB). In the cold-water condition, before the breath-hold trials were conducted subjects practiced breathing underwater with the suit zipped up and hood on (first with the dive mask on and then with the dive mask off).

The order of the submersion conditions followed a modified balanced design; the PF, F and H conditions were balanced, and the WB condition was last for every session. For each subject, the order was the same for both warm- and cold-water sessions. WB was last for all subjects because in this condition the body became wet and cold. If WB was not done last, the breath-hold time in subsequent conditions might be affected, as the body would already be cold. Also, if WB occurred during the first three submersions, subjects would have to exit, doff the wet suit, dry off, warm up, and then don another dry transport suit. With this strategy subjects would have to fully exit the tank, and doff and don their suit(s) between each submersion in order to maintain between-submersion consistencies; this would require an inordinate amount of time.

In every breath-hold trial, subjects breathed normally, took one deep breath (avoiding hyperventilation), held their breath as long as possible, and then breathed through the mouthpiece for 90 s. At the beginning of each session, subjects sat on the platform with the suit zipped and hood on, and performed a Control breath-hold. In the remaining submersion trials, subjects held their breath while kneeling on the bottom of the tank. They remained underwater
for the 90-s post breath-hold breathing; an audible signal informed them every 30 s during this period.

There was a 5-min break between submersions. During each break, subjects sat on the platform above the water, breathed through the mouth piece for 1 min, then through a face mask for 3 min, and switched back to the mouth piece for the final min. This protocol enabled continuous respiratory and metabolic measurements throughout the entire session, while relieving the subject from the strain of breathing through a mouth piece for an extended period of time (38-40 min). After every breath-hold trial in the water, subjects were shown the Whole Body Cold Discomfort Scale and asked to provide a response. At the end of the cold-water session, subjects were warmed in 40°C water.

Data Analysis

The following parameters were determined: breath-hold time, change in heart rate during each breath-hold, peak $\dot{V}_E$, mean steady state $\dot{V}_E$, time to steady state $\dot{V}_E$, and predicted endurance time for the HUEBA system in the post-breath-hold period.

Breath-hold time (BHT) was determined manually from the end of the large inspiration to the beginning of the next inspiration; this corresponds to the time the head could be under water. Change in heart rate was the difference from the start of breath-hold to the lowest value during the breath-hold.

Peak $\dot{V}_E$ was the highest value recorded in the post breath-hold period. Mean steady state (MSS) $\dot{V}_E$ was determined as follows: visual inspection of the graph of $\dot{V}_E$ over time was used to estimate the point at which post breath-hold ventilation no longer decreased and leveled off. Data from this point to the end of the post breath-hold period (up to 90 s) was then
averaged. Then, time to steady state (TSS) $\dot{V}_E$ was defined as the first point at which $\dot{V}_E$ decreased to the mean steady state value.

Predicted endurance time (PET) was then calculated for the HUEBA system (for a standard air volume of 55 L) as follows: First, the cumulative air volume consumed during the post breath-hold period was calculated by adding tidal volumes from each breath during that period (e.g., up to 90 s). The following equation was then applied.

$$\text{PET (min)} = \text{PBH time (min)} + \left[\text{HUEBA volume (L)} - \text{PBH volume (L)}\right] \cdot \left[\text{MSS} \cdot \dot{V}_E \text{ (L min}^{-1})\right]^{-1};$$

where PBH = post breath-hold, and HUEBA volume = 55 L.

All statistical analyses were accomplished with the SigmaStat package within SigmaPlot 14. For heart rate in each condition, a paired t-test was used to compare the heart rates at the start of breath-hold with the lowest heart rates during breath-hold; this determined whether the change in heart rate during breath-hold was significant. Repeated measures two-way analysis of variance (ANOVA) (factor A, skin exposure; factor B, water temperature) then compared the change in heart rate during breath-hold, and the other physiologic variables. This analysis was also applied to the Whole Body Cold Discomfort Scale. Since this scale has 21 points (0-10 with increments of 0.5), results were treated as interval data, therefore justifying a parametric analysis (Knapp 1990). Post hoc analyses for significant differences were accomplished using the Holm-Sidak test. Statistical significance was set at ($P < 0.05$). All data are expressed as mean ± SD.

**Results**

Subjects were 29 ± 10 years old, weighed 78 ±14 kg, and were 177 ±7 cm tall. In one whole body exposure trial, the amount of water entering the suit was determined by adding the
weight of water drained from the helicopter suit to the weight difference of the suit ensemble before and after submersion. In this trial, 13.7 L of water entered the suit.

**Breath-hold Time**

For BHT (Figure. 2), there was statistical significance for exposure condition (P < 0.001) temperature (P < 0.001) and interaction (P = 0.029). In all submersion conditions, BHT was shorter in cold water by 12-19 s (P < 0.001). In both water temperatures, submersion decreased BHT compared to control (P < 0.001). In both water temperatures, BHT was significantly lower in WB than all other conditions (P < 0.001). The only significant difference between the PF, F and H conditions was between PF and H in cold water (P < 0.05). Partial face immersion in cold water decreased breath-hold time from 52 ± 17 s (Control) to 33 ± 14 s. Breath-hold time further decreased to 10 ± 4 s in the whole body condition.
Figure 2. Mean breath-hold time for all exposure conditions in cold (8°C) and warm (20°C) water. Blue circles denote 8°C cold water and the red triangles denote 20°C warm water (n=12). Vertical bars, standard deviation; * indicates significant differences between water temperatures (P < 0.05). Horizontal brackets indicate differences between exposure conditions (P < 0.05); bracket colors correspond to water temperature symbols of the same color. Control (out of water, suit zipped and hood on); Partial Face (hood and mask on); Face (hood on and mask off); Head (hood and mask off); and Whole Body (suit unzipped, hood and mask off)

**Change in Heart Rate during Breath-hold**

For several WB trials, heart rate data collection was interrupted when water entered the suit; therefore, all WB data were withdrawn from the analysis. Additionally, data collection failed for one or more of the PF, F or H conditions for some subjects. Therefore, heart rate data was only analyzed for five subjects for whom complete data was available for Control, PF, F and H conditions for both water temperatures. Heart rate decreased significantly during the breath-
hold in all control and exposure/temperature conditions (P < 0.001). This decrease was not significantly different between any conditions (the decrease ranged from 21 ± 15 to 32 ± 19 beats min⁻¹). Thus, there were no statistical differences in the decrease in heart rate during breath-hold for any exposure condition, temperature, or interaction (P = 0.9).

**Peak Minute Ventilation Post Breath-hold**

For peak $\dot{V}_E$ (Figure 3, top), there was statistical significance for exposure condition (P < 0.001) but not for temperature (P = 0.68) or interaction (P = 0.70). Peak $\dot{V}_E$ immediately post breath-hold was unaffected by water temperature, but increased with increased skin exposure in both water temperatures. In warm water, peak $\dot{V}_E$ was significantly greater in WB (79 ± 43 L·min⁻¹) than Control (47 ± 22 L·min⁻¹) (P < 0.001) and PF (P < 0.01). In cold water, peak $\dot{V}_E$ was significantly greater in WB (86 ± 43 L·min⁻¹) than Control (45 ± 23 L·min⁻¹) and all other exposure conditions (P < 0.02).

**Mean Steady State Ventilation**

For mean steady state $\dot{V}_E$ (Figure 3, bottom), there was statistical significance for exposure condition (P < 0.001) temperature (P < 0.001) and interaction (P < 0.001). MSS $\dot{V}_E$ was higher in cold water in H and WB conditions (P < 0.005). MSS $\dot{V}_E$ increased from Control to WB in both warm water (14 ± 4 to 22 ± 6 L·min⁻¹) (P < 0.02) and in cold water (14 ± 4 to 40 ± 16 L·min⁻¹) (P < 0.05).
Figure 3, top. Mean peak minute ventilation post breath-hold breathing period (up to 90 s); bottom. Mean steady state ventilation for all exposure conditions in cold (8°C) and warm (20°C) water (n=12). Blue circles denote 8°C cold water and the red triangles denote 20°C warm water. Vertical bars, standard deviation; * indicates significant differences between water temperatures (P < 0.05). Horizontal brackets indicate differences between exposure conditions (P < 0.05); bracket colors correspond to water temperature symbols of the same color. Control (out of water, suit zipped and hood on); Partial Face (hood and mask on); Face (hood on and mask off); Head (hood and mask off); and Whole Body (suit unzipped, hood and mask off)
**Time to Steady State Ventilation Post Breath-hold**

For TSS (Figure 4), there was statistical significance for exposure condition (P < 0.001) and temperature (P < 0.001) but not for interaction (P = 0.08). TSS in the WB condition was higher in warm water (53 ± 14 s) than cold water (30 ± 21 s) (P < 0.001). In warm water, TSS for WB was higher than all other conditions (P < 0.005) which were not different from each other. There were no effects of condition on TSS in cold water.

![Time to steady state ventilation post breath-hold](image)

Figure 4. Mean time to steady state ventilation post breath-hold for all exposure conditions in cold (8°C) and warm (20°C) water (n=12). Blue circles denote 8°C cold water and the red triangles denote 20°C warm water. Vertical bars, standard deviation; * indicates significant differences between water temperatures (P < 0.05). Horizontal brackets indicate differences between exposure conditions (P < 0.05); bracket colors correspond to water temperature symbols of the same color. Control (out of water, suit zipped and hood on); Partial Face (hood and mask on); Face (hood on and mask off); Head (hood and mask off); and Whole Body (suit unzipped, hood and mask off)
**Predicted Endurance Time of HUEBA Post Breath-hold**

For PET (Figure 5), there was statistical significance for exposure condition (P < 0.001) and temperature (P < 0.02) but not interaction (P = 0.2). PET was similar in Control for both water temperatures (about 3 min 48 s). In both water temperatures, PET decreased from Control in all exposure conditions (P < 0.05) and was lower in WB than all other conditions (P < 0.02). PET for PF, F and H conditions were not different from each other in any water temperature; in cold water their pooled average (2 min 29 s) was two times longer than WB (1 min 11 s) (P < 0.02), and in warm water their pooled average (3 min 5 s) was about 50% longer than WB (2 min 10 s) (P < 0.02).

![Figure 5. Mean predicted endurance time for all exposure conditions in cold (8°C) and warm (20°C) water (n=12). Blue circles denote 8°C cold water and the red triangles denote 20°C warm water. Vertical bars, standard deviation; * indicates significant differences between water temperatures (P < 0.05). Horizontal brackets indicate differences between exposure conditions (P < 0.05); bracket colors correspond to water temperature symbols of the same color. Control (out of water, suit zipped and hood on); Partial Face (hood and mask on); Face (hood on and mask off); Head (hood and mask off); and Whole Body (suit unzipped, hood and mask off).]
Whole Body Cold Discomfort Scale

Data for Whole Body Cold Discomfort (Figure. 6) passed the tests for normality (Shapiro-Wilk) and equal variance (Brown-Forsythe). For these data there was statistical significance for exposure condition (P < 0.001) and temperature (P < 0.001) but not interaction (P = 0.075). Whole Body Cold Discomfort was significantly higher in cold water for all conditions (P < 0.05). In both water temperatures, Whole Body Cold Discomfort in WB was significantly higher than all other conditions (P < 0.001). In cold water, there were significant differences between PF, F and H (P < 0.02). In warm water the only significant difference was found between PF and H (P < 0.03).

Figure 6. Mean whole body cold discomfort during underwater breath-hold trials in cold (8°C) and warm (20°C) water (n=12). Blue circles denote 8°C cold water and the red triangles denote 20°C warm water. Vertical bars, standard deviation; * indicates significant differences between water temperatures (P < 0.05). Horizontal brackets indicate differences between exposure conditions (P < 0.05); bracket colors correspond to water temperature symbols of the same color. Partial Face (hood and mask on); Face (hood on and mask off); Head (hood and mask off); and Whole Body (suit unzipped, hood and mask off).
Discussion

We believe this is the first study to quantify the effects of water temperature and the amount of skin exposure on both breath-hold time and subsequent minute ventilation when the whole body and head are completely submersed below the water. We also predicted how these factors would affect endurance time of a standard HUEBA system. Our hypotheses were generally confirmed. Decreasing water temperature and increasing skin exposure reduced breath-hold time (to as low as 10 s), generally increased minute ventilation, and decreased predicted endurance time of a 55-L HUEBA system (to as short as 1 min 11 s).

Our decrease in breath-hold time is consistent with earlier studies. Hayward et al. demonstrated that decreasing water temperature from 15 to 0°C reduced breath-hold duration in uninsulated subjects during whole body and head submersion (Hayward, Matthews et al. 1984). Similarly, breath-hold duration in 5°C water, was reduced as different protective suits allowed increased skin cooling (e.g. dry suit, wet suit and cotton overalls respectively) (Tipton and Vincent 1989). The maximum effect of skin cooling on breath-hold was seen between control (out of water) and cotton overalls in 5°C water (45 to 9 s respectively). This effect was similar to our decrease from control to whole body exposure in 8°C water (52 to 10 s respectively). In a related study, breath-hold time during face only immersion was also reduced as water temperature decreased from 15 to 0°C (Jay and White 2006).

The present increase in peak $\dot{V}_E$ with whole body exposure in cold water, supports earlier findings in 10 and 15°C head out immersions (Mekjavic, La Prairie et al. 1987, Burke and Mekjavic 1991) where the magnitude of the gasp response (an indicator of respiratory drive and determined by mouth occlusion pressure at 0.1 s after onset of inspiration) was highest in whole body exposure, followed by upper torso and arm exposure.
Our increase in steady state $\dot{V}_E$ with colder water and increased skin exposure, is consistent with studies in which mean $\dot{V}_E$ increases with less thermally protective clothing (Martin, Diewold et al. 1978, Tipton and Vincent 1989, Tipton, Stubbs et al. 1990) or greater skin exposure (e.g., whole body vs torso and/or limbs) (Keatinge and Nadel 1965, Tipton and Golden 1987). Decreasing water temperature from 25 to 5°C also increases mean $\dot{V}_E$; (Keatinge and Nadel 1965, Tipton, Stubbs et al. 1991).

Following peak $\dot{V}_E$, the time to decrease to steady state $\dot{V}_E$ was shorter in cold water and longest with WB exposure in 20°C water. Little attention has been paid to variations in the time to recover to a steady state $\dot{V}_E$. Keatinge and Nadel observed that after maximum ventilation, there was a rapid decline to near normal values within 20-30 secs in 25°C showers (Keatinge and Nadel 1965). Although they report that this decline was less abrupt in 0°C, no details or data were provided.

In the present study, breath-holding stimulated a similar decrease in heart rate in all conditions including Control (in air). This is consistent with findings by (Hayward, Matthews et al. 1984) who demonstrated similar decreases in heart rate during breath-holds in water temperatures ranging from 35°C (thermoneutral) to 0°C.

**Possible Mechanisms for Results**

In general, cold water exposure can elicit two opposing sets of responses. Body cooling elicits the cold shock response which includes decreased breath-hold time, inspiratory gasp and hyperventilation; (Hayward, Matthews et al. 1984) the magnitude of these responses are dependent on the amount of skin exposed, the amount of skin cooling and rate of skin cooling (Mekjavic, La Prairie et al. 1987). Conversely, selective cooling of the face elicits the dive
reflex consisting of increased breath-hold time and decreased ventilation, heart rate and cardiac output (Mukhtar and Patrick 1986). During combined head and body submersion, the ultimate responses will reflect the balance between these two stimuli. Since water cooling and increased skin exposure generally decreased breath-hold time and increased steady state $\dot{V}_E$, it would seem the cold shock response predominated in these conditions.

Peak $\dot{V}_E$ following cold water breath-hold, has not been well-documented with different water temperatures (e.g., 8 and 20°C), however, since this variable is a function of respiratory drive, it would be expected to be higher in colder water. This was not the case however. Although colder water may increase respiratory drive immediately following breath-hold, it also shortened breath-hold time which would result in decreased arterial CO$_2$ compared to 20°C water. Thus, respiratory drive during whole body/head cooling may have been affected by offsetting stimuli (e.g., increased thermal drive from body surface cooling, and decreased chemical drive and thermal drive from head cooling).

**Practical Implications**

Workers who are transported via helicopter to off shore oil rigs are not always specifically trained for cold water survival. Cheung et al. demonstrated generally poor breath-hold ability in 228 offshore survival students, even during head-out immersion in 25°C water (median, 37 s; range, 5.4-120 s) (Cheung, D'Eon et al. 2001). This would be expected to be much worse during whole head submersion in cold water.

Anything that increases underwater survival time in the immediate post-crash submersion period should increase the chance of escape from a helicopter that has crashed in water. Survival during submersion depends on breath-hold time and subsequent endurance time
of a HUEBA (if it is available). This study has demonstrated that in cold water a helicopter transport suit and dive mask can substantially increase both breath-hold time (from 10-33 s) and HUEBA endurance time (from about 1 to 2.5 min) through decreased ventilation and thus, air consumption. The most significant factor regarding use of the suit and mask, is having the zipper done up completely with additional benefits provided by the hood and dive mask.

Therefore, practical training for potential helicopter occupants should obviously emphasize proper use of the suit and mask. Occupants could also be informed that breath-hold time may be increased if they have enough time to take 1-5 deep breaths before submersion; this is long enough to increase breath-hold time without creating a risk for shallow water blackout (Modell 2010). Training could also include habituation and/or psychological training (Barwood, Dalzell et al. 2006, Barwood, Datta et al. 2007, Barwood, Corbett et al. 2017).

Potential Limitations

The use of a mouthpiece during submersion did not diminish the validity of our results, as occupants would breathe through a mouthpiece if they had a HUEBA in real life. Although our submersions lacked the element of surprise and psychological stress of an actual helicopter crash, we feel the general conclusions regarding water temperature and skin exposure extend not only to real life conditions but also to colder water.

An actual HUEBA was not used to determine endurance time because this would require subjects to be submerged until the HUEBA was emptied (e.g., up to 3 min in cold water). This was not done for several reasons: 1) because the submersions in different exposures would then vary according to endurance time; 2) this would require a substantial cumulative submersion time (ranging as high as 10-11 min in cold water); 3) it would be difficult if not
impossible to guarantee an exact, and equal, air volume for every trial; and 4) breathing
underwater from a compressed air source presents an added level of risk (e.g., barotrauma) even
at shallow depths.

The protocol followed a modified balanced order. It was necessary to conduct the WB
condition last for several reasons: this condition resulted in significant cooling and discomfort
and would likely have affected results for any conditions that followed WB; if WB was not the
last condition, it would be necessary to allow the subject to warm up and change into a dry
helicopter suit before the next trial. In order to standardize each rest-submersion cycle, subjects
would need to change suits and take the same extended period between breath-holds; this would
complicate and lengthen the protocol unnecessarily. Because WB resulted in so much more
cooling that the other conditions, we do not feel that the results for this condition are due to the
order of testing, rather it is due to the more intense skin cooling.

Finally, it was not possible to determine if any of the responses were sex-dependent
because only two females participated. Future studies involving larger numbers of males and
females are required to determine if any sex-dependent differences exist.

Summary and Conclusions

The results of this study confirm that proper skin coverage is required for protection
against rapid skin cooling and the cold shock response. It further demonstrates the potential
negative effects of wearing a protective suit with the hood off and zipper(s) undone while flying
over cold water. This information should be shared with helicopter occupants to convince them
of the need to wear their protective equipment in full accordance with manufacturer
recommendations.
CHAPTER 4: SUMMARY
The aim of this study was to determine the effects of varying skin exposures on underwater breath-hold time and subsequent minute ventilation in warm (20°C) and cold (8°C) water. This study is relevant regarding survival in helicopter crashes in water. Since a crashed helicopter often turns upside down, trapping the occupants under water, factors that affect the ability to breath-hold will greatly affect the probability of escaping to the surface. It was hypothesized that colder water temperature and increased skin exposure would decrease underwater breath-hold time, increase subsequent minute ventilation and by extension decrease the predicted endurance time of a ~ 55 L HUEBA device. Our study found that increased skin exposure and colder water temperature decreased breath-hold time, generally increased subsequent minute ventilation and decreased the predicted endurance time of the HUEBA device. Findings from this study are consistent with previous studies that have evaluated the effects of water temperature or skin exposure on breath-hold and minute ventilation. The cold shock response and increased rate of skin cooling have generally been found to attenuate underwater breath-hold time and increase minute ventilation. This study further presents the effects of water temperature and skin exposure on the endurance time of a HUEBA; which have not been previously studied. Although a mouthpiece connected to room air (inspiratory) and metabolic cart (expiratory) was used during post breath-hold breathing instead of an actual HUEBA, the results from this study are still applicable to real life situations where a HUEBA is used during an underwater escape.

Results from this study have significant applications for education and preparation of helicopter occupants. It demonstrates the potential negative effects of wearing a protective suit with the hood off and zipper(s) undone while flying over cold water. Thermal protective suits and dive masks should be provided, and occupants must wear the suits zipped up with hoods on
and don the dive mask prior to crashing if possible. This will greatly increase survivability. This information should be shared with all helicopter passengers to convince them of the need to wear their protective equipment in full accordance with manufacturer recommendations.
REFERENCES


APPENDIX A

CONSENT FORM

RESEARCH PARTICIPANT INFORMATION AND CONSENT FORM

Title of Study: Effect of skin exposure and water temperature on breath holding and subsequent ventilation

Protocol number: NSERC Discovery Grant (2010-17)

Principal Investigator: Gordon Giesbrecht
211 Max Bell Centre,
University of Manitoba,
Winnipeg, MB - R3T 2N2
Phone: 474-8646

Co-Investigator: None

Sponsor: NSERC
350 Albert Street,
Ottawa, ON – K1A 1H5

This consent form, a copy of which will be left with you for your records and reference, is only 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. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.
This study has been approved by the University of Manitoba, Education Nursing Research Ethics Board. This study is part of the required master’s thesis work for Victory Madu. She will be collecting and analyzing the data and the study will be submitted for publication. The Principle Investigator (Gordon Giesbrecht) and two research assistants (Daryl Hurrie and Kaitlyn Tymko) may assist with conducting the laboratory sessions described below.

1. PURPOSE OF THE STUDY

This project will determine the effects of varying amount of thermal protection on breath holding ability and subsequent ventilation at cool (22°C) and cold (5°C) temperatures. This project is relevant regarding survival in helicopter crashes in water. Since a crashed helicopter often turns upside down trapping the occupants under water, factors that affect the ability to breath hold will greatly affect the probability of escaping to the surface.

2. STUDY PROCEDURES

You are being asked to take part in this study because you have fulfilled the criteria of being a healthy adult between the ages of 18-60 years. You are eligible to participate if you meet the criteria described in two screening documents (see Screening and Informed Consent below).

You are not eligible for the study if you have any adverse responses to cold exposure (such as Raynaud’s Syndrome), or have any cardiorespiratory disease or answer ‘yes’ to any question in either of the two questionnaires. A total of 8-10 participants will participate in this study.

General Protocol

Each subject will participate in three laboratory sessions: 1) a familiarization session (about 45 minutes); and 2) two experimental sessions (about 2 hours each). These sessions will be run by masters student Victory Madu.

1) Familiarization session. Subjects will read and sign an Informed Consent, then complete screening documents. Anthropometric measures will then be taken.

A Survitec Helicopter Transport Suit will be worn. The suit has a zipper which can be done up to make the suit water tight (e.g., a dry suit). Subjects will also have a dive mask that is commonly provided to passengers of helicopters traveling over water. Thus, there can be varying amounts of protection against cold water exposure since the suit can be either zipped or partially unzipped, the hood can be up or down, and the mask can be on or off.

2) Experimental sessions. The process will be the same for each session except that the water temperature will be either 5°C or 22°C. In each session, there will be four submersion/breath hold trials. The conditions and procedures for these trials will be as follows:

   Four Submersion Conditions
a. Suit zipped, hood up, and dive mask on
b. Suit zipped, hood up, no dive mask
c. Suit zipped, hood down, no dive mask
d. Suit partially unzipped, hood down, no dive mask

These four conditions would all be tested on the same day with the order balanced.

Specific procedures

**Familiarization session**

**Screening and Informed Consent**

Upon arriving at the lab, we will fully describe the study and collect signed informed consent and screening questionnaires. (Appendices C and D). You will be asked to complete two screening questionnaires (the *Get Active Questionnaire* and the *Medical Screening Questionnaire for Studies Involving Cold Exposure*). If you answer ‘yes’ to any of the questions, you will not be eligible to participate.

**Anthropometric measurements**

We will record age, weight, height, and skinfold thicknesses at four sites: biceps, triceps, subscapular, and suprailiac. Subjects will also stand on scale that measures bioelectric impedance analysis (BIA). These procedures will be used to calculate body surface area and/or % body fat.

Subjects will then put on a Survitec Helicopter Transport Suit and enter a water tank (22°C) that is 1.5 meters deep. They will place a mouth piece (that is connected to tubing that will provide air to breath when the subject is under water. They will then practice the underwater submersion process in two stages:

**Practice trials**

First, they will breath normally through the mouth piece and then gradually submerse themselves by sitting down on an underwater chair; this will result in the top of the head being completely submersed but only by a few centimeters. Once they have done this enough times to become comfortable with putting their head under water and breathing via the mouthpiece, they will move to phase two.

Then, they will take a deep breath and hold their breath while quickly submersing their heads as described above. When they can no longer hold their breath, they will then breath through the mouthpiece for a few minutes. Once they are comfortable with the procedure, the session will be over.

**Experimental sessions**

The process will be the same for each session except that the water temperature will be either 5°C or 22°C. In each session, there will be four submersion/breath hold trials. The conditions and procedures for these trials will be as follows:

**Instrumentation**
At the beginning of each experimental session, subjects will be instrumented as follows:

1. 12 heat flux disks (2 cm in diameter) will be taped to the skin to measure skin temperature and heat transfer from the skin.
2. Oxygen consumption will be continuously measured with a metabolic cart. Subjects will be asked to wear a face mask that will collect the expired breath. On the experimental day, measurement of oxygen consumption will allow quantification of the metabolic cost of shivering.
3. Immediately following each submersion/breath hold trial, whole body cold discomfort will be evaluated using a numerical rating scale ranging from 0 (not cold at all) to 10 (unbearably cold) (Appendix E).

Four Submersion Conditions

1. Suit zipped, hood up, and dive mask on
2. Suit zipped, hood up, no dive mask
3. Suit zipped, hood down, no dive mask
4. Suit partially unzipped, hood down, no dive mask

These four conditions would all be done on the same day with the order balanced.

Procedures

1. Subjects would start from a standing position with head out of the water.
2. They would have a mouth piece in (with an inspired air tube coming from the room, and an expired air tube going to our metabolic cart).
3. They would then take one large breath and sit down on an underwater chair, enough to submerge their head completely (they would have a weight belt on to enable this).
4. They would then hold their breath as long as they could, and then, just breath through the mouthpiece for 10 minutes.

After each submersion/breath hold trial, subjects will exit the water and remove their suit and, if their suit is dry, put that suit back on, or if the suit is wet, replace it with a dry one. This will control for a similar time and level of activity between trials.

3. RECORDING DEVICES - There will be no audio or video recording involved.

4. BENEFITS

By participating in this study, you will be helping the researchers learn about the contribution of water temperature and skin insulation on breath hold ability and breathing through a mouthpiece. This will help us to gain a better understanding of strategies to increase chances of surviving a helicopter crash in water. There may or may not be a direct benefit to you from participating in this study.

5. POTENTIAL RISKS AND DISCOMFORTS

There are no expected harms of the study per se and the risks and/or discomforts involved are minimal:
Cold exposure

The study involves wearing in an insulated helicopter transport suit and standing in a tank of cold water (5°C) which is 1.5 meters deep. The subject will then lower the body and head just under water to breath hold as long as possible, and then breathe normally for a maximum of 10 minutes through a mouthpiece that provides air from above the water surface (this is not compressed air, since the head will be just a few cm below the surface). In three of the conditions, only parts of the head or face will be exposed to the cold water and the cold feeling will be minimal. In the fourth condition the zipper on the suit will be partially undone allowing cold water to come into the suit. This will cool the body as well as the head. Although it may be uncomfortable (especially in the fourth condition), the cold exposure will not cause any health problems or decrease core temperature in any of the conditions.

Breath holding under water

Cold exposure will decrease normal breath hold ability, however, when the subject wants to breath, they merely start breathing through the mouth piece they already have in their mouth. If they are uncomfortable at any time they can simply stand up and their head and airway will be out of the water. Thus, there is no risk of cold-induced medical problems, and minimal risk of getting water in the mouth.

6. ANONYMITY AND CONFIDENTIALITY

Your identity will remain confidential and will not be disclosed without your permission. You will not be identified in any written reports or publications. Data will be coded and names will not be revealed at any time. Only group data or coded (non-identifiable) individual data will be presented or exposed.

Any data that can be identified with you will be stored separately by Dr. Giesbrecht in paper or digital form and will be kept (in secure file cabinet or password protected files) in archives. Personal data such as name and contact information will be kept for 5 years and then destroyed (September 01, 2023), unless you indicate willingness to be contacted for future studies. Only Dr. Giesbrecht and his graduate assistants working on the study will have access to your identity and data. Study results will not be identified with individual participants and will be kept on file digitally and/or in paper form indefinitely.

7. REMUNERATION

You will be reimbursed for your time, effort and discomfort and incidental expenses (e.g., parking) by an amount of $25 per laboratory session (for a total of $75). You will be paid in full for any session in which you start, whether you complete that session or not.

Payment will be in the form of a cheque mailed after the last experiment with delay of 3 to 6 weeks.
8. VOLUNTARY PARTICIPATION / WITHDRAWAL FROM THE STUDY

Your decision to take part in this study is voluntary. You may refuse to participate or you may withdraw from the study at any time without consequence; you may do this verbally in person or by telephone, or via email. If anyone from the investigation team feels that it is in your best interest to withdraw you from the study, they may remove you without your consent. If you would like to withdraw from the study at any time, please contact Dr. Gordon Giesbrecht in person, via email (gordon.giesbrecht@umanitoba.ca) or phone at (204) 474-8646 so he is aware that you no longer wish to participate.

We will tell you about any new information that may affect your health, welfare, or willingness to stay in this study.

9. FEEDBACK / DEBRIEFING

A written summary of this study will be created by December, 2018, and forwarded to you if you desire.

Would you like to receive a summary report of this study once it is completed? Yes / No

If yes, please provide your e-mail or mailing address:

________________________________________

10. DISSEMINATION OF RESULTS

This study is part of the required master’s thesis work for Victory Madu. Ms. Madu will be collecting and analyzing this data, and the study will be submitted for publication in a scientific journal. No personal or identifying information will be included in any manuscript or presentation without written permission.

11. FUTURE STUDIES RECRUITMENT

Are you willing to be contacted regarding possible participation in future studies of this type? Yes / No

If yes, please provide your e-mail address and phone no.

E-mail address: __________________________ Phone no: __________________________

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a
subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator at (204) 474-7122, or humanethics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Participant name (print): _____________________________
Participant signature: ______________________ Date___________(day/month/year)

Primary Investigator: Dr. Gordon Giesbrecht
Primary Investigator Signature: _______________________ Date ________________ (day/month/year)
APPENDIX B

GET ACTIVE QUESTIONNAIRE

Get Active Questionnaire

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP) – has post-secondary education in exercise sciences and an advanced certification in the area – see csep.ca/certifications or health care provider is advisable. This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.

☐ I am completing this questionnaire for myself.
☐ I am completing this questionnaire for my child/dependent as parent/guardian.

<table>
<thead>
<tr>
<th>PREPARE TO BECOME MORE ACTIVE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>YES</strong></td>
<td><strong>NO</strong></td>
</tr>
<tr>
<td>1 Have you experienced ANY of the following (A to F) within the past six months?</td>
<td></td>
</tr>
<tr>
<td>A A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?</td>
<td></td>
</tr>
<tr>
<td>B A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?</td>
<td></td>
</tr>
<tr>
<td>C Dizziness or lightheadedness during physical activity?</td>
<td></td>
</tr>
<tr>
<td>D Shortness of breath at rest?</td>
<td></td>
</tr>
<tr>
<td>E Loss of consciousness/fainting for any reason?</td>
<td></td>
</tr>
<tr>
<td>F Concussion?</td>
<td></td>
</tr>
<tr>
<td>2 Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?</td>
<td></td>
</tr>
<tr>
<td>3 Has a health care provider told you that you should avoid or modify certain types of physical activity?</td>
<td></td>
</tr>
<tr>
<td>4 Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?</td>
<td></td>
</tr>
</tbody>
</table>

**NO** to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

**YES** to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE

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PAGE 1 OF 2
Get Active Questionnaire

ASSESS YOUR CURRENT PHYSICAL ACTIVITY
Answer the following questions to assess how active you are now.

1. During a typical week, on how many days do you do moderate- to vigorous-intensity aerobic physical activity (such as brisk walking, cycling or jogging)?
   - DAYS/WEEK

2. On days that you do at least moderate-intensity aerobic physical activity (e.g., brisk walking), for how many minutes do you do this activity?
   - MINUTES/DAY

   For adults, please multiply your average number of days/week by the average number of minutes/day:
   - MINUTES/WEEK

   Canadian Physical Activity Guidelines recommend that adults accumulate at least 150 minutes of moderate- to vigorous-intensity physical activity per week. For children and youth, at least 60 minutes daily is recommended. Strengthening muscles and bones at least two times per week for adults, and three times per week for children and youth, is also recommended (see csep.ca/guidelines).

GENERAL ADVICE FOR BECOMING MORE ACTIVE
Increase your physical activity gradually so that you have a positive experience. Build physical activities that you enjoy into your day (e.g., take a walk with a friend, ride your bike to school or work) and reduce your sedentary behaviour (e.g., prolonged sitting).

If you want to do vigorous-intensity physical activity (i.e., physical activity at an intensity that makes it hard to carry on a conversation), and you do not meet minimum physical activity recommendations noted above, consult a Qualified Exercise Professional (QEP) beforehand. This can help ensure that your physical activity is safe and suitable for your circumstances.

Physical activity is also an important part of a healthy pregnancy.

Delay becoming more active if you are not feeling well because of a temporary illness.

DECLARATION
To the best of my knowledge, all of the information I have supplied on this questionnaire is correct. If my health changes, I will complete this questionnaire again.

I answered NO to all questions on Page 1

I answered YES to any question on Page 1

Check the box below that applies to you:

☐ I have consulted a health care provider or Qualified Exercise Professional (QEP) who has recommended that I become more physically active.

☐ I am comfortable with becoming more physically active on my own without consulting a health care provider or QEP.

Sign and date the Declaration below

Name (+ Name of Parent/Guardian if applicable) [Please print]

Signature (or Signature of Parent/Guardian if applicable)

Date of Birth

Date

Email (optional)

Telephone (optional)

With planning and support you can enjoy the benefits of becoming more physically active. A QEP can help.

☐ Check this box if you would like to consult a QEP about becoming more physically active.

(This completed questionnaire will help the QEP get to know you and understand your needs.)

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Get Active Questionnaire – Reference Document

Advice on what to do if you have a **YES** response

Use this reference document if you answered **YES** to any question and you have not consulted a health care provider or Qualified Exercise Professional (QEP) about becoming more physically active.

1. Have you experienced ANY of the following (A to F) within the past six months?

<table>
<thead>
<tr>
<th>A</th>
<th>A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?</th>
<th>Physical activity is likely to be beneficial. If you have been treated for heart disease but have not completed a cardiac rehabilitation program within the past 6 months, consult a doctor – a supervised cardiac rehabilitation program is strongly recommended. If you are resuming physical activity after more than 6 months of inactivity, begin slowly with light- to moderate-intensity physical activity. If you have pain/discomfort/pressure in your chest and it is new for you, talk to a doctor. Describe the symptom and what activities bring it on.</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?</td>
<td>Physical activity is likely to be beneficial if you have been diagnosed and treated for high blood pressure (BP). If you are unsure of your resting BP, consult a health care provider or a Qualified Exercise Professional (QEP) to have it measured. If you are taking BP medication and your BP is under good control, regular physical activity is recommended as it may help to lower your BP. Your doctor should be aware of your physical activity level so your medication needs can be monitored. If your BP is 160/90 or higher, you should receive medical clearance and consult a QEP about safe and appropriate physical activity.</td>
</tr>
<tr>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Dizziness or lightheadedness during physical activity</td>
<td>There are several possible reasons for feeling this way and many are not worrisome. Before becoming more active, consult a health care provider to identify reasons and minimize risk. Until then, refrain from increasing the intensity of your physical activity.</td>
</tr>
<tr>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Shortness of breath at rest</td>
<td>If you have asthma and this is relieved with medication, light to moderate physical activity is safe. If your shortness of breath is not relieved with medication, consult a doctor.</td>
</tr>
<tr>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Loss of consciousness/fainting for any reason</td>
<td>Before becoming more active, consult a doctor to identify reasons and minimize risk. Once you are medically cleared, consult a Qualified Exercise Professional (QEP) about types of physical activity suitable for your condition.</td>
</tr>
<tr>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Concussion</td>
<td>A concussion is an injury to the brain that requires time to recover. Increasing physical activity while still experiencing symptoms may worsen your symptoms, lengthen your recovery, and increase your risk for another concussion. A health care provider will let you know when you can start becoming more physically active, and a Qualified Exercise Professional (QEP) can help get you started.</td>
</tr>
<tr>
<td>YES</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After reading the **ADVICE** for your **YES** response, go to Page 2 of the Get Active Questionnaire – Assess your current physical activity.
Get Active Questionnaire – Reference Document

ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE

Use this reference document if you answered YES to any question and you have not consulted a healthcare provider or Qualified Exercise Professional (QEP) about becoming more physically active.

2 Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?

☐ YES

If this swelling or pain is new, consult a healthcare provider. Otherwise, keep joints healthy and reduce pain by moving your joints slowly and gently through the entire pain-free range of motion. If you have hip, knee or ankle pain, choose low-impact activities such as swimming or cycling. As the pain subsides, gradually resume your normal physical activities starting at a level lower than before the flare-up. Consult a Qualified Exercise Professional (QEP) in follow-up to help you become more active and prevent or minimize future pain.

3 Has a healthcare provider told you that you should avoid or modify certain types of physical activity?

☐ YES

Listen to the advice of your healthcare provider. A Qualified Exercise Professional (QEP) will ask you about any considerations and provide specific advice for physical activity that is safe and that takes your lifestyle and healthcare provider’s advice into account.

4 Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?

☐ YES

Some people may worry if they have a medical or physical condition that physical activity might be unsafe. In fact, regular physical activity can help to manage and improve many conditions. Physical activity can also reduce the risk of complications. A Qualified Exercise Professional (QEP) can help with specific advice for physical activity that is safe and that takes your medical history and lifestyle into account.

After reading the ADVICE for your YES response, go to Page 2 of the Get Active Questionnaire – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

WANT ADDITIONAL INFORMATION ON BECOMING MORE PHYSICALLY ACTIVE?

- csep.ca/certifications
  CSEP Certified members can help you with your physical activity goals.

- csep.ca/guidelines
  Canadian Physical Activity Guidelines for all ages.

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APPENDIX C

MEDICAL SCREENING QUESTIONNAIRE

Medical Screening Questionnaire for Studies Involving Cold Exposure

1. Do you have any history of cardiac disease (e.g., heart murmur or palpitations, chest pain on exertion)?
2. Do you have any history of respiratory disease (e.g., asthma, chronic bronchitis)?
3. Do you have diabetes or thyroid disease?
4. Do you have any negative reactions caused by cold exposure (e.g., Raynaud’s Phenomenon, hives, rashes, trouble breathing)?
5. Do you have epilepsy?
6. Do you have any other neurological diseases such as multiple sclerosis?
7. Do you have any history of kidney disease?
8. Do you have any history of liver disease?
9. Do you have any history of claustrophobia?

Name (print): __________________________

Signature: ____________________________

Date: ________________________________
APPENDIX D

ETHICS APPROVAL

PROTOCOL APPROVAL

TO:    Gordon Giesbrecht
       Principal Investigator

FROM:  Zana Lutfiyya, Chair
        Education/Nursing Research Ethics Board (ENREB)

Re:    Protocol #E2018:048 (HS21828)
       Effect of Skin Exposure and Water Temperature on Breath Holding and
       Subsequent Ventilation

Effective:  May 10, 2018       Expiry:  May 10, 2019

Education/Nursing Research Ethics Board (ENREB) has reviewed and approved the above
research. ENREB is constituted and operates in accordance with the current Tri-Council Policy
Statement: Ethical Conduct for Research Involving Humans.

This approval is subject to the following conditions:

1. Approval is granted only for the research and purposes described in the application.
2. Any modification to the research must be submitted to ENREB for approval before
   implementation.
3. Any deviations to the research or adverse events must be submitted to ENREB as soon as
   possible.
4. This approval is valid for one year only and a Renewal Request must be submitted and
   approved by the above expiry date.
5. A Study Closure form must be submitted to ENREB when the research is complete or
   terminated.
6. The University of Manitoba may request to review research documentation from this project
   to demonstrate compliance with this approved protocol and the University of Manitoba
   Ethics of Research Involving Humans.

Funded Protocols:
   - Please mail/e-mail a copy of this Approval, identifying the related UM Project
     Number, to the Research Grants Officer in ORS.

Research Ethics and Compliance is a part of the Office of the Vice-President (Research and International)
umanitoba.ca/research
APPENDIX E

WHOLE BODY COLD DISCOMFORT SCALE

Whole body Cold Discomfort Scale

0. No Sensation of Cold
1.
2. Slightly Cold
3.
4. Fairly Cold
5.
6. Moderately Cold
7.
8. Very Cold
9.
10. Unbearable Cold