THE EFFECTS OF WATER TEMPERATURE, GENDER AND EXERCISE ON BREATH HOLDING FOLLOWING SUDDEN FACE IMMERSION

CENTRE FOR NEWFOUNDLAND STUDIES

TOTAL OF 10 PAGES ONLY MAY BE XEROXED

(Without Author's Permission)

JONATHAN POWER

THE EFFECTS OF WATER TEMPERATURE, GENDER AND EXERCISE ON BREATH HOLDING FOLLOWING SUDDEN FACE IMMERSION

By

© Jonathan Power

Centre for Newfoundland Studies
MAY 11 2006
MEMORIAL UNIVERSITY OF NEWFOUNDLAND

A thesis submitted to the

School of Graduate Studies

in partial fulfilment of the

requirements for the degree of

Master of Science in Kinesiology

School of Human Kinetics and Recreation

Memorial University

May 2004

St. John's Newfoundland

Library and
Archives Canada

Published Heritage
Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et
Archives Canada

Direction du
Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

0-494-06653-9

Your file Votre référence
ISBN:
Our file Notre reterence
ISBN:

NOTICE:
The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:
L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

Thesis Abstract

A potential risk that workers face when commuting to offshore oil platforms is the helicopter ditching or crashing in cold ocean water and inverting. This happens if the helicopter's flotation bags fail to deploy. In this scenario a person's chance of survival appears to depend on their ability to make a successful breath hold swim from the sunken fuselage to the surface. Since each passenger should be wearing full body immersion suit, only the face is exposed to the cold water during a breath hold swim. As such, the two studies in this thesis examined if water temperatures (between 0°C and 20°C), gender and exercise can affect a typical sized person's maximum breath hold time (BHT_{max}) following a sudden facial immersion. In the studies the typical size males were significantly taller ($p \leq 0.05$) and heavier ($p \leq 0.001$) than the typical size females. The first study examined the effects of water temperature and gender on BHT_{max} for participants at rest with a sudden facial immersion. The second study examined the same effects on BHT_{max} during moderate intensity upper body exercise. For resting participants, lower water temperatures resulted in significantly shorter BHT_{max} and females had shorter BHT_{max} than males. In study 2 during moderate intensity upper body exercise, BHT_{max} was not affected by water temperature but males continued to have significantly longer BHT_{max} than females. During the exercise condition the males had a BHT_{max} of ~ 25s across all breath hold conditions, and the females had a BHT_{max} of ~15s across all immersion conditions. In conclusion, the effect of water temperature on breath holding is evident for resting but not in exercise conditions. Although in both studies

males had significantly greater BHT_{max} than females, it remains to be established if this is an effect of gender or physical size.

Acknowledgments

I would like to thank Dr. Matthew White for his help, assistance and support from start to finish on this thesis. Erin Bradbury, I would also like to thank for her help with the completion of the first section of this thesis, a task I would not have been able to complete alone. I also want to thank Lise Petrie for providing invaluable help and assistance in the practical design and setup of both experiments. To Michael Powell, Amanda Hall, Julia Jennings and Elena Alexandrou: thank you for the continued support. Additionally I want to extend a big thank you to Dr. Colin Higgs for providing invaluable support and assistance throughout the duration of this degree. A very big thank you to Baxter Pope and all the employees in the Technical Services department of Memorial University for doing amazing work in short amounts of time. My gratitude is also extended to Dr. Stephen Cheung at Dalhousie University for his assistance and helpful insight and to the SafetyNet research group for their continued interest and support. To all the participants in the studies: thank you for allowing me to tape, poke, prod you, and immerse your faces in cold water. I know it was not the most fun in the world, so thank you very much for being very patient and very co-operative during my experiments.

Referred papers from this thesis were submitted and accepted as follows:

1. White M.D., Power J. T., Bradbury E. E., Pope J.D., Petrie L., and Cheung S.S. Maximum breath hold time during face immersion across gender and water temperatures from 0 to 20°C, European Undersea Baromedical Conference, Brugge, Belgium, Sept 4-8, 2002, pp.143-147.

2. Power J. T., Cheung, S.S., Petrie, L. White, MD. Breath-hold duration and heart rate responses across gender during moderate intensity exercise after sudden face immersion. European Undersea Baromedical Conference, Copenhagen, Denmark, Aug 27-31, 2003, pp. 41-45.

Table of Contents

List of Tables

List of Figures

List of Definitions and Abbreviations

Definitions:

Apnea: Absence of breathing

Bradycardia: A decrease in heart rate to usually less than 60 beats per minute.

Cold Shock Response (CSR): A series of physiological responses which include an initial, large involuntary gasp followed by uncontrollable hyperventilation, tachycardia and a constriction of the peripheral blood vessels. The CSR occurs when a person become suddenly immersed in cold water.

Cold Sensitivity Index (CSI): A measurement (given in $Pa \cdot sec \cdot cm^{-2} \cdot {}^{\circ}C^{-1}$) which represented the variability of the gasp response between different areas of the body after adjusting for surface area and decline in temperature (2).

Diving Response (DR): A series of physiological responses including a bradycardia, apnea, a constriction of the peripheral blood vessels and an elevation in blood pressure. The response is thought of to conserve oxygen. The DR is evident when a person performs a breath hold with their face immersed in cold water.

Expiratory Reserve Volume (ERV): The volume that can be maximally expired from the level of the functional residual capacity (3).

Forced Vital Capacity (FVC): The volume of gas which is exhaled during a forced expiration starting from a position of full inspiration and ending at complete expiration (3).

Functional Residual Capacity (FRC): The volume of gas present in the lungs and airways at the average end-expiratory level (3).

Inspiratory Capacity (IC): The maximal volume that can be inspired from functional residual capacity (3).

Tachycardia: An increase in heart rate to rates greater than 100 beats$\cdot$min^{-1}

Timed Forced Expiratory Volume ($FEV_{1.0}$): The volume of gas which is exhaled during a forced expiration starting from a position of full inspiration in 1 s (3).

Vital Capacity (VC): The volume change at the mouth between the positions of full inspiration and complete expiration (3).

VO_{2PEAK}: A measurement of peak oxygen uptake during physical activity which will fall between 66% and 86% of an individual's maximal value for oxygen uptake (1).

Abbreviations:

BHT_{max}: Maximum Breath Hold Time: The longest duration that a person is able to hold their breath without inspiring or expiring. The BHT_{max} is measured in seconds from the time after a participant finished inspiring to when they expired.

HR_{min}: Minimum Heart Rate: The minimum observed heart rate; measured in beats·min^{-1}.

LPC: Limb protected condition

RPM: Revolutions per minute

SaO_2: Actual amount of O_2 bound to haemoglobin divided by the maximum binding capacity of O_2. Expressed as a percentage.

TPC: Torso Protected Conditions

T_{sk}: skin temperature

References

1. **Bar-Or O and Zwiren LD**. Maximal oxygen consumption test during arm exercise--reliability and validity. *J Appl Physiol* 38: 424-426, 1975.

2. **Burke WE and Mekjavic IB**. Estimation of regional cutaneous cold sensitivity by analysis of the gasping response. *J Appl Physiol* 71: 1933-1940, 1991.

3. **Quanjer PH, Tammeling GJ, Cotes JE, Fabbri LM, Matthys H, Pedersen OF, Peslin R, Roca J, Sterk PJ, Ulmer WT and et al.** Symbols, abbreviations and units. Working Party Standardization of Lung Function Tests, European Community for Steel and Coal. *Eur Respir J Suppl* 16: 85-100, 1993.

Chapter 1 Thesis Overview

1.1 Introduction and Overview of Thesis

Workers traveling in helicopters to the North Atlantic offshore oil platforms are dressed in survival suits that provide a large degree of thermal insulation from the cold ocean water but leave the face exposed. These passengers can become suddenly immersed in cold water during a helicopter crashing or ditching, and subsequent sinking if the flotation bags fail to deploy. When the face is exposed to cold water either a cold shock response (CSR) or a dive response (DR) could occur (8, 15). Either of these responses can influence their maximum breath hold time (BHT_{max}) that would be needed for their subsequent swim to the surface. A review of literature in Chapter 2 of this thesis has been conducted on both the CSR and the DR and their affects on BHT_{max}. The literature reviewed was found to support that both responses can possibly occur in these conditions (1, 2, 7, 9-11, 13, 16). It was not clear which of these responses would predominate after a sudden face immersion. Compared to the temperatures found in the North Atlantic Ocean, the majority of the work on the dive response cited in the literature review (1, 11-13) used relatively warm water temperatures (~25 – 26°C) for face immersion studies. In addition breath holding in these studies did not examine whether or not gender affected BHT_{max}. Gender was examined since: (i) longer breath holding durations have been related to larger pulmonary capacities (6), (ii) since pulmonary capacities are a height dependent (5) and (iii) since height varies by gender. Further review showed little work has focused on breath holding, face immersion and exercise (3, 4, 14) as would be needed for such underwater swims or egress. As such the research hypothesis and testable questions for this thesis are stated at the end of Chapter 2 based on this existing evidence in the literature.

The first study we conducted is given in Chapter 3 and it examines the effects of varying water temperatures from 0 to 20°C on BHT_{max} and minimum heart rate (HR_{min}) across gender after a sudden, resting face only immersion. Our goal was to try to replicate the face immersion conditions of a resting person wearing a full body immersion suit with their face immersed in cold water. The second study in Chapter 4 added upper body submaximal exercise to a similar protocol as that employed in Chapter 3. This was to more closely replicate the exercise the person may perform while trying to make a breath hold swim from the sunken helicopter fuselage. With this we asked what is the affect of this added exertion on BHT_{max} , HR_{min} and hemoglobin oxygen saturation (SaO_2) across gender.

Chapter 5 gives summaries, conclusions and responses to the research hypothesis and testable questions stated in Chapter 2. Chapter 5 concludes with a brief statement of the practical implications of the results from these experiments.

1.2 Co-authorship statement

1) Design and Identification of the research proposal:

The design and identification of my two part research proposal was a collaborative effort between Dr. Matthew White, and myself. Between September 2001 and May of 2002, myself and Dr. White discussed ideas of possible topics for my research proposal. We both decided to further build on the stationary face immersion portion of my proposal by adding exercise to the protocol.

2) Practical Aspects of the Research

The implementation of the equipment and fine-tuning the protocol for the first part of my research project was a collaborative effort between myself, Erin Bradbury and Lise Petrie after consultation with Dr. White. The first part of the thesis data collection was completed by both Erin Bradbury and myself. The practical implementation of the protocol for the second part of my research project was a joint effort between Lise Petrie and myself, with Dr. White providing the necessary input. Data collection for the second part of the project was done by Lise Petrie and myself. Both experiments were conducted in Dr. White's laboratory.

3) Data Analysis

The data analysis for the first part of my research project was a collaborative effort between Erin Bradbury and myself with supervision and guidance given by Dr. White. The data analysis for the second study was completed by Dr. White and myself.

4) Manuscript Preparation

For both studies in this thesis, I prepared first drafts of both manuscripts and I also prepared the first draft of the review of literature. Dr. White provided the necessary feedback, comments and corrections as they were needed for all components of my thesis writing. There were numerous exchanges of the thesis between Dr. White and myself and these were most at our weekly meetings.

1.3 References

1. **Andersson JP, Liner MH, Runow E and Schagatay EK.** Diving response and arterial oxygen saturation during apnea and exercise in breath-hold divers. J Appl Physiol 93: 882-886, 2002.

2. **Arnold RW**. Extremes in human breath hold, facial immersion bradycardia. Undersea Biomed Res 12: 183-190, 1985.

3. **Bergman SA, Jr., Campbell JK and Wildenthal K**. "Diving reflex" in man: its relation to isometric and dynamic exercise. J Appl Physiol 33: 27-31, 1972.

4. **Butler PJ and Woakes AJ.** Heart rate in humans during underwater swimming with and without breath-hold. Respir Physiol 69: 387-399, 1987.

5. **Cherniack RM and Raber MB**. Normal standards for ventilatory function using an automated wedge spirometer. Am Rev Respir Dis 106: 38-46, 1972.

6. **Cheung SS, D'Eon NJ and Brooks CJ**. Breath-holding ability of offshore workers inadequate to ensure escape from ditched helicopters. Aviat Space Environ Med 72: 912-918, 2001.

7. **Cooper KE, Martin S and Riben P**. Respiratory and other responses in subjects immersed in cold water. J Appl Physiol 40: 903-910, 1976.

8. **Gooden BA**. Mechanism of the human diving response. Integr Physiol Behav Sci 29: 6-16, 1994.

9. **Hayward JS** and Eckerson JD. Physiological responses and survival time prediction for humans in ice-water. Aviat Space Environ Med 55: 206-211, 1984.

10. **Keatinge WR and Nadel JA**. Immediate respiratory response to sudden cooling of the skin. J Appl Physiol 20: 65-69, 1965.

11. **Mukhtar MR and Patrick JM.** Ventilatory drive during face immersion in man. J Physiol 370: 13-24, 1986.

12. **Sterba JA and Lundgren CE**. Breath-hold duration in man and the diving response induced by face immersion. Undersea Biomed Res 15: 361-375, 1988.

13. **Sterba JA and Lundgren CE**. Diving bradycardia and breath-holding time in man. Undersea Biomed Res 12: 139-150, 1985.

14. **Stromme SB, Kerem D** and Elsner R. Diving bradycardia during rest and exercise and its relation to physical fitness. J Appl Physiol 28: 614-621, 1970.

15. **Tipton MJ.** The initial responses to cold-water immersion in man. Clin Sci (Lond) 77: 581-588, 1989.

16. **Tipton MJ and Golden FS**. The influence of regional insulation on the initial responses to cold immersion. Aviat Space Environ Med 58: 1192-1196, 1987.

Chapter 2 Review of Literature

2.1 Introduction

In the province of Newfoundland, many people work in or near cold water environments. Until about 11 years ago, one of the main occupations for many people in the province was fishing. With two offshore oil platforms operating approximately 300 km off of the coast of Newfoundland, many people in the surrounding Atlantic Provinces are now employed on these two drilling platforms. One danger of working in the offshore oil industry is the possibility of becoming accidentally immersed in open water and drowning. In 2001, 34 people died in Canada due to falling into natural water (1). It was not reported if these drownings occurred close to shore or not, but capable swimmers have been known to drown relatively close to safety (37). While it is generally thought that these drowning victims succumbed to hypothermia, they were not in the water long enough to develop such a decrease in body temperature (37).

When people suddenly become immersed in cold water a series of responses is thought to occur that may ultimately cause them to drown. These sudden cold water responses are an important area of study because they have applications for those who work in offshore environments. Understanding why and how a person can drown in the water close to safety is studied with the view to help prevent deaths due to accidental immersion. This area of study would be very beneficial to people who work in or near cold water such as North Atlantic Ocean fishers or people who work on oil platforms on the ocean. In Newfoundland, the offshore oil installations can only be reached by taking a two hour helicopter ride over the ocean (Cougar Helicopters – Personal Communication). If the helicopter was to suffer a malfunction and crash and/or ditch in the open ocean water and the floatation bags failed to inflate, the crew would experience a sudden cold water immersion (7). In a retrospective study by the UK Civil Aviation Authority (CAA) ~83.1% of the military passengers survived a helicopter crash or ditching in the offshore, but 82.6% of these survivors subsequently drowned (12). This suggests that these deaths are preventable.

When the body is suddenly immersed in cold water two major different responses occur: the cold shock response (CSR) and the diving response (DR) (37). This review of literature will focus on the nature and mechanisms of these two responses and why it is relevant to understand these responses on breath holding with sudden face immersion in cold water. It is thought that the CSR and the DR both have the potential to influence the length of time people can hold their breath (21, 24, 29).

2.2 Cold Shock Response

Overview of the Cold Shock Response

Upon sudden immersion in cold water, the first response observed is the CSR, and it is this response that is thought to cause the majority of the offshore drownings (37). The CSR is a series of physiological responses that are known to include tachycardia

(13), peripheral vaso-constriction (30), a large inspiratory gasp (29, 31), and hyperventilation (29, 31). The respiratory components of the CSR pose the greatest threat to survival to a person who becomes suddenly immersed in cold water because they are likely to involuntary inhale water as they gasp or hyperventilate, and subsequently drown (13).

Cold Shock Response and Its Components

The effects of cold water on respiratory responses have received considerable attention in the scientific literature. An early study by Keatinge et al. (29) suggested that cold water can have a significant effect on ventilation. This was one of the first studies of human responses to cold water that helped develop a better understanding of the CSR. The experiment involved ice chips and water being placed in a bucket above a seated subject. In order to control for lung compliance, straps were fitted tightly around the subject's chest to prevent deep breathing. The participants were first showered with water at a comfortable temperature of 34°C, and then abruptly switched to a random shower temperature between 0°C and 46.5°C. The investigators found that lower water temperature showers increased ventilation significantly more when compared to warmer temperature showers. In the same study, through the use of decerberate cats, Keatinge et al. concluded that the cerebrum did not affect ventilation. When the decerberated cats were sprayed with cold showers, hyperventilation also occurred. The speed at which the hyperventilation occurred indicated that it was a reflex rather than a conscious response

(29). This early research suggested that hyperventilation occurred when the body came into contact with cold water and suggested it limits the ability for a person to hold their breath.

In a subsequent study by Hayward et al. (24) 10 lightly clothed males and females conducted a full body immersion in 0°C water. The goal of this study was to determine the effects of full body cold water immersion on thermal, metabolic, heart rate and ventilatory responses (24). Hayward et al. found that that there was a 426% and 442% increase in ventilation ($l \cdot min^{-1}$) over their pre-immersion values for males and females, respectively. The researchers also concluded that the responses observed upon immersion in water at 0°C were similar in magnitude to immersion in water ranging from 5 to 15°C. An increase in ventilation after immersion in water at 10°C was also found by Tipton and Golden (40). Twelve healthy males performed three 10 min head out immersions in water at 10°C. During the first few minutes of immersion, the average ventilation increased by more than 1000%, and at the end of the immersion ventilation was still twice that of normal resting conditions (40). Tipton et al. (38) expanded on these findings, when they examined the effect that different water temperatures had on the initial responses to cold water immersion. Eight healthy males performed simulated underwater helicopter escapes in both 10°C and 25°C water. The mean BHT_{max} was reduced in time for 10°C water condition compared to 25°C. For Tipton et al (41)., in a later experiment, eight healthy males performed three, two minute head out immersions at water temperatures of 5, 10 and 15°C. A fourth immersion was performed at 10°C, in which the subject hyperventilated prior to immersion. The participants' mean ventilation were found to be higher at water temperatures of 5 and 10°C compared to 15°C water. A difference in ventilation was found between 5 and 10°C, but only after 20 and 30 seconds of immersion (41). Ventilation at 5 and 10°C, also took longer to decrease and stabilize to levels that were still higher than pre-immersion values, when compared to immersions at 15°C (41). Of the three immersion water temperatures, the largest breath on immersion or inspiratory gasp was seen at 15°C, with an average of 2.7 liters across of the subjects. The gasps at 5 and 10°C produced values of 2.0 and 2.3 liters, respectively (41). The results of this study also suggested that hyperventilation prior to any full body immersion will not have any effect on respiratory responses to cold water (41).

Another study on the same topic by Mekjavic et al. (31) looked at how respiratory responses are affected by cold water immersion, but instead of using ventilation as an indicator of the magnitude of the response, the investigators used mouth occlusion pressure. The investigators deemed that this would be a more accurate measurement of respiratory changes and respiratory effort (31). The rationale behind this choice was that it was thought hydrostatic pressure put on the chest wall during full body immersion in combination with a shift in blood to the thorax, may hamper mechanical movements during ventilation (31). Mouth occlusion pressure was measured with a pressure transducer (Pa) and an oscillographic recorder. Each subject breathed through the mouth piece and the shutter closed at 100 ms, and then re-opened. While the shutter was closed, the pressure was measured from the subject's inspiratory efforts. Five participants performed five head out immersions in 10°C water while wearing shorts as a control test, then immersed again in four different protective garments designed for helicopter pilots. The four different compositions of the suits included: (A) Gortex, (B) Cotton Ventile, (C) Nomex/insulate and (D) Nomex/Neoprene (31). Suits A and B were designed to be somewhat water tight, while C and D operated on the principle of a wet suit, and allowed some water to enter the suit and cool the skin through contact (31). The results indicated that upon initial immersion in water, the mouth occlusion pressure was significantly positively correlated to the peak rate of skin temperature decrease following immersion (31). The shorts-only immersion showed the greatest response to immersion. All of the protective suits gave similar results with each of them decreasing the gasp response by similar amounts when compared to the shorts-only immersion. The study illustrated another means of quantifying respiratory effort following an immersion in cold water.

The potentially detrimental effect that the large inspiratory gasp followed by acute hyperventilation has in cold water immersion is an increased risk of aspirating water, which can lead to drowning (37). Another danger associated with the acute hyperventilation is the possibility of becoming hypocapnic (27, 37). When hyperventilation occurs, the body's CO_2 levels can rapidly fall. When blood CO_2 concentrations reach a low enough level, hypocapnia forms in sensory and motor cells which can result in a decrease in their activation threshold (15). Large falls in blood CO_2 concentrations can also lead to a cerebral hypoxia which is thought to occur due to a reduction in cerebral blood flow and a shift to the left in the hemoglobin dissociation curve ultimately reducing the supply of oxygen to the brain (37). This cerebral hypoxia is thought to cause the disorientation and a clouding of consciousness seen in participants immersed in cold water (13). It has also been noted that hyperventilation in people seems to be greater in rough, choppy water compared to calm, still water at the same temperature in laboratory conditions (13). This supports the view that emotional factors may also play a part in increasing the rate of respiration when people experience a sudden immersion in cold water (13).

Cold Shock Response and Tachycardia

Tachycardia is also one of the components of the CSR (37). Hayward et al. (24) found that the participants experienced a sharp increase in heart rate when immersed in cold water. After a two-minute immersion the resting heart rates of the male participants increased by 42% and the females increased by 49%. Even after twenty minutes of immersion, the male heart rate remained about 15% greater than resting and females remained at a heart rate 20% greater (24). Similar results were reported by Tipton (41) who compared the effects of three different water temperatures on human physiological responses. It was found that the subject's heart rate increased by 25% upon immersion and remained higher than resting values during the course of the immersion (41). It was noted though that the heart rate was much lower for 15°C during the course of the immersion as compared to 5°C and 10°C (41).

Cold Shock Response and Peripheral Vasoconstriction

Tachycardia is not the only cardiovascular effect seen when exposed to cold water. A peripheral vasoconstriction and a decreased peripheral blood flow are known to occur with cold immersion (30). These responses coupled with the increase in heart rate can place a great degree of strain on the cardiovascular system. In addition to this, the surfaces responsible for the CSR are not similar across the surface of the body.

Cold Shock Response and Regional Surface Sensitivity

Another aspect to consider is certain areas on the body surface have a greater contribution to the initiation of the CSR response (8, 29, 40). Keatinge found that, while cold showers to the extremities and to the lower back gave an increase in ventilation, they were only small increases when compared to showers given to the trunk (29). Tipton et al. (40) covered selective areas of the body and protected them from cooling by cold water to measure the cardio-respiratory responses when different body areas were immersed in cold water. Twelve males performed three immersions in water at a temperature of 10°C wearing three different clothing assemblies. The first assembly consisted of swimming trunks, the second consisted of the torso being covered in a waterproof survival suit and the third consisted of the limbs being covered with sections from a survival suit. It was found that the results for the torso protected conditions (TPC) and the limb protected condition (LPC) did not differ significantly except for heart rate, in which the TPC gave a higher heart rate when compared to the LPC (40). Ventilation for the two protected conditions were roughly similar, as was the frequency of the breaths (beats·min^{-1}). The standard control condition of just swimming trunks produced responses much greater than either protected condition (40). This study contradicted the findings by Keatinge who showed that different areas of the body gave different ventilatory responses to cold water (29). Keatinge proposed that the extremities of the body had a habituation effect because they were exposed to the cold, air or water, on a more frequent basis than the trunk (29). It is thought that variations in cold receptor distribution, sensitivity and the degree of facilitation and inhibition make it extremely hard to identify where differences lie in the regions exposed with TPC and LPC (40). Tipton et al. concluded that more detailed investigation is needed to determine if different areas of the body trigger more pronounced reactions to the CSR (40).

More detailed research was carried out by Burke and Mekjavic (8). Using a protocol similar as Tipton et al. (40), different areas of the body were selectively cooled and measurements of the gasp response were used to determine what areas might give a more pronounced CSR than others. Seven males performed ten head out immersions, five in cold, 15°C water, and five in luke warm or, 34.4°C water. There were five different exposure conditions, 1) whole body, 2) arms, 3) upper torso, 4) lower torso and 5) legs. A custom made segmented dry suit was used to cover the different areas of the body while leaving the tested region exposed. The suit was water-proof and prevented the covered areas of the body from being cooled. For this experiment mouth occlusion pressure (measured in Pa) was used again to estimate the magnitude of the respiratory effort as an index of the CSR. When the participants performed the immersions, it was found that there was a greater gasp response seen at water of 15°C than at 34.4°C (8). The upper torso gave the largest increase in mouth occlusion pressure (8), the lower torso gave a response at about half of the upper torso, while the legs and the arms gave much lower responses (8). The authors calculated a cold sensitivity index (CSI) which represented the variability in the gasping response between regions. The CSI in each condition took into account differences between conditions in exposed surface area of the body and the rate of temperature decline, given in $Pa \cdot sec \cdot cm^{-2} \cdot {}^{\circ}C^{-1}$ (8). The results suggested that the upper torso had the greatest cold sensitivity when compared to the whole body, the arms, lower torso and the legs. The upper torso had a cold sensitivity almost three times greater than that for the whole body (8). The lower torso also had a higher cold sensitivity value than the whole body. The authors concluded when the upper torso was suddenly cooled it gave the largest CSR compared to other areas of the body (8). They suggested that proper covering and insulation of the upper torso may help reduce the large inspiratory gasp of the CSR if a person were to suddenly experience a sudden cold water immersion (8).

Mechanism of the Cold Shock Response

Burke et al. (8), suggested that the upper torso is the area that will give the largest CSR upon sudden cold water, but the question remains what causes the CSR? Up to this point it has just been observed that cold water making contact and cooling the skin will trigger the response, but what is the underlying mechanism behind the triggering of the CSR? It has been reported in numerous studies that the respiratory and cardiovascular effects of the CSR occur almost instantly upon submersion in cold water (13, 29, 31, 40). Keatinge reported, the speed at which the respiratory responses occurred indicated that hyperventilation may be a reflex response to stimulation of cold receptors (29). In the same study, decerebrate cats also experienced an increase in ventilation when exposed to cold showers (29). They concluded that the reflex respiratory response to cold showers must be mediated at the mid brain level for cats and that their cerebrum is not essential for the response (29). It is possible that the same reflex may hold true for humans, in that the responses seen in cold water immersion may be mediated at the mid-brain level as well. The lack of release of adrenal catecholamines reported by Keatinge et al. (28), coupled with the speed of the response, is more evidence that the responses are reflexive in nature. Mekjavic observed that increases in respiratory drives were found when changes in skin temperature occurred, and not deep body temperatures as measured by rectal probes (31). The authors hypothesized that the cold receptors (6) in the skin, through sensory nerves, may stimulate the central nervous system which then stimulates the alpha motor neurons that innervate the diaphragm causing it to contract (31). Cooper et al. (13) provided support to the hypothesis that it is cold receptor stimulation that triggers the CSR when they saw similar results for subjects immersed in cold water baths.

Cooper et al. examined the effects of heating the skin prior to cold water immersion (13). Twelve healthy volunteers, 6 male and 6 female, performed head-out immersions in water ranging from 8.7°C to 21°C and compared against control immersions in water at 34°C. Each subject performed two immersions: one without any prior heating and one with prior heating in a sauna. Heating in the sauna allowed for just the skin temperatures to increase with very little change in core temperature (13). The order in which the participants performed the immersions with heating or without were randomized in order to circumvent a habituation effect (13). When the participants had no prior heating to immersion in the sauna their mean ventilation was 55 $L \cdot min^{-1}$ upon initial immersion in the water (13), however when they were heated prior to immersion to an average skin temperature of 40°C, the mean ventilation was only 35 $l \cdot min^{-1}$ upon initial immersion (13). The results showed that sauna heating greatly reduced the initial respiratory responses to cold water immersion (13). It is possible that the reduction in ventilatory responses was due to the cold receptors containing more heat, thus taking longer to cool. When the participants were pre-heated and immersed, the observed skin temperature initially fell quickly from 40°C to 20°C, but then a more gradual decrease was reported (13), so that skin temperatures were found to be higher in preheated conditions as compared to no prior preheating at the end of the immersion. Subcutaneous fat levels were also measured and no correlations were found between the values and those of respiratory responses. This suggests that subcutaneous fat will not offer any protection in the form of insulation from the CSR in part because the cold receptors that trigger the response are located very close to the surface of the skin and are not insulated from the cold by adipose tissue (13).

2.3 The Diving Response

Overview and Components of the Dive Response

The second main response to sudden immersion in cold water is known as the Dive Response (DR). The dive response is defined as a pattern of respiratory, cardiac and vascular responses triggered by breath hold diving (21). Diving animals, such as the seal and the duck, have a pronounced DR which allows them to remain under the water for extended periods of time (20). Currently it is thought that all air-breathing mammals posses a DR, including humans, however, it is much less pronounced as compared to a seal (16, 21). The DR consists of a marked bradycardia (3), vaso-constriction (2), apnea (21) and an elevated blood pressure (22), all of which are thought to help conserve oxygen stores and prolong BHT_{max} (21). Much like the CSR, the DR is triggered by cold water immersion; however the DR is triggered by cold water making contact with the facial region and the voluntary or involuntary cessation of breathing (21).

Dive Response and Bradycardia

The bradycardia component of the DR was investigated by Arnold (3). Twenty seven participants performed face only immersions at two water temperatures, ice water ranging from 0°C-2°C and room temperature water, 23°C-25°C. Five of the participants from the twenty seven were taken and studied further by performing 45 s breath holds at a variety of water temperatures ranging from 0°C to 35°C (3). When the twenty seven participants performed the breath holds at 0°C it was observed that after thirty seconds of immersion the heart rate fell from a mean of 72.1 beats·min^{-1} to 46.4 beats·min^{-1} (3). Some extreme results were reported during the course of the experiment. One subject's heart rate dropped to less than 30 beats·min^{-1}, another dropped to less than 20 beats·min^{-1} while another on one occasion had their heart rate drop from 72 to 7.2 beats·min^{-1}. Arnold noted in the study that the colder the water temperature used for face immersion produced the lower heart rates (3).

The observations of Arnold et al (3) were supported by a Tipton et al. who examined the effect of clothing on diving bradycardia (36). The participants performed full body immersion in three different clothing arrangements, even though the authors acknowledged that a face immersion was the "classical method" for triggering the DR (36). The first was a cotton overall assembly consisting of swimming trunks, cotton long johns, a woollen pull pullover, woollen socks and a one piece cotton overall (36). The second arrangement was a wet suit worn over the cotton overall assembly, and the third consisted of a dry suit worn over the cotton overall assembly. This study also found that bradycardia increased as the degree of cold stress increased for all the different kinds of clothing (36).

Dive Response and Hemoglobin Saturation

As previously stated, the proposed purpose of the DR is to help conserve oxygen and prolong BHT_{max} (21). Andersson et al. (2) examined oxygen saturation of hemoglobin to investigate if breath holding while performing a face immersion would help to augment the DR compared to breath holding in the air (2). Eight healthy males performed different thirty second apneas, some in the air, and the others with their face immersed in 10°C water. While performing each apnea in air and water, the participants pedaled on a cycle ergometer with a constant resistance of 100 W (2). The results suggested that the DR was augmented by facial immersion (2). A breath hold in the air decreased the heart rate to 75% of control values, whereas a breath hold in water caused it to decrease to 67% of control values (2). Skin blood flow also exhibited a similar trend; when participants performed a breath hold in air, the skin blood flow decreased to 71% of control values, whereas a breath hold in water caused a reduction to 61% of control values. Saturation percent was employed as an indicator of how much oxygen remained bound to hemoglobin in the blood. Andersson et al. found that, when participants performed a breath hold with the face immersed in the water, the SaO_2 levels dropped to 94.8% of control values, while apnea in the air caused the levels to drop by a significantly greater amount to 93.2% (2). These results suggested that during the breath hold in the water with exercise, the DR was more pronounced than for the same breath hold conditions in air. This was reasoned to allow for a greater oxygen conservation effect in the body (2). Skin blood flow, heart rate, and oxygen consumption were also all lower with facial immersion, breath holding and exercise than in air. This experiment supports the view that cold water making contact with the face is one of the components of the DR (21). Also apparent from the study was that a DR was evident with breath holding in air, as indicated by the decreased heart rate and skin blood flow. However, when the participants performed the facial immersion this gave a more marked decrease in heart rate and skin blood flow indicating a stronger DR during exercise with face immersion in cold water is evident, as compared to an apnea for the same exercise and breath holding conditions in air (2).

Dive Response and Apnea

Another component of the DR is a reported apnea (21). If the function of the DR is to create an oxygen conservation effect, then in theory we should be able to have an extended BHT_{max} due to the oxygen conservation effect and the enhanced apnea. A study by Hayward et al. (25) examined the effect of varying water temperatures on BHT_{max} of totally submerged individuals and related it to the intensity of their diving bradycardia under the same circumstances. The experiment involved 20 males and females, wearing one piece bathing suits, who were assigned to one water temperature from a range of 0 to 35°C in 5°C intervals. The participants were positioned above an immersion tank on a slide that had a collapsible chair. This chair could be collapsed suddenly at any time, dropping the subject into the immersion tank. The subject held their breaths prior to immersion to determine what their BHT_{max} was prior to immersion. As well, base line heart rates were established prior to immersion while the participants were seated on the slide. When asked the subject was instructed to hold their breath and the chair was collapsed to given a sudden immersion in the water. The participants floated face down in the water while still holding their breath to the point of breaking, for a second BHT_{max} during full body immersion. There were no significant differences reported between males and females for any measured variable, consequently the findings of the study had both sexes put into one group. The average BHT_{max} for no submersion was reported to be 60.5 seconds and any submersion in water reduced this time significantly (25). Immersion in water at a temperature of 0°C reduced BHT_{max} to 15 seconds, 5°C to 27 seconds, 10°C to 18 seconds and 15°C to 25 seconds. At the warmer water temperatures (30 and 35°C), the breath hold times were 40s and 48 s respectively. From the reported results, 0°C water reduces a person's BHT_{max} by 75% from their non-immersion values, while 35°C reduced the value by only 20%. The mean heart rate observed upon immersion dropped drastically from those of pre-immersion values. The average heart rate before immersion was 102.5 beats·min^{-1}. Immersion in water at 0°C caused the average heart rates to drop to 51 beats·min^{-1}, at 5°C to 55 beats·min^{-1}, 10°C to 54 beats·min^{-1}, and 15 to 52 beats·min^{-1}. At the warmer water temperatures of 30 and 35°C, there was not much difference in HR_{min}, compared to the cold temperatures, with 30°C producing a HR_{min} of 55 beats·min^{-1}and 35°C producing 57 beats·min^{-1}. The results showed a strong effect of water temperature on BHT_{max} (25). Their results clearly show colder water temperatures decreased BHT_{max} relative to warmer water temperatures. This is in contrast to other studies reviewed by Gooden (21) that supported colder water temperatures with face immersion prolong maximal breath hold times. This reduction in BHT_{max} could be caused by the CSR response (8, 31, 41) which may trigger a gasping reflex and acute hyperventilation, shortening the mean breath hold times. Since the CSR is thought to be initiated by cold water making contact with cutaneous cold receptors on the torso (8, 29) it is possible that during the whole body submersions in the Hayward et al. study (25) the full body immersions triggered the CSR and possibly overrode any potential benefit of the DR.

Later work on the CSR has shown that full body immersion in colder water temperatures should produce a tachycardia upon initial immersion (40, 41). However Hayward et al. (25) saw a decrease in heart rate during immersion in cold water temperatures as soon as the participants were immersed. Even at a temperature of 5°C, they saw a decrease in heart rate from 102 beats·min^{-1}to 52 beats·min^{-1}. A later study by Tipton et al. (40) found that on immersion in water at 10°C, an increase in heart rate was seen. It is possible that the bradycardia component of the DR overrode the tachycardia component of the CSR enough to cause a decrease in heart rate. The respiratory responses of the CSR may have overridden any prolonged BHT_{max} the DR may have produced (21). It would appear that there is contradictory evidence in the literature regarding whether a CSR or a DR is seen upon sudden immersion in cold water.

Mechanism of the Dive Response

When water makes contact with the face it stimulates the ophthalmic branch of the trigeminal nerve. The trigeminal nerve innervates the area around the forehead, eyes and nose (22). The cardio-vascular changes that result from the DR are produced from stimulation from the brain stem to the heart and peripheral arteries (19). The resulting bradycardia is thought to be due to parasympathetic activity via the vagus nerve which attenuates the cardiac pacemaker and slows the heart rate (21). It is suggested that the peripheral vasoconstriction component of the DR is a result of increased activity of the sympathetic nerve system which supplies the blood vessels in the arms and calf, causing them to constrict and reduce blood flow (17). The developing apnea from the DR is thought to be caused by the slowing of beats·min^{-1} nerve impulses to the diaphragm and intercostal muscles, which may result in the reduction of inspiratory efforts and this helps prolong the subsequent breath hold (21). The general view in the diving physiology community (21) is that colder water temperatures with face immersion can give an increase in BHT_{max}. Sterba et al. (33) examined the effect of flushing of the face with both warm and cold water, however, showed no effects on breath hold time. A diving mask was setup to allow the continuous movement of water across the face at a desired temperature. The two water temperatures employed were 35°C for the warm- and 20°C for the cold-condition. It was evident that the cold condition did not change the BHT_{max} significantly with respect to the warm condition (33). This may possibly be the result of the cold-condition employing a water temperature of 20°C that was too high to trigger a pronounced DR. Other components of the DR, including bradycardia and vaso-constriction, were reported which indicated that the DR occurred, albeit with a smaller magnitude (33).

2.4 Exercise, Facial Immersion and the Dive Response

In addition to the literature discussing the dive response for resting participants, are studies of participants exercising with their faces immersed in water. These studies are relevant to a helicopter egress that would most likely involve a swim to the surface and are discussed below in the context of the DR. Several studies have looked at the heart rate of water immersed, exercising participants (5, 14, 26, 35) while others have studied exercising participants who were submerged (9, 32) or just had their faces immersed (5).

Whole Body Immersion Studies

Scholander (32) found that, in two out of twenty one Australian aboriginal pearl divers, a larger bradycardia occurred when the divers were swimming to the surface of the water as compared to when they sat quietly in the water and held their breath. These results could be interpreted that exercise may increase the magnitude of the DR and breath hold duration; however the choice of participants in this experiment may have influenced the outcome. All participants for Scholander's study were trained divers, who dived for pearls and shells for a living. It is possible that these individuals possess more developed DR components and breath hold abilities than an untrained diver. As a result, the magnitude of the bradycardia that developed in these individuals may be a result of years of training to dive, rather than simply swimming to the surface. Also, out of a total subject size of twenty one, the larger bradycardia during active swimming was only seen in two participants (32). Whether or not these two participants were the only ones to produce these results, or they were the only two measured for it, is unclear. As a result of only seeing a greater exercise induced bradycardia in two participants, it is difficult to conclude from the study that the greater bradycardia was a result of exercise (32).

Butler and Woakes (9) examined the effect of underwater swimming (~28°C) on minimum heart rates during a series of apneas. The investigators found that when the participants performed a stationary apneic full immersion, the heart rate dropped from resting level of 67 beats·min^{-1} to 48 beats·min^{-1} during the full immersion. When the participants performed an apneic underwater swim, their heart rate increased to 106 beats·min^{-1}, but then fell rapidly to 48 beats·min^{-1}(9). The BHT_{max} was also affected by the exercise condition. While the participants were sitting, completely immersed in the water, the mean breath hold duration was 59 s. When the participants swam under water, the mean breath hold duration was reduced to 33 s (9).While it has been previously reported that a heavy workload would reduce breath hold times and as a result reduce the bradycardia (4), Butler and Woakes suggested, based on their heart rate responses, that a moderate intensity workload could benefit the DR. This is due to their observation that if exercise precedes apnea, there was a faster reduction in HR (9). Although a faster reduction in HR would be beneficial in conserving oxygen, the HR had to fall from a higher rate in the exercising participants, due to the initial increase in HR from exercise.

A similar study was conducted by Strømme et al. (35) in which thirty male and ten female participants performed a series of apneas both in air and with face immersion in water during both resting conditions and exercising conditions. They found that during exercising conditions with facial immersion, there was a greater bradycardia observed than during apneic facial immersions during rest (35). The lowest HR observed during the exercising conditions was approximately 45 beats·min^{-1}and that during resting was 50 beats·min^{-1}. The initial heart rate at the start of the facial immersion apnea during the exercising condition was 110 beats·min^{-1}, compared to 90 beats·min^{-1}during the resting condition (35). This result is similar a study by Bergman et al. (5) showing even though the exercising condition produced a larger bradycardia, the lowest HR observed was not much lower compared to the resting condition. This indicated that exercising during an apneic facial immersion starts with a higher initial heart rate but is followed with a subsequent greater drop resulting in a bradycardia of a much larger magnitude compared to resting conditions. Again the absolute HR remained higher in the exercise condition compared to the resting condition with face immersion and breath holding. Strømme et al. concluded that there is no clear relationship between an individual's work intensity and the magnitude of the bradycardia they may develop during an apneic facial immersion (35).

Face Only Immersion And Exercise

Bergman et al (5) studied the effects of both isometric and dynamic exercise during apnea both in the air and with facial immersion. Ten men of normal height and weight who were not trained athletes performed a series of apneas in air and water during varying intensities of dynamic exercise or during sustained isometric contraction. When the participants pedaled on a cycle ergometer at 600 kpm·min^{-1} (5934 N·m·min^{-1}) and performed an apnea with a facial immersion in water at 15°C, a mean drop in heart rate of ~52 beats·min^{-1}occurred, compared to 44 beats·min^{-1} when they pedaled at 300 kpm·min^{-1} (2941 N·m·min^{-1}) (5). The drop in heart rate during rest with face immersion was 24 beats·min^{-1} (5). While the exercise conditions in this study produced a larger breath-hold-induced reduction in HR during face immersion compared to resting, neither condition yielded an absolute lower HR than the resting condition. The lowest HR observed for the resting condition with apnea was 53 beats·min^{-1} whereas for the exercise conditions of 300 kpm·min^{-1} (2941 N·m·min^{-1}) and 600 kpm·min^{-1} (5934 N·m·min^{-1}) the lowerst HR were 55 beats·min^{-1}, and 81 beats·min^{-1}, respectively. Both exercise conditions started with higher heart rates (300 kpm·min^{-1} (2941 N·m·min^{-1}) = 99 beats·min^{-1}, 600 kpm·min^{-1}(5934 N·m·min^{-1}) = 133 beats·min^{-1}) than the resting conditions (77 beats·min^{-1}). Based on Bergman et al. study (5), it appears that exercise creates a higher initial heart rate and the bradycardia with face immersion during exercise was of a larger relative magnitude, compared to resting conditions with face immersion.

2.5 Offshore Safety Applications

Sudden Face Immersion: Cold Shock Response or Dive Response?

It remains to be determined for sudden face immersions if a DR or a CSR is the predominant response. Through either the triggering of the CSR or the DR, a person's BHT_{max} duration can be affected. A major impact this would have is on people traveling to and from offshore oil platforms who find themselves trapped underwater in a crashed helicopter, as their BHT_{max} would appear to be the most important factor to their survival. Tipton et al. (38) had eight male participants perform a simulated escape from a helicopter passenger seat. The participants were strapped to a chair that was lowered and then inverted in a pool at a temperature at either 25°C or 10°C. Once they were lowered and inverted, the participants had to detach themselves from the seats, and climb hand over hand on a ladder attached to the bottom of the pool (38). When the participants performed a breath hold in 10°C while resting, the mean BHT_{max} was 30.4 s. When the participants performed a breath hold while also releasing themselves from the chair and climbing hand over hand on the ladder, the BHT_{max} dropped to 17.2 s (38).

Cheung et al. (11) examined the BHT_{max} of participants who worked in the offshore oil industry performing a breath hold while floating face down in the prone position dressed in a survival suit in 25°C water. Out of the 228 participants tested, 107 were currently working in the offshore oil industry, 25 worked in the military and the rest were people training to work in the offshore oil industry. The large sample size used in this study of offshore oil workers allows for an excellent representation of the offshore workers in general. The mean BHT_{max} for the offshore oil workers in the air was found to be 58.9 s, which dropped down to 40.5 s when they held their breath while floating face down in the water. The mean breath hold times of both 17.2 s. (38) and 40.5 s. (11) are not sufficient for people to perform a successful underwater breath hold escape in all conditions (7). Brooks et al. (7) investigated the amount of time required for 18 participants to successfully escape from a simulated helicopter fuselage submersion in 24°C pool water. The minimum breath hold time required for the last subject to escape from the simulator was found to be between 32.09 to 92.14 s in normal lighting conditions (7). When the participants performed the escape with no lighting at all, the minimum time for the last person to escape was found to be 37.75 s (7). When we compare the BHT_{max} times found by Tipton et al. (39) and Cheung et al. (11) to Brook's findings, it is evident that there is a large difference between the breath hold times and the time required to escape from a submerged helicopter. The escape times in Brook's study are a best case scenario, as the participants performed the escapes in calm, warm water (~25°C), and controlled laboratory conditions. The participants were also fit, highly qualified, highly practiced and prepared themselves both mentally and physically ahead of time for the breath hold (7). The participants also knew that if they could not evacuate the simulator through the windows (as in a real underwater escape), there was an emergency escape they could go out through, which some participants did (7).

In a real-life situation after a helicopter sinking, the water will undoubtedly be colder and the participants may experience a great degree of fear and anxiety from the crash and disorientation of a possible inversion of the fuselage, which can also increase a person's chance of aspirating water (37). It is, therefore, possible that the escape times from Brook's study (7) are optimistic and that if people were to find themselves in a real underwater escape from a sunken fuselage, the times could be much longer. If this was the case, it would seem based on the reported mean BHT_{max} of people performing breath holds in cold water conditions (11, 25, 34, 39, 42), that the passengers trapped underwater may need a supplementary breath source, such as a compressed air bottle or a re-breathing device, to ensure a successful escape.

2.6 Gender Comparisons

An extensive literature review did not reveal any studies that directly compared mean breath-holding times of males and females. Some studies that examined breath holding times did use both genders, but the data was collapsed into one set (11, 35). Several studies have looked at the differences in cardiovascular responses to cold between gender (10, 18, 23, 43, 44). Men have been shown to have a greater decrease in HR compared to females when exposed to cold air (43), while women have shown a greater decrease in skin blood flow compared to men when undergoing body cooling (10). Women have also shown to be able to maintain a greater core body temperature than men when cooled in cold air (18) indicating that women may be more insensitive to cooling (23). Females are generally smaller in physical height, and as result have smaller lung sizes, which may affect BHT_{max} and total body oxygen content possibly leading to shorter breath hold times than males. These studies suggest a comparison of gender responses for breath holding during face immersion is needed.

In conclusion, this literature review summarized the physiological responses to human face immersion. It was evident little research has focused on the face immersion conditions expected for passengers that are attempting an egress from a sunken, inverted helicopter fuselage. As such the experiments included in this thesis examined different conditions that could be typical of the helicopter egress environment. Although it is recognized breath holding may vary as a function of body size, in this thesis males and females of typical size and weight were included to assess their breath holding capabilities. This was to help answer the practical question: can they hold their breaths long enough to escape a helicopter in which conditions?

2.7 Research Hypotheses

Study 1: It was hypothesized that in subjects performing stationary face immersions, lower water temperature would reduce maximum breath hold times and increase minimum heart rate as a consequence of a greater cold shock response and a reduced dive response. It was also hypothesized that gender will affect maximum breath hold times and minimum heart rate. Finally it was hypothesized that pulmonary capacities, irrespective of gender, will positively correlate with maximal breath holding times.

Study 2: It was hypothesized for subjects performing face immersions with upper body sub-maximal exercising, that lower water temperature would reduce maximum breath hold times, minimum heart rate, and oxygen saturation concentrations as a consequence of a greater cold shock response and a reduced dive response. It was also hypothesized that gender will affect maximum breath hold times and minimum heart rate during upper body exercise with face immersion.

2.8 Testable Questions

When participants are performing a stationary facial immersion in varying water temperatures:

i) Do BHT_{max} and HR_{min} differ between gender with sudden face only immersion?

ii) Do BHT_{max} and HR_{min} differ between water temperatures of 0, 5, 10, 15, 20°C and air temperature of 24°C with sudden face-only immersion?

When participants are performing a facial immersion with moderate intensity upper body exercise in varying water temperatures:

i) Do BHT_{max}, HR_{min}, and SaO_2 differ between gender with a face immersion during exercise and breath holding?

ii) Do BHT_{max}, HR_{min}, and SaO_2 differ between water temperatures of 5, 10 and 20°C and air temperature of 24°C, with face immersion during exercise and breath holding?

2.9 References

1. Deaths, by cause - Chapter XX: External causes of morbidity and mortality (V01 - Y98), age group and sex, Canada, 2001 (Number): Statistics Canada, 2001.

2. **Andersson JP, Liner MH, Runow E and Schagatay EK**. Diving response and arterial oxygen saturation during apnea and exercise in breath-hold divers. *J Appl Physiol* 93: 882-886, 2002.

3. **Arnold RW**. Extremes in human breath hold, facial immersion bradycardia. *Undersea Biomed Res* 12: 183-190, 1985.

4. **Asmussen E and Kristiansson NG**. The "diving bradycardia" in exercising man. *Acta Physiol Scand* 73: 527-535, 1968.

5. **Bergman SA, Jr., Campbell JK and Wildenthal K**. "Diving reflex" in man: its relation to isometric and dynamic exercise. *J Appl Physiol* 33: 27-31, 1972.

6. **Boulant JA and Dean JB**. Temperature receptors in the central nervous system. *Annu Rev Physiol* 48: 639-654, 1986.

7. **Brooks CJ, Muir HC and Gibbs PN**. The basis for the development of a fuselage evacuation time for a ditched helicopter. *Aviat Space Environ Med* 72: 553-561, 2001.

8. **Burke WE and Mekjavic IB**. Estimation of regional cutaneous cold sensitivity by analysis of the gasping response. *J Appl Physiol* 71: 1933-1940, 1991.

9. **Butler PJ and Woakes AJ**. Heart rate in humans during underwater swimming with and without breath-hold. *Respir Physiol* 69: 387-399, 1987.

10. **Cankar K, Finderle Z and Strucl M**. Gender differences in cutaneous laser doppler flow response to local direct and contralateral cooling. *J Vasc Res* 37: 183-188., 2000.

11. **Cheung SS, D'Eon NJ and Brooks CJ**. Breath-holding ability of offshore workers inadequate to ensure escape from ditched helicopters. *Aviat Space Environ Med* 72: 912-918, 2001.

12. **Clifford WS**. Helicopter Crashworthiness, A Review of U.K. Military and World Civil Helicopter Water Impacts from 1971-1992. In: *CA Reports 96005*, 1996.

13. **Cooper KE, Martin S and Riben P**. Respiratory and other responses in subjects immersed in cold water. *J Appl Physiol* 40: 903-910, 1976.

14. **Craig AB, Jr. and Medd WL.** Man's responses to breath-hold exercise in air and in water. *J Appl Physiol* 24: 773-777, 1968.

15. **Djarova T, Ilkov A, Varbanova A, Nikiforova A and Mateev G.** Human growth hormone, cortisol, and acid-base balance changes after hyperventilation and breath-holding. *Int J Sports Med* 7: 311-315, 1986.

16. **Elsner R and Gooden B.** Diving and asphyxia. A comparative study of animals and man. *Monogr Physiol Soc* 40: 1-168, 1983.

17. **Finley JP, Bonet JF and Waxman MB.** Autonomic pathways responsible for bradycardia on facial immersion. *J Appl Physiol* 47: 1218-1222, 1979.

18. **Glickman-Weiss EL, Cheatham CC, Caine N, Blegen M and Marcinkiewicz J.** Influence of gender and menstrual cycle on a cold air tolerance test and its relationship to thermosensitivity. *Undersea Hyperb Med* 27: 75-81., 2000.

19. **Gooden BA.** The diving response in clinical medicine. *Aviat Space Environ Med* 53: 273-276, 1982.

20. **Gooden BA.** The evolution of asphyxial defense. *Integr Physiol Behav Sci* 28: 317-330, 1993.

21. **Gooden BA.** Mechanism of the human diving response. *Integr Physiol Behav Sci* 29: 6-16, 1994.

22. **Gooden BA, Lehman RG and Pym J.** Role of the face in the cardiovascular responses to total immersion. *Aust J Exp Biol Med Sci* 48: 687-690, 1970.

23. **Graham TE.** Thermal, metabolic, and cardiovascular changes in men and women during cold stress. *Med Sci Sports Exerc* 20: S185-192, 1988.

24. **Hayward JS and Eckerson JD.** Physiological responses and survival time prediction for humans in ice-water. *Aviat Space Environ Med* 55: 206-211, 1984.

25. **Hayward JS, Hay C, Matthews BR, Overweel CH and Radford DD.** Temperature effect on the human dive response in relation to cold water near-drowning. *J Appl Physiol* 56: 202-206, 1984.

26. **Hong SK, Song SH, Kim PK and Suh CS.** Seasonal observations on the cardiac rhythm during diving in the Korean ama. *J Appl Physiol* 23: 18-22, 1967.

27. **Keatinge WR and Evans M**. The respiratory and cardiovascular response to immersion in cold and warm water. *Quarterly Journal of Experimental Physiology*: 83-94, 1961.

28. **Keatinge WR, McIlroy MB and Goldfien A**. Cardiovascular Responses to Ice-Cold Showers. *J Appl Physiol* 19: 1145-1150, 1964.

29. **Keatinge WR and Nadel JA**. Immediate respiratory response to sudden cooling of the skin. *J Appl Physiol* 20: 65-69, 1965.

30. **Lin YC**. Circulatory functions during immersion and breath-hold dives in humans. *Undersea Biomed Res* 11: 123-138, 1984.

31. **Mekjavic IB, La Prairie A, Burke W and Lindborg B**. Respiratory drive during sudden cold water immersion. *Respir Physiol* 70: 121-130, 1987.

32. **Scholander PF, Hammel HT, Lemessurier H, Hemmingsen E and Garey W**. Circulatory adjustment in pearl divers. *J Appl Physiol* 17: 184-190, 1962.

33. **Sterba JA and Lundgren CE**. Breath-hold duration in man and the diving response induced by face immersion. *Undersea Biomed Res* 15: 361-375, 1988.

34. **Sterba JA and Lundgren CE**. Diving bradycardia and breath-holding time in man. *Undersea Biomed Res* 12: 139-150, 1985.

35. **Stromme SB, Kerem D and Elsner R**. Diving bradycardia during rest and exercise and its relation to physical fitness. *J Appl Physiol* 28: 614-621, 1970.

36. **Tipton M**. The effect of clothing on "diving bradycardia" in man during submersion in cold water. *Eur J Appl Physiol Occup Physiol* 59: 360-364, 1989.

37. **Tipton MJ**. The initial responses to cold-water immersion in man. *Clin Sci (Lond)* 77: 581-588, 1989.

38. **Tipton MJ, Balmi PJ, Bramham E, Maddern TA and Elliott DH**. A simple emergency underwater breathing aid for helicopter escape. *Aviat Space Environ Med* 66: 206-211, 1995.

39. **Tipton MJ, Franks CM, Sage BA and Redman PJ**. An examination of two emergency breathing aids for use during helicopter underwater escape. *Aviat Space Environ Med* 68: 907-914, 1997.

40. **Tipton MJ and Golden FS**. The influence of regional insulation on the initial responses to cold immersion. *Aviat Space Environ Med* 58: 1192-1196, 1987.

41. **Tipton MJ, Stubbs DA and Elliott DH**. Human initial responses to immersion in cold water at three temperatures and after hyperventilation. *J Appl Physiol* 70: 317-322, 1991.

42. **Tipton MJ and Vincent MJ**. Protection provided against the initial responses to cold immersion by a partial coverage wet suit. *Aviai Space Environ Med* 60: 769-773, 1989.

43. **Wagner JA and Horvath SM**. Cardiovascular reactions to cold exposures differ with age and gender. *J. Appl. Physiol* 58: 187-192, 1985.

44. **Wagner JA and Horvath SM**. Influences of age and gender on human thermoregulatory responses to cold exposures. *J. Appl. Physiol* 58: 180-186, 1985.

Chapter 3

Breath Holding After Sudden Face Immersion in Water: Influences of Gender and Water Temperatures

Breath Holding After Sudden Face Immersion in Water: Effect of Gender and Water Temperature

[1]J. T. Power, [1]E. E. Bradbury, [2]S. S. Cheung, [1]L. Petrie and [1]M. D. White

[1]School of Human Kinetics and Recreation
Memorial University of Newfoundland
St. John's, Newfoundland, Canada
A1C 5S7

[2]Environmental Ergonomics Laboratory
School of Health & Human Performance
Dalhousie University
Halifax, Nova Scotia, Canada

The infrastructure for this study was funded by a Canadian Foundation for Innovation New Opportunities grant and the research was part of the Cold Working Conditions Component of the Safety Net group that is funded by Canadian Institutes for Health Research

Keywords: breath holding, diving bradycardia, face immersion, gender

3.1 Abstract

The purpose of this study was to determine if gender and water temperatures would affect on maximum breath hold time (BHT_{max}) following a sudden face immersion. Six males and six females of college age and normal physique volunteered to participate in this study. The subject lay in the prone position and rested for 10 min prior to breath holding trial in the air (~24°C) or with face immersion in water at 0,5,10,15 and 20°C. Males in the study were significantly taller ($p<0.01$) and heavier ($p<0.05$), but had the same age and body mass index as the females. Across 6 breath hold conditions, males had a significantly longer breath hold time ($0.001< p<0.05$) than females. With breath holding in air and with face immersion in 10, 15 and 20°C water there were similar HR responses between gender, but at 0 and 5°C females HR_{min} were significantly greater ($p <0.01$). For the entire group of 12, positive and significant correlations ($p <0.05$) were found between inspiratory capacity and BHT_{max} at water temperatures of 0, 10, 15, 20°C. In conclusion, the results showed as BHT_{max} decreased at lower water temperatures and males had longer BHT_{max} than females in all conditions. It remains to be established if this is a gender or size dependent effect. The best predictor of a longer BHT_{max} in these conditions was a larger inspiratory capacity.

3.2 Introduction

Helicopters have a high center of gravity and after a ditching or crashing in open water will rapidly invert and sink if the floatation bags fail. Survivors of the helicopter's impact and submersion appear to need to subsequently perform a breath hold swim to the surface. Brooks et al (1) demonstrated for highly experienced participants that the minimum egress time from a submerged 15 to 18 passenger Super Puma 18 fuselage ranged from 28 to 92 seconds. For several of their participants in 25°C water (1) and for 34% of the participants in a complementary study (4), breath hold times were insufficient to reach the surface. In an epidemiological study the survival rate of the initial impact for military passengers travelling in a helicopter that crashed or ditched in the ocean was 83.1% (5) but 82.6% of the initial survivors appeared to have drowned (5). Together these studies (1, 4, 5) support that these passengers may have performed an unsuccessful underwater breath hold swim from a submerged helicopter. As such, any factors influencing ventilation and maximal breath hold times (BHT_{max}) in these conditions need to be identified to help prevent such drownings.

Two such factors influencing ventilation and maximal breath hold times (BHT_{max}) are gender and water temperature. An extensive literature review did not reveal studies comparing breath-holding times across gender. Several studies have looked at the differences in cardiovascular responses to cold between gender (2, 8, 12, 17, 18). While males have also been shown to have a greater decrease in HR than females when exposed to cold air (17), women have shown a greater decrease in skin blood flow compared to males when undergoing body cooling (2). Females are also generally smaller in physical height, and as result have smaller lung sizes, which may affect BHT_{max} (4) leading to shorter breath hold times than males. Together these studies suggest a comparison of gender responses for breath holding during face immersion is needed.

Lower water temperature during face immersion has been shown to lengthen the BHT_{max} in conditions that produced a dive response (10). However, it is not clear if this relationship holds during a sudden face immersion, such as during an underwater helicopter egress. Some studies indicate absence of a dive response in anxious/stressed individuals (20, 21), such as individuals in an underwater helicopter egress scenario As such it remains to be established if this relationship between BHT_{max} and water temperature holds across gender for a condition of sudden face immersion.

The present study investigated BHT_{max} and HR responses across gender during face-only immersion in water temperatures from 0 to 20°C. Males and females of normal height and weight were studied to assess if there was a gender dependence of the dive response and BHT_{max} in these conditions. The first questions asked were if water temperature or gender affected BHT_{max} after a sudden face only immersion. Also associations between pulmonary capacities and BHT_{max} values were evaluated to establish if the same predictors of breath holding times evident at water temperature of 25°C (4) were also evident across this lower range of water temperatures.

3.3 Methods

3.3.1 Participants:

Six healthy males and six females volunteered for this experiment and their physical characteristics are given in Table 3.1. The sample size was determined with a power calculation. This calculation was based on a difference worth detecting of 15%, an alpha level of 0.05, a beta value of 0.8 and the standard deviations of each group at 7% of the estimated means. The protocol received clearance from the appropriate institutions' human ethics committees and participants gave a signed informed consent prior to participation.

3.3.2 Instrumentation:

Participants lay on a cushioned table in the prone position when they immersed their faces into a stirred face bath (49.5 cm x 35 cm x 23 cm) that was insulated by Styrofoam. The water flowed to and from the face bath and a LAVDA K-2/R chiller/heater unit (Brinkmann Instruments) with an adjustable set-point (range 0 to 40°C) in insulated polyethylene tubing. Forehead and chest temperature were measured using copper constantan thermocouples secured to the skin surface with adhesive tape. Temperature signals were acquired by a National Instruments (USA) data acquisition system controlled by Labview Software on a personal computer. Heart rate (HR) was recorded by telemetry (Polar, USA) at two min intervals for a ten min period prior to each breath hold and every five seconds during a breath hold. All participants wore the same garments during the experiments with a clo value of ~1.

A 13 litre Spirometer (Collins, USA) was employed to measure pulmonary capacities. The measures taken included Inspiratory Capacity (IC), Expiratory Reserve Volume (ERV), Vital Capacity (VC), Forced Expired Volume in 1 sec (FEV1.0) and Forced Vital Capacity (FVC). The typical breath holding size (or volume) reproducibility of the seated participants was assessed by measuring typical breath hold volumes with the spirometer on three trials. The typical breath hold volume values were obtained by having the participants perform a breath hold as if they were going to immerse their faces in the face bath while connected to the spirometer. The amount of air inhaled and held by each subject was recorded as the volume for their typical breath hold. For each subject the IC was also compared between the prone and seated position and the mean difference between the two positions was less than 5 ml.

3.3.3 Protocol:

Maximum breath hold times (BHT_{max}) were collected for each subject in six conditions. Five breath hold conditions were with the face immersed in water at either 0°, 5°, 10°, 15° or 20°C. The sixth breath hold condition was without face immersion in room temperature of 24 ± 1°C. Each subject had three successive trials in each breath hold condition and the subject's mean value for the 3 successive trials was employed in the subsequent analyses. The recording of the time started when the subject's face made contact with the water, and ended when the participants pulled their head up out of the water. The participants were instructed not to hyperventilate before holding their breath and not to breathe out while under water. The orders of breath hold conditions were presented in randomized order so as to eliminate any possible training or cumulative effect resulting from repetitive face immersions. The subject was informed beforehand of the water bath temperature for each trial. Between each face immersion trial, at each water temperature, the subject rested until their forehead temperatures returned to pre-immersion values before the next face immersion and breath hold. All BHT_{max} were not revealed to the subject until all three trials ended in a given breath hold condition. As such the subject was not informed of how much time was passing for each BHT_{max}. This approach was employed so the subject would not be trying to beat a previous BHT_{max}.

3.3.4 Statistical Analyses:

An ANOVA model was employed with a repeated factor of water temperature (0°C, 5°C, 10°C, 15°C, 20°C and Air) and non-repeated factor of gender (Male, Female). Means comparisons across gender were made in each of the six breath hold conditions. The reproducibility of breath hold size/volumes were evaluated with an intraclass correlation coefficient and a one way ANOVA comparing means of breath hold volumes between three trials. The level of significance for the comparisons was set at 0.05.

3.4 Results

The subject's physical characteristics and resting heart rates are given in Table 3.1. The males were significantly taller ($p = 0.005$), weighed more ($p = 0.02$) but their age, body mass index and resting pre-immersion heart rates were not significantly different than the females.

Except for the ERV, all pulmonary capacities (Table 3.2) for males were significantly greater than for the females ($0.0001 < p < 0.001$). The reproducibility of volitional breath holds volumes by the participants were assessed in three trials. The breath hold volumes in each trial were 1620 ± 261 ml, 1679 ± 278 ml and 1575 ± 244 ml were not significantly different. The intraclass correlation coefficient (R) between the 3 breath holds trials was significant ($R = 0.98$, $p < 0.0001$) indicating a high reproducibility of breath hold size/volume of the participants. The mean voluntary breath hold volume for these participants was 52 ± 7 % of their IC.

Positive and significant ($p < 0.05$) correlations were evident for the group of 12 participants between IC and BHT_{max} at face bath temperatures of 0, 10, 15 and 20°C (Table 3.3). There was also a trend for a positive significant correlation between IC and BHT_{max} at the face bath temperature of 5°C. For other pulmonary capacities including, VC, $FEV_{1.0}$ and FVC, there were also some positive significant correlations to BHT_{max} (Table 3.3).

For BHT_{max} with faces immersed in water there was a significant main effect for water temperature ($F=4.0$, $p=0.01$) and gender ($F=9.0$, $p=0.03$). Across all face bath temperatures (0° to 20°C) and in 24°C in the air, the mean BHT_{max} at each water temperature was significantly ($0.001 < p < 0.05$) for males than for females (Fig. 3.1). At face bath temperatures of 0°, 10° and 15°C the males more than doubled the females BHT_{max}, while at temperatures of 5°C, 20°C and in air the BHT_{max} for the females was a little more than half that of the males (Fig. 3.1). After adjusting for pre-immersion conditions (air BHT_{max} – water temperature BHT_{max}), it was found that there were no longer any significant differences between male and female BHT_{max} across all water temperatures (Fig. 3.1).

There was no main effect of water temperature or gender for heart rates. Heart rates during face immersion only showed significantly greater values for females than males at the face immersions of 0°C and 5°C (Fig. 3. 2). At all other face bath temperatures there were no significant differences across gender for heart rate during immersion and breath holding. After adjusting for pre-immersion differences (air HR_{min} – water temperature HR_{min}), there were no longer any significant differences between male and female HR_{min} at the lower water temperatures. There were significant differences in HR_{min} at the air – 15°C and air – 20°C conditions (Fig 3.2).

There were no significant differences across gender for forehead skin temperatures (Fig. 3.3). The average values of forehead skin temperatures for both males and females decreased from approximately 32 °C with breath holding in air to approximately 14°C with face immersion in the 0°C water bath.

The levels of significance and correlation coefficients between pulmonary capacities and BHT_{max} for males and females combined are given in Table 3-3. Figure 3-4 gives scatter plots of inspiratory capacity and forced vital capacity expressed as a function of BHT_{max} for males and females combined.

3.5 Discussion

This is the first study to our knowledge that compares the effect of cold-water face immersion on maximum breath hold time (BHT_{max}) across gender. It was clear that the males were able to hold their breath for a greater amount of time when compared to females in air and at all face bath temperatures (Fig. 3.1). Face immersion with breath holding in water temperatures lower than 15°C gave the greatest decrements in BHT_{max}. However, this decrement from non-immersed values was more apparent for males than females (Fig. 3.1).

The second main finding of this study was that for males at all temperature face immersions gave a bradycardia of approximately 15 beats·min^{-1}relative to their pre-immersion heart rates resting HR of ~74 (Table 3.1, Figure 3-2). However, for both genders as face bath temperatures decreased, there was no trend for a greater bradycardia and there was decreased voluntary apnoea or BHT_{max}. This is in contrast to the review of Gooden (10) who summarized a series of face immersion studies that clearly indicated face immersion in lower water temperatures gave a more pronounced bradycardia and apnea as indicative of a more pronounced Dive Response (DR). In agreement with our results, however, Hayward and colleagues (13) saw no influence of water temperature on HR level after a sudden facial and whole body immersion of their participants in water from 0 to 35°C. Also Hayward et al's participants, similar to the participants in the current study (Fig. 3-1), had shorter breath-hold times at lower water temperatures. It appears that the literature is equivocal in regard to the influence of decreasing water temperature on DR bradycardia and voluntary apnoea.

It is thought that the main purpose of the diving response (DR) is to allow for a greater BHT_{max} through a series of physiological responses including a bradycardia, peripheral vasoconstriction and smaller decreases in oxygen saturation (9, 10). The DR is thought to be triggered through cold water making contact with the face and stimulating the ophthalmic branch of the trigeminal nerve (10, 11). The stimulation of the nerve will trigger responses in the Cardio Inhibitory center (CIC), Vasomotor Centre (VMC) and the Respiratory Center (RC) (6, 7, 10). The CIC sends a signal through the vagus nerve giving a decrease in HR, while the VMC initiates impulses that cause a constriction in peripheral arterioles (10). The stimulus to the RC will cause the diminution of nerve impulses to the diaphragm resulting in a prolonged voluntary apnoea (10). An inverse relationship exists between the DR and water temperature, resulting in more pronounced BHT_{max} or HR_{min} responses seen at lower temperatures in a calm lab condition (10, 14, 15, 19). The present results (Fig. 3.1) contradict this expected prolonged BHT_{max} normally seen with a DR. This suggests the CSR predominated with face immersion as is evident for whole body immersions (2). The input that initiates the CSR is thought to be from surface temperature sensitive neurons. It follows that a strong correlate of the CSR was shown to be the rate of skin temperature cooling following a sudden whole body immersion in cold water (2). Since human beings are not diving mammals, we appear to have a more developed CSR than DR, even though the DR has a survival advantage. It is also possible that the unpleasant sensation of immersing one's face in the water may cause a sense of fear and anxiety. This could possibly trigger the *fight or flight* response, which would result in an increase in heart rate and an urge to hyperventilate, both of which may decrease the apnoea and the bradycardia associated with the DR. Anxious participants demonstrating a *fight or flight* response were also shown not to demonstrate the DR, even in quiet lab conditions (10, 20, 21).

It appears to follow that the significantly taller males and females (Table 3.1), who as a function of their height (3) had a greater pulmonary capacity, were able to hold their breath longer across all water temperatures examined. The results support taller individuals both in air and with face immersion are able to hold their breaths for longer periods of time as previously reported for breath holding with face immersion in 25°C water (4). Greater pulmonary capacities, principally the IC, acted as a significant predictor of longer BHT_{max} in our participants in the current conditions (Table 3.3, Fig. 3-4). This positive association between BHT_{max} and pulmonary capacities was more pronounced for the entire group of 12 participants than for the within gender correlations (data not shown). This suggests a larger variance in pulmonary capacities is needed before a relationship is evident with BHT_{max}. The results also indicated the females were significantly shorter (Table 3.1) and have significantly lower pulmonary capacities (Table 3.3) than the males. Although lower pulmonary capacities were shown to give shorter BHT_{max} after face immersion (4), it is difficult to immediately assume that the decreased

BHT_{max} our females showed was an affect of gender. To establish if the difference in BHT_{max} is an effect of body size or an effect of gender a future study of BHT_{max} and face immersion is needed that includes groups of tall and short participants within each gender. That study could help affirm or refute the current finding of a gender difference in the DR as indicated by males having a more pronounced bradycardia than females during face immersion.

When we adjusted for pre-immersion differences in breath hold time ($\triangle BHT_{max}$) (Fig 3.1) there are no longer any significant differences between males and females. This lends support to the hypothesis that breath hold times may be more dependent on size rather than gender since these results suggest that males may have a larger capacity than females which may be a size dependent factor. Also after adjusting for pre-immersion differences in heart rate ($\triangle HR_{min}$) there were also no longer any differences between gender at the lower water temperatures (0°and 5°C), but significant differences became evident at the higher temperatures of 15° and 20°C with the females having a higher HR_{min} than males (Fig 3.2). It may be that the higher temperatures were not cold enough to trigger a bradycardia of the same magnitude in the females as seen in the males, however previous studies (13, 16) have not reported a differences in HR_{min} between gender during facial immersions.

In conclusion, the results of this study indicated that water temperature had a significant affect on BHT_{max}. At lower water temperatures there was a decreased BHT_{max}

with respect to both breath holding in higher water temperatures or to breath holding with no facial immersion in air. Although the results support that there was an affect of gender on BHT_{max}, it remains to be established if this is a gender or size dependent effect since BHT_{max} is a function of stature and stature differed significantly across gender. Finally the results support that the best predictor of a longer BHT_{max} in these conditions was a larger inspiratory capacity.

3.6 References:

1. **Brooks CJ, Muir HC and Gibbs PN**. The basis for the development of a fuselage evacuation time for a ditched helicopter. *Aviat Space Environ Med* 72: 553-561, 2001.

2. **Cankar K, Finderle Z and Strucl M**. Gender differences in cutaneous laser doppler flow response to local direct and contralateral cooling. *J Vasc Res* 37: 183-188., 2000.

3. **Cherniack RM and Raber MB**. Normal standards for ventilatory function using an automated wedge spirometer. *Am Rev Respir Dis* 106: 38-46, 1972.

4. **Cheung SS, D'Eon NJ and Brooks CJ**. Breath-holding ability of offshore workers inadequate to ensure escape from ditched helicopters. *Aviat Space Environ Med* 72: 912-918, 2001.

5. **Clifford WS**. Helicopter Crashworthiness, A Review of U.K. Military and World Civil Helicopter Water Impacts from 1971-1992. In: *CA Reports 96005*, 1996.

6. **Fagius J and Sundlof G**. The diving response in man: effects on sympathetic activity in muscle and skin nerve fascicles. *J Physiol* 377: 429-443, 1986.

7. **Finley JP, Bonet JF and Waxman MB**. Autonomic pathways responsible for bradycardia on facial immersion. *J Appl Physiol* 47: 1218-1222, 1979.

8. **Glickman-Weiss EL, Cheatham CC, Caine N, Blegen M and Marcinkiewicz J**. Influence of gender and menstrual cycle on a cold air tolerance test and its relationship to thermosensitivity. *Undersea Hyperb Med* 27: 75-81., 2000.

9. **Gooden BA**. The evolution of asphyxial defense. *Integr Physiol Behav Sci* 28: 317-330, 1993.

10. **Gooden BA**. Mechanism of the human diving response. *Integr Physiol Behav Sci* 29: 6-16, 1994.

11. **Gooden BA, Lehman RG and Pym J**. Role of the face in the cardiovascular responses to total immersion. *Aust J Exp Biol Med Sci* 48: 687-690, 1970.

12. **Graham TE**. Thermal, metabolic, and cardiovascular changes in men and women during cold stress. *Med Sci Sports Exerc* 20: S185-192, 1988.

13. **Hayward JS, Hay C, Matthews BR, Overweel CH and Radford DD**. Temperature effect on the human dive response in relation to cold water near-drowning. *J Appl Physiol* 56: 202-206, 1984.

14. **Kawakami Y, Natelson BH and DuBois AR**. Cardiovascular effects of face immersion and factors affecting diving reflex in man. *J Appl Physiol* 23: 964-970, 1967.

15. **Song SH, Lee WK, Chung YA and Hong SK**. Mechanism of apneic bradycardia in man. *J Appl Physiol* 27: 323-327, 1969.

16. **Stromme SB, Kerem D and Elsner R**. Diving bradycardia during rest and exercise and its relation to physical fitness. *J Appl Physiol* 28: 614-621, 1970.

17. **Wagner JA and Horvath SM**. Cardiovascular reactions to cold exposures differ with age and gender. *J. Appl. Physiol* 58: 187-192, 1985.

18. **Wagner JA and Horvath SM**. Influences of age and gender on human thermoregulatory responses to cold exposures. *J. Appl. Physiol* 58: 180-186, 1985.

19. **Whayne TF, Jr. and Killip T, 3rd**. Simulated diving in man: comparison of facial stimuli and response in arrhythmia. *J Appl Physiol* 22: 800-807, 1967.

20. **Wolf S, Schneider RA and Groover ME**. Further studies on the circulatory and metabolic alterations of the oxygen-conserving (diving) reflex in man. *Trans Assoc Am Physicians* 78: 242-254, 1965.

21. **Zbrozyna AW and Westwood DM**. Cardiovascular responses elicited by simulated diving and their habituation in man. *Clin Auton Res* 2: 225-233, 1992.

Table 3.1: Participants' physical characteristics, age and resting heart rates over the 10 minutes period prior to face immersions. Values in the table are mean ± Standard Error (SE), * = p <0.05, ** = p <0.01)

	Age (y)	Height (m)	Weight (kg)	Body Mass Index (kg • m-1)	Resting HR
Females	26.8 ± 3.7	1.62 ± 0.04	62.4 ± 5.4	23.7 ± 1.5	77 ± 4
Males	23.0 ± 0.8	1.76 ± 0.02	79.4 ± 3.2	25.6 ± 0.9	74 ± 4
P	NS	**	*	NS	NS

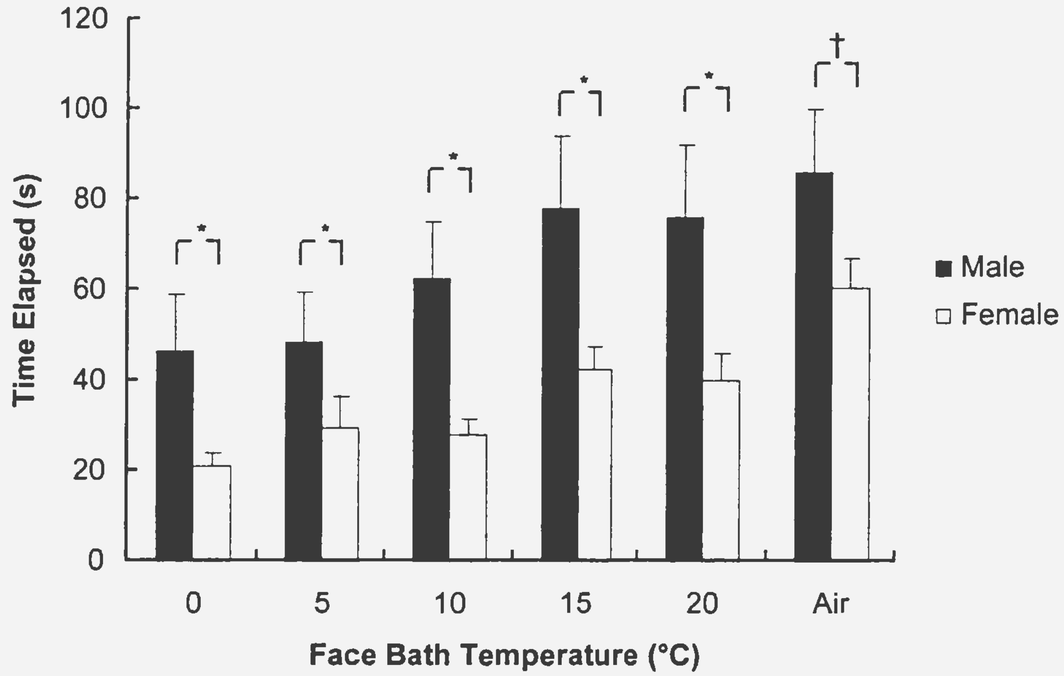
Table 3.2: Resting pulmonary capacities (mean ± SE) for 6 male and 6 female participants. (Inspiratory Capacity (IC); Expiratory Reserve Volume (ERV); Vital Capacity (VC): Forced Expired Volume in 1 sec (FEV1.0) and Forced Vital Capacity (FVC)). (*** = p = 0.001, **** = p<0.001, NS = Non Significance)

	IC (ml)	ERV (ml)	VC (ml)	FEV1.0 (ml • s-1)	FVC (ml)
Male Mean	3650	2683	5183	3900	5092
Male ±SE	177	246	177	106	147
Female Mean	2267	2142	3358	2600	3383
Female ±SE	182	322	266	234	275
	****	NS	****	***	****

Table 3.3: First order correlation coefficients between BHTmax at 0°, 5°, 10°, 15°, 20°C and in air with pulmonary capacities in all participants. For a sample size of 12 participants an r value of 0.58 was significant at a $p = 0.05$. Abbreviations in Table are given in the title of Table 3.2. (* = $p<0.05$)

	IC	ERV	VC	FEV1.0	FVC
(n)	(12)	(12)	(12)	(12)	(12)
BHT_{max} 0°C	0.59*	0.57	0.38	0.39	0.39
BHT_{max} 5°C	0.57	0.18	0.44	0.40	0.44
BHT_{max} 10°C	0.59*	0.17	0.57	0.61*	0.59*
BHT_{max} 15°C	0.59*	0.08	0.46	0.49	0.90*
BHT_{max} 20°C	0.59*	0.17	0.57	0.61*	0.59*
BHT Air (24°C)	0.24	0.26	0.51	0.43	0.51

Figure 3.1: Upper Panel: Male and female BHTmax for water temperatures of 0°, 5°, 10°, 15° and 20°C and room air (~24°C) during a resting face immersion. Lower Panel: rBHTmax are adjusted for pre-immersion differences in BHTmax that were measured in room air (* = p< 0.05, † = p < 0.001, NS = Not Significance)



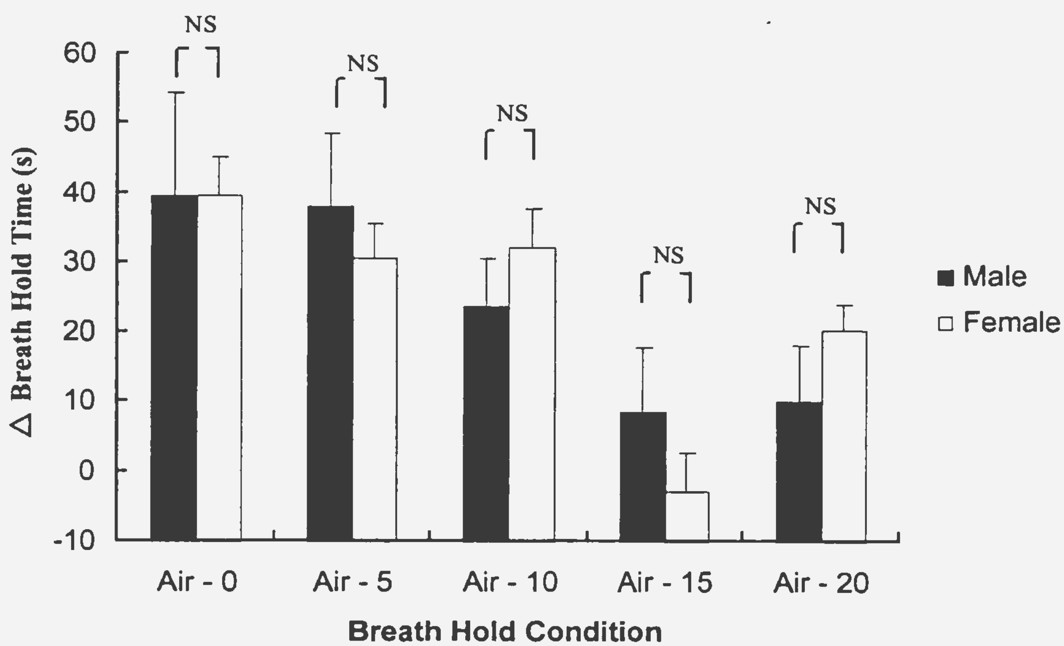


Figure 3.2: Upper Panel: Male and female HRmin in beats·min-1during a resting face immersion with breath holding at water temperatures of 0°, 5°, 10°, 15° and 20°C and room air (~24°C). Lower Panel: rHRmin values are adjusted for pre-immersion differences in HRmin that were measured in room air (* = p<0.05, † = p<0.01, NS = not significance).

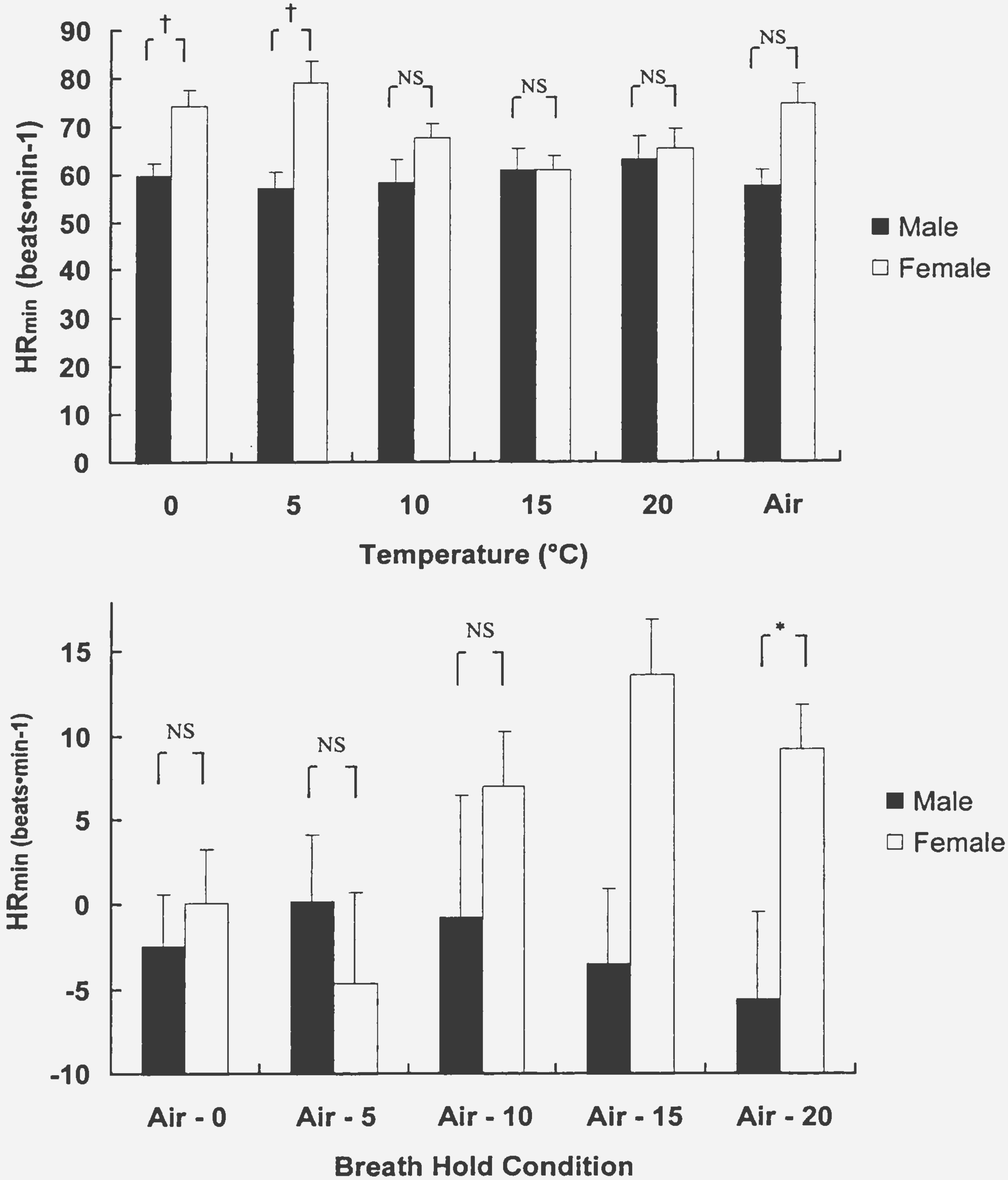


Figure 3.3: Male and female minimum mean forehead skin temperatures observed pre-immersion (Air) and during immersion at water temperatures of 0°, 5°, 10°, 15°, and 20°C. (NS = Not significance)

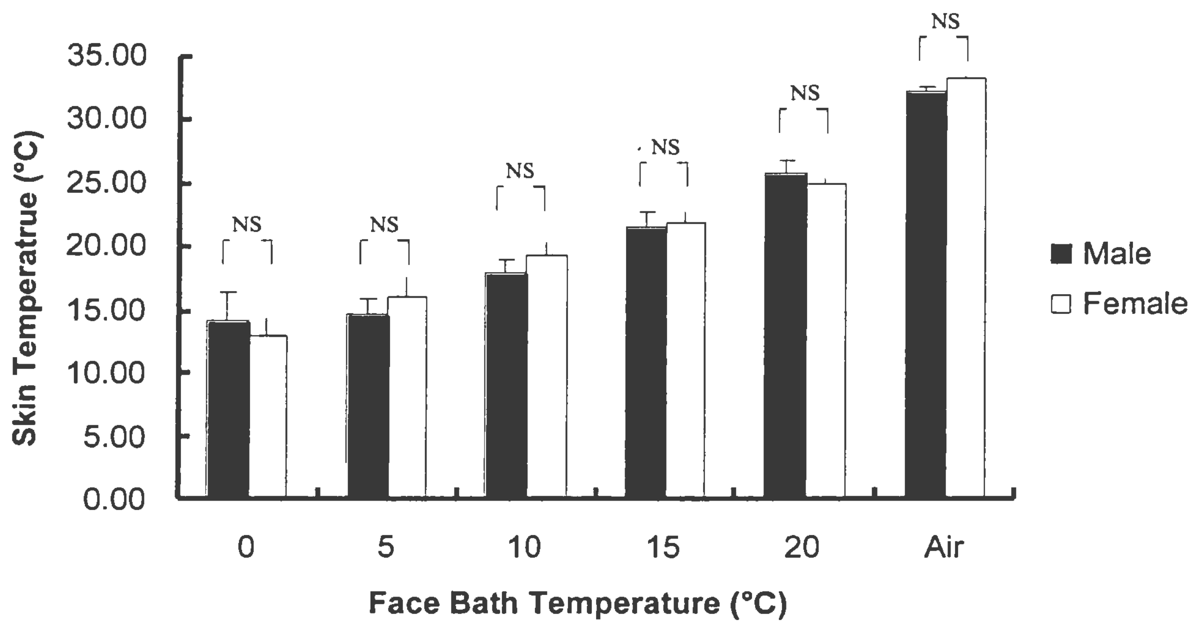


Figure 3.4a: Inspiratory capacity (IC) correlations with maximum breath hold time in 6 males and 6 female participants at face bath temperatures of 0°, 5° and 10°C (* = two data points).

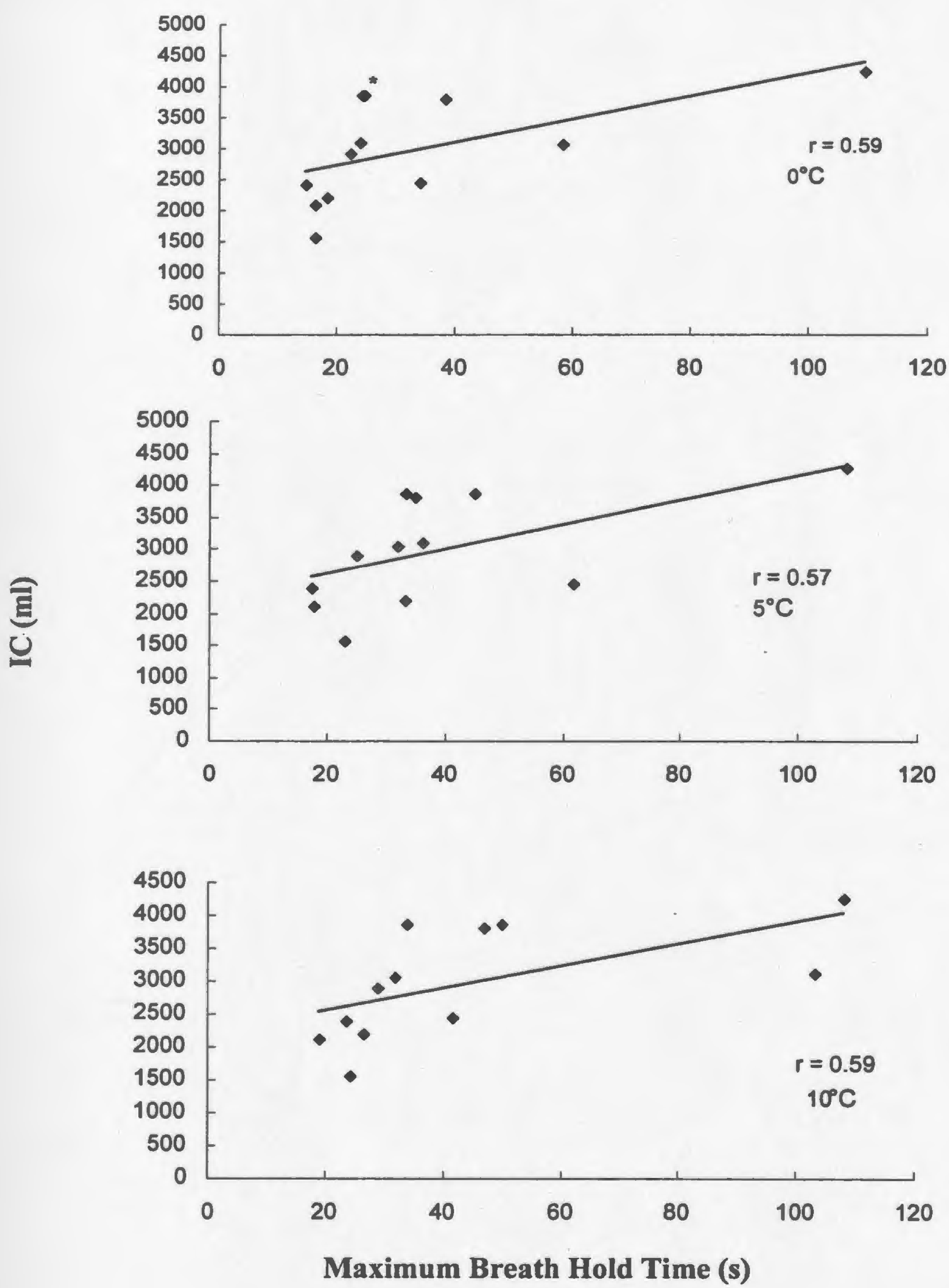
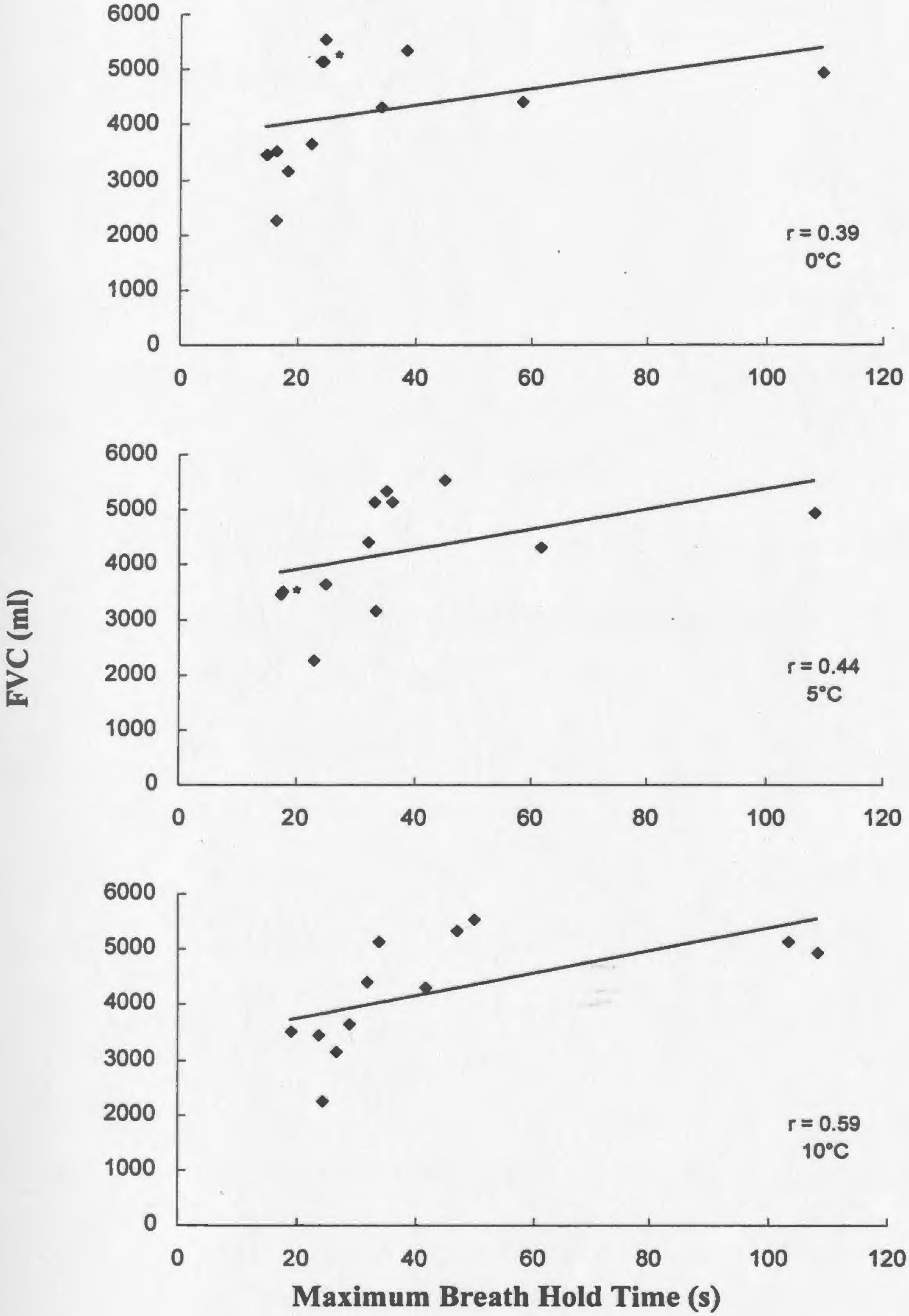


Figure 3.4b: Forced Vital Capacity (FVC) correlation with maximum breath hold time in 6 males and 6 female participants at face bath temperatures of 0°, 5° and 10°C (* = two data points).



Chapter 4

Breath Hold Duration and Heart Rate Responses Across Gender During Moderate Intensity Exercise After A Sudden Face Immersion

4.1 Abstract

It was investigated if gender, water temperature and exercise influence BHT_{max}, HR minimum (HR_{min}), and hemoglobin saturation (SaO_2) during moderate intensity upper body exercise. Six males and six females who were all healthy and college aged (25 ± 2 y.o.a., mean ± SE) participated in the study. Males were significantly taller ($p<0.05$) and heavier ($p<0.0001$) than the females. Participants lay in a prone position while resting or while exercising on an arm crank ergometer. In 3 trials the subject's face was suddenly immersed at the start of exercise, and breath holding in a water bath at 5°C, 10°C or 20°C. In one trial there was no face immersion during exercise and participants held their breath in room air during exercise (~24°C). On average the participants exercised at 76.2 ± 0.6% of their maximum HR and this level of exertion was not significantly different between gender. During exercise in air and in the 3 breath-holds a significantly greater BHT_{max} by males was evident compared to females ($0.0001<p<0.001$). Irrespective of breath holding condition, the average BHT_{max} during exercise was 25. 6 ± 1.6 s for males and 14.9 ± 0.9 s for females ($p<0.001$). After adjusting for pre-immersion differences in breath holding ability, there was no effect of gender or water temperature on BHT_{max}. The HR_{min} during breath holding was significantly ($0.0001 \leq p \leq 0.05$) lower for males than females in air and across the 3 water temperatures. After adjusting for the higher resting pre-immersion heart rates of females, males had significantly greater HR_{min} during breath holding only in air ($p<0.05$). In conclusion, results support males had longer BHT_{max} and lower HR_{min} than females

during face immersion with exercise. Also, it may be that exercise override the affect of water temperature on BHT_{max} and HR_{min}.

4.2 Introduction

Work in the offshore oil industry often requires travel to and from the oil rigs over rough open ocean water in a helicopter. In the event the helicopter was to crash or ditch while travelling over water, a person's survival may depend on their maximum breath hold time (BHT_{max}) while they perform an underwater escape from the submerged fuselage. A study published by Clifford in 1996, found that in 273 of the people that were involved in a helicopter crash in the UK, the survival rate was 83.1% (11) and of the 46 fatalities, 38 people, or 82% drowned (11). Brooks et al. found that it took 28 to 92 seconds for 15 to 18 people to escape from a submerged Super Puma helicopter simulator (7), while Cheung et al. found that 34% of 228 trainees (47% of which worked in the offshore industry), could not hold their breath long enough for Brook's proposed minimum escape time of 28 seconds (10).

Passengers travelling in a helicopter over open water in Atlantic Canada are required to wear full body immersion suits, which leave only a small area of the face exposed. If the helicopter was to crash and the passengers become submerged underwater, only their face would be exposed to the cold ocean water. It has been shown that cold water immersion can alter BHT_{max} and minimum heart rate (HR_{min}) (8, 17, 20, 23, 24). It has also been suggested that a stronger dive response (DR) is evident with colder water temperatures (16) and that the DR can be further augmented with exercise (6, 22).

The DR activates both the sympathetic and parasympathetic nervous systems, while the Cold Shock Response (CSR) is mediated only via the sympathetic nervous system. It is unknown during sub-maximal exercise with face immersion if the DR or the CSR response will be evident. Exercise is known to trigger an increased sympathetic nervous system activity, potentially suppressing the DR. Previous work has suggested that increased workload while exercising with the face immersed will decrease BHT_{max}, even though other components of DR may be heightened (6). This apparent contradiction of a heightened DR with shorter breath hold times remains to be resolved. It has also been shown that there are gender differences in cardiovascular and thermoregulatory responses to body cooling (9, 15, 27) and these may further influence the DR and possibly BHT_{max}. To this end we previously investigated the effects of gender and water temperature on BHT_{max} (28) and found that gender and water temperature both influenced breath hold time.

To build from this previous result (28) the present study added sub-maximal, upper body exercise to the face immersion protocol to more closely simulate conditions for a person trying to escape from a submerged helicopter. We asked in these conditions if water temperature of 5°, 10° and 20° and gender would affect components of the DR response including BHT_{max}, HR_{min}, and hemoglobin (Hb) saturation.

4.3 Methods

4.3.1 Participants:

Twelve healthy adults volunteered for this experiment, 6 males and 6 females, ages 20-44 with a mean age of 25.3 ± 1.94 years of age. The participants were fully informed regarding the procedure and all questions were answered to the best of the investigator's ability. This study received ethical approval from the Human Investigation Committee at Memorial University and the Office of Human Research Ethics and Integrity at Dalhousie University.

4.3.2 Instruments:

A flat horizontal tilt table was used to allow the participants to lie in the prone position with minimal difficulty for all procedures. The water bath consisted of a basin measuring 49.5 cm x 35 cm x 23 cm insulated by 2 inches of Styrofoam. Water was circulated through the bath with the use of a Polyscience VWR Chiller/Heater (Model 1.196, Bostol CT, USA), where the water was chilled or heated as needed and then flowed to and from the basin through insulated tubing. The unit relied on a digital controller to set the water temperature, which prevented any large variance in water temperature from occurring.

The subject's forehead and chest temperature were recorded using copper constriction thermocouples attached using waterproof Elastoplast plastic adhesive tape. Temperature values were acquired by a National Instruments data acquisition system controlled by a personal computer using Labview software. The subject's heart rates were collected by telemetry (Polar, USA). Oxygen saturation values were measured using a Radical Massimo SET (Model: Radical) pulse oximeter placed on all participants earlobe. Values were recorded from the pulse oximeter using the National Instruments data acquisition system controlled by the computer using the Labview software. During the upper body $\dot{V}O_{2PEAK}$ trials, participants were dressed in shorts and T-shirts, as well as the face immersions. A $\dot{V}O_{2PEAK}$ is a measurement of peak O_2 uptake which will fall between 66% and 86% of a person's maximal value for O_2 uptake ($\dot{V}O_{2MAX}$) (19). $\dot{V}O_{2PEAK}$ trials were performed on a Monark fly wheel, mechanically braked, arm only cycle ergometer with the participants lying prone on the tilt table. Participants were secured to the table across the lower back and on the knees to prevent them from moving forward on the table. Metabolic measurements were made with a MMC Horizon System metabolic cart by Sensor Medics calibrated against 100% nitrogen and 16% oxygen/4% carbon dioxide/balanced nitrogen. The $\dot{V}O_{2PEAK}$ values were calculated as the total amount of oxygen consumed $ml \cdot kg^{-1} \cdot min^{-1}$ of body weight of the subject.

4.3.3 Protocol:

The participants performed a $\dot{V}O_{2PEAK}$ test on a separate day prior to any facial immersions. The participants were positioned and secured on the tilt table and rested for 3 min. After the rest period participants began to pedal at a rate of ~30 rpm with no initial resistance. Every minute during the $\dot{V}O_{2PEAK}$, resistance on the wheel was increased by 0.5 kp (4.9 N). The participants pedaled until the point of exhaustion or until they could not maintain the required load at 30 rpm, at which point the trial was terminated. This protocol was modified from the Bar-Or et al. upper body $\dot{V}O_{2MAX}$ protocol (5). Heart rates were recorded every thirty seconds during the course of the $\dot{V}O_{2PEAK}$ up until termination.

The participants performed facial immersions at temperatures of 5°, 10° and 20°C, with three trials done at each temperature. A BHT_{max} was performed at an ambient temperature of 24°C in the air for three trials. These trials were before any face immersion conditions. During each of the breath hold trials, in the water and in the air, participants pedaled on the arm only ergometer at a set workload of 50% of their calculated $\dot{V}O_{2PEAK}$ at a cadence of 30 rpm. The order of the temperatures in which the participants performed the breath holds were randomized, but they were informed before the beginning of each immersion what the temperature would be. Prior to performing any immersions, the participants rested in the prone position on the tilt table for 10 minutes to allow for a baseline heart rate to be recorded every two minutes during the period. Participants performed three successive immersions at each bath temperature, with the participants resting in between each trial until their fore-head temperatures returned to pre-immersion values. The participants were instructed not to hyperventilate before the immersions and not to breathe out while underwater. The duration of each immersion was withheld from the participants until all three trials were completed for the given temperature to prevent the participants from trying to beat a previous immersion time. During the course of the immersions, the participants had a snorkel in their mouths as a safety precaution in case they accidentally inhaled water while immersed. While the participants were immersed in the basin, they were kept unaware of how much time had passed to again prevent them from trying to beat a previous time. The duration of the breath hold began when the subject's face entered the water and ended when the participants pulled their face up from the water. Heart rates were recorded every five seconds during the face immersions or air breath holds.

4.3.4 Statistical Analyses:

An ANOVA model with repeated factors of breath hold conditions of air (~24°C) and water (5°C, 10°C, 20°C) and non-repeated factors of gender (M,F). Post hoc tests were completed with one-way ANOVA tests across gender. The level of significance or alpha was set at $p \leq 0.05$.

4.4 Results

The subject's physical characteristics are given in Table 4.1, with the males being significantly taller ($p \leq 0.005$), heavier ($p \leq 0.001$) and having a greater BMI, than the females ($p \leq 0.001$) but there was no significant difference between the age of the groups ($p = 0.466$). The subject's resting heart rates 10 minutes prior to any breath holding are given in (Table 4.2). During the course of the breath holds, there was no significant difference between the male's and female's resting heart rate.

The male's average BHT_{max} was significantly greater than the females in all experimental conditions (Fig. 4.1) ($0.001 < p < 0.05$). However within each gender, there were no significant differences in BHT_{max} across water temperatures. Irrespective of immersion condition, the males had a significantly greater ($p = 0.008$) average BHT_{max} of 25.6 ± 2.8 s than the female average BHT_{max} of 14.9 ± 1.7 s (Fig 4.2). After adjusting for pre-immersion conditions (air BHT_{max} – water temperature BHT_{max}), it was found there was no longer any significant difference in BHT_{max} between males and females across all water temperatures (Fig. 4.3).

Across all breath hold conditions, the males had a significantly lower ($0.001 < p < 0.05$) observed mean HR_{min} then females (Fig. 4.4). However there were no significant differences in HR_{min} across all breath hold conditions within each gender (Fig 4.4). Irrespective of immersion condition, the males had a significantly lower ($p = 0.01$)

observed average HR_{min} of 103.5 ± 2.0 beats·min^{-1}than the females average of 125.9 ± 4.7 beats·min^{-1} (Fig. 4.5). After adjusting for pre-immersion conditions (air HR_{min} - water temperature HR_{min}), the only significant differences in ΔHR_{min} between gender was at 20°C (Fig. 4.6).

There were no significant differences between male and female mean SaO_2 values (Fig. 4.7a) and minimum SaO_2 values (Fig 4.7b) across all breath holding conditions. Also, there were no significant differences for minimum SaO_2 values within each gender across all breath holding conditions. The male's mean SaO_2 values ranged from 97.0 ± 0.6% (10°C) to 95.5 ± 0.5% (Air), and the minimum values ranged from 95.4 ± 0.9% (10°C)to 92.7 ± 1.5% (Air). The female's mean SaO_2 values ranged from 95.4 ± 0.8 (Air) to 94.4 ± 1.4% (5°C), and the minimum values ranged from 93.92 ± 1.20% (Air) to 93.39 ± 1.51% (5°C). There was no apparent trend in the mean or minimum SaO_2 values across the different breath holding conditions.

There were no significant differences between gender across all breath holding conditions for forehead skin temperature (Fig 4.8). There were no significant differences across breath holding conditions irrespective of gender for BHT_{max}, HR_{min}, SaO_2 and forehead skin temperature.

4.5 Discussion

This is the first study to our knowledge that compares the maximum breath hold times (BHT_{max}) across gender during facial immersions at different water temperatures with submaximal upper body exercise. Across all breath holding conditions, the males had a significantly greater BHT_{max} than the females (Fig 4.1), but there was no difference in BHT_{max} within each gender from the lowest to highest temperature face immersion (Fig. 4.1). When we compared the male and female BHT_{max} irrespective of the breath hold condition, the males had a significantly greater value than the females (Fig. 4.2). However, when we adjusted for pre-immersion values, there were no longer any significant differences between the male and female BHT_{max} at each water temperature (Fig. 4.3). The average BHT_{max} times for both males and females observed in this study are lower than those suggested to successfully escape from a submerged helicopter (7). A supplementary breathing aid may be required to assist passengers to extend their BHT_{max} and successfully escape from a submerged helicopter

The second main finding of this study is that at each given breath hold condition the males had a significantly lower HR_{min} than the females (Fig. 4.4). Also the minimum heart rate (HR_{min}) was not affected by breath hold condition (Fig. 4.4). Across all breath hold conditions, the observed HR_{min} did not change significantly between breath holding conditions. For the mean male and female HR_{min} irrespective of breath hold condition, the male value of 103.5 ± 2.0 beats·min^{-1}was significantly lower than the females' value of 125.9 ± 4.7 beats·min^{-1} (Fig. 4.5).

The third main finding of this study was that mean SaO_2 percentage levels did not differ significantly between gender at each breath hold condition (Fig. 4.7a). There was also no significant difference in minimum SaO_2 levels across all breath hold conditions between males and females (Fig 4.7b).

Brooks et al. found under calm lab conditions that the minimum egress time for participants to escape from an inverted, submersed helicopter was dependent on ambient lighting conditions. The escape times ranged from 28 to 92 seconds, with longer times observed in dark conditions, compared to normal lighting (7). Cheung et al. found in breath holding trials that out of a sample of 228 trainees (47% of who worked in the offshore oil industry) 34% did not have a BHT_{max} of at least 28 seconds that would be needed for this helicopter egress (10). When we compare the BHT_{max} results of the current study, we find that the male average of ~25 seconds is just slightly below the minimum time to escape successfully from a submerged inverted helicopter. The female average of ~14 seconds is roughly only half of the time needed to ensure a successful escape based on Brook's 28 second value (7). Clearly with a moderate exercise and breath holding, even in calm lab conditions, breath holding duration is inadequate for a successful submerged helicopter egress.

Earlier studies have looked at the effects of exercise on HR during face immersion (4, 6, 8, 13, 14, 18, 21, 25), and more recent studies have looked at the effect of the DR on SaO_2 values during breath holding (1, 2). Previous studies have reported that exercise during a face immersion can possibly increase the magnitude of the bradycardia seen in the DR (6, 21, 25). These studies found that if the participants exercised before and during an underwater breath hold, the heart rate dropped at a much faster rate than if just performing a resting underwater breath hold (6, 21, 25). Even though the heart rate dropped at a much faster rate, it never reached an absolute lower heart rate as compared to the stationary face immersion. In the current study, we did not find that a bradycardia developed during the course of the face immersion with exercise. Each subject experienced the expected increase in HR as expected for submaximal exercise with no face immersion (Fig. 4.4). It is possible that the breath holds were not long enough for a marked bradycardia to develop at any given water temperature or that the level of exertion of the participants created a tachycardia that overrode any slowing of the heart rate induced by face immersion.

The DR may be able to extend an individual's BHT_{max} through a series of oxygen conserving mechanisms (16). Many earlier studies have examined the effect of apneic facial immersions on BHT_{max} and HR (3, 20, 22, 23), but in these studies breath holding was at rest and not during exercise. Two of the studies found very little difference in BHT_{max} (22, 23) between resting breath holding in the air and in the water. Another study (20) found that facial immersion increased a person's BHT_{max}, however the participants in this study breathed a mixture of gas that contained 50% O_2, which was also humidified. This increase in O_2 concentration may have helped to offset breath hold induced hypoxia, thus artificially increasing the subject's $BHT_{max.}$ Hyperoxia is also known to induce a bradycardia (25).

A recent study conducted by Andersson et al. (2) examined the effect of apneic facial immersions on SaO_2 levels. The investigators found that when their participants exercised on a seated, cycle ergometer and performed 30 second breath holds in water (10°C), there was less of a reduction in SaO_2 levels as compared to when they performed breath holds with exercise with no face immersion (2). In an earlier study conducted by Andersson et al. (1), similar results were found in stationary participants, in that apnea with a face immersion resulted in less of a decrease in SaO_2 as compared to breath holds performed with no face immersion. In the current study, it was found that there was no significant difference in either the observed minimum or mean SaO_2 values between breath holds in the air or at any water temperature. It is possible that the participants did not hold their breath long enough for the DR to activate and trigger an oxygen conserving mechanisms. The male BHT_{max} of ~25 sec and the female's of ~14 sec (Fig. 4.1) are of shorter duration than those reported in Andersson's study when they found a reduction in the rate of decrease in SaO_2 during breath holding with face immersion.

The results of this study are in disagreement with previous works (2, 6, 8, 25) that suggest exercise can heighten the DR in similar conditions to those employed presently by producing a more marked bradycardia but in agreement with others (6). In previous studies (8, 25) the level of exertion in each subject was not controlled. As such some participant's levels of exertion may have been low enough to allow the DR to be triggered producing the bradycardia. In the present study, all of our participants worked at 50% of their own VO_{2PEAK}, therefore they exerted themselves to the same relative level while performing the breath hold trials. This level of exertion may have possibly overridden the cardiac impulses arising from the cardio-inhibitory center which would trigger the expected bradycardia (16), resulting in the absence of a decreased heart rate. Because the participants were also exercising at a moderate intensity, it is also doubtful that peripheral vaso-constriction had occurred, as normally seen with the DR. During exercise the active muscles would cause an increased blood flow to the arms (26). The absence of the bradycardia, increased blood flow to the working arm muscles, and the increased use of O_2 stores may have lead to a decreased DR and to the shorter breath hold times seen in this study.

Contrary to our previous study (28), we found no effect of water temperature on BHT_{max}. It is possible that while the participants were exercising and increasing cutaneous blood flow, heat production was also increased, resulting in the participants having a higher mean forehead skin temperature. It has been shown that heating of the skin can reduce the body's responses to sudden cold water immersion (12). Our participants may have had enough heat produced in their faces that the DR may have not been triggered resulting in BHT_{max} and HR_{min} being unaffected by water temperature.

In conclusion, when participants performed moderate intensity upper body exercise at 50% of their VO_{2PEAK} after a sudden face immersion, water temperature did not affect BHT_{max}, HR_{min}, or SaO_2. The results also suggested that there is a gender difference between BHT_{max} and HR_{min} during these conditions. When participants perform apneic facial immersions, moderate intensity upper body exercise may influence BHT_{max} and HR_{min} more so than water temperature. .

4.6 References

1. **Andersson J and Schagatay E**. Arterial oxygen desaturation during apnea in humans. *Undersea Hyperb Med* 25: 21-25, 1998.

2. **Andersson JP, Liner MH, Runow E and Schagatay EK**. Diving response and arterial oxygen saturation during apnea and exercise in breath-hold divers. *J Appl Physiol* 93: 882-886, 2002.

3. **Arnold RW**. Extremes in human breath hold, facial immersion bradycardia. *Undersea Biomed Res* 12: 183-190, 1985.

4. **Asmussen E and Kristiansson NG**. The "diving bradycardia" in exercising man. *Acta Physiol Scand* 73: 527-535, 1968.

5. **Bar-Or O and Zwiren LD**. Maximal oxygen consumption test during arm exercise--reliability and validity. *J Appl Physiol* 38: 424-426, 1975.

6. **Bergman SA, Jr., Campbell JK and Wildenthal K**. "Diving reflex" in man: its relation to isometric and dynamic exercise. *J Appl Physiol* 33: 27-31, 1972.

7. **Brooks CJ, Muir HC and Gibbs PN**. The basis for the development of a fuselage evacuation time for a ditched helicopter. *Aviat Space Environ Med* 72: 553-561, 2001.

8. **Butler PJ and Woakes AJ**. Heart rate in humans during underwater swimming with and without breath-hold. *Respir Physiol* 69: 387-399, 1987.

9. **Cankar K, Finderle Z and Strucl M**. Gender differences in cutaneous laser doppler flow response to local direct and contralateral cooling. *J Vasc Res* 37: 183-188., 2000.

10. **Cheung SS, D'Eon NJ and Brooks CJ**. Breath-holding ability of offshore workers inadequate to ensure escape from ditched helicopters. *Aviat Space Environ Med* 72: 912-918, 2001.

11. **Clifford WS**. Helicopter Crashworthiness, A Review of U.K. Military and World Civil Helicopter Water Impacts from 1971-1992. In: *CA Reports 96005*, 1996.

12. **Cooper KE, Martin S and Riben P**. Respiratory and other responses in subjects immersed in cold water. *J Appl Physiol* 40: 903-910, 1976.

13. **Craig AB, Jr.** Heart rate responses to apneic underwater diving and to breath holding in man. *J Appl Physiol* 18: 854-862, 1963.

14. **Craig AB, Jr. and Medd WL**. Man's responses to breath-hold exercise in air and in water. *J Appl Physiol* 24: 773-777, 1968.

15. **Glickman-Weiss EL, Cheatham CC, Caine N, Blegen M and Marcinkiewicz J**. Influence of gender and menstrual cycle on a cold air tolerance test and its relationship to thermosensitivity. *Undersea Hyperb Med* 27: 75-81., 2000.

16. **Gooden BA**. Mechanism of the human diving response. *Integr Physiol Behav Sci* 29: 6-16, 1994.

17. **Hayward JS, Hay C, Matthews BR, Overweel CH and Radford DD**. Temperature effect on the human dive response in relation to cold water near-drowning. *J Appl Physiol* 56: 202-206, 1984.

18. **Hong SK, Song SH, Kim PK and Suh CS**. Seasonal observations on the cardiac rhythm during diving in the Korean ama. *J Appl Physiol* 23: 18-22, 1967.

19. **Millerhagen JO, Kelly JM and Murphy RJ**. A study of combined arm and leg exercise with application to nordic skiing. *Can J Appl Sport Sci* 8: 92-97, 1983.

20. **Mukhtar MR and Patrick JM**. Ventilatory drive during face immersion in man. *J Physiol* 370: 13-24, 1986.

21. **Scholander PF, Hammel HT, Lemessurier H, Hemmingsen E and Garey W**. Circulatory adjustment in pearl divers. *J Appl Physiol* 17: 184-190, 1962.

22. **Sterba JA and Lundgren CE**. Breath-hold duration in man and the diving response induced by face immersion. *Undersea Biomed Res* 15: 361-375, 1988.

23. **Sterba JA and Lundgren CE**. Diving bradycardia and breath-holding time in man. *Undersea Biomed Res* 12: 139-150, 1985.

24. **Stewart LM, Guz A and Nye PC**. Human ventilatory response to immersion of the face in cool water. *Adv Exp Med Biol* 450: 127-131, 1998.

25. **Stromme SB, Kerem D and Elsner R**. Diving bradycardia during rest and exercise and its relation to physical fitness. *J Appl Physiol* 28: 614-621, 1970.

26. **Vander A, Sherman J and Luciano D**. *Human Physiology: The Mechansims of Body Function*. Boston, Massachusetts: WCB McGraw-Hill, 1998.

27. **Wagner JA and Horvath SM**. Cardiovascular reactions to cold exposures differ with age and gender. *J. Appl. Physiol* 58: 187-192, 1985.

28. **White MD, Power JT, Bradbury EE, Pope JD, Petrie LC and Cheung SS**. Maximum breath hold time during face immersion across gender and water temperatures from 0 to 20°C. *European Undersea Baromedical Conference*, Brugge, Belgium, 2002, p. 143-147.

Table 4.1: Participants' physical characteristics and age (* = $p \leq 0.05$, ** = $p \leq 0.001$)

	Age	Height (m)	Weight (kg)	BMI
Male	23.8 ± 0.8	1.77 ± 0.02	84.5 ± 2.8	26.9 ± 0.5
Female	26.8 ± 3.9	1.63 ± 0.03	57.6 ± 3.1	21.5 ± 0.8
p	NS	*	**	**

Table 4.2: Mean resting heart rates of participants for 10 minutes with , prior to breath holding with submaximal upper body exercise. Each subject was lying in the prone position. Each column in the table is the data for one subject (M =Male, F=female).

Subject # and Heart Rate (beats·min^{-1})

Time Elapsed (min)	1 M	2 M	3 M	4 M	5 M	6 M	7 F	8 F	9 F	10 F	11 F	12 F
2	76	76	69	76	59	77	85	89	70	81	66	78
4	70	71	71	70	64	77	83	90	71	82	68	84
6	68	75	68	76	63	74	83	85	73	79	70	84
8	67	76	74	75	62	76	80	85	75	80	66	83
10	79	75	74	74	66	77	85	87	76	76	75	82
Average	72	74	71	74	63	76	83	87	73	80	69	82

Figure 4.1: Mean male and female maximum breath hold time (BHTmax) for water temperatures of 5°, 10° and 20°C and room air (~24°C) during submaximal upper body exercise (* = p <0.05).

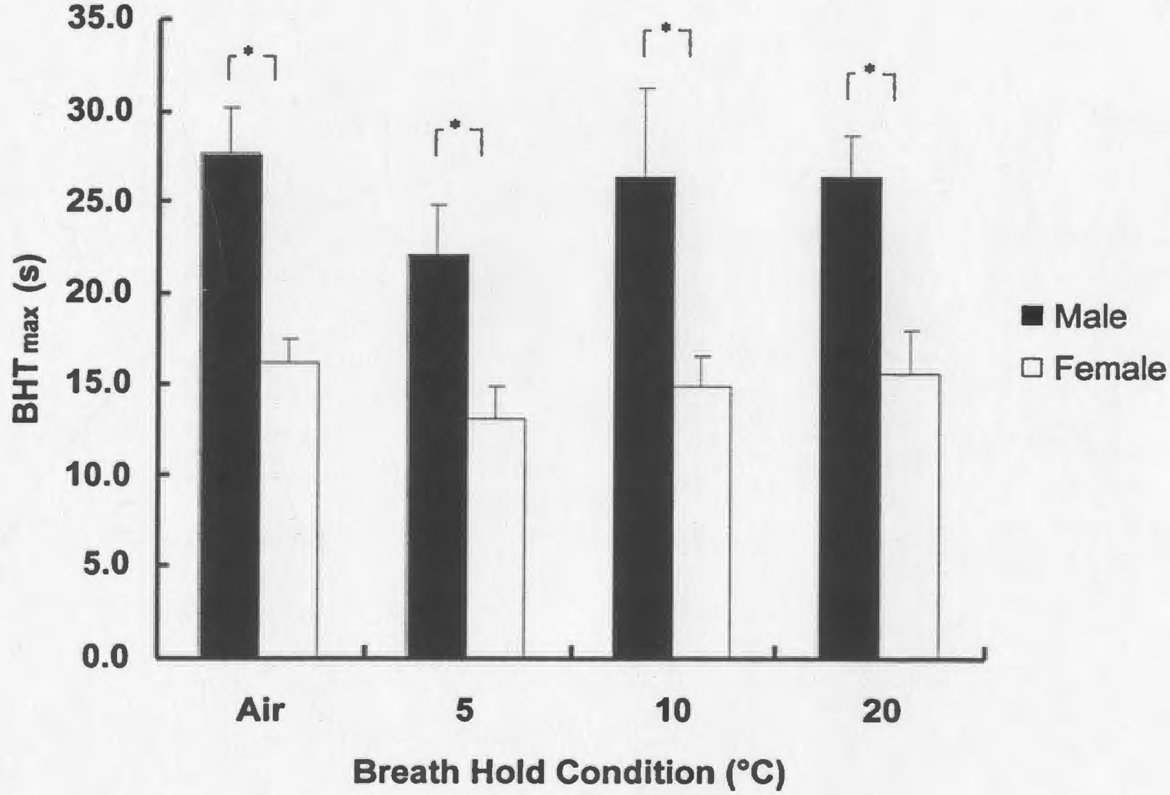


Figure 4.2: Mean male and female maximum breath hold time irrespective of breath hold condition during submaximal upper body exercise (* = p <0.05).

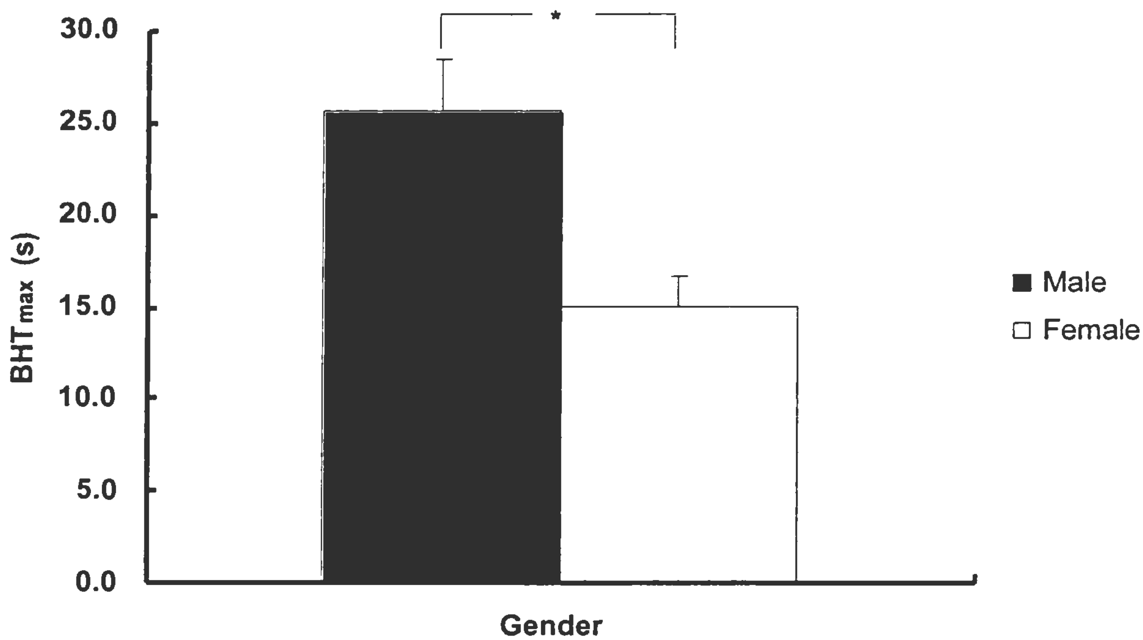


Figure 4.3: Maximum delta breath hold times ($\triangle BHT_{max}$) across gender at water temperatures of 5°, 10° and 20°C during submaximal upper body exercise with face immersion. The $\triangle BHT_{max}$ values are adjusted for pre-immersion differences in BHT_{max} that were measured in room air (24°C) (NS = not significant).

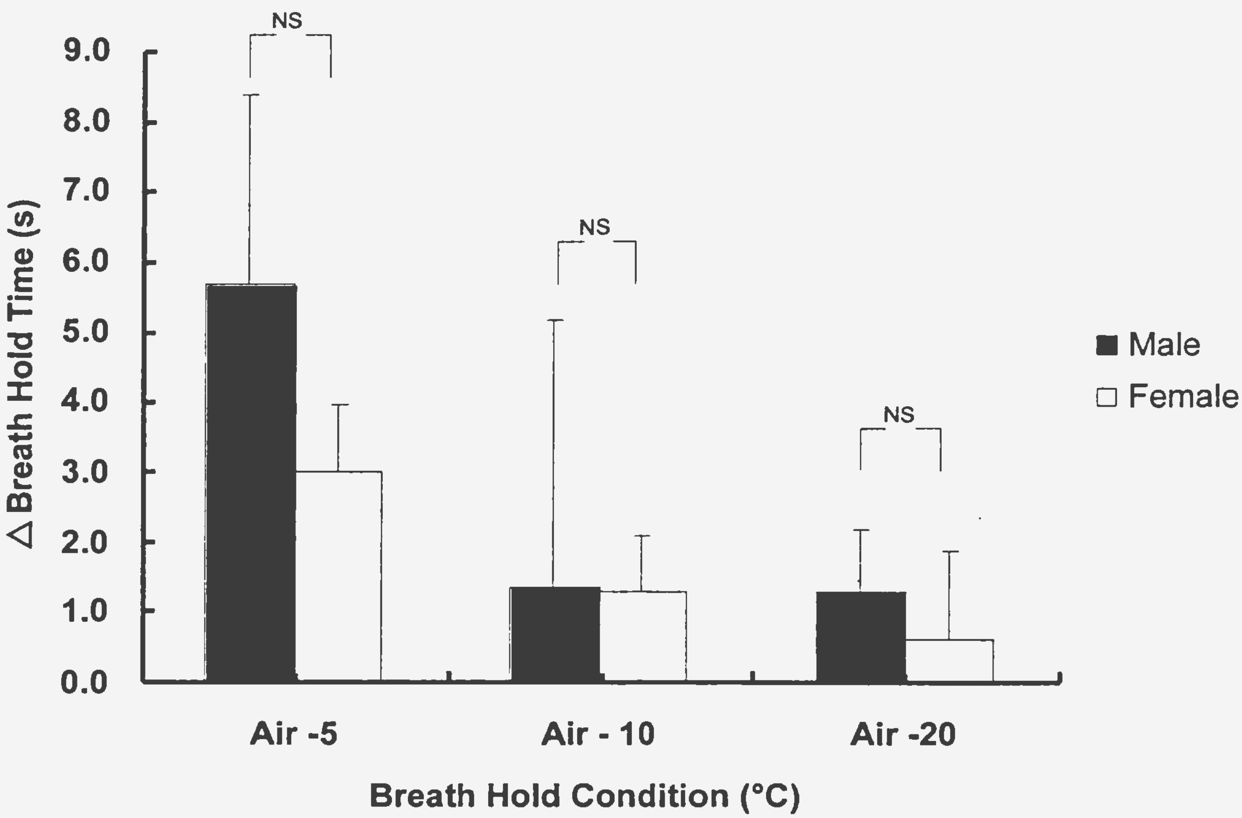


Figure 4.4: Mean minimum heart rate (HR_{min} beats·min^{-1}) across gender during resting conditions, and in breath hold conditions with exercise and face immersion in 5°, 10° and 20°C water and in room air (24°C) (* = $p < 0.05$, †= $p < 0.001$, NS= not significant).

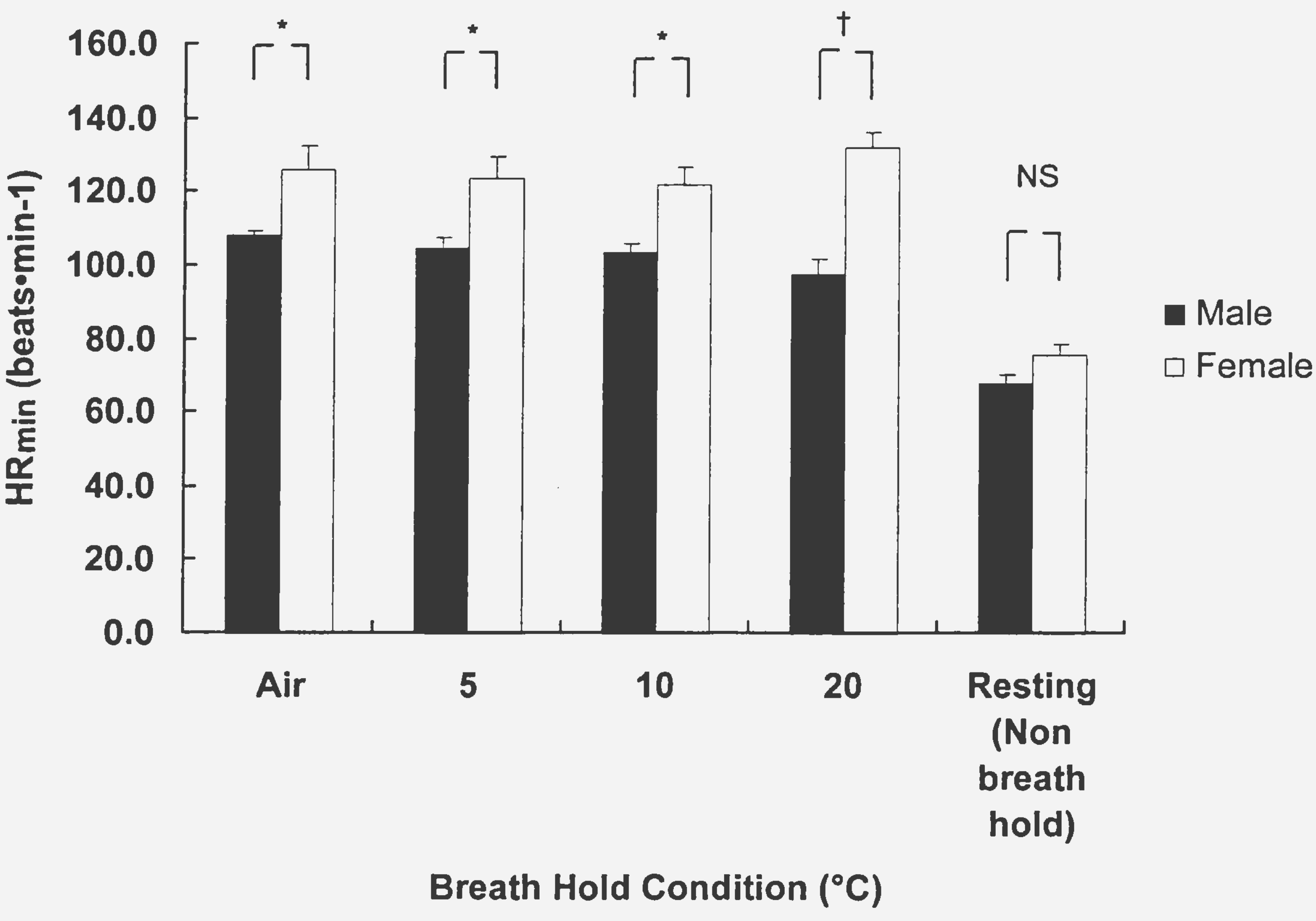


Figure 4.5: Mean minimum heart rate (HR_{min}, beats·min^{-1}) across gender during face immersion and submaximal upper body exercise irrespective of breath hold condition (* = p<0.05)

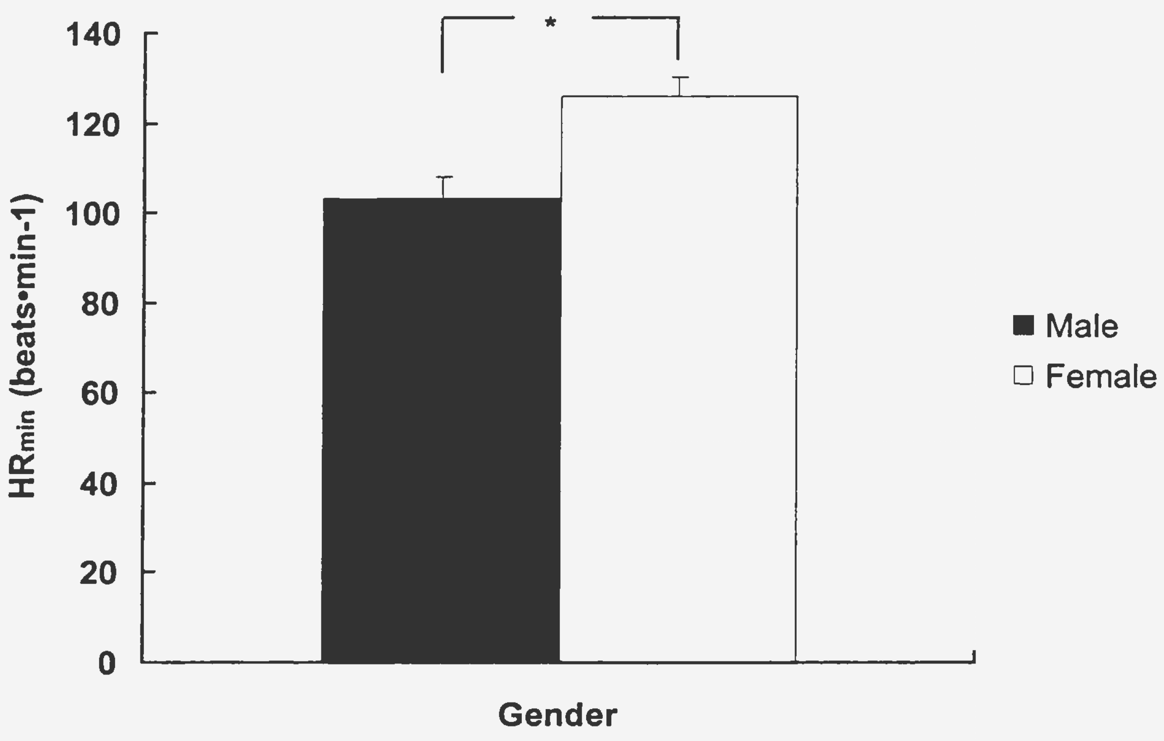


Figure 4.6: Minimum delta heart rate values ($\triangle HR_{min}$ beats·min^{-1}) across gender at temperatures of 5°, 10°, and 20°C during submaximal upper body exercise with face immersion. The $\triangle HR_{min}$ values are adjusted for pre-immersion differences in HR_{min} that were measured in room air (24°C) (* = $p < 0.05$, NS = not significant)

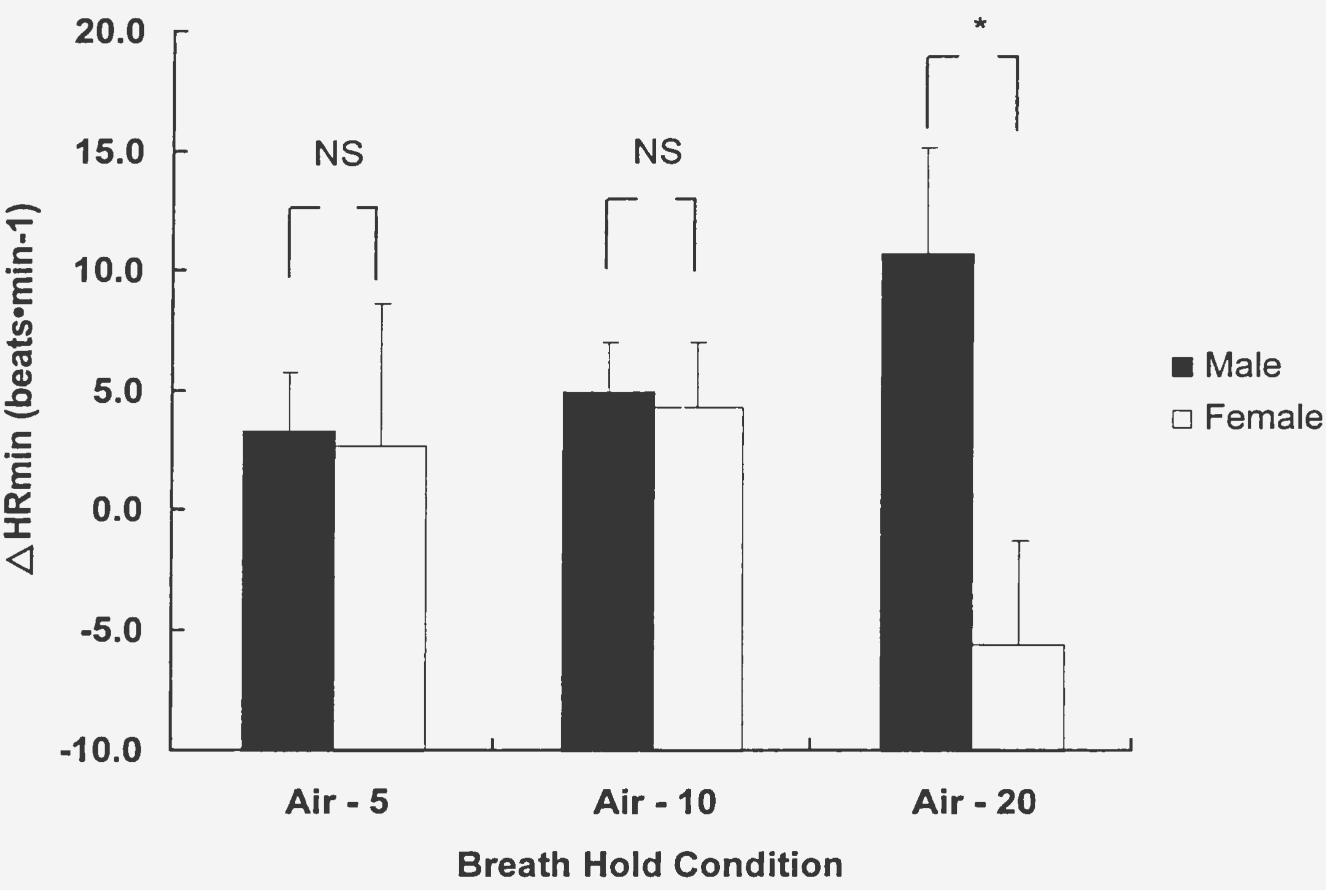


Figure 4.7a: Mean oxygen saturation (SaO_2) during face immersion and submaximal upper body exercise in breath holding conditions of 5°, 10° and 20°C water and in air (24°C) (NS = not significant).

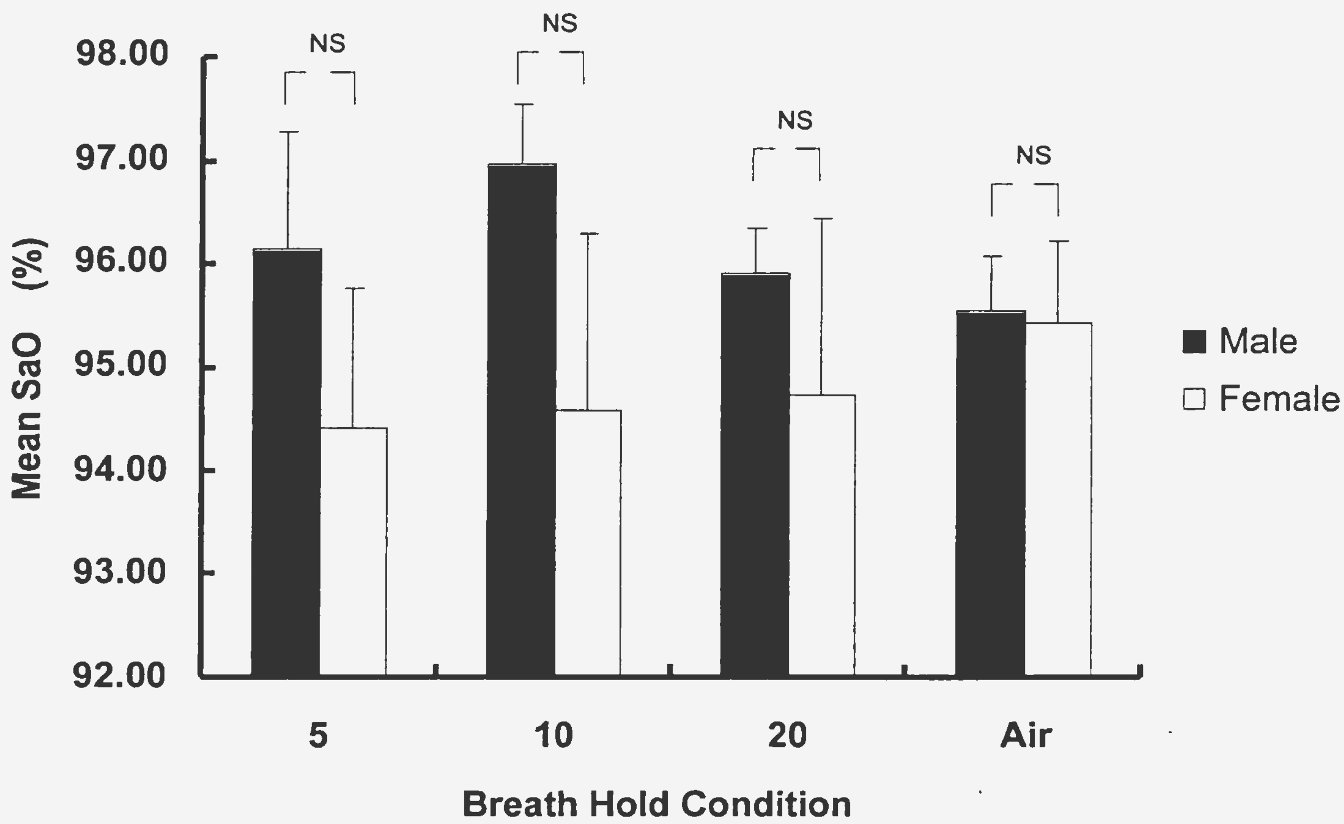


Figure 4.7b: Minimum oxygen saturation (SaO_2) during face immersion and submaximal upper body exercise in breath holding conditions of 5°, 10° and 20°C water and in air at 24°C (NS = not significant).

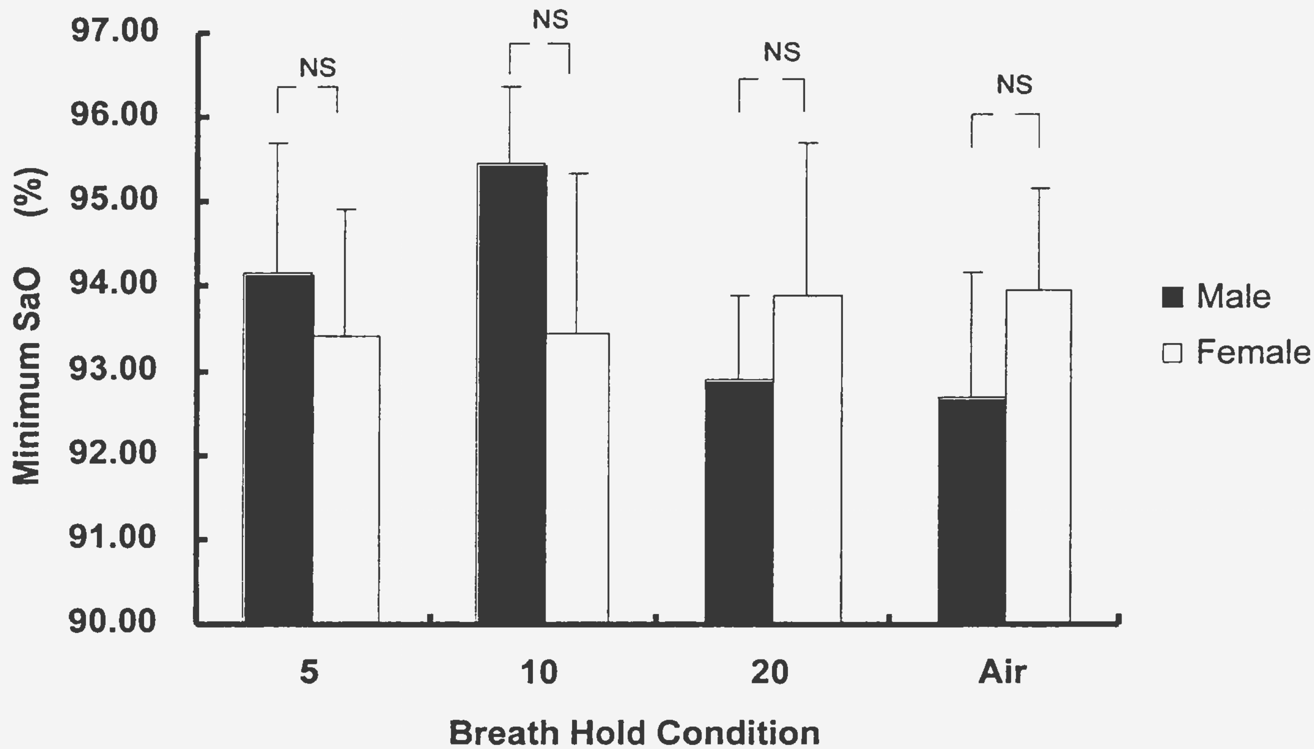
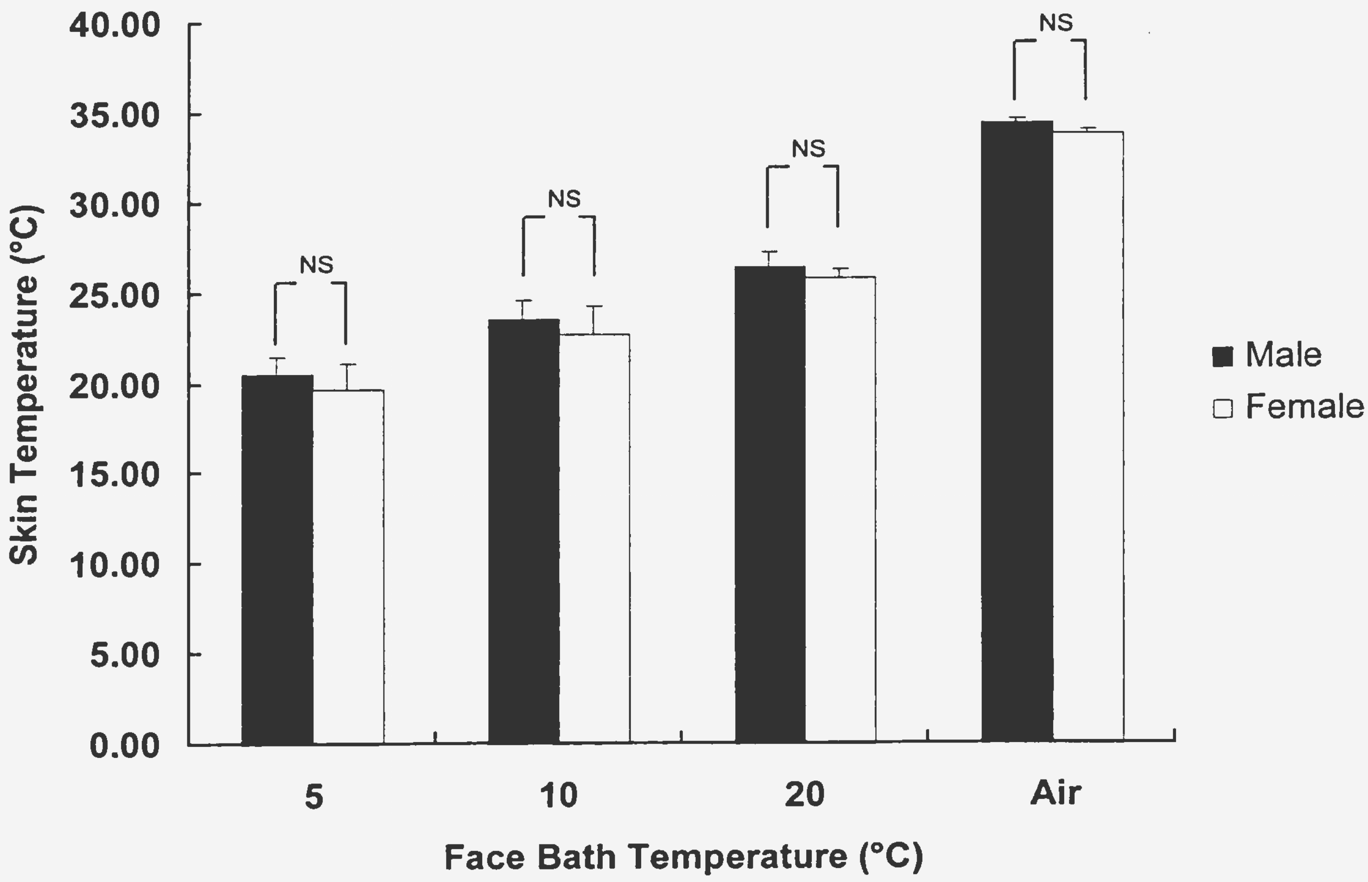


Figure 4.8: Male and female mean forehead skin temperature pre-immersion (Air ~24°C) and during immersion at water temperatures of 5°, 10° and 20°C. (NS = No significance)



Chapter 5

Summary

5.1 Responses to Research Hypotheses

In Chapter 3 it was hypothesized that in subjects performing stationary face immersions, lower water temperature would reduce maximum breath hold times and increase minimum heart rate as a consequence of a greater cold shock response and a reduced dive response. It was also hypothesized that gender will affect maximum breath hold times and minimum heart rate. Finally it was hypothesized that pulmonary capacities, irrespective of gender, will positively correlate with maximal breath holding times.

In Chapter 4 it was hypothesized for subjects performing face immersions with upper body sub-maximal exercising, that lower water temperature would reduce maximum breath hold times, minimum heart rate, and oxygen saturation concentrations as a consequence of a greater cold shock response and a reduced dive response. It was also hypothesized that gender will affect maximum breath hold times and minimum heart rate during upper body exercise with face immersion.

The study in Chapter 3 showed cold water during resting, face only immersions gave reduced BHT_{max}, but did not during the exercising conditions in study in Chapter 4. As such the hypothesis of temperature reducing BHTmax was supported for study 1 but not for study 2. Gender affected both BHT_{max} and HR_{min} during both resting and exercising conditions, with the males having a greater BHT_{max} and lower HR_{min} for both studies. As such the the hypothesis that gender affected BHT_{max} and HR_{min} was supported by both studies. These gender differences observed, however, need to be verified with a study matching males and females for pulmonary capacities.

The results of these studies suggest that mean breath hold times may be insufficient to perform a successful underwater escape from a sunken helicopter. If this is the case, the use of a supplementary breathing aid may be required to perform the underwater escape successfully.

In the first study there was little indication that a DR of significant magnitude occurred. Lower water temperatures produced lower breath hold times compared to warmer temperatures which indicate the DR did not take effect and extend breath hold time even though HR_{min} decreased as the face bath temperature dropped. In a facial immersion, when the DR is evident, both the parasympathetic and sympathetic nervous systems are activated. Based on the results of the first study, the sympathetic nervous system seemed to pre-dominate, and may have lead to the observed reduced breath hold times and lack of a pronounced DR. The results of the second study suggest that the DR did not occur once again. Irrespective of gender, there was no significant difference in BHT_{max}, HR_{min} and SaO_2 indicating that the DR was no active. Since the subjects were exercising at a moderate intensity, the sympathetic nervous system should have been active suggesting a possible reason that the DR was not observed. The level of work the subjects were performing while breath holding may have caused the sympathetic nervous system to dominate over the parasympathetic nervous system, resulting in an apparent absence of the DR.

The participants of the second study had a greater mean forehead skin temperature compared to the stationary condition (Fig 5.1) which may have resulted in a DR of a diminished magnitude. Due to the increased forehead skin temperature, the participants of the current study may have had a reduced DR, resulting in BHT_{max} being unaffected by water temperature.

5.2 Answers to Testable Questions:

When participants are performing a stationary facial immersion in varying water temperatures:

1) Do BHT_{max} and HR_{min} vary as a function of gender with sudden face only immersion?

BHT_{max} and HR_{min} did vary as a function of gender. The males had longer BHT_{max} times and lower HR_{min} compared to females.

2) Do BHT_{max} and HR_{min} vary as a function of water temperature with sudden face only immersion?

BHT_{max} and HR_{min} did vary as a function of water temperature. BHT_{max} decreased as a function of water temperature and HR_{min} decreased as a function of water temperature.

For study 2 in Chapter 4 when participants were performing a facial immersion with moderate intensity upper body exercise in varying water temperatures:

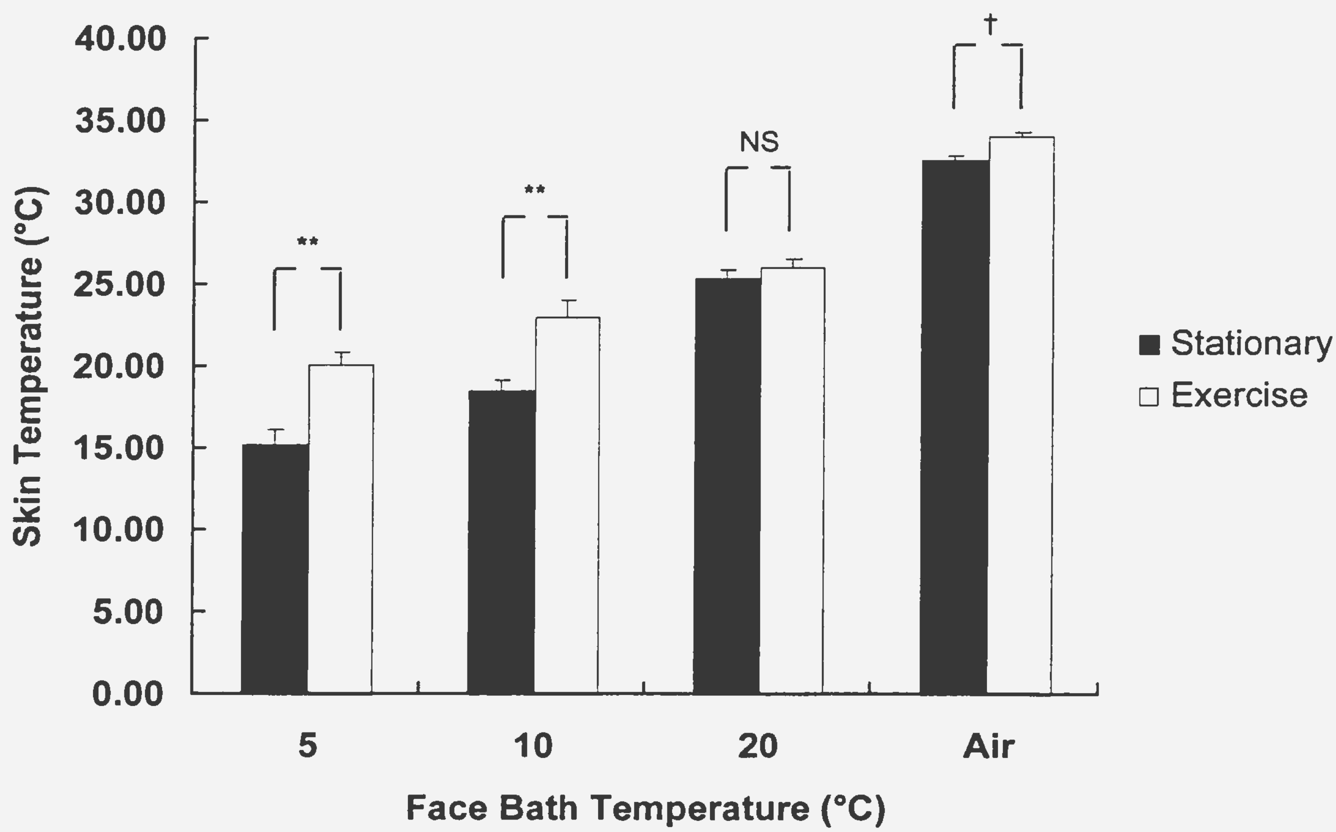
1) Do BHT_{max}, HR_{min}, and SaO_2 vary as a function of gender with a face immersion during exercise and breath holding?

BHT_{max} and HR_{min} but not SaO_2 varied as a function of gender. Males had a longer BHT_{max} and lower HR_{min} than females. There was no difference between water temperatures in SaO_2.

2) Do BHT_{max}, HR_{min}, and SaO_2 vary as a function of water temperature with face immersion during exercise and breath holding?

BHT_{max}, HR_{min}, and SaO_2 did not vary as a function of water temperature.

Figure 5.1: Participant forehead skin temperatures during immersion in water at 5°, 10°, and 20°C and in air (~24°C) during resting and exercising conditions. 2 way ANOVA of non repeated measures with factors of temperature and gender . (** = $p \leq 0.01$, † = $p \leq 0.001$, NS = no significance)



Chapter 6 Overall Thesis References

1. **Deaths, by cause - Chapter XX**: External causes of morbidity and mortality (V01 - Y98), age group and sex, Canada, 2001 (Number): Statiistics Canada, 2001.

2. **Andersson J and Schagatay E**. Arterial oxygen desaturation during apnea in humans. *Undersea Hyperb Med* 25: 21-25, 1998.

3. **Andersson JP, Liner MH, Runow E and Schagatay EK**. Diving response and arterial oxygen saturation during apnea and exercise in breath-hold divers. *J Appl Physiol* 93: 882-886, 2002.

4. **Arnold RW**. Extremes in human breath hold, facial immersion bradycardia. *Undersea Biomed Res* 12: 183-190, 1985.

5. **Asmussen E and Kristiansson NG**. The "diving bradycardia" in exercising man. *Acta Physiol Scand* 73: 527-535, 1968.

6. **Bar-Or O and Zwiren LD**. Maximal oxygen consumption test during arm exercise--reliability and validity. *J Appl Physiol* 38: 424-426, 1975.

7. **Bergman SA, Jr., Campbell JK and Wildenthal K**. "Diving reflex" in man: its relation to isometric and dynamic exercise. *J Appl Physiol* 33: 27-31, 1972.

8. **Boulant JA and Dean JB**. Temperature receptors in the central nervous system. *Ann Rev Physiol* 48: 639-654, 1986.

9. **Brooks CJ, Muir HC and Gibbs PN**. The basis for the development of a fuselage evacuation time for a ditched helicopter. *Aviat Space Environ Med* 72: 553-561, 2001.

10. **Burke WE and Mekjavic IB**. Estimation of regional cutaneous cold sensitivity by analysis of the gasping response. *J Appl Physiol* 71: 1933-1940, 1991.

11. **Butler PJ and Woakes AJ**. Heart rate in humans during underwater swimming with and without breath-hold. *Respir Physiol* 69: 387-399, 1987.

12. **Cankar K, Finderle Z and Strucl M**. Gender differences in cutaneous laser doppler flow response to local direct and contralateral cooling. *J Vasc Res* 37: 183-188., 2000.

13. **Cherniack RM and Raber MB**. Normal standards for ventilatory function using an automated wedge spirometer. *Am Rev Respir Dis* 106: 38-46, 1972.

14. **Cheung SS, D'Eon NJ and Brooks CJ**. Breath-holding ability of offshore workers inadequate to ensure escape from ditched helicopters. *Aviat Space Environ Med* 72: 912-918, 2001.

15. **Clifford WS**. Helicopter Crashworthiness, A Review of U.K. Military and World Civil Helicopter Water Impacts from 1971-1992. In: *CA Reports 96005*, 1996.

16. **Cooper KE, Martin S and Riben P**. Respiratory and other responses in subjects immersed in cold water. *J Appl Physiol* 40: 903-910, 1976.

17. **Craig AB, Jr.** Heart rate responses to apneic underwater diving and to breath holding in man. *J Appl Physiol* 18: 854-862, 1963.

18. **Craig AB, Jr. and Medd WL**. Man's responses to breath-hold exercise in air and in water. *J Appl Physiol* 24: 773-777, 1968.

19. **Djarova T, Ilkov A, Varbanova A, Nikiforova A and Mateev G**. Human growth hormone, cortisol, and acid-base balance changes after hyperventilation and breath-holding. *Int J Sports Med* 7: 311-315, 1986.

20. **Elsner R and Gooden B**. Diving and asphyxia. A comparative study of animals and man. *Monogr Physiol Soc* 40: 1-168, 1983.

21. **Fagius J and Sundlof G**. The diving response in man: effects on sympathetic activity in muscle and skin nerve fascicles. *J Physiol* 377: 429-443, 1986.

22. **Finley JP, Bonet JF and Waxman MB**. Autonomic pathways responsible for bradycardia on facial immersion. *J Appl Physiol* 47: 1218-1222, 1979.

23. **Glickman-Weiss EL, Cheatham CC, Caine N, Blegen M and Marcinkiewicz J**. Influence of gender and menstrual cycle on a cold air tolerance test and its relationship to thermosensitivity. *Undersea Hyperb Med* 27: 75-81., 2000.

24. **Gooden BA**. The diving response in clinical medicine. *Aviat Space Environ Med* 53: 273-276, 1982.

25. **Gooden BA**. The evolution of asphyxial defense. *Integr Physiol Behav Sci* 28: 317-330, 1993.

26. **Gooden BA**. Mechanism of the human diving response. *Integr Physiol Behav Sci* 29: 6-16, 1994.

27. **Gooden BA, Lehman RG and Pym J**. Role of the face in the cardiovascular responses to total immersion. *Aust J Exp Biol Med Sci* 48: 687-690, 1970.

28. **Graham TE**. Thermal, metabolic, and cardiovascular changes in men and women during cold stress. *Med Sci Sports Exerc* 20: S185-192, 1988.

29. **Hayward JS and Eckerson JD**. Physiological responses and survival time prediction for humans in ice-water. *Aviat Space Environ Med* 55: 206-211, 1984.

30. **Hayward JS, Hay C, Matthews BR, Overweel CH and Radford DD**. Temperature effect on the human dive response in relation to cold water near-drowning. *J Appl Physiol* 56: 202-206, 1984.

31. **Hong SK, Song SH, Kim PK and Suh CS**. Seasonal observations on the cardiac rhythm during diving in the Korean ama. *J Appl Physiol* 23: 18-22, 1967.

32. **Kawakami Y, Natelson BH and DuBois AR**. Cardiovascular effects of face immersion and factors affecting diving reflex in man. *J Appl Physiol* 23: 964-970, 1967.

33. **Keatinge WR and Evans M**. The respiratory and cardiovascular response to immersion in cold and warm water. *Quarterly Journal of Experimental Physiology*: 83-94, 1961.

34. **Keatinge WR, McIlroy MB and Goldfien A**. Cardiovascular Responses to Ice-Cold Showers. *J Appl Physiol* 19: 1145-1150, 1964.

35. **Keatinge WR and Nadel JA**. Immediate respiratory response to sudden cooling of the skin. *J Appl Physiol* 20: 65-69, 1965.

36. **Lin YC**. Circulatory functions during immersion and breath-hold dives in humans. *Undersea Biomed Res* 11: 123-138, 1984.

37. **Mekjavic IB, La Prairie A, Burke W and Lindborg B**. Respiratory drive during sudden cold water immersion. *Respir Physiol* 70: 121-130, 1987.

38. **Millerhagen JO, Kelly JM and Murphy RJ**. A study of combined arm and leg exercise with application to nordic skiing. *Can J Appl Sport Sci* 8: 92-97, 1983.

39. **Mukhtar MR and Patrick JM**. Ventilatory drive during face immersion in man. *J Physiol* 370: 13-24, 1986.

40. **Quanjer PH, Tammeling GJ, Cotes JE, Fabbri LM, Matthys H, Pedersen OF, Peslin R, Roca J, Sterk PJ, Ulmer WT and et al.** Symbols, abbreviations and units. Working Party Standardization of Lung Function Tests, European Community for Steel and Coal. *Eur Respir J Suppl* 16: 85-100, 1993.

41. **Scholander PF, Hammel HT, Lemessurier H, Hemmingsen E and Garey W**. Circulatory adjustment in pearl divers. *J Appl Physiol* 17: 184-190, 1962.

42. **Song SH, Lee WK, Chung YA and Hong SK**. Mechanism of apneic bradycardia in man. *J Appl Physiol* 27: 323-327, 1969.

43. **Sterba JA and Lundgren CE**. Breath-hold duration in man and the diving response induced by face immersion. *Undersea Biomed Res* 15: 361-375, 1988.

44. **Sterba JA and Lundgren CE**. Diving bradycardia and breath-holding time in man. *Undersea Biomed Res* 12: 139-150, 1985.

45. **Stewart LM, Guz A and Nye PC**. Human ventilatory response to immersion of the face in cool water. *Adv Exp Med Biol* 450: 127-131, 1998.

46. **Stromme SB, Kerem D and Elsner R**. Diving bradycardia during rest and exercise and its relation to physical fitness. *J Appl Physiol* 28: 614-621, 1970.

47. **Tipton M**. The effect of clothing on "diving bradycardia" in man during submersion in cold water. *Eur J Appl Physiol Occup Physiol* 59: 360-364, 1989.

48. **Tipton MJ**. The initial responses to cold-water immersion in man. *Clin Sci (Lond)* 77: 581-588, 1989.

49. **Tipton MJ, Balmi PJ, Bramham E, Maddern TA and Elliott DH**. A simple emergency underwater breathing aid for helicopter escape. *Aviat Space Environ Med* 66: 206-211, 1995.

50. **Tipton MJ, Franks CM, Sage BA and Redman PJ**. An examination of two emergency breathing aids for use during helicopter underwater escape. *Aviat Space Environ Med* 68: 907-914, 1997.

51. **Tipton MJ and Golden FS**. The influence of regional insulation on the initial responses to cold immersion. *Aviat Space Environ Med* 58: 1192-1196, 1987.

52. **Tipton MJ, Stubbs DA and Elliott DH**. Human initial responses to immersion in cold water at three temperatures and after hyperventilation. *J Appl Physiol* 70: 317-322, 1991.

53. **Tipton MJ and Vincent MJ**. Protection provided against the initial responses to cold immersion by a partial coverage wet suit. *Aviat Space Environ Med* 60: 769-773, 1989.

54. **Vander A, Sherman J and Luciano D**. *Human Physiology: The Mechansims of Body Function*. Boston, Massachusetts: WCB McGraw-Hill, 1998.

55. **Wagner JA and Horvath SM**. Cardiovascular reactions to cold exposures differ with age and gender. *J. Appl. Physiol* 58: 187-192, 1985.

56. **Wagner JA and Horvath SM**. Influences of age and gender on human thermoregulatory responses to cold exposures. *J. Appl. Physiol* 58: 180-186, 1985.

57. **Whayne TF, Jr. and Killip T, 3rd**. Simulated diving in man: comparison of facial stimuli and response in arrhythmia. *J Appl Physiol* 22: 800-807, 1967.

58. **White MD, Power JT, Bradbury EE, Pope JD, Petrie LC and Cheung SS**. Maximum breath hold time during face immersion across gender and water temperatures from 0 to 20°C.. *European Undersea Baromedical Conference*, Brugge, Belgium, 2002, p. 143-147.

59. **Wolf S, Schneider RA and Groover ME**. Further studies on the circulatory and metabolic alterations of the oxygen-conserving (diving) reflex in man. *Trans Assoc Am Physicians* 78: 242-254, 1965.

60. **Zbrozyna AW and Westwood DM**. Cardiovascular responses elicited by simulated diving and their habituation in man. *Clin Auton Res* 2: 225-233, 1992.