Physiological changes following swimming in cold water in triathlon and military operations

Temperaturephysiology and cold water swimming with wetsuit or drysuit.

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2 ABBREVIATIONS AND ACRONYMS

BMI: Body Mass Index.

ECG: Electrocardiogram

LOESS: Locally Estimated Scatterplot Smoothing (Local Polynomial Regression-Line)

MBD: Magnitude Based Differences

METS: Metabolic Equivalents

NORNAVSOC: Norwegian Naval Special Operation Command. «Marinejegere»

SOF: Special Operation Forces

T1: Transition 1. The place where there is a transition from swim to bike during a triathlon

T2: Transition 2. The place where there is a transition from bike to run during a triathlon.

WCI: Wind Chill Index

WCT: Wind Chill Equivalent Temperature

3 LIST OF PAPERS

Study I

Melau, Jørgen; Mathiassen, Maria; Stensrud, Trine; Tipton, Mike; Hisdal, Jonny. 2019. «Core Temperature in Triathletes during Swimming with Wetsuit in 10°C Cold Water» *Sports* 7, no. 6: 130. https://doi.org/10.3390/sports7060130

Study II

Melau, Jørgen; Hisdal, Jonny; Solberg, Paul André. 2021. «Impact of a 10000m cold water swim on Norwegian Naval Special Forces recruits». – Accepted Journal of Special Operation Medicine. April 20, 2021

Study III

Høiseth, Lars Øivind; Melau, Jørgen; Bonnevie Svendsen, Martin; Nyborg, Christoffer; Eijsvogels, Thijs; Hisdal, Jonny. 2021. «Core temperature during cold-water triathlon swimming». Submitted MDPI Sports, May 18, 2021.

4 SYNOPSIS

Introduction

Low water temperature is regularly faced by many organizers of open water swims and military operations. To make this activity as safe as possible, more knowledge about how cold water affects the human body, as well as physical performance, is warranted. This knowledge can also substantially impact drowning prevention and lifesaving measures in professional work environments and leisure activities in and around water.

Aim

The primary aim of this thesis was to investigate the physiological response to swimming in cold water in subjects wearing a wetsuit or drysuit.

Methods

Three different studies were performed in this thesis. In Study I, the participants were active triathletes swimming in 10°C open water with a wetsuit. In Study II, the participants were Special Forces recruits (NORNAVSOC) swimming 10000m in 5°C open water with a drysuit. In Study III, the participants were part of a triathlon race, and data collection was performed during and after the swim. In all studies we included core temperature measurements and body composition measurements of the study subjects. In Study I and II, skin temperature measurements was included. In Study II, we in addition included biomarkers (CK, CRP, Cortisol, and Testosterone), reaction time, dexterity tests, and muscle power of the subjects. Study III was performed at Norseman Xtreme Triathlon in the races in 2017, 2018 and 2019.

Results

The main findings in Study I, was that the rectal temperature was maintained for the first 10 minutes of the swim in all participants. For the majority of participants, the core temperature dropped below the start temperature during the swim. The mean fall in rectal temperature was 0.9°C (SD 1.1). For all participants with a drop in core temperature, a further reduction was observed after the swim(afterdrop), with a mean decrease of 0.6°C (SD 0.3). In Study II, the mean reduction in core temperature was 0.4°C during the swim. An afterdrop was observed in all participants, with an average drop of

1.1±0.3°C. The decrease in mean skin temperature was 9.8±3.3°C during the exercise. There was a clear reduction in lower body power, reaction time, grip strength, and dexterity immediately after the swim. One day after the swim (24h), most effects were minor or had returned close to the baseline. In Study III, we measured core temperatures during racing and found no association between body core temperature at the end of the swim leg, and swim time, sex or BMI. However, one participant got hypothermic during the swim, and this is considered important.

Conclusion

While there is a clear pattern that participants swimming in cold water have a gradually decreased core temperature, there is also a tendency that the core temperature is maintained for the first 10-15 minutes of exposure. However, an important observation in all studies was the high heterogeneity of the core temperature response. In Study I, we observed variation between the test subject from practical no drop in core temperature to a drop in more than 4°C under the same conditions. Afterdrop occurs in many athletes who cool during the swim; however, the magnitude is possibly negligible. The drop in core temperature is strongest associated with exposure time for cold water. In this thesis, we have not found other variables that can explain differently. Still, an important finding in this thesis is that individual participants can get hypothermic, even if the mean drop in core temperature is small.

5 INTRODUCTION

5.1 The beginning

Since 2005 I have been the chief of the Safety and Medical Team at Norseman Xtreme Triathlon. For several years, Norseman has been known in the triathlon community as one of the world's most demanding races. It starts at 0500 in the morning with a jump from a ferry into the dark and rather cold water in the Hardanger fjord. The swim is 3800 meters long, into Eidfjord, a small village surrounded by spectacular mountains. In Eidfjord, the athletes pull off their wetsuits, dry off, and put on their cycling garments. Then they begin their 180 km bike ride up and over the Hardangervidda plateau, down to Geilo, further into Imingefjell, and towards Austbygdi. In Austbygdi, they drop off their bikes and start running. The run is 42 km (Marathon) and starts completely flat, but after 25km, the climb up to Mt. Gaustatoppen starts. The finish line is at Mt.Gaustatoppen at 1883 meters above sea level. In total, through the course, there is an ascent of 5000 meters. The environmental condition is a popular topic to discuss among athletes and organizers every year: the cold waters, the heat in the valleys, and the fog in the mountains. One year, there were showers of snow at the finish line at Mt. Gaustatoppen.

In 2015 we met up a few days before the race. Standing on the beaches in Eidfjord, we measured a water temperature of 10°C. Unfamiliar with how this could impact the athletes, we first did a test swim ourselves. After that, we decided to shorten the swim that year. Later, Professor Jonny Hisdal encouraged me to do a PhD on the topic.

5.2 History of core temperature

As early as history records, there have been anecdotal stories about the importance of core temperature and effort on how to keep warm. Early concepts of temperature were known long before the development of the thermometer. In ancient times, fever or elevated skin temperature was already considered a vital sign of disease. Talmudic medicine writings, originating in Babylonia, shows notes of fever that can be traced back to Akkadian inscriptions from the 6th century BC.[1] It was not until the Hippocratic physicians constructed the theory of the balance among blood, phlegm, black bile, and yellow bile the concept of fever developed further.[2] This approach proposed that fever was a result of an overload of yellow bile. According to Hippocrates, fever originated with an excess of bile, which was consistent with many infections of that era.[3]

The ancient Greeks probably knew the central principles of the thermometer 2000 years ago.[4] However, the practice of monitoring body temperature for the use of diagnosis of a disease is of uncertain origin. As far as the oldest reference to devices used to measure temperature, we must back to Heron of Alexandria and Philon of Byzantium that is believed to have had several devices available in the first and second century BC.[4,5]

In more recent times, Galileo Galilei manufactured an instrument to measure temperature changes around the year 1592. The instrument was using the expansion of water with increased temperature as a technique.[3,5] It is worth noting that there are several possible inventors of the modern thermometer, even though Galileo is typically credited this honor.[5]

Galileo's thermometer had a grading system, but it is not known details on how it was graded. It did not have an apparent numerical scale. In 1612, Sanctorius Sanctorius included a numerical scale on a thermometer, using the snow's temperature and the temperature of a candle flame as reference values.[6] Daniel Gabriel Fahrenheit, a dutch instrument maker, developed a mercury-based thermometer in 1714. Further, he introduced the first standardized temperature scale, the Fahrenheit scale.[3,6] The Fahrenheit scale was first described in a paper submitted to the Royal Society in 1724. It had three reference points; the body temperature, assigned the number 96; the ice point, assigned the number 32, and the temperature of a mixture of ice, water and salt, assigned the number 0.[6]

Today many countries, including the European countries, use the standardized SI-derived unit, Celsius. The Swedish astronomer, Andreas Celsius, developed his temperature scale in 1741, where 0 represented the boiling point of water and 100 represented the freezing point of water.[7] Later, the scale was reversed by the biologist Carolus Linnaeus in 1743. The unit was initially called centigrade but was renamed *Celsius* in 1950.[3,8]

Precise body core temperature measurements are vital to study human temperature regulation and clinical medical practice. However, the use of the word "core" is in itself inaccurate. The body interior does not contain a uniform temperature in all locations, and no site is necessarily better than the other. The choice of location depends on what the purpose of the temperature measurements is.

Modern medicine temperature measurements include measuring temperature on the forehead, in the ear channel, axillary, orally, and rectally. Various more invasive methods are also in widespread use, such as measuring in the esophagus or the bladder. The accuracy of the multiple techniques varies.[9,10] In clinical medical practice, the most common site has for long been to use rectal temperature measurements.

The rectal method is a temperature sensor that is inserted at least 100mm into the rectum. When inside, it gives a dependable measurement of the large tissues of the deep body. It, therefore, provides a value for the average core temperature. The outside environment does not influence the sensor. There are some pitfalls to the method. It does not give a valid value for brain temperature, and it is slow regarding changes in core temperature.[11,12] For some subjects, the method can be disliked, mainly because of the concept itself.[13] There is also a factor of hygiene and the possibility of spreading viral diseases.

In clinical practice, especially emergency medicine and prehospital medicine, there are some obvious challenges with measuring core temperatures. The use of the rectal method is not feasible in an outdoor and perhaps harsh environment. Moreover, the use of the ear channel is often obstructed with water or snow, or the tightening of the probe to the ear channel is inadequate. This relates mainly to the prehospital care in ambulance services, air ambulance providers, and rescue groups worldwide.

For research purposes, several methods are acceptable, considering what type of research is done. The use of a rectal probe is often suitable and accurate. However, for research in sports or military operations, this method might not be appropriate because it might hamper the athlete or soldier's motion during operation. In recent years, ingestible temperature measuring pills have come up as an interesting method for such research purposes. The technique was described already in the 1960´s, and is nowdays increasingly in use.[14] The temperature pills are validated and found to be suitable for research purposes.[15]

5.3 Background

5.3.1 Triathlon

In Study I and Study III, participants in triathlon races were investigated. Endurance races, such as marathon and triathlon, emerged during the '80s and has steadily grown in popularity. Particularly long-distance triathlons are getting more and more popular.[16–18] The first modern triathlon was organized in San Diego in 1974.[19] Long-distance Triathlon originated on the islands of Hawaii in 1978. Fifteen athletes started on Waikiki Beach's shore in Honolulu with a combination of the three toughest endurance races in Hawaii, a 3800-meter swim, a 180km bike ride, and a 42.2km run (Marathon). The race moved to Kailua-Kona in Hawaii in 1981, where the race is still held as the legendary Ironman World Championship.[20] Ironman Hawaii is often acknowledged as one of the world's most challenging endurance races.[20] However, in 2003, the Norseman Xtreme Triathlon started in Norway with 23 athletes on a ferry.[21] It soon became known as one of the toughest triathlons in the world. However, Norseman has very different challenges than those of Ironman Hawaii.

Distinct from the heat and the wind at Ironman Hawaii, athletes at Norseman Xtreme Triathlon experience challenges from the cold and the wind. On race day in Ironman Hawaii, water temperature is expected at ~25.5°C.[22] Air temperatures range from 26 to 32°C, with a humidity range from 64%-67%.[23] Crosswinds during the cycling split may sometimes get as strong as 28 m/s. In contrast to Ironman Hawaii, water temperature in Norseman Xtreme Triathlon range from ~10.0°C–17.5°C, the air temperature on the cycling split at ~5–20°C, and air temperature on the running split at ~5–28°C. At the finish at Mountain Gaustatoppen, the air temperature may vary from ~0–12°C. (Authors personal measurements)[1]

5.3.2 Special Operation Forces

In Study II, recruits undergoing the selection period in a Special Operation Forces (SOF) unit was investigated. SOF has a particularly physical and psychological demanding occupation.[24–26] By the nature of military operations, soldiers are exposed to a multitude of stressors. SOF are military units that are uniquely selected, organized, trained, and equipped. These units are using specialized methods and employment forms. SOF operators typically work in small units, with high hazard risk and often far from friendly base.[27]

NORNAVSOC is a maritime SOF unit in the Norwegian armed forces, the «Marinejegere». Naval Special Forces are in particular focused towards training and equipment geared to conduct special operations on, under, and from the sea, and the Norwegian Naval Special Forces routinely do operations in cold environments.

[1] Author has measured environmental temperatures at Norseman Xtreme Triathlon each year during the last 15 years.

5.4 Basic Human Thermoregulation

5.4.1 Heat balance

Heat balance refers to the balance between the rate of heat loss or heat gain to the body and the rate of internal heat production. Meaning that there is a balance between the heat that is transferred from the body to the environment or heat transfer from the environment to the body, up against the internal heat production in the body. As humans continuously produce heat due to metabolism, this must generally be lost in the same rate to the environment for the body to remain in heat balance. The general equation describing the heat balance is:

$$(M - W) = (\pm K_{sk} \pm C_{sk} \pm R_{sk}) + (C_{res} + E_{res}) + E_{sk} \pm S$$

The metabolic rate of the body (M) supplies energy to enable the body to do mechanical work (W), and the remainder is emitted as heat.[28,29] K_{sk} is conduction from the skin, C_{sk} is convection from the skin and R_{sk} is radiation from the skin. These three is the sum of heat transfers via the skin, that moves the heat from high temperatures to low temperatures. This means that the heat can be transferred both ways. C_{res} is the convective heat tranfer between the air and the lungs and E_{res} is the evaporative heat loss from the respiratory tracht. E_{sk} is evaporative heat transfer from the skin and S is the storage of heat. Storage of heat is temporary and should ideally be zero.[28,30]

The raised heat production during physical activity creates a challenge for the body, as heat production often surpasses the capacity to lose heat.[31,32] Therefore, the result is a raised Tcore. This increase in Tcore can be further raised with insufficient heat loss due to high ambient temperature or humidity.[33] On the opposite side, high heat loss will eventually lead to decreased Tcore if not heat production is raised. Hence, the goal for preventing hypothermia is to acquire heat balance.

Humans are endothermic, meaning that we produce most of our heat by internal heat production, and are less dependent on the external environmental temperature. In contrast, we have ectothermic (poikilothermic) animals such as fishes and reptiles, that don't possess the same capacity to produce adequate heat to keep themselves warm.[34]

Heat is transferred from warm to colder objects, induced by temperature differences. It can take place by conduction, convection, and radiation.[35,36] Most calculations of heat loss in humans are performed on a naked human sitting in a room with normal room temperature. In real life, the degree of heat loss will vary based on many different factors. The following few paragraphs, therefore, give a theoretical overview of heat loss. Obviously, for this thesis, it is variable which distribution of heat loss is most prominent, especially for swimming. Heat loss can also occur without a temperature difference by a change of state from liquid to gas (evaporation).

Conduction is heat transfer through solid objects or air. Usually, the heat loss by direct contact to a surface is relatively low, around as little as 3%.[35,37] However, the degree of heat loss can change, for example, if a person is reclining flat on a surface because the area in contact with a solid object is increased. When conduction occurs, there is a temperature difference between the objects in contact.[37] The heat loss rate is also reliant on the thermal conduction of the material. As an example, aluminium has a much higher thermal conduction than wood.[38]

Convection is the transfer of heat from a body to moving molecules like liquid or air.[39–41] Typically, it varies with the type and speed of air or the liquid, as well as the fluid type. In water, heat flows into the water by conduction, and the water direct to the surface becomes warmer. If the water is in movement, the warm water is substituted by cold water and accelerated heat loss.[41]

Radiation occurs when heat is transferred between bodies, not in contact, via electromagnetic radiation.[30,41] This includes ultraviolet light from the sun and infrared radiation from a body.[35] Radiation has the most significant heat loss typically, and as much as 60% of the heat loss can occur through radiation.[37] All objects that are hotter than absolute zero (-273°C or O°K) emit heat through radiation. If the body is warmer than the surroundings, a greater proportion of heat will be transferred from the body than to the body. The power of the radiation emitted by a surface is proportional to the area and to the fourth power of the surface temperature. In humans, this means that heat loss through radiation is conditional to the skin temperature.[42]

Evaporation is a transformation of the state of the liquid on a surface to vapor. Heat is shifted from a warmer body to the water molecules on the surface of the skin. When the water is warmed, evaporation occurs. Even when the environment is cold, we lose heat by evaporation. When a person is not sweating, evaporation yet occurs at a rate of about 600-700 mL/day. Evaporation is a fundamental cooling capability especially in high environmental temperatures.[37,41] The impact of evaporative cooling from the skin is highly individual since our ability to sweat is variable. Some individuals can produce up to 4.7 liters of sweat, which potentially can cause heat loss up to an equal of 2500 watts from evaporative cooling.[43]

A fundamental type of heat exchange is countercurrent heat exchange. In humans, arteries and veins are located close to each other. Often they are located in pairs. In the extremities, warm blood from the core carries heat through the arteries out to the peripheral areas of the extremities. When returning through the veins, countercurrent heat exchange is engaged so that the blood carries heat back to the core that is warmer than if no countercurrent effect would be involved.[41] This is a way humans are using to minimize heat loss through the extremities.[44] The amount of convective heat transfer between arteries and veins is primarily determined by the distance between the vessels.[45]

5.4.2 Temperature regulation

Concerning human temperature, the body can be divided into two primary compartments. The core, includes the cerebral, thoracic and abdominal areas. And the shell, containing the region outside the core, including the skin, subcutaneous layers and muscles.[13] The human body monitors the temperature at different locations. The core temperature is monitored centrally in the pre-optic area of the hypothalamus and possibly also in the spinal cord. The shell temperature is monitored via skin sensors and neuronal feedback is given to the thermoregulatory center in the hypothalamus.[39]

The hypothalamus is the coordinating center for thermoregulation. Since the 1960s, there has been a broad acceptance of a model of temperature regulation around the concept of hypothalamic proportional control.[46,47] Hammel and his coworkers used unanesthetized dogs when cooling down the hypothalamus. They fixate needle thermodes in the skull of the dogs and infuse warm or cold water. Based on this and several other studies, they proposed the concept of a hypothalamic proportional control around an adjustable set-point. This set-point is often analogized to a thermostat in a building. The set-point temperature spans within a narrow range, which is regulated by a continuous interaction between the thermoregulatory center and feedback from the core and peripheral sensors.[48,49] The set-point temperature varies through the day(±0.5), with a maximum temperature in the evening and a minimum temperature in the early morning.[50,51] This is due to the circadian rhythm. Age[52,53] and gender influence the set-point temperature. The latter is due to the menstrual cycle, giving females in reproductive age a Tcore ~0.4oC higher in the luteal phase.[54,55] The hypothalamic proportional control model has been the dominant idea for more than 50 years. Yet, this model has been challenged by other concepts of human thermoregulation.[56,57] Still, of all concepts of thermoregulation proposed, none has been unanimously accepted.[58]

A vital function of temperature regulation is the existence of a feedback system. Negative feedback is a tool that maintains the body within particular limits. The body will do this by opposing a change that differs from normal.[59] The Tcore is sensed by thermosensors. These thermoreceptors have two subtypes, those responding to the cold and those responding to varmth. Pheripheral thermosensors are found in skin and central thermosensors are found in the hypothalamus, spinal cord, viscera amd large veins.[35] Thermosensors send out afferent action potentials received by the thermoregulatory center in the hypothalamus. The thermoregulatory center produces efferent action potentials, triggering effector mechanisms in a way that maintains Tcore relatively constant. This feedback system means that an increase or decrease in Tcore will be balanced by one or more effector mechanisms. For example, in the cold, the threatening of a decrease in Tcore is compensated by vasoconstriction. Conversely, a high Tcore may activate the sweat glands to bring Tcore down. When Tcore reaches its set-point temperature, feedback stops the process by deactivating the effector mechanisms.[60]

Heat is generated within the human body and is a fundamental by-product of the metabolism in the cells. This process is yet not fully understood. Metabolism points to the chemical reactions within the cells, where energy is derived from food molecules. These molecules are protein, fat, carbohydrates, and water. The process is called cellular respiration and transforms into Adenosine Triphosphate (ATP). This transformation does not use all of the carbon components, and much of the energy is therefore transformed into heat.[28,61] Humans require ATP to supply energy to the cells used in membrane transport, mechanical work, and chemical reactions. Heat is also produced when ATP is hydrolyzing into Adenosine Diphosphate (ADP) since this process is relatively ineffective in the human body.[62] Additional ways of heat production is muscle movement. The viscous movement of the muscles creates friction within the tissue, which again produces heat.[61]

Adaptation is a general term that includes acclimatization and acclimation. The term acclimatization refers to adaptation in a natural setting. It occurs by reducing the strain caused by stressful changes in a natural climate. The term acclimation refers to adaptions in artificial settings. These adaptations are caused by experimentally induced stressful changes in particular climate factors.[63] Therefore, the difference between the two is if it occurs within a natural habitat or not. The term acclimation will be used when both natural and artificial environments may apply.

5.4.3 Wind Chill

Directly adjoining the skin, air or water molecules form a boundary layer.[64] The molecules in the boundary layer move more slowly and are less disturbed by normal convective flows. In general, when a fluid flows over a surface, the fluid that is in direct contact with the surface is stopped. The stop is caused by the shear stress to the surface. The boundary layer is the layer where the flow adjusts from zero at the surface, to maximum flow in the flow´s main stream.[65] The concept of boundary layers is fundamental in the theory of heat transfer. The thicker the layer, the better insulation. The layer can increase in thickness with hair, or, as in many animals, with feathers. Additionally, the hair can erect to make the boundary layer larger, consequently protecting the human temperature better in colder weather.[64]

It is well known that wind raises the risk of frostbite in a cold environment.[66,67] The faster the wind, the more rapidly the skin cools. The wind chill factor is an expression that combines the effect of wind speed and low temperature. It is a correlation between increased wind speed and convective heat transfer from the body. It was first formulated as the Wind Chill Index (WCI) due to pioneering research in Antarctica in 1941.[68] The researchers put a small plastic bottle on the roof of the expedition building. They then estimated the time it took to freeze the water inside. Combining various wind speeds and temperatures from these observations, they developed WCI.

Several researchers have criticized the use of WCI since its publication.[69,70] Most notable that WCI underestimates airspeed's effect on the convective heat transfer from exposed body parts.[67] Therefore, new scales have been proposed. The Wind Chill Equivalent Temperature (WCT) has been used gradually since mid-1970.[71] However, its origin is unknown.[69] WCT uses dry-bulb temperature and wind speed. The scale has been revised regularly during the last years, and its accuracy and use are still debated.[72,73]

5.4.4 The skin

The human response to environmental temperature changes can be summarised into two factors. First, the behavioral response is the most important and has the most considerable impact on human thermophysiology. The behavioral response is how we dress, seek shadows or shelters, and more. Alternatively, if we use wetsuits or drysuits to protect us in the water.

The second response is physiological. This is essentially the capability to vasoconstrict in the cold and vasodilate in the heat. It is mainly the blood vessels in the skin and muscles of extremities that contribute to this. If blood vessels in the skin vasoconstrict, we reduce our blood flow in the skin and reduce heat loss. If we vasodilate our blood vessels in the skin, this is ideal for increasing blood flow and increasing heat loss.

If it is very cold or very varm, the human body has, in short, two additional responses to apply. When it is cold, we can increase our metabolism with thermogenesis. We divide this into two parts, shivering and non-shivering thermogenesis. Shivering thermogenesis is involuntary repeated muscle contractions, delivering most of the metabolic energy produced as heat. In humans, shivering is by far the greatest contributor of heat.[74,75] Non-shivering thermogenesis occurs in brown adipose tissue (BAT). The main function of BAT is heat production when activated by cold exposure.[76,77] Previously it was thought that BAT only existed in humans and was gradually lost later in life. Now, it is clear that also adults have active BAT.[78] BAT is presented superficially in the supraclavicular area and also in the neck, spine and perirenal regions.[79] BAT has a unique uncoupling protein (UCP1) that uncouples protons in the mitochondria during the synthesis of ATP, allowing more energy to be dissipated as heat.[80] This makes it very energy consuming in cold environments. Recently it has also been suggested that muscle tension during resting conditions could have a role in Tcore regulation.[81] On average, a resting awake individual produces around 80-100 watt (W). Non-shivering thermogenesis can add up to 11 W extra[82] Shivering thermogenesis, however, can add up to 300 W extra.[83] On the contrary, when it is very hot, we increase our sweat production, and we cool the skin by evaporation.

The human skin is a large organ that serves as a barrier between the external and internal environment. In adults, the surface is approximately 2 m^2.[84] The skin is also a sensory organ that contributes to homeostasis by sensing various disturbances or changes. During a normal, thermoneutral situation, there is a balance between heat production and heat loss. This balance is tuned precisely with vasomotor alterations in the skin, more explicitly, either vasodilatation or vasoconstriction.[29]

The blood flow in the skin can respond considerably to environmental changes. The skin can generate powerful vasodilatation during heating of the body. The cutaneous blood flow differs enormously and can increase from 300 mL/min and up to 8 L/min.[85] In humans, studies suggests a local temperature of 42°C produces maximal dilatation of skin blood vessels.[86,87]

Conversely, cold exposure causes vasoconstriction, which decreases heat loss from the body and shields against hypothermia. When vasoconstriction occurs, the blood is shunted away from the skin surface via deeper veins. Heat is then conserved in the core. A local cold exposure can decrease skin blood flow to near zero.[88] However, this prolonged vasoconstriction can cause ischemia and tissue hypoxia, leading to nonfreezing cold-induced injuries.[89]

When exercising or in higher environmental temperatures, the vasomotor adjustment is not sufficient to maintain this balance. The heat production rises, and there is a risk of overheating the body. In these conditions, the body needs a higher volume of heat loss. The body then modifies its heat loss towards added evaporation of sweat from the skin.[90] When the cold exposure is higher or prolonged, the vasoconstriction is not enough to preserve body heat. Then the body starts shivering.[91]

In the context of thermophysiology, humans have two types of skin. These are nonhairy glabrous skin and hairy non-glabrous skin. Glabrous skin covers specialized organs for non-evaporative heat loss.[84,92] These are distinguished by specific characteristics, including the lack of hair, dense vascularization, and a large surface-to-volume ratio. They also have the presence of arteriovenous anastomoses.[93] In some studies, the therm acral and non-acral skin is used, relating to peripheral parts, particularly the palms and the soles.[94]

An arteriovenous anastomosis is a shunt in the microcirculation of the skin that permits the blood to bypass the smallest capillaries.[95] Instead, the blood flows straight from the small arteries to the small veins. Therefore, since this shunting bypass the capillaries, the transport of substances to or from the tissues is hindered. However, it has a substantial effect as a mechanism for heat transfer. The opening of the arteriovenous anastomosis gives a much higher cutaneous blood flow, thus greater heat loss. According to Poiseuille's law,[96] a doubling of the radius of the blood vessel will give a 16 fold increase in blood flow. The arteriovenous anastomosis is found in the skin of the hands, feet, ears, lips, and nose and almost exclusively on the glabrous surfaces. However, they are much more present in the nailbeds and the hands and feet.[93,97] When the ambient temperature is below the thermoneutral zone, the arteriovenous anastomoses are closed. On the opposing side, when the ambient temperature is above the thermoneutral zone, they are open most of the time.

Walløe (2016) argues that arteriovenous anastomoses have a vital role in thermoregulation within the thermoneutral zone.[93] The temperature control center in the hypothalamus regulates the opening and closing of the arteriovenous anastomoses, finetuning the blood flow to the skin.

5.4.5 Thermoneutral zone

Core temperature is usually regulated within narrow limits in humans, which is essential since survival depends on retaining core temperature inside this range. This narrow range is still maintained when there are drastic fluctuations in environmental conditions. The average human core temperature has for more than 100 years generally been accepted to be around 37°C. The reference value of 37°C was defined in 1868 by the German physician Carl Wunderlich.[2] This standard has lately been disputed, and revision has been proposed.[48,49] A novel study from Protsiv et al. concludes that the average normal core temperature has decreased by 0.6°C in the USA since the Industrial Revolution.[98] It is now generally accepted that normal core temperature is within a span rather than a fixed value. The range in rectal temperature is now considered to be 36.8-37.1°C and 36.7-37.5°C for men and women respectively.[49]

The thermoneutral zone refers to the ambient temperature range where the internal thermoregulatory regulation is relatively constant without regulatory changes in heat production or heat loss.[99,100] The thermoneutral zone is a range that is debated, and still, the exact upper and lower limit is considered uncertain.[101] The lower limit starts at about 21°C for humans with average weight and about 18°C for overweight adults. Humans try to avoid the two extremes of the thermoneutral zone, which is sweating and shivering.[93] In water the thermoneutral zone is much higher, around 35°C for a naked person.[64]

5.5 Cold Water

Water has several characteristics that are different from air. In water, the human skin surface is in nearly 100% contact with water, and conduction and convection are the primary heat transfer methods.[37,102] Evaporation of sweat cannot be used, since the environment is humid and fully saturated.[103] Radiation is negligible in areas that are submerged. Compared to air, water conducts heat exceptionally well.[102] Therefore the heat loss in water can be substantial, with a potential heat loss up to 25-30 times faster when immersed in water.[104] Even if the potential heat loss due to the conductive heat loss is of great magnitude, humans cool about 4 times faster in water. This is because physiological responses to generate heat are initiated much earlier and with greater power in the water.[105] Still, the magnitude is varying between studies, probably due to methodological differences. Consequently, swimming can give much more significant heat loss than other activities such as cycling or running at equivalent ambient temperatures. In general, the greater the temperature gradient between the skin and the environment, the greater the rate of heat loss.

The flow of heat from the human body core to the cold water goes through several layers of resistance. These occur both inside the body and, in some circumstances, as well as outside. During resting immersion in cold water, there is a conductive gradient between the deep tissues of the human body and the skin. The heat flows from high to lower temperatures, therefore transferring heat from the core to the surface. The deep tissues have a higher temperature than the muscles, and the muscles have a higher temperature than the skin, which again has a higher temperature than the cold water. Thus, the heat loss could be considerable during cold water immersion. Adding to this, the unperfused muscles have an insulation capacity, supplying up to 70% of total body insulation.[64] When using muscle for swimming, the muscles are perfused, and the insulation capacity is decreased, resulting in greater heat loss at the same intensity.[106,107] Furthermore, convective heat loss increases when the water moves across the skin or by the swimmer's movement in the water. Hence, the heat exchange due to convection between the body and water depends on the temperature gradient between the two and the speed of the motion of the water close to the body.

In water, the humidity is irrelevant; hence evaporative heat loss is negligible. In an unprotected nude swimmer, the environment is completely saturated. The same transpires with a wetsuit, where water enters the wetsuit's inside. Inside a drysuit, the air is fully saturated very fast.[103] The radiant heat loss component is also negligible in water.[108] Moreover, adding a wetsuit could act as a radiant barrier in itself.[109]

5.5.1 Cold Water Immersion Death

There is much research indicating a cardiac source of several of the deaths during immersion. In a study from Greece, there was a considerable number of immersion deaths that had a cardiovascular cause.[110] The authors found that 49% of the drowning victims had a cardiovascular pathology when autopsied. In another retrospective study from Croatia, swimming and diving related deaths over a 14 years period were studied. The conclusion was that a primary cause of death due to swimming was organic heart disease.[111] Still, a Swedish study of 2166 drowning victims pointed that 14% had a cardiac disease as a possible contributing factor when autopsied.[112]

In a case series study by Harris et al., (2017) they revealed that cardiovascular disease was a high and unexpected cause of mortality during triathlon races in the USA from 1985-2016.[113] As many as 44% of the autopsied athletes in this study had a cardiovascular abnormality. Out of them, 67% had a significant coronary artery disease, and 15% had cardiomyopathy. Notably, the study also investigated the survivors from cardiac arrest. It revealed that 10% of race-related cardiac arrests survived. Probably due to correctly performed cardiopulmonary resuscitation and defibrillation. However, one of the main findings from the study from Harris et al. is that most of the deaths during triathlon racing occurs during the swim part of the race. Of the 13 cardiac arrest cases that survived, five occurred during the swim, two during the bike, one during the run, and four at the finish line. Although a limited number of cases, this alerts organizers to have an increased level of preparedness during the swim and at the finish line. Medical professionals and equipment must be geared towards advanced cardiopulmonary resuscitation.

Drowning can occur in any fluids and at any temperature. While there are various definitions of drowning, there is consensus on distinguishing between submersion and immersion in physiology. Submersion relates to the situations where the airways are below the liquid's surface, whereas immersion relates to when the airways are above the surface. If an individual falls accidentally into the water, one can easily imagine that the airways can be both above or below the waterline.

In the context of present thesis, the various aspects of a cold water immersion will be reviewed. An overview of the stages after an accidental cold water immersion follows, and all the stages are discussed elsewhere in this thesis.

The first stage is a cold shock. When entering cold water, there is a high risk of experiencing a cold shock. The cold shock is at its peak after 30 seconds. Within 2 minutes, the body has adapted to the cold environment, and the cold shock declines.[114] The most notable physiological response to the cold shock is hyperventilation with an unintentional gasp reflex, tachycardia, and a rapid increase in blood pressure.[115,116] A rapid entering of cold water can also trigger the autonomic conflict, described in more detail in chapter 5.5.2.

The next stage of cold water immersion is swim failure. This is due to the rapid cooling of the skeletal muscles and superficial nerves.[103,114,117] The result of this cooling is a decrease in swim technique and, in the end, a swim failure. This can be fatal in a survival situation, where one needs to swim to a safe haven for rescue. A decrease in swim technique is also harmfull during competitive or recreational swimming in open water.

The third stage is hypothermia. While hypothermia has tended to be set as the cause of death after cold water immersion, this will, for several cases, be an oversimplification. Hypothermia is rarely seen during the first 30 minutes of immersion,[118,119] which again assumes that the victim survives the cold shock and swim failure phase of cold water immersion.

The fourth stage is the rescue phase. Not all authors present cold water immersion in four stages, but it has lately been proposed to include the rescue phase.[103,116]

5.5.2 Autonomic conflict

A paper from Shattock and Tipton proposes a theory that a specific cardiac arrhythmogenic response is responsible for deaths during cold water immersion.[120] They call this response the autonomic conflict. They found some unexplained statistics in the material on cold water immersions and drowning, namely that 67% of drowning occurs with competent swimmers. Furthermore, 55% of the victims are within 3 meters of safety, like a pier, boat, or land. So they suggest that many of the deaths previously associated with hypothermia alternatively is due to the autonomic conflict. A rapid cold water immersion while simultaneously attempting to breath-hold activates two potent responses from the autonomic nervous system: the cold shock response and the diving response. The cold shock response is a response from the sympathetic nervous system. It gives tachycardia, respiratory gasp, hyperventilation, vasoconstriction, and hypertension.[116] The diving response is mainly a response from the parasympathetic nervous system. It can promote sinus bradycardia, vasoconstriction, hypertension, and an expiratory apnoea. The diving response has a primary goal of saving oxygen and thereby extending the time the individual can be underwater without an oxygen supply.[121]

The simultaneous impact from the two responses of the sympathetic and parasympathetic autonomic nervous system carries an extended risk of cardiac arrhythmias, hence the name autonomic conflict. This frequently goes undetected post mortem, as electrical disturbances in the heart are nearly impossible to reveal during an autopsy. Further, like certain arrhythmias, electrical disturbances in the heart may lead to agonal gasping, with the following possible aspiration of water. These findings could then be connected to drowning during an autopsy, while it may be caused by the autonomic conflict.[120] In most humans, the heart response to a cold water immersion is tachycardia and thereby dominated by the cold shock reflexes discussed elsewhere. Nevertheless, for some individuals and in some circumstances, the autonomic conflict occurs.[120]

5.5.3 Afterdrop

Afterdrop is a continued cooling of a human body's already cold core temperature even if the body is removed from the cold environment. During the early stages of rewarming a hypothermic patient in a clinical setting, the deep body temperature could continue to drop for the first 10-30 minutes before it starts to rise. In some studies, the afterdrop is termed "Post-immersion cooling", however in this thesis, the term afterdrop will be used.

The exact mechanism of afterdrop is not fully elucidated. However, it is likely that both the rate of conductive and convective heat transfer from the core to the shell is important.[122–124] These two processes probably are working concurrently.

Conductive afterdrop refers to the conduction of heat down a thermal gradient from a warmer core to a colder periphery. This type of afterdrop is particularly prevalent in the rectal region because of the larger mass of adipose and muscular tissues.[124]

Convective afterdrop is due to the venous return of cooler blood from the extremities.[123] The convective afterdrop transports more heat and, unlike the conductive afterdrop, is affected by which method of rewarming the rescuers' practice.[122] In a hypothermic patient, the tissues in the peripheral regions are colder than the core. Hence, any movement that increases blood flow from the core to the peripheral regions will increase the volume of cold blood returning to the heart. This type of movement could be hoisting a victim vertical from the sea, allowing a hypothermic victim to stand or walk, limb movement, and more. Such movement increases the cardiac work and could possibly lower the core temperature even more.[122]

Afterdrop has been debated to be of clinical importance if a victim is on the threshold to severe hypothermia, where the heart is susceptible to arrhythmias. There have been a few case reports of afterdrop with a drop as much as 5-6°C,[125,126] however, such large drop in temperature is rare. Physiological experiments with mild hypothermia have demonstrated an afterdrop of up to 1,0°C.[127–129] It is, therefore, important to address in future studies whether the afterdrop effect is of great concern.

Some studies have proposed that a more substantial afterdrop occurs if the victim is exercising after the cold exposure.[130,131] These suggestions are interesting regarding present research. Both triathletes and NORNAVSOC recruits usually have a high level of exercise after coming out of cold water. Giesbrecht et al. showed that exercising after cold water exposure had a mean afterdrop of 1.1°C±0.4. When shivering or shivering and exercise combined, the afterdrop had a mean of 0.35°C±0.3 and 0.45°C±0.2, respectively. In addition to conductive and convective heat-loss, the extent of afterdrop during exercise presumably also depends on the local metabolic heat production in the periphery. Since there is a close relationship between muscle activity and blood flow, the convective afterdrop mechanism would conceivably increase the afterdrop during exercise. Increased peripheral muscular heat production during exercise also decreases the thermal gradient from core to peripheral heat loss.[130] Hence, afterdrop is therefore predicted to be greater when exercising.

5.5.4 Wetsuit

A possible way of protecting the human body from the cold waters is to use a wetsuit. The wetsuit is now commonly used by divers, surfers, swimmers, and others to protect them from the cold waters. Wetsuits made for swimming are typically made of neoprene. Neoprene was manufactured already in the 1930s by DuPont company.[132] However, the first wetsuits made by neoprene were developed and produced in the 1950s.[132] Although several manufactures are claiming their inventions of the wetsuit, it is widely recognized that Hugh Bradner is the inventor of the modern neoprene wetsuit.[133] He proposed that the divers did not have to be dry to stay warm in the water. This was a theory that contradicted the prevailing theory behind the drysuit at the time.

Wetsuits provide insulation to the cold by trapping a thin layer of water between the body and the inside of the wetsuit.[134] The trapped water heats up rapidly and then reduces the thermal gradient and heat loss between the core of the body and the water surrounding the individual wearing the wetsuit. Kang et al. showed the thermoregulatory effects of using a wetsuit on Korean female divers.[135] The divers decreased 0.4°C in summer and 0.6°C in winter during a two-hour dive with a wetsuit. When not using a wetsuit, they reached a core temperature of 35°C within 60 minutes in summer and 30 minutes in winter.

A byproduct of using a wetsuit for swimming is that the swimming times are reduced. This is probably due to the increase in buoyancy and therefore reduced drag.[136] This effect is highly appreciated by the users and constantly developed further by manufacturers. The wetsuit also protects from ultraviolet exposure, stings from marine organisms, and rash from reefs and sand.

When using a wetsuit, the practitioners have to ensure that it has a proper fit. There is much debate on what a proper fit is, and this is something that is an unknown essential factor in the sports- and diving communities.[137] If the wetsuit has a too loose fit, it will allow cold water to enter when the practitioners move. If this happens, the already heated water between the skin and the neoprene will be replaced by colder water. The manufacturer usually has their own sizing charts for finding the proper fit on a wetsuit for customers.

5.5.5 Drysuit

A drysuit protects the diver from the cold water by preventing the water from entering. Therefore the diver is dry throughout the dive while wearing the drysuit, with the possible notable exception of his vaporized perspiration. The idea of keeping the diver dry has been used for many years. The first practical application that is a direct ancestor to today's drysuits was developed by Augustus Siebe around 1840.[138]

One key advantage of wearing a drysuit is that one can vary the insulation layer worn inside the drysuit. The diver can wear thick, woolen garments or even heated suits beneath the drysuit. It has been popular in the technical diving communities to use Argon as an inflation gas for the drysuit. This is due to its thermal properties, with a study on manikins demonstrated a significantly improved thermal protection when Argon was used.[139] The use of Argon for providing extra thermal insulation compared to air has, however, been disputed.[140,141]

A three-layer system is generally the construction concept of modern drysuits. The base layer is made to transport water away from the skin. The skin of the diver is continually sweating, making it exposed to evaporative heat loss. The mid-layer of the drysuit is constructed to provide insulation and thereby reducing conductive heat loss. The outer layer is a shell that provides a watertight barrier to reduce convective heat loss.[103] In military diving in the Nordic countries, only drysuits are used. The reason is that in deep water, it is cold (~3°C) all through the season.[141] Hence, the Nordic Naval divers are exposed to the cold year-round, and therefore there is an immense interest in making thermal comfort optimal.

5.6 Hypothermia

There have been various definitions of hypothermia. Some have suggested definitions of hypothermia when the core temperature drops below 36°C.[142] This could be relevant in trauma patients out on the accident scene. The idea for this definition is that trauma patients tend to have a worse outcome when the core temperature is lower.[143] The European Resuscitation Council Guidelines suggest a 36°C degree definition of hypothermia on infants.[142] Interestingly they do not define hypothermia as a core temperature below 35°C in adults in their 2021 guidelines, as they did in their 2015 guidelines.[144] However, there is a general agreement that the definition of accidental hypothermia should be a measured core temperature below 35°C.[122,144–146] Still, any environmental conditions that cause a drop in core temperature below 36°C could be considered potentially vulnerable. This is because human thermoregulation is very precise, and already at core temperatures below 36°C, physiological changes occur.

There exists no accurate definition of what core temperature is. That is because there is no detailed description of the location where core measurements should be performed. The challenge is that temperature varies within the human body and also within the core. It is, however, generally accepted that core temperature is the temperature of the vital organs, including the brain. The different aspects around the measurement of core temperature are addressed elsewhere in the present thesis.

In prehospital and field settings, there are some obvious challenges with core temperature measurements. The use of a rectal probe is not always feasible, and several other measurement methods can be problematic since the devices in use can be affected by sunlight, snow, and rain. To help overcome this, a commonly used system in these communities is the Swiss Staging System.[147] This is a system for practical fieldwork, especially for non-medical rescue staff. The system uses a few simple criteria that easily could be monitored by non-medical rescuers. The criteria in use are the degree of consciousness, the presence or absence of shivering and cardiac activity(pulse). An easy read table can transform the monitored vital signs into a suggested five-range scale of core temperature. With the presence of medical staff and more advanced equipment, the monitoring could be followed up by measuring the core temperature, skin temperature, Glasgow Coma Score, heart rate, respiratory rate and more. In spontaneous breathing patients, a tympanic low-reading thermometer is recommended. In suspected severely hypothermic patients (Grade IV or V) in the field, using an esophageal thermometer is recommended for medical professionals when the patient has a secure airway.[142]

The coldest ever surviving patient was reported in Northern Norway in 1999.[148] A female expert skier fell, down into a small waterfall. There she was there trapped under ice and rocks and overflooded continuously by icy water from the waterfall. Three hours later, she was admitted to the operating room at the university hospital. At this time, she had no spontaneous respiration or circulation, her pupils were maximally dilated, and the electrocardiogram showed no activity. After five minutes on cardiopulmonary bypass, they recorded a temperature of 13.7°C. After eight minutes, ventricular fibrillation started, which converted to a pulse generating cardiac rhythm after 15 min. At this time, the rectal temperature was measured to 14.2°C. However, the pharyngeal and oesophageal temperature had raised to 25.0°C and 31.5°C, respectively. After nine hours of resuscitation, she was transferred to an Intensive Care Unit. Today, she is alive and well functioning as a physician.

When a victim starts cooling, shivering thermogenesis is one of the first physiological responses. Shivering is triggered by the cooling of the skin. The shivering results in increased metabolism, with following increased ventilation, heart rate, cardiac output, and mean arterial pressure.[149] All these parameters can be seen increasing while the core temperature decreases. When the core temperature reaches approximately 32°C, the same parameters are seen decreasing. Shivering is to cease at approximately 30°C, and then metabolism gradually decreases alongside the further decrease in core temperature.[122]

When the core temperature cools further, the thermoregulatory system is affected increasingly. Within the temperature range from 32°C to 28°C, the brain is cooled, leading to confusion, apathy and a gradual decrease in consciousness. However, the cooled brain reduces cerebral oxygen demand. Further, the circulating blood volume is decreased, leading to hypovolemia. This is due to cold-induced diuresis and extravascular plasma shift. When the heart's temperature is below 30°C, cardiac output and heart rate drop significantly. Abnormalities in the heart's electric signals can lead to arrhythmias such as premature atrial and ventricular contractions.[150] Below 28°C consciousness is lost. The heart is now highly susceptible to ventricular fibrillation. The ventilatory response has an immensely decreased response to carbon dioxide, leading to relentless hypoventilation and acidosis.[151]

Hypothermia has traditionally been graded into mild (35°C to 32°C), moderate (32°C to 30°C) and severe (30°C and below).[152(p265)] In recent years, using a more practical approach in prehospital medicine has been suggested. The Swiss staging system presented above provides easy scaling in outdoor environments where a thermometer is not feasible.[147]

6 AIM AND RESEARCH QUESTIONS

The general aim of this thesis was to explore and elucidate the thermophysiological consequence of cold water swimming in subjects using a wetsuit or drysuit.

6.1 Specific research questions

- How will time in water affect core temperature when swimming with a wetsuit in 10°C water?
- Is a potential decrease in core temperature influenced by low fat or muscle mass of subjects in cold water?
- How is the core temperature affected after the subject is out of the cold water, and the wetsuit or drysuit is removed?
- Is there a deterioration of dexterity, muscle force, and reaction time after cold water swimming?

7 MATHERIALS AND METHODS

7.1 Study populations

7.1.1 Study I

Recruitment took place via social media, in groups where triathletes are frequently known to be found. The study population consisted of both recreational and elite triathletes. There was a wide variation of experience with the sport as well as a variety of individual fitness level. There was a requirement that they were capable of swimming 3800 meters continuously in less than one hour and 45 minutes and use their personal wetsuit. 3800 meters was determined because this is an official long-distance triathlon swim. According to the European Society of Cardiology, upon final inclusion, the participants were screened by a medical doctor and a nurse for cardiovascular risk factors.[153,154]

7.1.2 Study II

In Study II, we included recruits from the NORNAVSOC qualification training program. These are already thoroughly selected and trained to become NORNAVSOC operators if the selection period is completed. NORNAVSOC has strict physical fitness requirements, and the participants were, therefore, a relatively homogenous group.

7.1.3 Study III

This study was performed over three years during the Norseman Xtreme Triathlon. Participants in the race were invited to join in a larger research program at the race, and the temperature study included in this thesis is a part of this more extensive research program. All participants were active triathletes. Hence they have a physical fitness level probably higher than the general population.

7.2 Measurements

7.2.1 Core temperature

There are several methods for measuring the core temperature in humans. There is a general acceptance that using esophageal temperature at the left auricle level in the anterior surface of the left atrium and close to the descending aorta is a "Gold standard".[155] A small temperature sensor is inserted through the nose and advanced to the correct position. However, this method's practical complexity and technical requirements makes it primarily feasible in a laboratory or clinical environment. When measuring core temperature, the method we utilize will depend much on the practical application.

For our first study, therefore, rectal temperature measurement method was used. We used a wired temperature probe. The method has less complexity and technical requirements than the esophageal method and still provides adequate accuracy. The probe was inserted in the rectum by the study subject after instructions by the researchers. The probe was inserted 10cm past the anal sphincter. The temperature probe was then wired to a logger (Veriteq Spectrum Precision Thermistor Logger 1400, Surrey, BC, Canada), and the logger was placed in a watertight box. The watertight box was attached to the study subjects' back and logged the temperature every minute.

Figure 1. The wired rectal probe and the watertight box for the logger used in Study I. (Photo by Jørgen Melau)

Ingestible temperature sensors have some distinct benefits in field-based studies. The sensors are wireless, so the study subjects do not need a wire out of their anus. They are relatively noninvasive, which means that the study subjects can carry out their planned activity without noticing their temperature being measured.

In Study II and Study III, core temperature was measured continuously with ingestible temperature pills. (BodyCap, e-Celsius Performance capsule, Hérouville Saint-Clair, France) The pill size is 17.7 x 8.9 mm and can be pre-programmed by researchers to sample temperature data at different time intervals. (15s, 30s, 1min, 2min, 5min)(BodyCap Medical 2017) The pill can store up to 2000 readings. The temperature data is stored within the pill and can be read out by researchers by holding a reading device (BodyCap, e-Viewer Performance monitor, Hérouville Saint-Clair, France) within 1-3 meter of the subject. The pill is discharged from the system by natural means (via feces), and on average, stays within the body for 24-48 hours. The core temperature can be observed live on the monitor or downloaded as a bulk after the intervention is finished. The researchers can download the stored data as a Comma Separated Values (CSV) file or Portable Document Format (PDF) file.

Figure 2. The Bodycap e-Celsius® Performance pill used in Study II and Study III. (Photo by Jørgen Melau)

The pill was swallowed approximately 2 hours before the swim in the second study. Based on our previous experience, it takes on average 6 hours for the pill to get into the lower gastrointestinal tract to accurately reflect core temperature. This seems to be mainly due to the study subjects' ingestion of water or sports drinks, which interfere with the pill's temperature readings. However, during the data collection in Study II, the subjects could not drink during the swim. Therefore, we anticipated that the readings would not be affected by the subjects ingesting water during the swim. It also would not be beneficial to wake the NORNAVSOC recruits up during the night to swallow the pill.

In our third study, the pills were swallowed 6-8 hours before the start of the swim. This is, again, due to previous experience where it takes a very long time before the pills give reliable readings without being affected by the study subjects drinking. Athletes in our third study are very enthusiastic about staying well hydrated before the race start. When ingesting 6-8 hours before start, there is a risk of the pill being passed before race start. However, we concluded that the risk of losing data was smaller than the risk of inaccurate data.

The ingestible pills used in Study II and Study III have been reported to underestimate core temperature during cycling by 0.34°C when compared to a rectal probe.[156] However, prior to the current studies, the manufacturer has implemented modifications to the calibration procedure and accounted for this systematic error. With a new validation upon the rectal probe, the pill now returns excellent agreement in core temperatures.[15]

There are specific contraindications against using an ingestible temperature pill. These are a bodyweight less than 36.5kg, motility disorders of the gastrointestinal tract, people with swallowing disorders, people with or presenting a risk of intestinal disorders that can lead to obstruction of the digestive tract, and for people who have to undergo strong electromagnetic field (like MRI) during the period of use of the pill. (BodyCap Medical 2017) During the informed consent process in preparation for our studies, the participants were screened for these potential contraindications. (Appendix 15.2 and 15.3) If any of the contraindications were present among the participants, they were excluded from the studies.

7.2.2 Skin temperature

In Study I, a YSI 400 skin sensor (YSI 400, YSI Incorporated, OH, USA) was used to measure skin temperature. The sensor was taped to the left chest approximately 8 cm below the clavicle. The sensor was wired and connected to the same logger box that measured rectal temperature. Data was downloaded as Comma Seperated Value (CSV) files after the swim.

In Study II, Skin temperature was measured using iButtons DS1922L (Maxim Integrated Products, Inc, USA). An iButton is a relatively small temperature sensor with the shape of a coin (16×6 mm). It has the capability to measures temperature and store the data within the sensor.[157] The iButtons can be pre-programmed, allowing the researchers to choose a specific sampling rate in seconds and choose a sampling resolution of 0.5°C or 0.0625°C. After the data collection, data were download as a CSV file.

Figure 3. iButton temperature sensors used for measuring skin temperature in Study II. (Photo by Jørgen Melau)

The iButton has been validated for use in physiology studies on humans.[157–159] The validation studies have been performed in a controlled lab environment.

There is some tolerable and possible bias regarding the influence of environment and microclimate when using iButtons.[160] The validity of the iButton could perhaps be decreased with an increased temperature gradient between the skin and the environment. This can be corrected by choosing the optimal placement site on the body and by the covering being used. In our studies, we have used Tegaderm (3M Health Care, Saint Paul, MN, USA) as the attachment and covering for the iButtons. Tegaderm is an adhesive dressing and is used in a variety of similar studies.[161,162] However, we concluded that the practical utilization of iButtons outweighs the potential downsides.

7.2.3 Water temperature and environmental conditions

Water temperature was measured using a Fluke 51 calibrated thermometer (Fluke Corporation, Everett, WA, USA) The thermometer has a uncertainty of ±0.2°C after calibration. According to the competition rules from the International Triathlon Union, all water temperature measurements are done with the sensor at a depth of 60 cm.[163]

Environmental data were collected by two methods. In Study I and Study III (2017 and 2018), environmental data were collected from YR, a webpage with weather data from the Norwegian Meteorological Institute and the Norwegian Broadcasting Corporation.(NRK)[164] In Study II and Study III (2019), we used the Kestrel 5400 Heat Stress Tracker. (Nielsen-Kellerman, Boothwyn, PA, USA)

Figure 4. Kestrel 5400 (orange) and Fluke 51 (yellow)(Photo by Jørgen Melau)

7.3 Data analysis

For each study, a master database was created in Excel. (Microsoft Excel for Mac, Version 16.33, Redmond, WA, USA) All data from the studies were registred manually in this database, except the temperature data. All databases contained only a coded number for each participant was used to assure anonymization was achieved.

For Study I, the core and skin temperature data was downloaded from a logger box (Veriteq Spectrum Precision Thermistor Logger 1400, Surrey, BC, Canada) into Excel as CSV files. For Study II and Study III, the core temperature data was downloaded from the reading device (BodyCap, e-Viewer Performance monitor, Hérouville Saint-Clair, France) as CSV files into Excel. Data from the Excel databases were analyzed within Excel or with other software as described below. In this thesis, several methods and software are used.

7.4 Statistical methods

The null-hypothesis test has been a dominant method in inferential statistics since Fisher introduced the method in 1935, where he describes the technique in his book "The Design of Experiments".[165] Although equivalent methods were introduced by scientists years before, Fisher is respected as the founder of the null-hypothesis test.[166] Using the null-hypothesis test, we assume no actual difference within our samples. The researcher's objective is then to find if there is a relationship between exposure and outcome. Various statistical methods are used to assess the strength of proof that can disprove the null hypothesis.[167] In essence, we assume there is an absence of effect, and then try to disprove it.

A p-value is a probability associated with the test statistics. Assuming the null hypothesis is true, it estimates the chance of getting the outcome observed or an outcome more extreme.[168,169] A p-value is a number describing how likely it is that your data would have occurred by random chance, meaning seeing an effect when the null hypothesis is true. Therefore, the smaller the p-value is, the farther from the null hypothesis. A small p-value (typically ≤ 0.05) indicates that there is strong evidence against the null-hypothesis. Therefore we reject it. A large p-value indicates weak proof against the null-hypothesis, so we do not reject it. A p-value near the cutoff point can be considered marginal and should be interpreted in context.

The American Statistical Association has defined a p-value as:
"*the probability under a specified statistical model that a statistical summary of the data (e.g., the sample mean difference between two compared groups) would be equal to or more extreme than its observed value*".[170]

Using the null-hypothesis test requires predefining the cutoff value where the null-hypothesis is rejected. This cutoff point is defined as a significance level for the test. The most typical significant levels in biomedical research are 0.05 or 0.001.[171]

7.4.1 Study I

Study I presents line plots of core and skin temperature for each participant. During the first day of testing, when all participants were swimming full distance (3800meters), we observed a relatively linear drop in core temperature. We calculated the slope in Tre for all participants during the swim. The slope was calculated by linear regression using the last 20 minutes of the swim. The general equation of a regression line is:

$$y = a + bx$$

y is the dependent variable and x is the explanatory variable. (In the present study, x is time). a is the intercept. (the value of y when x=0) b is the slope. (often called inclination).[172,173] After finding the slope for each participant, we extrapolated the Tre further to estimate the magnitude of possible fall in core temperature.

Further, we investigated possible correlations between the slope in Tre and relevant variables. We found a significant correlation between slope in Tre and total fat mass. We also found non-significant tendencies for correlation between slope in Tre and bodyfat(%) and BMI. Our investigations revealed no further correlations. Since our sample size is relatively small, we cannot rule out that a correlation is absent due to low power in the statistical analyses performed.

One of the simplest ways to investigate a relationship between two variables is to produce a scatterplot. From this, we can get an overview of a possible relationship between variables by visual oversight. The main idea behind a linear regression is first to fit a line to the data, using least squares. Then we examine this relationship by estimating a correlation coefficient(R-squared), showing how tight linear fit our model has. We compute an equation that minimizes the distance between the fitted line and all data points. A model generally fits the data well if the differences between the observed values and the model's predicted values are small and unbiased. Last, we calculate a p-value of the correlation coefficient.[173,174]

R-squared is a statistical measure of how much variance is explained by the fitted regression line. It is the percentage of the response variable variation that a linear model explains. R-squared is always between 0 and 100%. In general, the higher the R-squared, the better the model fits our data. In Study I, the R-squared is generally low. Hence, Study I has low statistical power, and it is hard to provide solid conclusions.

7.4.2 Study II

The null-hypothesis test has several much-debated shortcomings and is not without flaws.[175–177] Several have tried to find solutions to these shortcomings and argue that the use of p-values is not enough.[178] Many say that the p-value should not be a strict threshold but interpreted in context to the findings investigated.[179] Applications of this could be presenting data with sample size and meaningful effect size. While the weaknesses of the null-hypothesis test are acknowledged widely among statisticians, it appears that it is not that obvious among other researchers.[180] Some journals have even banned using the null-hypothesis test and p-values.[181]

Therefore, there was an opportunity during the present Ph.D. studies to learn and investigate other possible methods. In Study II, we used Magnitude Based Differences (MBD)[182,183] to assess our findings. In response to the critiques of the null-hypothesis test, many researchers have started including confidence intervals(CI) in research papers. The precise definition of confidence intervals is still debated. However, many would acknowledge that the confidence interval is "a range of values, calculated from sample observations, that is likely to contain the true population value with some degree of uncertainty".[184] The degree of uncertainty is selected by the researcher. Although the 95% CI is the most commonly used, it is possible to calculate the CI at any given level of confidence, such as 90% or 99%.

If CI is interpreted in a two-level scale related to positive or negative values, they represent no practical improvement than utilizing the null-hypothesis test.[182] The MBD method divides the results into three categories: beneficial change, harmful change, and trivial change. Four different inferences can be noticed from this when the CI represents the possible magnitudes.(Figure 5) When the confidence levels are solely within one of the three levels of magnitude, the interpretation is of no dispute. For example, the outcome is clearly beneficial if the confidence interval is entirely within the beneficial range. A CI that ranges between all levels of magnitude, is unclear. Further, a CI that spans two levels of magnitude differentiates the method from the null-hypothesis test. For example, a CI that spans beneficial and trivial is not harmful. Therefore the true value could not be harmful. This contrasts with the null-hypothesis test, where the conclusion would present a non-significant result. The MBD method argues that the results can still be of great value.

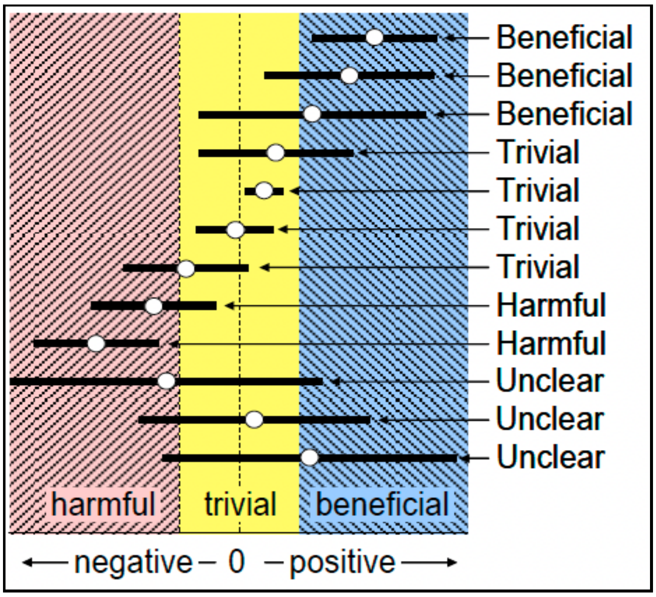

Figure 5. Value of outcome statistics. From "Making Meaningful Inferences About Magnitudes", Batterham and Hopkins 2006.

When the CI includes values in a positive or negative sense, it is stated in plain language that the effects could be substantial beneficial or harmful. Overall, the CI represents a clear outcome that can be reported as trivial, beneficial or harmful. The effects can be made more precise and informative by qualifying them with probabilities that reflect the uncertainty in the true value. The qualitative terms are assigned using the following scale: 0.5%, most unlikely or almost certainly not; 0.5–5%, very unlikely; 5–25%, unlikely or probably not; 25–75%, possibly; 75–95%, likely or probably; 95–99.5%, very likely; 999.5%, most likely or almost certainly.[185]

Going further with the MBD method, the magnitude of the effect is examined. Cohen has previously presented thresholds of 0.1, 0.3 and 0.5 for small, moderate and large correlation coefficients.[186] MBD has expanded this with 0.7 for very large and 0.9 for extremely large. When transposing this to standardized difference in means, the magnitude are assessed using the following scale: Trivial (T): <0.2, Small (S): 0.2-0.6; Moderate (M): 0.6-1.2; Large (L): 1.2-2.0; Very large (VL): 2.0-4.0; Extremely large (EL): <4.0.[185]

Prominent statisticians have criticized MBD. The major criticism is that MBD lacks a theoretical basis, has high error rates(primarily Type I errors), and is misused.[187–189] The developers of MBD have responded to the criticism continuously, remaining firm in their belief in its use.[190–192] A recent systematic review concludes that MBD has done direct harm to the sports science and medicine literature.[187] Again, the developers of MBD have reacted.[183] A total refusal of MBD is a drastic conclusion at the moment. However, given the heated debate among statisticians, it is probably wise to use the method with care. More evolution and knowledge about the method are feasible.

7.4.3 Study III

In Study III, we also used regression methods. Thus, some of the method are presented in chapter 7.4.1. Multivariable linear regressions were conducted. Core temperature at the end of the swim was set as the outcome variable, and swim time, BMI and sex were set as explanatory variables.

Interaction effect means that two or more exposures combined have a larger effect on a feature than the sum of the individual variables alone.[173,174] It is the combined effect of two or more predictor variables on the outcome variable. An alternative term for the interaction effect is effect modification. A solution to increase power, is by combining exposure groups. We, therefore, have combined swimtime and sex in our regression model. When including the interaction effect in the multivariable linear regression, significant main effects were found on swimtime and sex combined. (p=0.007) The interaction is probably essential when the interaction effect is statistically significant. Consequently, our study revealed that the interaction effect contributes in a meaningful way to the predictive capability of the regression analysis.

In this study, we had an outlier with a long swim time and low BMI. An outlier is an observation that looks extreme relative to the rest of the data. This was investigated using a histogram and can also easily be seen in Figure 2 in Study III. We also calculated the 25th and 75th percentile, which is the first and third quartile. (Q1 and Q3) A low outlier is defined as ≤ Q1 − (1.5 x IQR) and a high outlier ≥ Q3 + (1.5 x IQR)

None of the variables were statistically significant when excluding the outlier from the regression model. Therefore, Study III concluded that core temperature after the swim leg was not associated with swim time, BMI, or sex.

The race conditions were variable for the participants since the data were collected from three years of racing. Each year had a different water temperature, currents in the fjord, air temperature, winds and more. Therefore, an analysis of separate years could be feasible but would give lower statistical power.

8 Ethical considerations

Careful ethical thoughtfulness was considered due to the nature of the studies. Studies on people who swim in cold waters are potentially hazardous and have to be carefully prepared and performed. In all our studies, medical safety preparation has been an important part of the planning. Study I had safety preparations within the study group's control, and we planned all from start to finish. For Study II and III, the safety and medical contingency planning were prepared and performed by others. Our study group was able to do studies within the limits of this. Therefore, safety and medical attention were examined thoroughly by the study group before the studies started.

All three studies were conducted according to the declaration of Helsinki, stating that participants shall provide written, freely given and informed consent before inclusion.[193]

8.1 Study I

The Regional Ethics Committee evaluated the study protocol and concluded that the study was outside the health research act's scope. (ref: 2015/1533/REK Sør-Øst) The study therafter received a thorough pre-evaluation and on-site evaluation by the head of the Department of Vascular Diseases at Oslo University Hospital, Professor Jørgen Jørgensen.[2]

The safety was ensured by allowing the participants to swim one by one alongside a long pier, closely monitored by paramedics, a rescue swimmer, and a medical doctor. According to the current protocols, the safety team was set ut with equipment for handling drowning,[194] hypothermia,[122,144] cardiac arrest[195] and other medical emergencies.

8.2 Study II

The Regional Ethics Committee evaluated the study protocol and approved the study. (ref: 35176/REK sør-Øst C) In addition to the general ethical considerations outlined earlier, the recruits at NORNAVSOC were in a clear and detailed manner informed that their participation in our study would not influence the selection period's outcome. Inclusion in the study would not give them any favors in the selection, nor would a potential withdraw from the study give them

[2] Professor Jørgen Jørgensen died 14 jauary 2017.

any disadvantages. The study was a part of their ongoing regular training activity, and this training had been performed regardless the study group present or not.

During this study, safety was entirely the responsibility of NORNAVSOC. There was a Medical Officer present at all times and they were followed by boats all the time during the excersise. As researchers, we were only joining in an already planned and ongoing military exercise in the recruitment period. Consequently, we were only there as observers and researchers and had no role in the safety of the exercise. Due to the nature of training Special Operation Forces, we will give no further details of the exercise and the safety precautions.

8.3 Study III

The Regional Ethics Committee evaluated the study protocol and concluded that the study was outside the health research act's scope. (ref: 2017/1138 A/REK sør-Øst C) The study was then evaluated by the Data Protection Officer at Oslo University Hospital (ref: 2017/8299)

This study's implementation was done by several researchers, and some of them being used as both researchers and medical staff during the race. Such a combination requires careful planning. During the race, the priority for all healthcare professionals is accidents and acute illness. This is even though it is also an ongoing research project in which the healthcare professionals are involved. In practice, this has not led to any concurrent conflicts during the progress of this research project.

The race planning includes a thorough plan for safety and medical preparedness [196] and risk analysis.[197] The author of this thesis has developed these for many years. They include details on staffing health personnel, medical equipment required as well as handling adverse medical events.

9 RESULTS

9.1 Study I

Title: *Core Temperature in Triathletes during Swimming with Wetsuit in 10⁰C Cold Water*

What this study adds and what are the new findings

In this study, the participant's core temperature remained stable or slightly elevated for the first 10-15 minutes of the swim in 10°C water with a wetsuit. After 10 to 15 minutes, the participant's core temperature cooled in a near to linear slope. Still, the core temperature response is profoundly heterogeneous among individuals. Further calculations revealed that with a swim time of 135 minutes, nearly 50% of participants would suffer hypothermia after the swim. No participants dropped beneath 35°C during the first 30 min of the swim throughout the study.

How this study may have an impact on clinical practice and sporting activities in the future

This study proposes that organizers of swimming- and triathlon races, as well as athletes in training, could presumably safely swim in open water at 10°C for a maximum of 30 minutes or 1000 meters with a properly fit wetsuit. Nevertheless, individual factors seem to influence this, which for us at present is yet to be studied further.

9.2 Study II

Title: *Impact of a 10km cold water swim on Norwegian Naval Special Forces recruits*

What this study adds and what are the new findings

In Study II, recruits from the Norwegian Naval Special Forces were swimming with a drysuit in 5°C open water. The study showed a decline in most variables investigated. Skin temperature was reduced with 9.8±3.3°C, and core temperature was reduced by 1.5±0.8°C. Grip strength and dexterity showed a considerable reduction, while reaction time and leg power was slightly decreased.

How this study may have an impact on clinical practice and military activities in the future

This study shows that the recruits are adequately protected from hypothermia in their drysuit. However, the ability to have the best possible performance in critical operations is crucial for

Naval Special Forces soldiers. The observed declines in performance variables could impact weapon handling, using rescue equipment, climbing, rope handling, and more. The study also relates to other types of personnel like search- and rescue professionals, rescue divers, and other military divers.

9.3 Study III

Title: *Core temperature during cold-water triathlon swimming*

What this study adds and what are the new findings

In this study, 51 subjects had core temperature measured continuously during a 3800m swim in a triathlon race and 1 hour after the swim. The study shows considerable heterogeneity in core temperature during and after the swim.

How this study may have an impact on clinical practice and sporting activities in the future

This study demonstrates that while there are immense variations in the core temperature among athletes, medical crews and organizers must be prepared for individual athletes with possible clinical relevant low core temperatures. Preparedness and medical equipment must be geared towards this.

10 DISCUSSION

10.1.1 Core temperature

One of the main findings in these studies is the heterogeneity of the core temperatures during cold water swimming.

Even if the mean core temperature does not get dangerously decreased, we have participants in all three of our studies who suffer hypothermia. In terms of physiology research, this easily could be considered outliers. However, in reality, these incidents are vital. For an open water swim event organizer or during a military mission, having just one participant experiencing hypothermia could be disastrous. The fact that we have hypothermic participants in each of our studies raises concern and should be further studied and elucidated. Through our studies, we cannot find significant factors that can predict who gets hypothermic. We can, however, speculate if it is due to low fat mass and long swim time in cold water.

Decreased core temperature due to long swim time appears to be an essential finding in our studies. Our previously discussed hypothermic participants all had among the most extended swim times during the testing. In Study III, the participants with hypothermia(33.2°C) had a swim time of 128 minutes, which is close to the cut-off time for the race. (135 minutes) In our Study I, we estimated how long it would take for athletes swimming in 10°C water to reach a core temperature below 35°C. Using extrapolation of cooling slopes, we predicted that 47% of the athletes would drop more than 2°C in core temperature if swimming the max cut-off time (135 min) during Norseman Xtreme Triathlon in 10°C water. This study suggested that a maximum exposure time to swimming in 10°C water should be 30 minutes or a swim distance of 1000 meters (whichever comes first). Other studies also have found a relationship between swim time and core temperature.[104,198–200] Our studies indicate that limiting time in cold water is vital to avoid hypothermia. Those planning events and training in colder water should have a clear idea of the safety aspect of what cut-off times should apply.

Increased proportion of body fat has historically been associated with more moderate rates of core temperature coolings.[201,202] A connection between body fat and hypothermia protection is well studied,[203–205] although some studies contradict this.[198,199] While we cannot see a definite relationship between body fat and core cooling in our studies, our findings indicate that such a relationship might exist. That is even though the slope of change in core temperature fluctuates much among individuals.

There are two primary types of insulations in the body's periphery, fixed and variable.[206,207] Fixed insulation is defined as the percent of the individual's body fat. The perfusion of muscle and skin defines the variable insulation. The exact composition of insulation varies within regions of the body. However, in the limbs, 75-85% of insulations are provided by muscle tissue.[107,208]

Studies have found that muscles are the most essential heat insulator in a resting limb.[209] However, muscles are perfused when work increases, and the insulation is voided.[210] Therefore, when exercising in water, heat loss is increased. The exercising muscle transfers heat directly to the skin and there is an increased convective heat loss at the surface of the body[207] Relative low work rates will perfuse the muscle enough to decrease insulation. In a study by Noakes, a work rate of 4 METS abolished the muscles' insulation ability.[210] This makes a valuable point to discuss. The rate of heat loss is maximized by inducing a relatively low rate of exercise. On the other hand, the heat production induced by exercise will increase in direct proportion to the exercise intensity.[206] Putting this into the heat balance equation discussed in chapter 5.4 gives some insight into the thermophysiology of swimmers in cold water. Meaning, there is a higher amout of heat gain to the body due to intense exercise, than there is heat loss due to weakened insulation.

Studies have also revealed that swimming style makes an impact on heat loss. Using arms and legs in combination (like in most swimming styles) increases the rate of heat loss. This is probably due to disruption of surface insulation and increased circulation to the extremities.[209] However, legs-only swimming seems to have less heat loss. Evidence suggests that leg exercise in water is better than passive rest for maintaining Tcore.[211] This could possibly impact NORNAVSOC operators, often using a leg-only style while swimming on combat missions. In Study II, the NORNAVSOC use fin to propulse their swimming in a side swimming style, commonly used by combat swimmers and professional rescuers wearing drysuits. Still, leg-only swim is more energy-consuming than propulsion by arms.[212]

In Study I, there was a correlation between the slope of core temperature and total fat mass (p=0.04). Further, we observed a tendency for a relationship between the slope of core temperature and body fat (p=0.06) and BMI.(p=0.08) In Study III the participants also used a wetsuit, but we could not find a relationship between core temperature and total fat mass like the one described in Study I. The main difference separating Study I and Study III is that the participants are in race conditions in Study III, and that the water temperature is higher. One can speculate if there is a larger internal heat production while racing than during training. In Study II, the participants use a drysuit, which utilizes different techniques to provide thermal comfort during a cold swim. The mean core temperature decreased by 0.4°C during the swim. (37.4±0.3°C to 37.0±0.9°C)

10.1.2 Skin temperature

Skin temperature, in relation to our studies, is normally lower than core temperature. In warmer environments, the skin temperature increase, and the difference between skin- and core temperature is reduced. This is because skin temperature increases due to the increased blood flow to the skin to lose heat. Conversely, when humans are in cold environments, the blood flow to the skin is reduced. Following this is a reduced skin temperature and better preservation of heat in the core.[35]

In Study I and Study II, we measured the skin temperature of the participants. While the core temperature has a relatively slow progression upwards or downwards, the skin temperature varies much more rapidly and with a wider variation.[213] However, in more severe environmental conditions, the skin temperature fluctuates very much due to the environment.

In Study I, the skin temperature decrease rapidly during the first minutes of the swim. From there, it stayed relatively constant until the participants exit the water. The relatively constant skin temperature during swimming I choose to call the "skin temperature plateau". The skin temperature plateau is when the first cooling of the skin has occurred after entering the water. The first cooling goes for the first 5 minutes after entering the water. Then the skin temperature remains almost constant for the rest of the dive or swim. The same is not seen in Study II with NORNAVSOC recruits - where the participants continuously get decreased skin temperature. However, the main difference is that they are using a drysuit and a different position of measurement. Others have described the skin temperature plateau response during wetsuit swims.[117,214]

Amongst outdoor swimmers, it has been, for some, a habit of pouring hot or lukewarm water inside the wetsuit before a cold swim. This is seemingly supporting to keep body temperature up while swimming. It is based essentially on anecdotal narratives, although some wetsuit manufacturers endorse this practice.[215] However, if we heat inside the wetsuit, the skin gets warmer, and blood flow to the skin intensifies. It is possible that vasodilatation occurs when the skin is heated, leading to more cooling of the core. The same has been common practice in some

SOF environments, where a heated suit is occasionally used. This is valuable to look further into in future studies.

10.1.3 Dexterity

The hands and feet can react very quickly to cold environments, diminishing the blood flow to the extremities rapidly. This can, however, lead to reduced dexterity and gross motor function.[216] Reduced dexterity is one of our main findings in Study II. The NORNAVSOC recruits have a considerable decline in dexterity with a 249±83% increase in time to assemble a washer, nut and bolt in our experiment. The reduction in dexterity could have a considerable impact on NORNAVSOC operators. This is because their capacity to accomplish mission tasks such as climbing ladders, doffing diving gear, using their weapon, or operating emergency equipment could be rigorously weakened. Combining this with reduced handgrip strength, as also found in Study II, this is a possible severe impairment in capabilities.

From Sea Survival, Golden and Tipton, Loc 1446

> *«In one experiment, a swimsuited special-forces marine was asked to tear open a soft polyethylene container, remove the dummy flare inside the container, and fire the flare. He was able to do this in seven seconds in air. After 75 minutes in water at 12 degrees Celsius (54 degrees Fahrenheit), his grip strength declined to less than half and he required more than 2 minutes just to tear open the container. With numb fingers he could not manage the twisting action required to fire the flare, despite being in comparatively ideal conditions—seated in calm water and immersed only to chest level»*[217].

For triathletes, a reduction in dexterity and grip strength can have unfortunate influences on their performance. After exiting the water, they need to do a rapid change of gear in T1 before cycling. During cycling, they need to cautiously control their bike and operate brakes to avoid any mishaps. In a study by Saycell et al., triathletes mounting a bike after a cold swim in a flume showed reduced bike handling skills. Half of the participants could not grip the bike's handlebar after a non-wetsuit swim in 14°C water.[218]

Studies have shown that dexterity is reduced with a skin temperature below 15°C.[219] It is unclear if this reduction is dose-dependent, meaning that more extended time in cold water gradually reduces dexterity. Færevik et al. (2005) found no reduction in dexterity even if finger temperature was below 15°C.[220] They speculate if this could be due to short exposure time and that low finger temperature for a more extended time would decrease dexterity.

In all our studies, the participants have been a long time in cold water. We cannot separate if decreased dexterity is due to our studies' long exposure time or cold water temperatures. The NORNAVSOC recruits in our Study II is the only group we did measure dexterity. They had an exposure time with a mean time of 258.4±17.1 minutes, and the Tskin on their forearm was gradually reduced during their swim. Some have suggested that the best way to maintain dexterity is to keep core temperature within a normal range.[221] It could be of interest to test NORNAVSOC recruits' dexterity after a shorter time in the water.

10.1.4 Adaptation

There exists evidence that humans can acclimate to both altitude and heat. For many years it has been known that acclimatization to altitude is beneficial and, in some severe cases, necessary to high-altitude mountaineers. Already during the first ascent of Mt.Everest in 1953, the physiologist Griffith Pugh revealed that acclimatization to altitude was vital to reach the summit.[222,223] Nowadays, many elite endurance athletes are using altitude training to enhance their physical performance.[224,225] There is still much debate, although the debate in recent years is more of an ethical discussion, if athletes can use artificial habitats for acclimation or not. Further, several authors have described adaption to heat and have received much attention recently due to preparations for the Olympics in Tokyo.[229] Our capability to adapt to heat is thoroughly elaborated.

Based on the outcomes on heat and altitude acclimation studies, one could perhaps assume that there would be similar advantageous findings in cold acclimation studies. Does it have any benefits if we expose ourselves to cold before a sporting activity or occupational work, to be optimally prepared and perhaps perform better in cold environments? It is, however, not a consensus in the scientific community on this. First and foremost, one must specify what types of cold acclimation possibly exist.

One could probably claim that there is a behavioral adaptation to cold.[230] We learn through experience how to dress appropriately in the cold, to seek shelter, or to alter body position to reduce heat loss. Alternatively, we learn from others. Several online articles have been produced on preparing for cold water swims through our work at Norseman Xtreme Triathlon.[231,232] In this thesis, the focus primarily on physiological rather than behavioral adaptions.

In a review by Daanen and Van Marken Lichtenbelt, they conclude that adaptions to repeated severe cold exposures do not increase the likelihood of survival in cold environments.[233] However, it did lead to a reduced metabolism in several of the studies in the review. It is interesting to note that most of the studies are done with humans passively exposed to cold. This is in contrast to athletes at Norseman Xtreme Triathlon or recruits at NORNAVSOC in our studies. They all move and use muscles and produce a higher metabolism when exposed to cold environments. Only a few studies have investigated metabolic habituation during exercise. These are done with low-intensity exercise in cold water, much like our studies, and none of them finds that metabolic habituation is apparent during exercise.[234,235] In summary, it seems like the metabolic response when exercising in cold water is similar before and after adaptation attempts.

It is likely an acclimation to the cold shock response. The initial cold shock response occurring during the first 1-2 minutes of a cold water immersion can be reduced with repeated immersions. This was first shown by Keatinge and Evans in 1961[236] and has later been confirmed by others.[235] Our study population has a typical practice of "hardening" themselves with repeated cold water immersions. For example, Norseman athletes swim in colder water the weeks before the race to prepare for the cold swim in Eidfjord. The NORNAVSOC recruits usually do daily swim in icy cold water at camp. This "hardening" likely does a lot to habituate the cold shock response and is encouraged by the safety crew and officers.[237]

Of further interest, anxiety seems to increase the extent of the cold shock response and decrease habituation.[238] This is of particular interest. For Norseman Xtreme Triathlon participants, the race starts with a jump from a ferry into a deep fjord in dark and cold water. Therefore, organizers and safety crew should try to reduce anxiety among participants as much as possible to reduce the extent of the cold shock response. Furthermore, for NORNAVSOC operators, anxiety leading up to a mission should be attempted to be reduced as much as possible.

There is much indication that there is a psychological adaptation to cold water immersion. Studies have identified psychological factors as crucial determinants in survival during accidental cold water immersion.[239] As mentioned above, there is a physiological adaptation to the cold shock response with repeated exposures. When joined by mental skills training to improve voluntary control on breathing, this combination improves survival in real-life situations.[240] Some of these skills are included in drowning prevention campaigns like The Royal National Lifeboat Institution, "Respect the water."[241]

There is little evidence to support any acclimation that would enhance exercise performance and dexterity in the cold. There have been some studies investigating this, and they have not found evidence to support such acclimation.[242] Muller et al. indicated that cold habituated American football players did not perform better on manual dexterity tests than non-cold habituated men when exposed to acute cold.[243]

There have been studies that have been interpreted to show that there is a local cold acclimation. Nelms and Soper published a well-known study in 1962, concluding that British fish filleters had a better hand blood flow than a control group.[244] However, recent reviews dispute these findings and argue that they could be self-selecting bias victims.[245] It might be possible that only people with warmer hands became fish filleters. In the review by Cheung and Daanen, they conclude that there little or no evidence that there is a local cold acclimation with repeated cold exposures.[245] Further, they conclude that it is essential to keep the core temperature within normal to prevent local cold injuries.

10.1.5 Deflection period

In all of our studies, there is a period of 10-15 minutes where the core temperature peak or does not change. It is apparent that the core temperature on most participants does not start to decrease immediately. Some authors call this the deflection period.[117] While the term is not reported much in the literature, the phenomena are described in a few papers.[246–248] Knechtle et. al. followed an Ice Swimmer during three years of preparations for two official «Ice Miles» attempts, recording the core temperature during 65 preparation training swims.[249] One of their main findings, was that the core temperature increased within the first minutes if the swim.

The deflection period is a temporary increase in Tcore when exposed to cold environments.[250] The parameters to describe the deflection period are identifying the peak point and then measuring the duration until the peak and its magnitude. However, the knowledge of the deflection period is not fully elucidated. One suggestion is that the blood volume is pooled centrally due to vasoconstriction in the peripheries. Consequently, it takes some time before the cooling of the core initiates. Another suggestion is that increased muscle work enhances heat production and thus contributes to keeping core temperature stable. However, as discussed elsewhere in this thesis, enriched blood flow to the muscles also reduces its insulation capability. Therefore this needs further investigation.

In 2005 the experienced ice water swimmer Lewis Gordon Pugh sustained experimental testing during three long-distance polar swims in 0-3°C. water temperature.[248] His core temperature was continuously measured with rectal probes. Noakes and his team showed Pugh could raise his core temperature before the start of the polar swims and maintain this elevated core temperature for 20 minutes before declining. These researchers call this the anticipatory thermogenesis, which at the time had not been recorded with any other person. Later these findings have been confirmed by others. A study on a german ice-swimmer during many training sessions and races showed that the highest recorded core temperature 6-16 minutes after the race started.[249] They also claim that the so-called anticipatory thermogenesis is a normal physiological reaction among experienced ice swimmers.

In our Study I, most participants had a steady or increased core temperature during the first 8-15 minutes. Just one of the participants had a decreased core temperature already from the start, and this same individual got hypothermic during the testing with a core temperature as low as 33°C. Overall, the deflection was very variable in time to peak and quantity of core temperature increase. (Figure 6) Our analyses do not reveal any relationship between the participants and the magnitude of the deflection period.

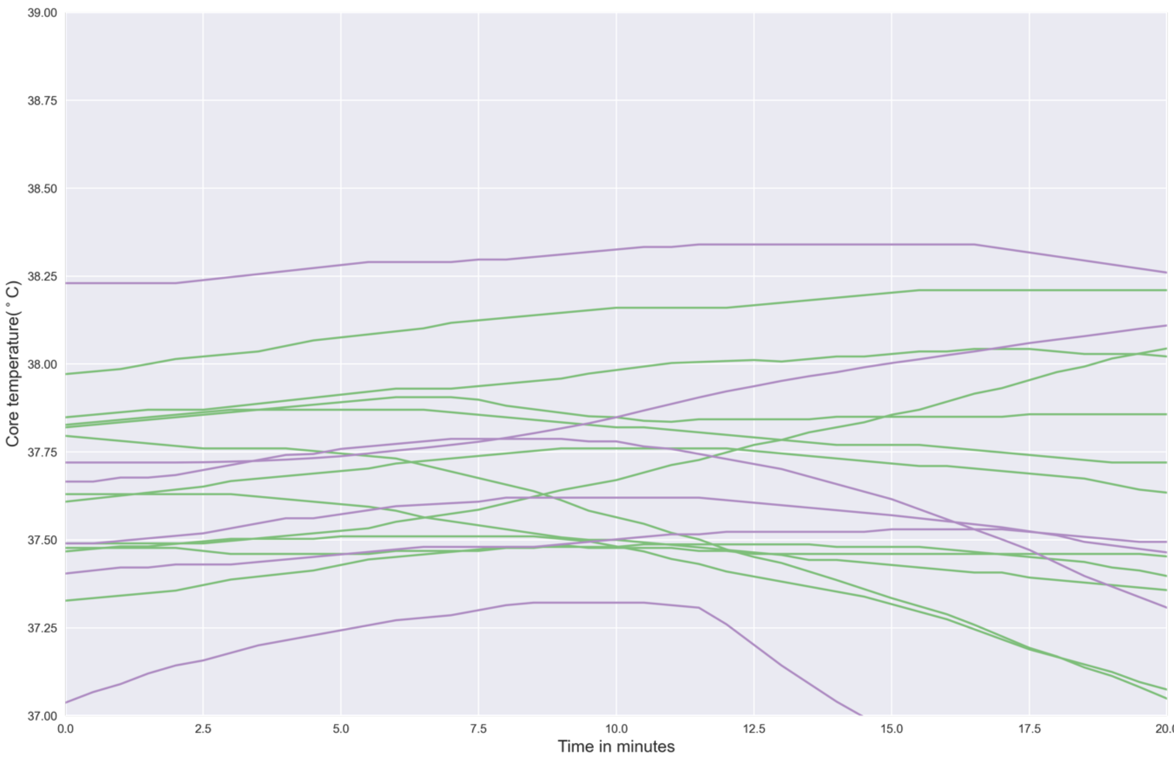

Figure 6. Core temperature for the first 20 minutes of the swim at Study I. Violet is female, and green is male.. Swimers use wetsuit and water temperature is 10°C.

In our Study II, it is interesting to see that all study subjects have this deflection period. They have an immediate increase in core temperature during the first 20 minutes. It is a relatively large increase in core temperature, with an increase from 0.4-0.8°C. Several additional factors can contribute to this. First and foremost, the participants use a drysuit with woolen undergarments. This insulates and protects them from heat loss.

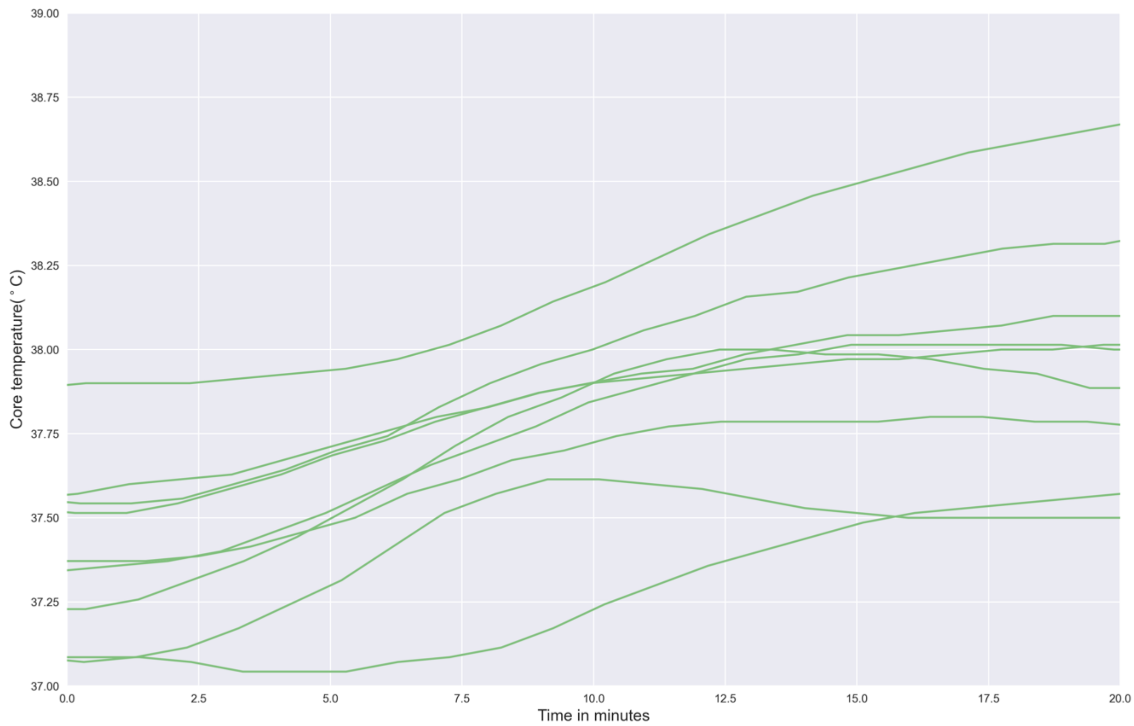

Figure 7. Core temperature of the first 20 minutes of the swim at Study II. Swimmers use drysuit and water temperature is 5°C. .

In distinction to Study I and Study II, we find no pattern of a deflection period in Study III. The first 20 minutes of the swim Study III is shown in figure 8. This study has some contrasting differences from the two other studies in that this is an actual race. It also differs because the participants jump into the water 5-15 minutes before the race starts and swim a few 100 meters to the starting line. Therefore it might be that a distinct deflection period is beginning before the race start. Our data and study design cannot differentiate the exact time each individual participants jump into the water. Therefore a definite analysis of a potential deflection period in Study III is not possible.

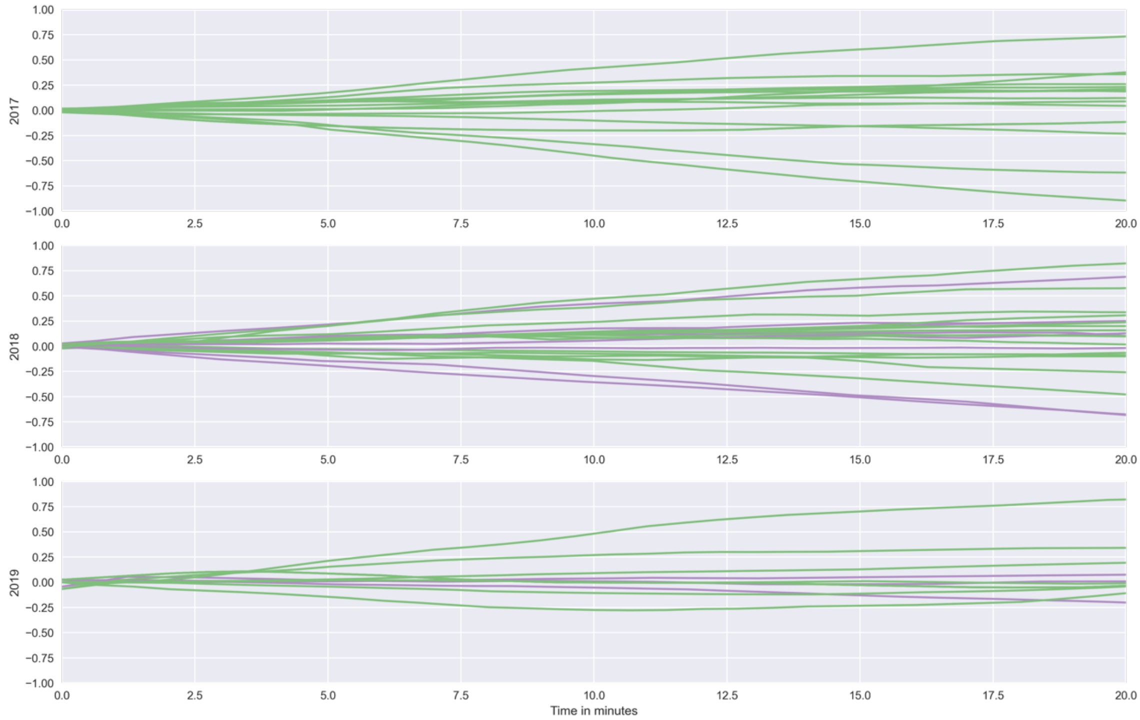

Figure 8. Change in core temperature for the first 20 minutes of the swim at Study 3. Violett is female, and green is male. Y-axis is change in core temperature in ℃ for each year. Swimmers use wetsuit.

Our studies cannot reveal why some of our subjects have this deflection period. It is apparent that a few have not. If this phenomenon had been more known to us beforehand, we would have included additional metrics such as assessing previous cold water experiences and include temperature monitoring before activity starts.

10.1.6 Afterdrop

In Study I and Study II, the lowest core temperatures are measured after the participants exit the water. Following this, there is a continuous lowering of core temperature with variable magnitude and time. Our findings that the core temperature most often is lowest 15-30 min after exiting the water is in conjunction with other studies.[115,129,218] Our three studies have some distinct differences that are interesting when discussing the afterdrop segment. In Study I, the participants was wearing a wetsuit and stopped exercising after the swim. In Study II, the participants were wearing a drysuit and stopped exercising after the swim. However, in Study III, the participants wore a wetsuit but continued to exercise straight after the swim. The participants in Study III are in a race situation, where they mount onto a bike when they are out of the water. The three studies are therefore in variable conditions in this particular part after the swim.

In our Study I, the afterdrop was on average 0.6°C with a reversed peak 25 minutes after exiting the water. All participants had doffed their wetsuit at that point and were indoors fully clothed. Most of them had already taken a hot shower, and some even were in a sauna when the lowest reading was measured. In Study II, the NORNAVSOC recruits had an afterdrop with an average of 1.1±0.3°C after exiting the water. At that time, they were all in a heated shelter with their drysuit entirely removed. In Study III, there was no clear evidence of an afterdrop in the athletes' participating in the study, while on an individual level, afterdrop can be suspected. However, we cannot exclude the possibility of variability in the methods or imprecision during data collection.

Still, this means that the lowest core temperature can possibly come while well onto the bike segment of the race for a triathlete. While our studies on triathletes cannot reveal any performance alterations, one can speculate if the redistribution of heat during the afterdrop process decays muscle function. In our Study II, the NORNAVSOC also had their lowest core temperature after exiting the water, meaning they could have a possible lowest core temperature well into a critical mission. In addition, our Study II revealed that the recruits had decreased body power and grip strength. If this also applies to triathletes, it might have a relevant impact on performance.

One interesting question is if the afterdrop has a larger magnitude during exercise due to increased muscular blood flow. If so, the impact on athletes and soldiers will be more pronounced. Several others have speculated on this.[131,218] The NORNAVSOC recruits have a larger afterdrop than the triathletes. Among several, this can indicate two possible effects. Either they get a larger afterdrop because they have been longer in the water or have a larger afterdrop because their muscular activities have been more substantial. Giesbrecht et al. showed a relatively large afterdrop when exercising after cold water exposure, with a mean afterdrop of 1.1°C.[130] In that particular study, the participants sat still in a cold water bath and started exercising after 51-70 minutes of cold water head-out immersion. Our participants in all three studies were exercising while in the water. The studies are therefore not directly comparable. Still, there is valuable to investigate if exercise during and after cold water immersion will give an afterdrop of magnitude. Unfortunately, we can not differentiate between these effects with the methods used in our studies.

10.1.7 Muscle activity and muscle perfusion

When muscle contracts during activity, it can significantly elevate internal heat production in the body. The earlier mentioned heat balance equation shows us that internal heat production (M -

W) must be balanced by an equal heat loss to the surrounding environment. In cold weather, there will be a large gradient between the cold ambient air and the warmer skin. Following this is an extensive heat loss predominantly via convection and radiation.[28] A reduction in skin blood flow reduces the Tskin, and the gradient between ambient air and the skin is decreased. If the reduction in skin blood flow is insufficient to limit heat loss, shivering thermogenesis will start to increase heat production with the firing of muscle fibers. Shivering is an effective process for heat production. However, it will hamper dexterity and exercise performance.[251]

For years, victims' death in cold water has often been attributed to hypothermia. Now, it is commonly acknowledged that hypothermia alone is unlikely to cause the death of immersion victims until at least 30 min.[116] This is because there is initially a high heat content in the core of the victim, and it takes time to exchange this heat to reduce the core temperature. Assuming the victim survives the first minutes of cold shock and possible autonomic conflict, the most likely cause of death is swim failure. A crucial element of swim failure, is the cooling of muscles.[117,252]

It has long been known that subcutaneous fat is an effective insulator in humans, protecting against heat loss. Studies show that humans with a higher amount of subcutaneous fat have a lower skin temperature but higher core temperature.[253,254] These studies are done in laboratory environments, with study subjects not using muscle activity to heat themselves. They sat quietly on a chair while the experiments were performed. In all our studies, we have measured or calculated fat content on the participants. However, we cannot find any relationship between decreased core temperature and fat content in our studies. While there is a weak relationship between lower fat mass and decreased core temperature in Study I, we believe other factors are more important in determining risks for decreased core temperature.

Some studies indicate that a thinner person starts to shiver at much higher water temperatures than a fatter person when exposed to cold water.[255] The benefit of shivering is that it substantially increases the metabolic rate and therefore raises heat production. However, shivering also induces vasodilatation in the arterioles supplying the muscles and thus increases muscle blood flow. Following this, the insulation effect of the muscles is reduced.[210]

In 1951, Griffith Pugh and colleagues published a study using human subcutaneous fat samples from a morgue to demonstrate that human fat had almost twice as much insulation properties as muscle.[222,256] In our studies, the participants, in distinction to Pugh's samples of cadavers, are very much alive. The muscles of our study participants, especially in the arms and legs, are constantly working. Consequently, having high perfusion of blood flow in the muscles.

The insulation characteristics of the muscles alter depending upon the level of muscular activity.[257] When the muscles become active, the muscles turning from beeing a insulator into a very effective heat conductor.[102] Rennie showed that in cold water and rest, the muscles accounted for 80% of total insulation, while subcutaneous fat was accounted for 20%.[106] For physical work up to 4-5 METS, the muscles are accountable for most of the reduction in insulation properties. Above 4-5 METS, also the superficial layers are affected to reduce the insulation properties further. Therefore, it is suggested that the muscles' insulating properties are lost when swimming already in low intensities.[102,107,210] Although all our investigations are done during rather long duration exercises, we assume that the intensity is relatively high. This is due to the nature of the investigations being done in race conditions or during a selection period. Study I is, in contrast, not a race or any natural external factors that should push the participants to abnormal high intensities during swimming. Still, since there is a loss of insulation properties of the muscles already at low intensities, we must assume that insulation by muscles is reduced during all our three studies.

There is a potential benefit of exercising in water to increase heat production and thereby decrease the total heat-loss. High-intensity exercise in cold water may result in slower rate of heat-loss than low-intensity exercise. However, the insulation properties of the exercising muscles is highly decreased as well as the potential of losing the insulation capacity of a boundary layer. Therefore it is hard to estimate the heat loss during exercise in water. Nevertheless, heat loss is likely dependent on the layer of subcutaneous fat, the intensity of the exercise, fitness, the clothing worn, water temperature and the activity undertaken.[102,210]

10.1.8 Prevention of hypothermia

To detect a swimmer in water that is on its way to being hypothermic can be very difficult. During organized activities in the water, there should be spotters on land. The spotters can be coaches, teachers, or other people affiliated with the activities. Hypothermia does not have a sudden onset. It takes time. The signs to look for while the swimmers are in the water is, first and foremost, the ability to maintain the proper swim technique. If the swim technique is gradually getting worse, this is a common sign that the muscles are getting colder.[114] If it is possible to reach the swimmer verbally by shouting from shore or a boat, the swimmer's consciousness can be evaluated. If there are any signs of the swimmer getting hypothermic, the swimmer should be advised to stop the activity and help out of the water if necessary.

The following sections will focus on handling a swimmer coming out of the water with suspected hypothermia. The focus is on laypersons, like trainers and swim buddies on site of the accident. For emergency and medical professionals, other considerations might apply, which are not discussed further in this thesis. Hypothermia can occur in most water temperatures commonly used for open water swimming worldwide, particularly in the Nordic countries.

A person can be cold and shivering when exposed to environmental cold, but with normal core temperature. When the body can withstand this with minimal physiological strain, such persons are cold stressed.[91] A person that is cold stressed is not hypothermic. Core temperature is reasonably above 35°C. The person might be shivering but is fully alert and capable of caring for themselves. Their movement and muscle function are normal. For these persons, we should reduce further heat loss by dry their skin and add dry clothing. Then the person should move around and focus on warming up with light exercise. Additionally, one could provide a high-calorie food or drink.[122,147] If there is any doubt if the person could be hypothermic, then the person should be considered hypothermic and treated as such.

If a victim's movement is impaired, but still the victim is alert and fully conscious, the core temperature is considered mild hypothermic. The core temperature is assumed to be from 35-32°C. The victim now should be managed gently and sit or lie down for at least 30 minutes. Remove wet clothing gently and dry the skin.[258,259] Shield from additional cooling using an insulating and vapor barrier, like the "Burrito wrap"(Appendix, Chapter 15.4).[260] If the victim is capable of swallowing, serve a high-calorie drink or food to support shivering. If possible, add an active heat source inside the "Burrito wrap". If no improvement after 30 minutes, evacuate to Casualty clinic("Legevakt") or call the emergency service at 1-1-3.

If the victim has an altered mental status, is not fully alert, and shivering starts to discontinue, the victim is assessed as moderate hypothermic. The core temperature is now estimated to be from 32-28°C. Emergency services should now be notified immediately. Dry off wet skin and shield the victim from further cooling. Use the "Burrito wrap" if possible, but handle the victim as gently as possible. Keep the victim horizontal and no standing or walking. Add an active heat source to the upper trunk area if available. If evacuation is needed to reach transport with an ambulance, lifeboat, or helicopter, evacuate as carefully as possible.

If the victim is unconscious but still has life signs (breathing/pulse), the victim is assessed as severe hypothermic. The core temperature is now considered to be below 28°C. The treatment is the same as with moderate hypothermia. However, careful evacuation should be started as soon as possible. The victim is in critical condition. If there are no obvious vital signs, breathing and pulse should be checked. One can use up to 60 seconds on this check, as the vital signs can be hard to monitor on very cold patients. If no breathing or pulse, then CPR must be started according to national guidelines.[195,261]

The use of an active heat source as rewarming of a hypothermic victim prehospital is somehow debatable.[262] There have been guidelines for hypothermic patients' prehospital care for several years, saying not to start heating the victim before arriving at a hospital. These guidelines possibly originated from the Napoleonic winter wars, where one of the conclusions was that a rapid rewarming of hypothermic patients could be dangerous.[263] While the conclusion on if to use active external rewarming prehospital is still debated, most guidelines now recommend its use.[122,260,264]

The Hypothermia «Burrito» wrap provides a simple and excellent protection and treatment base for hypothermia, although several options exist.[265] An insulation layer help protecting the victim from further heat loss. In a low wind condition, the insulation layer's thickness is the most crucial factor for achieving the least possible heat loss.[258] This layer can consist of several solutions, like a sleeping bag, duvet, wool blankets, down jackets and more. With increasing wind speed, it becomes increasingly essential with windproof outer layers. This layer can be a tarp, bubble wrap, plastic garbage bags and more. To protect from conductive heat loss to the surface, a compression-resistant mattress is fitting to use underneath the victim. If the victim is prepared while still wet, a vapor barrier should be wrapped between the victim and the insulation layer to protect the insulation layer from getting wet. This layer can be bubble wrap, plastic garbage bags, and more. If available, add an external heat source inside the insulation layer, but be cautious to avoid getting it straight against the victim's skin.

Figure 9. Demonstrating the «Burrito wrap». Photo by Kai-Otto Melau.

In an outdoor environment, it is essential to rapidly add layers of insulation around the victim to reduce the cooling of the core. The removal of wet clothes and drying of the skin has the purpose of stopping or reducing heat loss by evaporation. Guidelines recommend wet clothes removal, and some guidelines recommend using a vapor barrier between the patient and the insulation layer to reduce the evaporative heat loss.[147,258,259,264] The use of a vapour barrier also has the added benefit of protecting the insulation layer in the «Burrito wrap» from getting wet and thus has a reduced insulation effect due to increased conduction. If there is a prolonged evacuation in cold weather, moisture will accumulate inside the insulation layer.[266] This also benefits the use of a vapor barrier inside the insulation layer. While superior in many conditions, the removal of wet clothes can be hazardous in particular circumstances.[258] It requires some movement of the victim that can be unfavoured if the patient is severe hypothermic. If the victim is still in harsh outdoor weather, removing clothes might expose the victim to undesired wind, water, snow, and cold. For such particular conditions, a rapid wrap in a vapor barrier can be more expedient than removing the victim's clothes.

10.2 Methodological considerations

10.2.1 Measurements

In our Study I, we did use core temperature ingestible pills (BodyCap). Out of 70 pills distributed during the three years of the study, only 51 of the datasets could be interpreted. There are various reasons for this. Some pills had come out with the stool before the download of data could be carried out. Some presumably even before the race started. Some pills were not readable or had a large amount of missing data for unknown reasons.

The core temperature pills manufacturer recommends ingestion of the pills at a minimum of two hours before the start of sampling. The reason is not to have participants ingestion of water or sports drinks to interfere with the temperature measurements. However, during pilot studies, we have experienced that the pills need to be swallowed a lot longer before sampling to avoid interference with participants' water ingestion. We believe that the pills have to be swallowed 6-8 hours before sampling to minimize water ingestion disturbance, which is also concluded by others.[267]

In our Study II, we used iButtons to measure skin temperature. There are several methods for the placement of skin temperature sensors.[155] These methods include 4, 8, or 14 measuring sites, including weighted coefficients to calculate mean skin temperature. As our budget did not allow for more than one iButton sensor for each participant, we chose to use the left underarm in this study. In the ISO standard, the exact placement of individual sensors can be somewhat hard to pinpoint. We, therefore, chose a placement 5 cm above the wrist cuff of the drysuit the NORNAVSOC recruits used during the study. A placement nearer to the wrist would possibly interfere with the participants' wrist movement. Another reason to use the underarm was to investigate a possible correlation between the skin temperature in the underarm and the same hand's dexterity. However, it would have been valuable to have more sensors to get an overall view of the fluctuation in skin temperature from both central and peripheral sections of the body.

It could be feasible to use heat flux thermometry during our investigations. This method is validated and commonly used during surgery.[268,269] The most common equipment is bulky and not ideal for projects we have performed for this thesis. Recently, there has been developed equipment that does not include a heater but uses a machine-learning algorithm to estimate the core temperature. We have been testing some of these in current projects, intriguing for forthcoming projects. However, these new devices did not deliver accurate measurements in validation studies.[270]

10.2.2 Gender

During the last 25 years, there has been substantial growth in participation in ultra-endurance races. The increase has been primarily due to progressed participation from female athletes.[271] Moreover, there is increased recruitment of female soldiers in combat-oriented roles in the armed forces. Hence, Norwegian Special Operations Command organized a project in 2014, where they have explicitly begun to select female recruits.[272,273]

The thermoregulation in females fluctuates along the menstrual cycle. During the luteal phase, the control of both sweating and cutaneous vasodilatation elevates around 0.5°C higher core temperature.[274] The same is true in the high hormone phase when using oral contraceptives.[275] At present, the core temperature difference due to menstrual cyclus is not found to impact female athletes' performance. A study by Store et al., found a 0.3°C higher core temperature in the luteal phase. However, this did not affect cardiac drift or VO_{2max} during exercise in the heat.[276] There are currently, to our knowledge, no evidence to support that female have a weakness regarding thermoregulation when exercising in the heat.[274] In cold exposures, Iyoho et al found that females were more likely to experience more notable hypothermia than men.[277] Even though females have a larger fat content, they suggested this was due to lower shivering response.

There has been a considerable overweight in the number of male participants in thermophysiological studies.[216] Balancing gender participation should undoubtedly be reflected in future studies. Furthermore, stronger focus should be placed on studies centering on women's temperature regulation.

10.2.3 Statistical methods

Many researchers have criticized the Magnitude-Based Difference method.[188,189] The criticism has in particular debated MBD for having higher rates of type I errors. Some even allege that the method has done direct harm to the sports science and medicine literature.[187]

If MBD is a proper alternative to the conventional use of p-values is a discussion that presumably will continue for some time.[183,278] Therefore, the method should probably be used with caution and only if found appropriate for specific studies.

For this thesis, and in particular Study II, using the MBD method gave valuable insight into statistical thinking. The decision to use the method in further studies will depend mainly on the type of study and the method's continued development.

10.3 Future research perspectives

The focus on providing information to make open water swimming as safe as possible will continue. It seems to be a trend that more and more races are done in extreme environmental conditions. Larger groups of participants are needed, with more variation in fitness- and swim technique levels. Generally, there is a lack of studies focused on female thermoregulation, so further studies should consider this.

There is also increased focus on arctic warfare in the Nordic countries and NATO, with possible future conflicts in extremely cold environments. Soldiers need to be prepared to function as best they can in very cold environments. Safe training and equipment development need an increased focus on research in thermophysiology.

New sensor technology and solutions to combine sensors will give new and possible beneficial opportunities for researchers. Wearable technology can give more precise and continuous temperature, cardiac, respiratory, and activity monitoring. Then researchers can further analyze and visualize the data. In particular, regarding this thesis, the further development of core temperature sensors is wanted. A combination of precise and practical methods for measuring core temperature is highly desired in emergency medicine and sports medicine.

The availability of a massive amount of data allows the opportunity of using artificial intelligence. Recent advances in artificial intelligence and machine learning contain the potential to convert vast amounts of data from sensors into accurate, detailed, and valuable information. We can develop machine learning models that use relatively simple techniques to predict more complex situations. Since there are several unanswered questions in temperature physiology, artificial intelligence can help find answers that are not yet seen as easily today. Several studies are underway to give insight into the possibilities of combining artificial intelligence and temperature physiology.

There is a shortage of knowledge concerning Swim Induced Pulmonary Edema.(SIPE) Today, we cannot say for sure why SIPE occurs and how to avoid it. Therefore we do not know precisely where to look. However, a byproduct of our gathering of large amounts of data in different studies might give us valuable insight into the unknowns of SIPE.

11 CONCLUSIONS

Regarding the specific research questions, the conclusions are as follows:

- Longer swim time will increase the risk for severe drop in core temperature during swimming in cold water. In general, the coldest study subjects observed in this project had the longest swim time.
- Our studies can not find significant evidence that low fat and muscle mass reduce core temperature when swimming in cold water with a wetsuit.
- There is, for some individuals, a continued decrease in core temperature when they are removed from the cold water. This reduction seems to appear mostly in individuals that already have a continued cooling inclination during swimming.
- There is a deterioration of dexterity, muscle force, and reaction time after cold water swimming.

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13 ERRATA

14 PAPERS

Study I

sports

Article

Core Temperature in Triathletes during Swimming with Wetsuit in 10°C Cold Water

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Abstract: Low water temperature (<15°C) has been faced by many organizers of triathlons and swim-runs in the northern part of Europe during recent years. More knowledge about how cold water affects athletes swimming in wetsuits in cold water is warranted. The aim of the present study was therefore to investigate the physiological response when swimming a full Ironman distance (3800 m) in a wetsuit in 10°C water. Twenty triathletes, 37.6 ± 9 years (12 males and 8 females) were recruited to perform open water swimming in 10 °C seawater; while rectal temperature (Tre) and skin temperature (Tskin) were recorded. The results showed that for all participants, Tre was maintained for the first 10–15 min of the swim; and no participants dropped more than 2°C in Tre during the first 30 min of swimming in 10°C water. However; according to extrapolations of the results, during a swim time above 135 min; 47% (8/17) of the participants in the present study would fall more than 2°C in Tre during the swim. The results show that the temperature response to swimming in a wetsuit in 10 °C water is highly individual. However, no participant in the present study dropped more than 2 °C in Tre during the first 30 min of the swim in 10°C water.

Keywords: swimming; core temperature; skin temperature; Wetsuit; Triathlon; Endurance

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1. Introduction

Long distance triathlon is rising in popularity [1]. In 2003, the first "Norseman Xtreme Triathlon" was arranged in Norway, and the race soon became known as one of the toughest triathlons in the world [2]. Athletes swim 3800 m in the Hardangerfjord, bike 180 km with approximately 3000 meters of vertical ascent and then run 42 km, to finish at the peak of Mt. Gaustadoppen at 1883 meters above sea level [3]. The low water temperature (<15 °C) has generally been a challenge for the organizers. In 2015, the participants faced a water temperature of 10 °C, and the swim was then shortened to half the distance [4].

Low water temperature has been faced by many organizers of triathlons [5] and swim-runs [6] in the northern part of Europe during recent years, and more knowledge about how cold water affects athletes swimming in wetsuits is warranted.

The International Triathlon Union (ITU) has taken this into account in their regulations of racing water temperature and wetsuit usage in ITU sanctioned races [7]. Recently, scientific inquiries into the rationale behind these regulations have been made, and the rules have been modified accordingly [8]. The International Swimming Federation (FINA) has specified 16°C as their lowest water temperature in their Open Water Swimming Rules [9]. In a recent study [8], Saycell J, Lomax M, Massey H, et al. identified lean swimmers and cold water as significant risk factors for hypothermia. This has also been elucidated further, with new minimum water temperature limits for open water marathon swim racing [10].

Despite this, the knowledge of how deep body temperature is affected in triathletes swimming in wetsuits in cold water down to 10°C is limited. For the vast majority of triathletes, the swim portion is completed in <2 hrs.

The aim of this study was therefore to investigate the physiological response to swimming in a wetsuit in 10°C water. Based on previous experience, our hypothesis was that the deep body temperature (Tre) would decrease less than 1 $°C \cdot h^{-1}$ during swimming in 10 °C water with a properly fitting wetsuit, suggesting that the Tre would not drop more than 2°C (or below 35°C) during a full swim in an Ironman competition.

2. Materials and Methods

2.1. Participants

The study protocol was evaluated by the Regional Ethics Committee (REC) (ref 2015/1533/REK Sør-Øst), according to the principles of the declaration of Helsinki. Before inclusion, all participants provided written informed consent. Twenty participants (12 males, 8 females) were recruited for the present study. All were active triathletes, at elite- or recreational level. Recruitment took place via social media, and the individuals had to be able to swim 3800 meters non-stop in less than 1h and 45 min, not have any history of cardiovascular disease or arrhythmias and have their own wetsuit.

2.2. Measurements

Prior to the tests, medical screening was performed by the study doctor and a nurse. The screening included a medical survey and an ECG test (Cardiovit AT102 Plus, Schiller Handelsgesellschaft m.b.H., Sveits) in accordance with the recommendation of the European Society of Cardiology [11,12].

Baseline measurements, including weight, height, DXA-scan (Lunar Prodigy densitometer, GE Medical Systems, WI, USA) were performed 2 h before the start of the swim at the Norwegian School of Sport Sciences (NIH) in Oslo. Maximal oxygen uptake

($VO2_{max}$) was measured at NIH, within one week after the test by a Oxycon Pro analyzer (Jaeger Instrument, Carefusion/BD, San Diego, US) using a graded (5.3%) running test on a treadmill (Bari-Mill, Woodway, Wisconsin, US) with gradually increasing running speed each minute until exhaustion, according to Astrand, Rodahl et al. 2003 [13].
All participants had a warm-up of easy running (10 min) on the treadmill before the test started. During the test, all participants wore a nose clip (9015 Reusable Series, Hans Rudolph Inc., Kansas City, US) and used a silicone rubber mouthpiece (9060 Reusable Series, Hans Rudolph Inc., KS, USA). $VO2_{max}$ was identified when a plateau (a rise of less than 2 $mL \cdot kg^{-1} \cdot min^{-1}$ in VO2, despite increasing running speed) was observed. In addition, two more criteria of $VO2_{max}$ were applied, a respiratory exchange ratio (RER)>1.05 and heart rate of >95% of maximum heart rate.

After testing, the participants were transferred to the test site in the Oslofjord at Høvik, 20 min outside of Oslo city, where the temperature sensors were mounted on the participants. A skin sensor (YSI 400) was mounted on the upper left side of the chest (approximately 8 cm below *clavicula*) and a rectal probe (YSI 400, YSI Incorporated, OH, USA) was self-inserted by the athletes after instruction from the scientists. The rectal probe was inserted 10 cm past the anal sphincter. The sensors were connected to a logging device (Veriteq Spectrum Precision Thermistor Logger 1400, Canada) and temperatures were logged every minute from 15 min prior to the swim until a minimum of 45 min after the swim. No rewarming intervention was incorporated in this study. The logger was mounted in a custom-made waterproof box (length 12 cm, width 7 cm and height 4 cm) that was taped to the back of the outside of the participant's wet suit. The logging system did not affect swimming technique.

2.3. Swim Test

The testing was very time consuming, and due to safety reasons, we were not able to have more than one test subject in the water at a time. The swim test was therefore performed over a period of three consecutive days. Mean (SD) water temperature was 10.0 (0.7°C) and air temperature 7.4 (2.1°C) during the three test days. On day one, six participants swam 3800 m (82 (14) min), and on day 2 and 3, the swim time was shortened to a maximum of 55 min. In total, 13 participants performed 46 (5) min of swimming. To ensure the optimal fit of the wetsuit, the participants used their personal wetsuits, approved in accordance with the ITU Competition Rules for triathlon [7]. The thickness of the wetsuit should not exceed 5 mm of thickness anywhere, and have long arms and legs. In addition, a standard silicone swim cap was used, with no other aid for warming the body during the swim. During the first day, six participants were tested, and all of them swam a full Ironman distance (3800 m). After the first day of testing, we observed a rectal temperatrue (Tre) below 35°C in one of the participants, and we therefore decided to reduce the swim time to a maximum of 55 min the next two days to prevent a fall in Tre below 35°C. In none of the athletes who participated in the last 2 days of testing did the Tre fall below 35°C. The participants were swimming one at a time, a maximum of five meters from the pier and were constantly monitored by five paramedics and a rescue swimmer. A medical doctor was present at the test site at all times during the three days of testing. All rescue personnel where updated and trained in the latest protocols regarding hypothermia [14] and advanced cardiopulmonary resuscitation [15]. Mandatory rescue- and medical equipment was located on the pier for the paramedics and medical doctor to use if needed [16].

2.4. Data Analysis and Statistics

The study was powered to be able to detect a drop in core temperature >0.5 °C during the swim. Given a significance level of 0.05 and a power of 80%, 16 participants were needed, given a start temperature at 37.5 ± 0.5°C. Further, to compensate for a 20% dropout rate, a total of 20 participants were recruited to the study. Statistical analyses and all graphics were performed in SigmaPlot 10.0 (Systat Software, Inc, GmbH, Germany). Pearson Product Moment Correlation was performed to evaluate correlation between variables. Data are reported as mean (standard deviation) unless otherwise stated. A p-value <0.05 was considered statistically significant.

3. Results

One participant was excluded before swimming due to failing the medical screening, and in two participants, Tre was not recorded during the swim due to equipment failure. Seventeen participants (6 women) were therefore included in the final analysis (Table 1).

Table 1. Demographic, anthropometric and physiological characteristics of the study sample; as a total and for both women and men separately. Values are given as mean ± SD.

	Total	Women	Men
Number (n)	17	6	11
Age (yrs.)	37.6 ± 9.0	37.5 ± 10.3	37.6 ± 8.8
Body composition			
Weight (kg)	77.9 ± 7.4	66.4 ± 8.0	84.3 ± 12.9
Height (cm)	177.6 ± 7.4	173.4 ± 5.6	179.9 ± 7.3
LBM (kg)	58.3 ± 11.5	46.2 ± 5.4	65.0 ± 7.8
%BF (%)	23.3 ± 9.0	27.7 ± 6.6	20.9 ± 9.6
FM (kg)	17.2 ± 7.4	17.8 ± 5.3	16.7 ± 8.6
VO2max			
Relative (mL·kg⁻¹·min⁻¹)	57.5 ± 11.0	49.3 ± 6.6	62.4 ± 10.3
Absolute (L·min⁻¹)	4.5 ± 1.1	3.3 ± 0.5	5.2 ± 0.7
Training per week (hh:min)			
Total	9:30 ± 4:06	8:18 ± 4:54	10:18 ± 3:42
Swimming pool	1:36 ± 1:18	1:36 ± 1:24	1:36 ± 1:12

LBM is lean body mass; %BF is percentage body fat; FM is fat mass and $VO2_{max}$ is maximal oxygen uptake.

3.1. Rectal Temperature (Tre)

Before the swim, average Tre was 36.6 (0.1) °C. The Tre of all participants was maintained for the first 10 min of the swim. In 13 of the 17 participants, Tre dropped below starting value during the swim, with a statistically significant drop in Tre of 0.9 (1.1) °C in the group ($p < 0.001$). For all 13 participants that displayed a fall in Tre, a further fall ("afterdrop") in Tre was observed after the swim (0.6 (0.3) °C). The average (SD) time from exiting the water until lowest temperature was 25 (12) min. Tre for the participants that swam 3800 m (n = 4) are displayed in Figure 1, panel A, and panel B shows results for 13 athletes that swam for a maximum of 55 min.

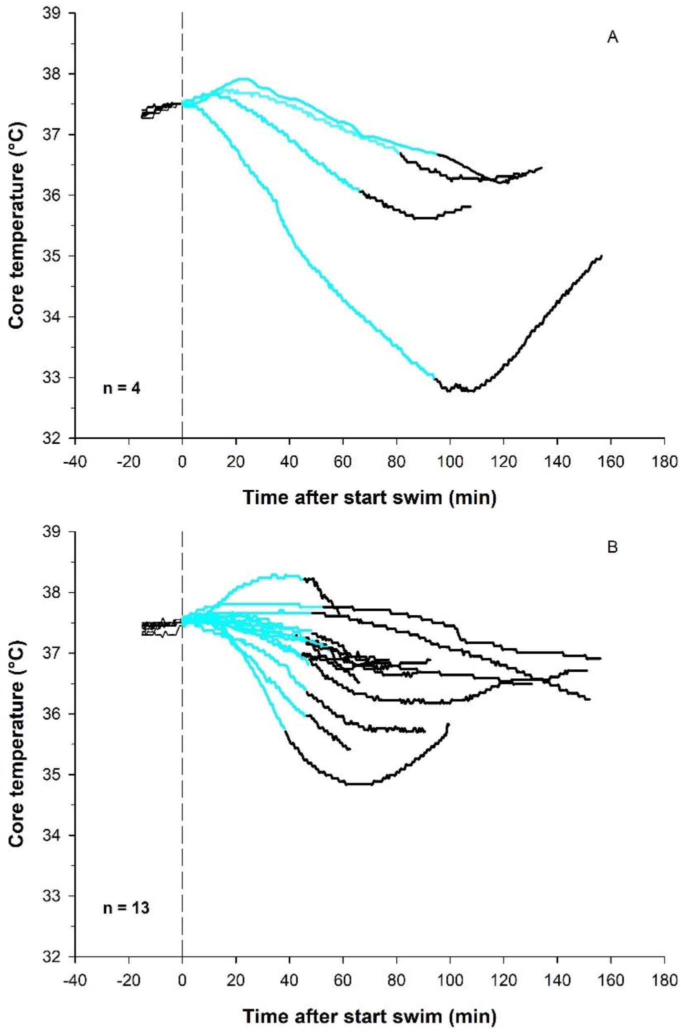

Figure 1. Tre before (black line), during (blue line) and after (black line) swimming in 10 °C water. Panel A shows results for the athletes that swam 3800 m in 82 (14) min (n = 4), and panel B shows results after the shortened swim to 46 (5) min (n = 13). For comparison, all temperature curves are adjusted to start at 37.5 °C at swim start.

The slope for the drop in Tre was on average 1.38 (1.24)$°C \cdot h^{-1}$. The results show that with an exposure time of 135 min, 47% (8/17) of the athletes would experience a drop in Tre larger than 2 °C (Figure 2). However, at 30 min of swim time, none of the participants in the present study experienced a drop in Tre >2 °C.

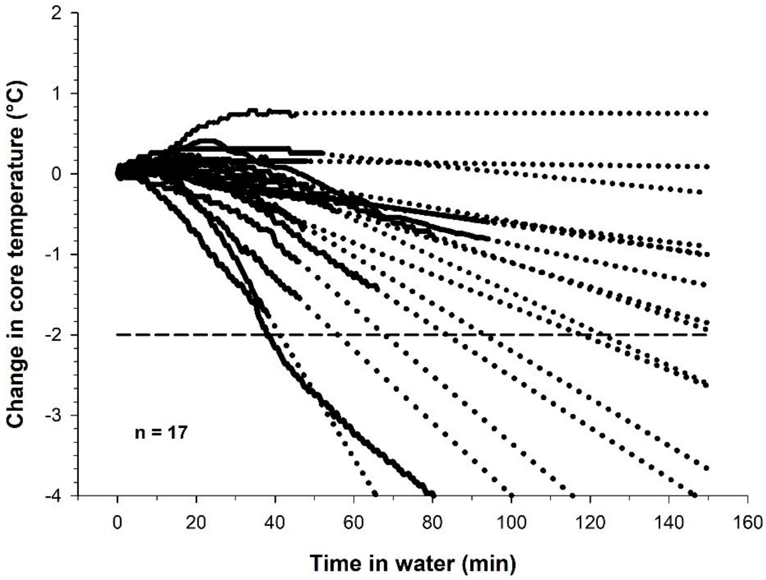

Figure 2. Solid line shows the development of Tre during swimming in 10 °C cold water. Dotted lines show extrapolated time course, based on the slope for Tre during the last 20 min of the swim (n = 17).

3.2. Skin Temperature (Tsk)

Due to technical problems with the skin sensors on three of the athletes, Tsk was successfully recorded during the swim in 14 of 17 athletes where Tre were recorded. Average Tsk beneath the wet suit was 33.3 (0.3) °C before the swim and was significantly reduced to 19.2 (1.7) °C during the first 30 min of the swim ($p < 0.001$). Tsk before, during and after the swim for all athletes are shown in Figure 3.

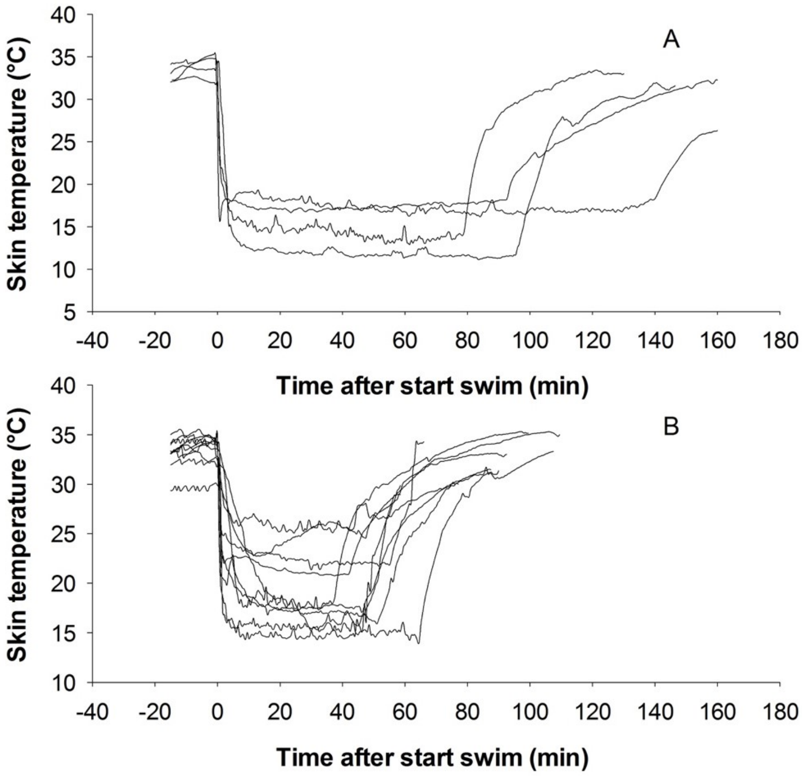

Figure 3. Tsk before, during and after swimming in 10 °C water with a wet suit. Panel A shows results for the 4 athletes that swam 3800 m in 82 (14) min (n = 4), and panel B shows results for 10 athletes that swam a shortened swim to 46 (5) min (n = 10).

3.3. Relation between Tre, Skin Temp, fat% and Gender

We observed a significant correlation between the slope for Tre during the swim and total fat mass (kg), ($r^2 = 0.25$, $p = 0.04$). There was a non-significant tendency for correlation between the slope for Tre during the swim and % bodyfat (%), ($r^2 = 0.21$, $p = 0.06$) and BMI ($r^2 = 0.13$, $p = 0.08$). No other significant correlations were observed between the slope for Tre during the swim and any of the other following relevant variables as; weight ($p = 0.33$), height ($p = 0.33$), age ($p = 0.51$), LBM ($p = 0.94$), average skin temp last 20 min of swim ($p = 0.86$), hours swimming training per week ($p = 0.47$) or gender ($p = 0.43$). In Figure 4, change in Tre, Tsk and, fat% and gender are shown for all participants.

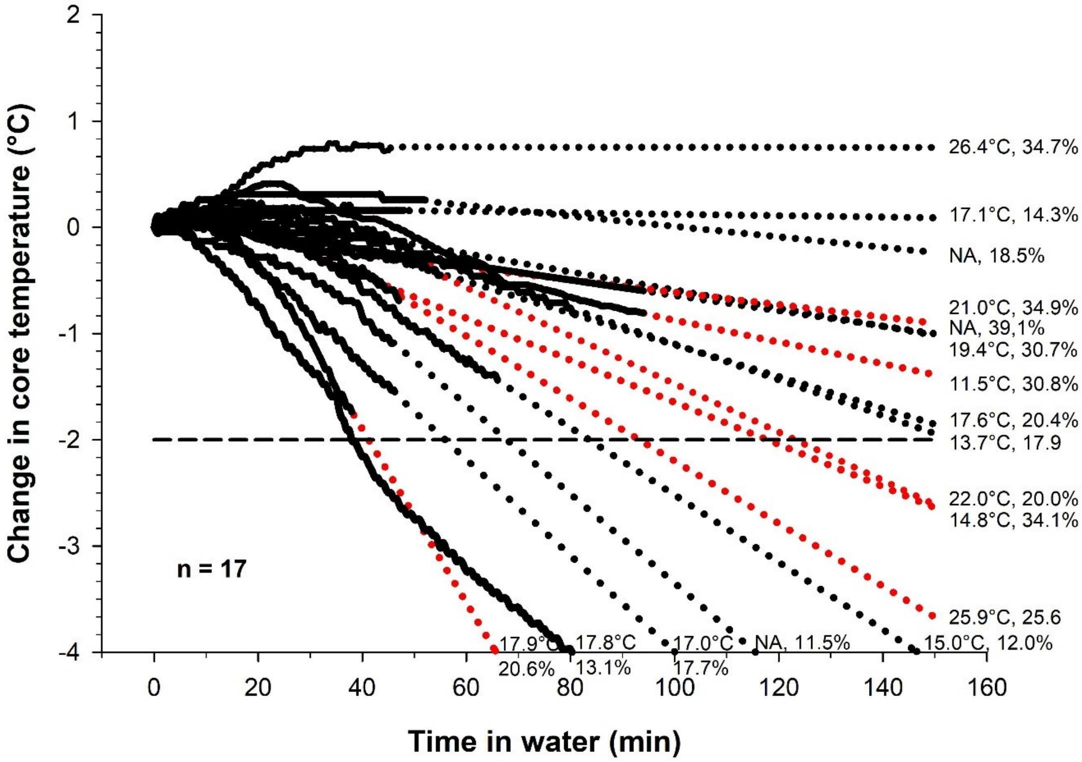

Figure 4. Solid line shows the Tre during swimming in 10 °C water. Dotted lines show the linearly extrapolated time course, based on the slope for Tre during the last 20 min of the swim (red dots = female). Average Tsk during swim and body fat % are presented for all participants (n = 17).

4. Discussion

The main finding in the present study was the heterogeneity in the temperature response to swimming in a wetsuit in cold water. However, for all participants, the Tre was maintained for the first 10–15 min of the swim, and no participants dropped more than 2 °C in Tre during the first 30 min of swimming in 10 °C water. However, given a swim time above 135 min, 47% (8/17) of the participants in the present study would be predicted to have greater than a 2 °C in Tre.

4.1. Rectal Temperature

The results from the present study showed that the participants were able to maintain the Tre for the first 10–15 min of the swim. An explanation for this is the cold-induced vasoconstriction at the skin's surface, and the time required to set up a conductive cooling gradient from the water to the deep body tissues. The conductive cooling gradient is dependent on the length of the conductive pathway (size/fatness of the individual) [17]. Further, after this initial period, Tre started to drop in 76% (13/17) of our test participants. The linear pattern of the temperature curve, made it possible to calculate a slope, and therefore the possibility to interpolate the curves and predict Tre if swimming had been prolonged. Several studies have shown the potential harmful effects of hypothermia [18– 20]. One of the study participants in the present study had a Tre as low as 33.1°C, classified as mild hypothermia. When this was discovered, we immediately took action to prevent similar cases, and the exposure time to cold water was therefore reduced during days 2 and 3 of the project.

The results from the present study displayed a large heterogeneity in the Tre response. One participant started to drop in Tre after 10.5 min, and another increased in Tre during the swim. The participant with the early drop had a body fat % of 13.1, and the one that increased had a fat % of 34.7. Further analysis also confirmed a significant correlation between low body fat % and drop in Tre. This is in line with previous findings in other studies [8,17]. This should be of interest for race organizers, as more elite athletes often have a lower body fat % and therefore are more prone to become hypothermic during swimming.

It is complicated to prescribe safe limits for swimming in cold water due to the interaction between many variables that may affect the cooling rate [8]. In addition to the absolute water temperature: exposure time, metabolic heat production, body composition, body mass and wetsuit construction (length and thickness) and fit may affect the cooling rate. One important research question in the present study was to estimate how long it would take before the athletes reached a Tre of 35°C or below. Figure 2 shows an estimation of this, where we have extrapolated the Tre cooling curves to predict when Tre exceeds a 2 °C fall. The cut-off for the swim in Norseman Xtreme Triathlon is 135 min. The average swim time during the last 10 years was approximately 82 min. The fastest athletes completed the swim in 50 min. The results from the present study show that given a water temperature at 10 °C, 47% of the athletes that swam for 135 min would drop more than 2°C in Tre.

Given a well-fitted wetsuit, our results indicate that to avoid hypothermia, the exposure time should be limited to a maximum of 30 min, in 10°C water. For the slowest swimmers, this would probably correspond to a maximum swim distance of 1000 m under such conditions.

4.2. Tsk

The results from the present study showed that the Tsk dropped immediately on entering the cold water and stabilized at a constant level within a few minutes. A relatively large variation in Tsk was observed between the participants during the swim (12–26 °C), however no significant relationship between the drop in Tsk and Tre was observed.

In the present study, the athletes used their own personal wetsuit of different brands, thickness and fit and this could possibly be the explanation for the lack of correlation between Tsk and drop in Tre. Evidence suggests a relationship between wetsuit fit and cardiovascular response [21]. The relationship between drop in Tre, Tsk and type and fit of wetsuit needs to be elucidated in further studies.

4.3. Post-immersion cooling

The post-immersion cooling observed in our study was on average 0.6 °C, and the lowest temperature was observed on average 25 min after the swim. The fact that Tre may continue to fall post- open water swim should be of interest to organizers. It is also important for triathlon organizers and triathletes to expect that Tre can fall in T1 (Transition Zone 1 – the shift from swimming to cycling during a triathlon) and during the first part of the cycling [8]. Race organizers and medical crew should have increased levels of alertness during these periods. Our findings on post-immersion cooling is also in accordance with previous published results from Nuckton et al. 2000 [22] who studied open water swimmers in 11.7°C water. In that study, post-immersion cooling was observed in 10 of 11 test participants. The effect is possibly worsened by the fact that triathletes are affected by the wind chill factor [23,24] during cycling (continued cooling). The International Triathlon Union (ITU) has taken this into consideration, as they have incorporated both air temperature and water temperature into their competition rules [7]. According to ITU competition rules, the swim can be shortened or cancelled according to a combined water temperature and air temperature.

4.4. Practical Implications

From a safety perspective, athletes competing in a race should never be exposed to environmental conditions that induce mild hypothermia or worse. The Tre therefore should not drop more than 2.0°C, or below 35°C. Taking into account the post-immersion cooling, the maximum drop during the swim should be less than 1.5°C to ensure athletes' body temperatures do not fall within hypothermic ranges during subsequent portions of the event. For those undertaking an open water swim only, it should be realised that the participants may have their lowest deep body temperature after the event when attempting, for example, to drive home.

4.5. Limitations

For practical reasons, the Tre continued to be measured 20–90 min after the swim. Ideally, the measurements should have been continued until the Tre was back to baseline values. Further, more details about the wetsuit (thickness, fit, conditions) is warranted. The surface temperature of the wet suit should also be measured to better explain the relationship between Tsk and the drop in Tre.

5. Conclusions

It is concluded that the temperature response to swimming in a wetsuit in 10 °C water is highly individual. However, the Tre of no participant in the present study cooled more than 2 °C during the first 30 min of the swim. To be on the safe side, this would probably correspond to a maximum swim distance of 1000 meters in 10 °C water. One would expect even the least able swimmers to cover 1000 meters in 30 min: with the caveat that they do not suffer swim failure due to neuromuscular cooling.

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Conflicts of Interest: The authors declare no conflict of interest

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Study II

Impact of a 10000m cold water swim on Norwegian Naval Special Forces recruits.

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Keywords: body temperature; skin temperature; military medicine; swimming; physical fitness; combat swimmer; combat diver

Abstract
Background
Special Operation Forces (SOF) operates regularly in extreme environmental conditions that may affect tactical- and physical performance. The main aims of the present study was therefore to elucidate the impact of a long cold water swim on SOF recruits dexterity, performance and reaction time.

Material and Methods
As part of their training, eleven recruits at Norwegian Naval Special Operation Command (NORNAVSOC) that were participating in a 10000m open water swim with a dry suit in 5°C cold water, volunteered to participate in the study. Before, immediately after, and 24h after the swim, grip strength, lower body power and dexterity were measured. In addition, core- and skin temperature were measured continuously during, and until 45min after the swim.

Results
After the swim, a moderate to large reduction in core temperature, lower body power and reaction time was observed. Moreover, very large to extremely large reductions in skin temperature, grip strength and dexterity was observed.

Conclusion
The results demonstrate that exposure to a 10000m swim in 5°C water using standard equipment lead to a significant drop in the recruits temperature and performance. Findings could have a meaningful impact on the planning of training, gear used and planning of operations for SOF.

Introduction

Special Operation Forces (SOF) has an exceedingly physical and psychological demanding occupation, which often include training and operations under stressful and challenging environmental conditions.[1] Due to climatic conditions, the Norwegian Naval Special Operation Command (NORNAVSOC) operators are regularly exposed to cold environments in many of their operations and training, especially during operations on, under, and from the sea. Water temperature during winter in the Nordic countries is regularly below 5°C (41°F). Therefore, one of the possible stressors applied to SOF operators, both in training and operations, is local cooling and hypothermia. Following that, it is vital to investigate the effects of cold weather and particularly in cold water operations among SOF personnel.

In an interesting study from Jimenez et al.[2] a decrease in core temperature, as well as cardiovascular and immunological changes to SOF operators, was reported. However, the knowledge of how exposure to swimming in cold water affects the performance of SOF operators is limited. As the SOF operators must prepare to do missions after exiting from cold water; it is crucial to understand how cold water influences the performance. A typical mission for a SOF operator could be a long swim into a target, where the mission transforms to involve tasks like climbing a ladder, using a weapon, clipping into a harness and more.

The main aim of the present study was, therefore, to elucidate the burden and impact of a long cold water swim on SOF operators dexterity, performance and reaction time. In addition, the impact on skin- and core temperature and biomarkers for stress and muscle damage was measured.

Methods

Design and recruits

Eleven male recruits (age 23.9±2.1, 83.3±6.8 kg) from NORNAVSOC that completed a 10000 m swim in the open sea during wintertime in Norway, as a part of their qualification training program to become a SOF operator, volunteered to participate in the study.

Ethical considerations

The study was approved by the regional ethics committee(REK) (REK south-east C-35176) and by the data protection officer at Oslo University hospital (19/28581). Before providing written informed consent, recruits received information about potential risks of participation and were particularly informed that a withdrawal from the research project would not influence the selection process to become a SOF operator.

Timeline and test descriptions

The recruits were familiarised with the tests 24h prior to the swim. Pretests were performed early in the morning (05:00-06:00 am) before entering the water. Immediately after the swim, the first set of tests were performed (0h). The last set of tests were performed 24h after finishing the swim. The recruits completed the swim with a kevlar drysuit (Ursuit, Heavy light Model “Norwegian Navy”, Turku, Finland) with latex sealing on the neck and wrists, completed with a neoprene long neck 7mm hood, 5mm neoprene five-finger gloves, fins and diving mask.

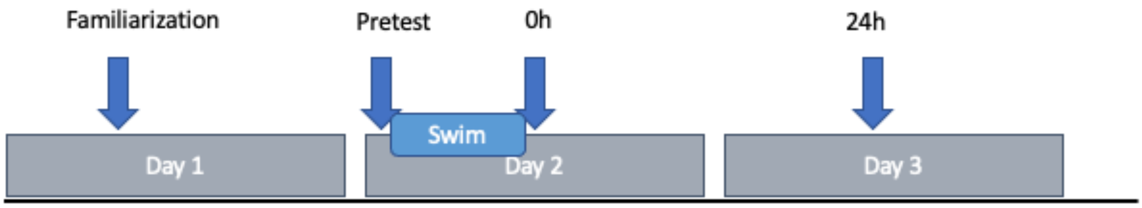

Figure 1. Timeline for familiarisation and testing.

Recruits rated their subjective recovery status before all test points using the Perceived Recovery Status Scale (PRS) on a scale ranging from 0 (not recovered at all) to 10 (completely recovered).[3] About 30min after the swim the recruits also rated their perceived exertion (RPE) on a scale ranging from 0 (nothing at all) to 10 (very, very hard).[4] A sheet was used allowing visual-cued responses, and then verbal answers were obtained.

Core temperature was measured continuously with a temperature sensor (BodyCap, e-Celsius Performance capsule, Hérouville Saint-Clair, France) that was swallowed approximately 2h before the swim. The capsule size is 17.7 x 8.9 mm and was programmed to sample data every 1-min. Skin temperature (Tskin). was measured using iButtons (Maxim Integrated Products Inc, iButton DS1922L, San Jose, CA, USA). The sensor was placed on the skin of the left underarm with adhesive dressing (3M Health Care, Tegaderm, Saint Paul, MN, USA) 5cm above the wrist cuff on the drysuit and measured the skin temperature on the subjects with 1-min intervals.

Body mass, fat mass and muscle mass were measured with a four-electrode bioelectrical impedance scale (Biospace, Inbody 720, CA, USA). Two tests of physical performance based on previous studies among SOF operators were conducted.[5,6] First, maximal grip-strength on both hands was measured with a dynamometer (JWL industries, Jamar Deluxe Hand Dynamometer model 0030J4, Chicago, IL, USA). The subjects held the dynamometer in their hand with a 90° angle in the elbow. Then the test subjects squeezed the dynamometer as hard as they possibly could for 3sec. Two separate tests on both right and left arm. The highest value was used in the analysis. Second, lower body power was measured with a countermovement jump (CMJ) on a force plate (HUR Labs Oy, Force Platform FP8, Tampere, Finland) using procedures described elsewhere.[5]

Blood samples were taken using serum vacutainers containing gel separators and clot activator (Becton, Dickinson and Company (BD), BD vacutainer SSD, Franklin Lakes, NJ, USA). The samples were clotted in room temperature for 30min before centrifuged at 2000g for 10min and refrigerated on site. All tubes were transported to a certified clinical laboratory (Fürst medisinsk laboratorium, Oslo, Norway) and analysed for Creatinine Kinase (CK), C-Reactive Protein (CRP), cortisol and testosterone.

Dexterity was measured using a test where the recruits should assemble two separate and different sized pairs of bolts, washers and nuts. Their assembly time was recorded. Reaction time was measured with a series of Stroop tests on an iPad (HindSoft Technology Pvt Ltd, EncephalApp software, New Dehli, India). The Stroop test is a validated test for measuring reaction time.[7]

Analyses (Statistics)
All data, except PRS and RPE, were log-transformed and analysed in Excel. Changes were calculated with t-tests in a spreadsheet allowing to control for two predictors making it possible to sort out the effect of other variables on the recruits' change in performance (such as the effect of change in core temperature on performance).[8] Primary analyses investigated changes occurring during the swim, with the following recovery 24h later. Secondary analyses investigated the possible mediating effects of changes in core- and skin temperature on the performance variables.
Magnitude of changes was evaluated with the following scale: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; >1.2, large; 1.2-2.0, very Large. All inferences were made with Magnitude Based Decision (MBD), particularly suggested for small samples.[9,10] Changes were evaluated with a 95 %confidence interval (CI) in relation to the smallest meaningful change (0.2 standard deviation (SD) the baseline SD), and it should at least have a 25% chance of benefit and less than 0.5% chance of harm to be clear. Effect of mediators (change in core- and skin temperature) where evaluated mechanistically; if the overlapped substantial positive and negative values (0.2 and 0.2), the effect was deemed unclear, and was otherwise evaluated probabilistically as described above. Plots were produced using programming language Python 3.7.6.,[11] and statistical data visualization packages MatPlotLib 3.1.1.[12] and Seaborn V0.10.1.[13]

Results
One subject dropped out before the swim started and one was taken out during the swim, for unknown reason, by the officers responsible for the swim. Therefore, in total, 9 of the 11 test subjects finished the 10000m swim and was included in the final analysis.

Baseline characteristics
Table 1. Baseline characteristics of the test subjects (n=9).

Variable	Mean±SD
Age (year)	23.9±2.1
Weight (kg)	83.3±6.8
Skeletal muscle mass (kg)	43.7±3.2
Body fat (%)	8.6±2.5
Swim time (min)	258.4±17.1
Start Tcore (°C)	37.4±0.3
Start Tskin (°C)	32.2±0.5

Tcore = core temperature. Tskin = skin temperature on the left arm.

Performance

Moderate, to very large negative effects, were observed for most variables on performance after the swim (0h), except for PRS, which were trivial. 24h after the swim, some changes were still clear and negative (see Table 2).

Table 2. Baseline values and percent changes at 0h and 24h, compared to baseline in performance variables during the study.

Variable	PreTest (Mean±SD)	Post 0h (%) (Mean±SD;CI)	Inference	Post 24h (%) (Mean±SD;CI)	Inference
STROOP (sec)	107±9	7.1±14.0; 11.1	M^{++}↓	-2.6±12.5; 9.1	S^{uncl}↑
Dexterity (sec)	27.3±6.3	249±83;173	EL^{++++}↓	-4.5±20.3; 14.0	S^{uncl}↑
PRS	4.2±1.2	0.0±0.0; 0.0 (CI)	T	14.4±8.8; 6.9	S^{**}↑
Grip right (kg)	58±8	-34.1±15.9; 7.7	VL^{++++}↓	-6.1±3.2; 2.3	S^{++}↓
Grip left (kg)	55±6	-40.6±47.1; 18.3	VL^{+++} ↓	-4.4±8.6; 6.2	S^{+}↓
CMJ height (cm)	33.2±5.4	-14.4±11.0; 7.1	M^{+++}↓	0.0±6.7; 5.1	T^{00}
CMJ power (W)	3743±392	-10.9±6.1; 4.1	M^{+++}↓	-5.7±4.3; 3.1	S^{+++}↓

PRS = Perceived Recovery Status, CMJ = Counter Movement Jump.
Trivial (T): <0.2, Small (S): 0.2-0.6; Moderate (M): 0.6-1.2; Large (L): 1.2-2.0; Very large (VL): 2.0-4.0; Extremely large (EL): <4.0
: Possibly beneficial, **: Likely beneficial, *: Very likely beneficial*
$^{+}$: Possibly harmful, $^{++}$: Likely harmful, $^{+++}$: Very likely harmful, $^{++++}$: most likely harmful
^{0}: Possibly trivial, ^{00}: Likely trivial, ^{000}: Very likely trivial, ^{0000}: Most likely trivial
^{uncl}: Unclear (need more data)
↑ = Better, ↓ = Worse

Blood samples

Moderate to very large clear elevated values were observed for CK and Cortisol, while testosterone was decreased after the swim (Post 0). For CRP the change was trivial. 24h after the swim cortisol and testosterone returned to near Pretest values, while CK and CRP were elevated from 0h to 24h. (See Table 3).

Table 3: Pretest, 0h and 24h absolute values in blood biomarkers during the study.

Variable	PreTest (Median±IQR)	Post 0h (Median±IQR)	Inference	Post 24h (Median±IQR)	Inference
CK (U/L)	284±132	322±210	M^{+++} ↑	314±307	M^{+++}↑
Cortisol (nmol/L)	659±117	846±120	L^{++++} ↑	675±140	T^{uncl}↓
CRP (mg/L)	5±5	4±5	T^{0000}	17±11	M^{+++}↑
Testosteron (nmol/L)	18±6	7±4	VL^{++++}↓	16±4	T^{+}↓

CK = Creatine Kinase, CRP = C-Reactive Protein.
Trivial (T): <0.2, Small (S): 0.2-0.6; Moderate (M): 0.6-1.2; Large (L): 1.2-2.0; Very large (VL): 2.0-4.0; Extremely large (EL): <4.0
: Possibly beneficial, **: Likely beneficial, *: Very likely beneficial*
$^{+}$: Possibly harmful, $^{++}$: Likely harmful, $^{+++}$: Very likely harmful, $^{++++}$: most likely harmful
^{0}: Possibly trivial, ^{00}: Likely trivial, ^{000}: Very likely trivial, ^{0000}: Most likely trivial
^{uncl}: Unclear (need more data)
↑ = Better, ↓ = Worse

Core- and skin temperature

The mean core temperature decreased from 37.4±0.3 ˚C to 37.0±0.9 ˚C during the swim. When including the afterdrop, core temperature dropped with 1.5±0.8 ˚C. An afterdrop was observed in all test subjects after the swim (green dotted line in Figure 2), with an average drop at -1.1±0.3 °C measured from the point when the subjects exited the water until the core temperature was at the lowest after the swim.

Figure 2 shows the change in core temperature. During the exercise, one of the recruits reached a core temperature of 34.4˚C, which is below the threshold of hypothermia (35˚C). Five of the recruits had a core temperature below 36˚C during the exercise. All lowest core temperature readings were measured after the recruits had exited the water.

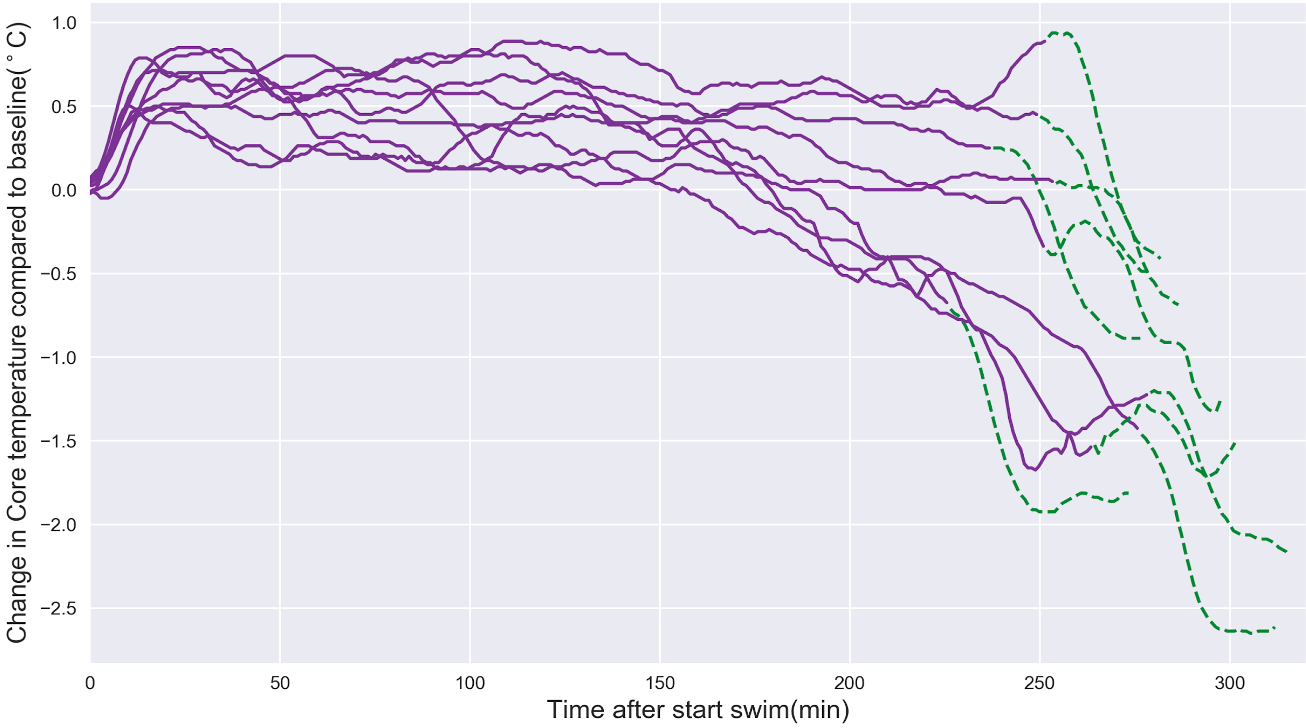

Figure 2. Change in core temperature compared to baseline during the swim (full purple line) and the first 45 min after the swim (dotted green line)

The skin temperature increased the first 20min of the swim before it gradually dropped the last part of the swim. The drop in Tskin was on average -9.8±3.3˚C during the exercise (see Figure 3).

Figure 3. Skin temperature plotted individually for the swim (purple line) and approximately 10 minutes after exiting the water (dotted green line).

Discussion

The main findings in the present study were the reductions in lower body power, reaction time, grip strength and dexterity immediately after the swim. After 24h, most effects of the swim were small or returned close to the baseline. After the swim, CK and Cortisol were elevated compared to baseline, while CRP was not changed compared to baseline.

During the first 15min of the swim, core temperature increased in all recruits, indicating elevated heat production compared to the heat loss. After the initial 15min, the core temperature was remarkable stable until 150min when some recruits started to decline (see Figure 2). This finding indicate well-functioning and proper insulated dry suits as long as the recruits are able to maintain normal swimming, and the drop in core temperature is probably caused by reduced heat production due to exhaustion. Further, after the swim, an afterdrop was observed in all recruits (Figure 2 - green, dotted lines) although they doffed in heated shelter. This physiological response is important to be aware of among operations in cold water. Reductions in skin temperatures of a similar magnitude have been associated with decreased internal muscle temperature, which in turn leads to decreased muscle force.[14] In our study, lower body power was reduced after the swim but normalised at 24h. The swim was rated moderate (RPE) by the recruits and may indicate that the energy cost was not considerable during the swim.

Maximum voluntary contractions grip strength has been shown to decrease after cold water immersion.[15] One interesting question is how long time it takes before grip strength returns to normal. Our study revealed that grip strength was back to near pretest levels after 24h. Therefore, with these novel findings, one can speculate that a decrease in skin temperature may affect performance and could be an essential variable to consider in addition to core temperature.

Although the recruits were swimming in a dry suit, and 5mm 5-finger neoprene gloves, the manual dexterity declined by nearly 250% during the swim. Studies have concluded that immersions of the hand in cold water for as short as 5min, result in impairment in both gross and fine manual dexterity.[16] It is worth noting that our study subjects were in the water for an average of 258 minutes, and we observed a clear gradual reduction in Tskin on the forearm (Figure 2). The blood flow to the hands responds rapidly upon cold, inducing vasoconstriction, which leads to decreased temperature in the fingers and hands. Due to the nature of the exercise, we were not able to measure skin temperature in the fingers of the recruits.

The large decrease observed in manual dexterity may be detrimental for operators as their ability to perform mission tasks such as weapon use or operate emergency equipment could be rigorously impaired.[17] Following the immediate impairment, ongoing cold exposure and vasoconstriction have several other adverse potential outcomes such as non-freezing cold injuries from decreased blood flow, leading to necrosis or immersion foot and frostbite.[18] Therefore preventing decreased Tskin and dexterity is vital.

In the present study, we induced two main stressors to the study subjects, cold water and demanding physical activity that elicit elevate cortisol and decrease testosterone level in line with previous studies.[5,19] We also observed an increase in CK in line with previous studies after strenuous exercise.[20,21] Surprisingly, and of notable interest, was the clear increase in CK despite that the recruits did not perform a typical weight-bearing activity as investigated in previous studies. Possibly, there is increased muscle damage in the legs due to the recruits propelling their motion with the use of fins. To our knowledge, muscle cooling or decreased core temperature does not increase CK levels. Therefore, this finding should be investigated further. The CRP levels were within normal ranges after the swim but elevated at 24h. Similar results are observed after long-distance racing were the CRP plasma values were elevated the day after.[21]

The recruits used fins to propel their 10000m swim. In general terms, large and stiff fins are more energy demanding, but increase the maximal propulsion per kick. Smaller and more flexible fins improve the economy of swimming at more sub-maximal speeds.[22] Zamparo et al. showed that the use of fins decreases the energy cost by around 50% when compared to flutter kick without fin. They further elucidated that kick frequency should be decreased as much as possible to reduce the energy cost.

Practical applications

We observed apparent declines in several variables in this study. The impact of these will be of importance when planning training and missions for the SOF operators. Individuals coming out of cold water might have degraded strength, dexterity and reaction time. Future studies should focus on how to prevent lowered core and skin temperature. For the individual, this might include improvement of cold water specific gear.

Limitations
First, the present study has a low sample size, and some meaningful effects were not clear. However, this is due to the nature of the training of NORNAVSOC recruits. Second, including a control group that was cooled, but not swimming would be beneficial to differentiate between the effects of strain and the effects of temperature. Third, all recruits in the present study underwent heavy strain before starting this study. Therefore, their baseline levels could already be outside normal range on some variables. Fourth, including more skin temperature measurements in different areas of the body could give some valuable information. Fifth, some variables were still negatively affected by the swim after 24h and optimally another measure after 48 h would be interesting.

Conclusion
The results demonstrate that exposure to a 10000m swim in 5°C water using standard equipment for the NORNAVSOC lead to a significant drop in the SOF recruits performance. Findings could have a meaningful impact on the planning of training, gear used and planning of operations for special forces.

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Author contributorship
P.A.S. and J.M. conceived the study concept. J.H. and PAS obtained funding. P.A.S. recruited participants. J.M. and P.A.S. planned the study, collected the data and analysed the data. J.M. wrote the first draft, and all authors read and approved the final manuscript.

Conflict of interest
The authors have no conflict of interest to declare

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Study III

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MDPI

Article

Core temperature during cold-water triathlon swimming

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Abstract: Triathlon and other endurance races have grown in popularity. Although participants are in general fit and presumably healthy, there is a measurable morbidity and mortality associated with participation. In triathlon, most deaths occur during the swim leg and increased knowledge about risk factors, such as hypothermia, is warranted. In the present study, we measured core temperature using an ingestible capsule in 51 participants during the swim leg of a full-distance triathlon. Water temperature was 14.4 - 16.4˚C, and the subjects used wetsuits. One subject with low body mass index and long swim time experienced hypothermia (<35 ˚C). For the remaining subjects, we found no association between core temperature and swim time, body mass index or sex. In conclusion, the present study indicates that during the swim leg of a full-distance triathlon using wetsuits in water temperature ≈15 ˚C, subjects with low body mass index and long swim times may be at risk for hypothermia.

Keywords: core temperature; swimming; triathlon; wetsuit

1. *Introduction*

Endurance races, such as marathon and triathlon, emerged during the ´80s, and have since grown in popularity. Although participants are generally fit and healthy, there is a measurable mortality, estimated at 0.5 to 1.7 per 100 000 participants [1,2]. Most deaths occur during the swim leg, and seem to be mainly related to cardiovascular disease [3]. However, the mortality also underscores the need for safety precautions and reduction of possible risk factors, such as hypothermia during the swim leg. Knowledge about these risks are also relevant to other events involving open-water swimming.

Thermoneutral water temperature at rest is approximately 35-35.5˚C [4]. Immersion in cold water may therefore lead to hypothermia, which is generally defined as a body core temperature <35˚C. Core temperature during swimming is the result of a complex interplay between metabolic heat production, heat loss to the water and heat transfer by conduction and convection within the body. Generally, it is believed that subcutaneous fat insulates from heat loss [5,6]. Increased muscle activity may both increase core temperature with metabolic heat production, but also increase heat loss to the water as there is a more uniform temperature distribution with increased muscle blood flow, reducing the insulating effect of otherwise hypoperfused tissue [4]. During swimming in cold water, swimming ability may be reduced, even in the absence of central hypothermia [7].

"Norseman Xtreme Triathlon" was first arranged in 2003. It consists of a 3800 m swim in Hardangerfjorden, a 180 km cycle leg, reaching 1200 m above sea level (MAMSL) and a 42.2 km run starting at 190 MAMSL, ending at Gaustatoppen, 1880 MAMSL. Although being arranged in the summer, both water and air temperatures are often low. The swim leg is covered in approximately 50 min by the fastest swimmers, and the cut-off time has been set to 135 min. Participants enter the water at any time after 04:45, and position themselves for the start which is at 05:00. In 2015, the water temperature was approximately 10˚C, leading to a shortened swim for safety reasons. However, it also led to an acknowledgment of the lack of data on which to perform qualified judgments on the risk of hypothermia during such races.

The aim of the present study was therefore to measure core temperature to estimate the possible incidence of hypothermia during the swimming leg of a cold-water full-distance triathlon. To evaluate a possible afterdrop, we also studied the first hour after ending the swimming leg.

2. Materials and Methods

The study was evaluated by the regional ethical committee (helseforskning.etikkom.no; REK references 2015/1533 and 2017/1138) and the Data Protection Officer at Oslo University Hospital (2017/8299). Subjects were recruited via social media and included after written informed consent. Exclusion criteria were history of gastrointestinal diseases or surgery, implanted medical devices, scheduled MRI scan within seven days after the race, pregnancy or weight below 36.5 kg.

Core temperature was recorded with ingestible temperature sensors (e-Celsius; BodyCAP, Hérouville Saint-Clair, France). Sensors were ingested the night before the race, pre-programmed to a sampling frequency at 2 min intervals. No specific instructions regarding pace, hydration or fuel ingestion were given. After crossing the finish line, data from the temperature sensors were downloaded (e-Viewer Performance monitor; BodyCAP, Hérouville Saint-Clair, France). Water temperature was given as the average of four readings through the swim. (Fluke 51; Fluke Corporation, Everett, WA, USA). Air temperature for 2017 and 2018 are from the Norwegian Meteorological Institute (Norwegian Meteorological Institute, 2019). Air temperature for 2019 was collected with a calibrated weather meter (Kestrel 5400 Heat Stress Tracker, Kestrel instruments, Boothwyn, PA, USA).

Temperature data were downloaded as .csv-files to Microsoft Excel [8] and handled in R 4.0.4 [9] using RStudio Version 1.4.1106 [10] using the Tidyverse packages [11]. Obviously erroneous data (e.g. from ingestion of water) were removed manually. In the multivariable regressions, a full model was calculated, thereafter removing interaction effects and main effects with the highest p-values. Data are mean (SD) or median (25th, 75th percentiles) unless otherwise stated. P-values <0.05

were considered statistically significant. Normality assumptions were checked using histograms, qq-plots and by plotting fitted values vs. residuals.

3. Results

3.1. Subjects

Seventy participants were recruited to participate in the study. However, data from 19 subjects could not be downloaded, leaving 51 subjects (9 women and 42 men) for analysis (2017 n=16; 2018 n=22; 2019 n=13) with age 38 (11) years, height 178 (8) cm, weight 76 (10) kg and body mass index (BMI) 24 (1.9) kg/m2. Swim time was 72 (65, 80) min. Water temperature was 14.4˚C in 2017, 16.1˚C in 2018 and 16.4˚C in 2019. Air temperature was 9.9˚C in 2017, 8.6˚C in 2018 and 15.6˚C in 2019 in the transition zone after the swim leg.

3.2. During swim

Temperature measurements during and the first hour after the swim leg are presented in Figure 1. Only one subject experienced hypothermia defined as body temperature <35˚C, in 2018. This subject´s lowest temperature was 33.2˚C, which was measured after 128 min swim.

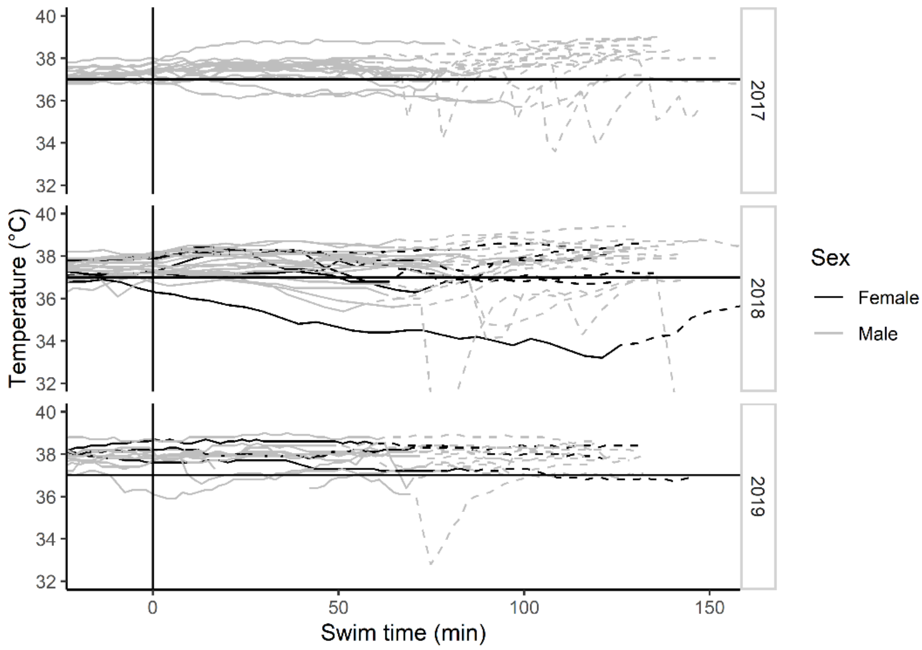

Figure 1. Solid lines are individual temperature recordings during the swim. Dashed lines are temperatures the first hour after the swim (transition and start cycling). Time 0 is race start (05:00).

We explored if the following variables were associated with temperature at the end of the swim leg; swim time, sex and BMI. When entering temperature at the end of the swim as outcome variable, we found significant main effects and interaction effect of swim time and sex (Table 1). The effects corresponded to an effect of time of -0.060˚C/min (95%CI -0.090 to -0.029, P <0.001) for women and -0.012˚C /min (95%CI -0.037 to 0.014, P = 0.50) for men. Temperature at the end of the swim, swim time sex and BMI are presented in Figure 2.

Table 1. Regression coefficients for all subjects. Temperature at end of swim is outcome variable.

	Estimate	95%CI	P-value
Swim time (min)	-0.060	-0.087 to -0.033	P < 0.001
Sex	-3.5	-6.1 to -0.79	P = 0.012
Swim time*sex	0.048	0.014 to 0.083	P = 0.007

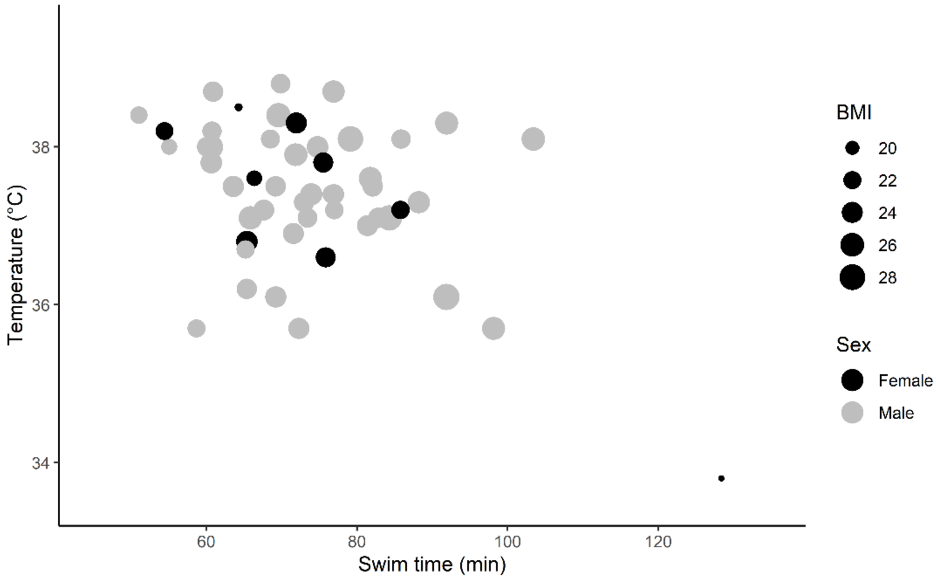

Figure 2. Temperature at end swim vs. swim time. BMI as point size, sex as color. BMI; body mass index.

There was, however, one outlier, and after removing this observation, none of the explanatory variables were statistically significant (Table 2). This was also found when entering all temperature observations during the swim with a first-order autoregressive [AR(1)] covariance structure due to repeated measures over time.

Table 2. Regression coefficients for subjects except outlier. Temperature at end of swim is outcome variable.

	Estimate	95%CI	P-value
Swim time (min)	-0.013	-0.037 to 0.011	P = 0.27
Sex	-0.10	-0.79 to 0.58	P = 0.76
BMI ($kg \times m^{-2}$)	-0.0086	-0.17 to 0.15	P = 0.91

3.3. After swim

Temperature measurements after ending the swim leg were plotted, and a local polynomial regression-line (LOESS) smoothing line was added (Figure 3). There was no obvious sign of afterdrop on the group-level based on the LOESS-line.

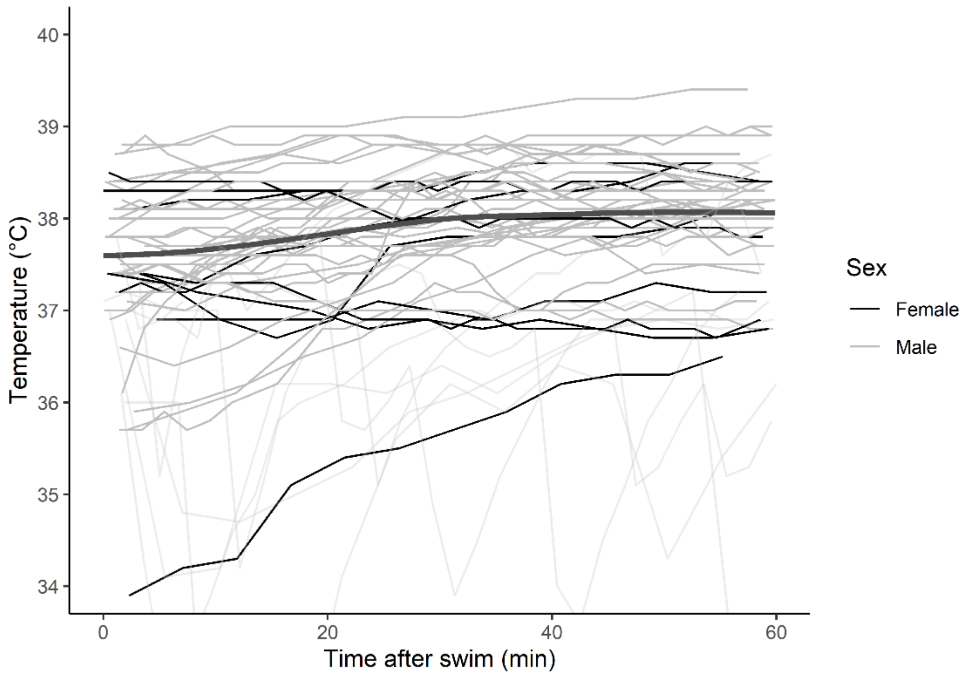

Figure 3. Temperature after end swim. Measurements from subjects with seemingly erroneous readings are faint, and not contributing to the wide black LOESS-smoothed line.

4. Discussion

The main finding of this study was the lack of association (after excluding one outlier) between swim time or BMI on body core temperature during the cold-water swimming leg of a full-distance triathlon. Further, there was no tendency for body temperature to change with time during the swim on a group level. However, one subject who seemed to constitute an outlier in this dataset experienced mild hypothermia.

The results of a study on core temperature measurements during a 20-min flume swim in different temperature and wetsuit combinations prompted minimum recommended water temperatures during triathlon of 12˚C and 16˚C with and without wetsuits, respectively [12]. The leanest subjects were the most susceptible to hypothermia. Another study from the same group studied swimming up to 2 hrs between 14˚C and 20 ˚C while not wearing a wetsuit [13]. This study led to the use of mandatory and optional use of wetsuits below 18˚C and 20˚C, respectively, during marathon swim. Again, the temperature rate of change was associated with skinfold thickness, and also heat production per body surface area. Importantly, the swimmers had a poor perception of their own core temperature [13], possibly due to adaptation [14]. As in the present study, sex did not seem to be an essential factor. When considering the safety of a triathlon swim, associations and changes on group level are of limited importance as care must be taken to decrease risk in single outliers. The perhaps most interesting observation in the present study was the one subject who experienced mild hypothermia during the swim with a lowest measured temperature of 33.2˚C. This subject had both the lowest BMI and the longest swim time. The long swim time could potentially contribute to hypothermia both through the effect of time and also due to low metabolic activity due to slow swimming, compatible with the notion that open-water swimmers should not be thin and slow [4,15]. This observation, combined with the knowledge of poor self-assessment of core temperature, needs to be considered when arranging open-water swims.

In a previous study of open-water swim at approximately 10˚C using a wetsuit, highly individual responses in core temperature were found [16]. Due to one subject experiencing hypothermia, most subjects were limited to 55 min swim. Although no subjects experienced hypothermia during the first 30 min, extrapolation of the temperature trajectories indicated that a large proportion would be hypothermic after a 135 min swim. In the present study, we did not find an association between swim time and core temperature. Further, when linearly extrapolating the temperature trajectory the last 30 min of the swim another 30 min, only two additional subjects would reach temperatures below 35˚C during this time. This was probably due to the relative warmth (14.4 to 16.4˚C) of the water during the three competitions combined with the use of wetsuits.

Afterdrop, i.e. a further reduction of core temperature after exiting the water has been repeatedly reported [16,17], and is presumably caused by both conduction and convection [18]. We did not find clear evidence for a significant afterdrop on a group level as judged by the loess-line. Interpretation of the individual data was complicated by the many seemingly erroneously low values, presumably due to ingestion of cold drinks, and these data should be interpreted with caution. However, the absence of a clear afterdrop is consistent with the lack of reduction in body temperature with time, again probably related to the relative warmth of the water.

In a large proportion (27%) of the subjects, temperature measurements could not be performed. The capsules were ingested the night before the race, and we believe that in most of the unsuccessful cases, the capsule was passed through the gastrointestinal tract before the reading was performed. Ingesting the capsule immediately before the race could have reduced this problem, but we wanted the capsule to be passed through the ventricle into the intestines before the race. Nonetheless, several readings immediately after the swim showed abrupt decreases, probably caused by drinking cold fluids. Some readings during the swim also seemed to have erroneously abrupt decreases, possibly caused by either ingesting sea water or the capsule being near the abdominal wall. The exclusion of these measurements was based on a subjective judgment, and thus encumbered with some uncertainty.

In the regression models, we started with a full model with the variables we considered biologically plausible (swim time, sex and BMI), starting with excluding statistically non-significant interaction effects. In univariable analyses, only swim time was statistically significant in the dataset including the outlier (results not shown). When excluding this observation, none of the variables were statistically significant in univariable analyses. We did not enter water temperature in the multivariable regression model due to the small variability in the measurements. However, in univariable analyses, water temperature was also statistically not significant.

5. Conclusions

We found no association at a group level between body core temperature at the end of the swim leg and swim time, sex or BMI in when using wetsuits in temperatures of 14.4 to 16.4˚C. This was however after excluding one outlier with low BMI and long swim time who experienced hypothermia, and our results thus indicate that participants under these circumstances may be at risk for hypothermia.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Regional Ethics Committee (REK; helseforskning.etikkom.no); REK references 2015/1533 and 2017/1138 and the Data Protection Officer at Oslo University Hospital (2017/8299).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to data protection regulations.

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15 Appendix

15.1 Consent Study I

Svømming med våtdrakt i kaldt vann

Forespørsel om deltakelse i forskningsprosjekt

”Hvordan påvirkes kjernetemperatur av 3800m svømming med våtdrakt i 10°C kaldt vann?”

Bakgrunn

Dette er et spørsmål til deg om å delta i et forskningsprosjekt som er et samarbeidsprosjekt mellom forskere ved Oslo Universitetssykehus, Olmpiatoppen og Norges Idrettshøgskole. Forskningsprosjektet støttes økonomisk fra Norges Triatlonforbund og Norseman Xtreme Triathlon. Triathlon er en idrett i sterk vekst. I Norge er det en utfordring for både utøvere og arrangører, at vannet i flere konkurranser kan være relativt kaldt. Vi ønsker å være med på å skape trygghet rundt arrangementene som arrangerer i områder med kaldt vann.

Hensikt

Hensikten med dette prosjektet er å måle kjernetemperatur hos utøvere som svømmer en lengde tilsvarende svømmeetappen på en langdistansetriathlon i 6°C - 12°C kald vann med våtdrakt godkjent for triathlon.

Hva innebærer studien?

Deltagelse i forskningsprosjektet vil innebære oppmøte på to forskjellige dager med inntil tre timer hver dag. Den ene dagen vil være medisinske og fysiologiske tester, samt en svømmetest i kaldt vann med våtdrakt. Tidspunkter for oppmøte vil i noen grad være mulig å tilpasse individuelt. Den andre dagen vil være en VO_2max test. Denne avtaler du helt som det passer for deg. Det er et mål for studien at vi har utøvere med variert bakgrunn innen triathlon. Vi krever av deg at du har en egen våtdrakt beregnet for svømming og at du kan gjennomføre en 3800 meter svømmetest i Songsvann.

Gjennomføring testing

Den medisinske og fysiologiske testen vil foregå på Idrettshøgskolens testlaboratorium ved Songsvann i Oslo. Her vil vi blant annet måle maksimalt oksygenopptak(VO_2max), muskel- og fettmasse og flere andre tester. Du vil også få et spørreskjema der vi vil kartlegge litt om din bakgrunn og erfaring innen triathlon.

Mulige fordeler og ulemper

Du vil få en grundig gjennomgang av dine fysiologiske kapasiteter ved Idrettshøgskolen. Du vil også være med på å bidra til å gjøre triathlon til en tryggere idrett.

Svømming i kaldt vann kan være ubehagelig. Vi har allerede gjort et pilotprosjekt, der vi ikke observerte noe nedkjøling på utøveren.

Du vil være godt sikret under hele svømmetesten, med lege og/eller sykepleier med erfaring fra akuttmedisin og nedkjøling.

Avidentifisering og lagring av resultater
Informasjonen som registreres om deg skal brukes som beskrevet i hensikten med studien. Alle opplysninger vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. Dine resultater vil bli avidentifisert og en kode vil bli benyttet til å knytte dine resultater og opplysninger til deg. Det er kun autorisert personell knyttet til prosjektet som har adgang til kode og navneliste. Resultatene vil bli lagret og bearbeidet på sykehusets forsknings-PC. Ferdigbehandlete data vil lagres i 10 år på Oslo Universitetssykehus sin forskningsserver og deretter slettes. Navnelisten med Svømming med våtdrakt i kaldt vann
koblingsnøkkel oppbevares ved Oslo Universitetssykehus og vil bli slettet ved prosjektets avslutning. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres.

Frivillig deltakelse
Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke til å delta i studien. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Om du nå sier ja til å delta, kan du senere trekke tilbake ditt samtykke uten at det påvirker din eventuelle øvrige behandling. Dersom du har spørsmål til studien, kan du kontakte oss.

Kontaktinformasjon
Dersom du er interessert, eller ønsker å vite mer om dette prosjektet kan du når som helst kontakte ph.d.-student/anestesisykepleier Jørgen Melau på e-post: jorgen@melau.no eller på telefon: 911 73 629 eller prosjektleder fysiolog dr. philos. Jonny Hisdal på e-mail: jonny.hisdal@medisin.uio.no eller på telefon: 92281977.

Vi ser frem til å høre fra deg!

Ytterligere informasjon om studien finnes i kapittel *A* – *utdypende forklaring av hva studien innebærer.*
Ytterligere informasjon om personvern og forsikring finnes i kapittel B – *Personvern, økonomi og forsikring.*

Samtykkeerklæring følger etter kapittel B.

Kapittel A- utdypende forklaring av hva studien innebærer

Kriterier for deltakelse

Alder ≥ 18 år
Du har en våtdrakt som er i god stand og beregnet for svømming
Du er i stand til å svømme 3800 meter utendørs

Prosjektet vil foregå i to omganger.

Medisinsk og Fysiologisk test

I forkant av svømmetesten vil du gjennomgå en legeundersøkelse, testing av fysisk kapasitet og kroppsammensetning. Disse testene vil bli utført på Idrettshøgskolen. Legeundersøkelse vil blir foretatt av en av de to legene tilknyttet prosjektet, og de fysiske testene og måling av kroppsammensettning vil bli foretatt av kvalifisert personell på Idrettshøgskolen. Kroppsscanning gjennomføres på Idrettshøgskolen med en Dxa Scan maskin.

Svømmetest

Kjernetemperaturen måles kontinuerlig fra ca 10 minutter før start og til 60 minutter etter at du har kommet opp av vannet. Det benyttes temperaturprobe som settes inn rektalt. Det måles også hudtemperatur på ulike steder på kroppen. Temperaturene lagres i en minnebrikke i ett belte som du har festet til brystet på innsiden av våtdrakten.

Måleutstyret registrerer også klokkeslett, hudtemperatur og hjertefrekvens, slag for slag under hele forsøksperioden.

Andre målinger

Vanntemperaturen måles etter FINA´s retningslinjer i midten av svømmeløypa på 40 cm dyp. Vi benytter kalibrert thermometer for å male vanntemperatur.

PROSJEKTPROTOKOLL Detaljert beskrivelse Del 1

Du vil i forkant av Medisinsk, Fysiologisk og svømmetest bli bedt om å gjøre følgende forberedelser:
fastende minimum siste 8 timer før oppmøte
ingen trening eller koffein (kaffe, te, energidrikker) siste 24 timer
ingen bruk av tobakk (snus, røyk) ≥12 timer før testing
ingen hard styrke- eller utholdenhetstrening ≥24 timer før testing
Studien innebærer at du kommer til Idrettshøgskolen, Songsveien 228, Oslo om morgenen/formiddagen/ettermiddag/kveld (Dette avtales nærmere). Hele testen er stipulert til å ta ~120 min.
Ved oppmøte vil du bli forklart prosedyrene og bedt om å signere et dokument på at du har fulgt instruksene du har mottatt skriftlig i forkant av deltakelse i studien .

Dersom du aksepterer dette, vil vi ved oppstart og i etterkant av studien foreta målinger som følger:

Måling av DXA (Kroppsscanning)
Måling av lungefunksjon før svømming
Medisinsk sjekk

Oppkobling av puls- og temperaturmålere
Svømme 3800 m i Songsvann
Testing av lungefunksjon like etter svømming
Avslutter målinger (60 min etter du har kommet opp av vannet)
Gjør avtale om når du skal teste VO_2 maks

Kapittel B - Personvern, økonomi og forsikring

Personvern
Opplysninger som registreres om deg er demografiske data som kjønn, alder, medisinsk diagnose, medisiner, høyde, vekt, kjønn og fysiologiske data. I tillegg registreres kontinuerlig under svømmingen en rekke fysiologiske data (hjerteslag, pustefrekvens, temperatur) fra måleinstrumentene. Dataene kodes og lagres på forsknings-PC og forskningsserveren ved Oslo Universitetssykehus. Nøkkelen for å koble ditt navn til dine data oppbevares nedlåst og er kun tilgjengelig for medarbeidere i studien. Oslo Universitetssykehus ved administrerende direktør er databehandlingsansvarlig.

Utlevering av materiale og opplysninger til andre
Hvis du sier ja til å delta i studien, gir du også ditt samtykke til at avidentifiserte opplysninger utleveres til Oslo Universitetssykehus, Aker.

Rett til innsyn og sletting av opplysninger om deg og sletting av prøver
Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede prøver og opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Økonomi og rolle
Studien er ikke finansiert. Det gis ingen kompensasjon for deltakelse.

Informasjon om utfallet av studien
Ved ønske, kan du som deltaker få tilsendt resultater av egne målinger. Dersom du ønsker informasjon om dine data fra studien kan du kontakte ph.d.-student/anestesisykepleier Jørgen Melau på e-post: jorgen@melau.no eller på telefon: 911 73 629 eller prosjektleder fysiolog dr. philos. Jonny Hisdal på e-mail: jonny.hisdal@medisin.uio.no eller på telefon: 92281977.

Samtykke til deltakelse i studien

Jeg er villig til å delta i studien

(Signert av prosjektdeltaker, dato)

Jeg bekrefter å ha gitt informasjon om studien

(Signert, rolle i studien, dato)

15.2 Consent Study II

FORESPØRSEL OM DELTAKELSE I FORSKNINGSPROSJEKTET

FYSIOLOGISKE ENDRINGER SOM FØLGE AV SVØMMING I KALDT VANN

Marinejegerkommandoen

Dette er et spørsmål til deg om å delta i et forskningsprosjekt der hovedmålet er å undersøke hvordan kroppstemperatur og fysisk prestasjon blir påvirket av svømming i kaldt vann. Du blir forespurt om å delta i dette prosjektet siden du er en del av Marinejegerkommandoens utdanning. Forskningsprosjektet er også en del av et doktorgradsprosjekt ved Universitetet i Oslo, og er et samarbeid med Marinejegerkommandoen, Forsvarets Spesialstyrker, Sykehuset i Vestfold og Oslo Universitetssykehus. Oslo Universitetssykehus er ansvarlig for studien.

HVA INNEBÆRER PROSJEKTET?

Hensikten med dette prosjektet er å få mer kunnskap om hvordan kroppen påvirkes av svømming i kaldt vann. Kroppstemperaturen din vil bli målt kontinuerlig gjennom hele konkurransen ved hjelp av en temperatursensor. (e-Celsius Performance®, BodyCap, France). Sensoren er formet som en liten pille som du svelger på normal måte. Denne vil registrerer kroppstemperaturen din så lenge den er i kroppen. Etter svømmingen vil vi kunne lese av målingene som er lagret i pillen ved hjelp av et spesialutviklet måleapparat som holdes inntil kroppen din. Du vil ikke merke noe til pillen underveis i svømmingen, og den forsvinner gjennom avføringen din. Samtidig vil vi også måle hudtemperaturen din, ved hjelp av sensorer på størrelse med et kronestykke, som festes på huden din.
En annen hensikt med studien er å se hvilke forandringer som kan sees i biomarkører (blodprøver) etter en lang og kald svømmetur. Særlig vil vi se på blodets koaguleringsevne i forhold til kroppstemperatur. Det er sett at lavere kroppstemperatur kan påvirke blodets koaguleringsevne, og dette vil kunne ha stor relevans for soldater på oppdrag. Spesielt ved oppdrag der det kan oppstå skader med større eller mindre blødninger. Vi vil ta blodprøver på tre stadier. Før du starter svømmeturen, med en gang du kommer i mål etter svømmingen, og dagen etter svømmingen.

I tillegg til disse målingene, vil vi også gjøre andre målinger både før, under og etter svømmingen.

- Hjertefrekvens blir målt ved hjelp av en pulsbelte under svømmingen.
- Det blir utført enkle styrketester før og etter.
- Vi vil teste kognitiv funksjon og finmotorikk før og etter svømmingen.
- Det vil bli registrert grunnlagsdata om deg, som alder, høyde, vekt og kjønn

Resultatene dine vil bli lagret avidentifisert, og det er ikke mulig å identifisere deg som person. Du vil tildeles et kodenummer som knyttes til alle resultatene som registreres fra deg. Dataene vil bli lagret på en sikker forskningsserver ved Oslo Universitetssykehus og kodelisten lagres på papir innelåst i henhold til sykehusets retningslinjer. Dersom du ønsker kan du i ettertid få tilsendt dine egne resultater.

MULIGE FORDELER OG ULEMPER

Denne forskingen vil først og fremst gi oss som forskere mer kunnskap om hvordan kroppstemperaturen og blodets funksjon påvirkes av eksponering til kaldt vann. Det finnes noe kunnskap om dette, men det er fortsatt mye vi ikke vet. En av hovedhensiktene er å gi Marinejegerkommandoen enda bedre verktøy for å planlegge og gjennomføre tryggere operasjoner. Det vil kunne ha relevans for hvordan man planlegger operasjoner, trening, samt å utvikle relevant utstyr. Resultatene fra dette prosjektet vil kunne bidra til økt kunnskap om dette. I tillegg vil du selv få mulighet til å se hvordan kroppen din påvirkes av å svømme i kaldt vann. Temperaturpillen du eventuelt skal bruke er grundig testet av produsenten og godkjent for bruk i studier som dette. Pillen har størrelse omtrent som en tablett paracet. Det finnes noen få kontraindikasjoner ved bruk av temperaturpillen, det vil si årsaker til at du ikke bør ta pillen. Kontraindikasjonene er også listet opp i slutten av dette informasjonsskrivet og du må skrive under på at du ikke har noen av disse før du kan inkluderes i studien.

FRIVILLIG DELTAKELSE OG MULIGHET FOR Å TREKKE SITT SAMTYKKE

Det er frivillig å delta i prosjektet. Dersom du ikke har noen kontraindikasjoner mot å bruke temperaturpillen og ønsker å delta, undertegner du samtykkeerklæringen på siste side. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke. Dersom du trekker deg fra prosjektet, kan du kreve å få slettet innsamlede prøver og opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner. Om du velger å trekke deg fra studien vil ikke det ha noen som helst påvirkning for din deltakelse i utdannelsen hos MJK. Dersom du senere ønsker å trekke deg eller har spørsmål til prosjektet, kan du kontakte PhD kandidat Jørgen Melau, telefon 911 73 629, jorgen@melau.no

HVA SKJER MED INFORMASJONEN OM DEG?

Informasjonen som registreres om deg skal kun brukes slik som beskrevet over. Du har rett til innsyn i hvilke opplysninger som er registrert om deg og rett til å få korrigert eventuelle feil i de opplysningene som er registrert. Alle opplysningene vil bli avidentifisert, det vil si behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En kode knytter deg til dine opplysninger gjennom en navneliste. Kodenøkkel vil være innelåst ved Sirkulasjonsfysiologisk avdeling ved Oslo Universitetssykehus, Aker. Den vil kun være tilgjengelig for denne forskergruppen.
Prosjektleder har ansvar for den daglige driften av forskningsprosjektet og at opplysninger om deg blir behandlet på en sikker måte. Alle innsamlede data vil bli slettet i 2029.

UTLEVERING AV OPPLYSNINGER TIL ANDRE

Resultatene fra prosjektet vil ikke bli utlevert til andre personer en de som er tilknyttet vår forskningsgruppe.

OPPFØLGINGSPROSJEKT

Ved behov kan du bli kontaktet for ytterligere opplysninger i etterkant av studien.

ØKONOMI

Du vil ikke få økonomisk kompensasjon for å delta på dette prosjektet.

SAMTYKKE TIL DELTAKELSE I PROSJEKTET

INFORMERT SAMTYKKE

Det finnes noen kontraindikasjoner mot bruk av temperaturpille. For at vi skal kunne vurdere om det er trygt for deg å bruke temperaturpillen må du svare på spørsmålene under:

(Sett ring rundt svaret ditt)

1. Har du hatt noen form for tarmsykdom? Ja Nei
2. Har du tidligere blitt operert i magen? Ja Nei
3. Har du elektriske implantater i kroppen (ICD eller Pacemaker)? Ja Nei
4. Har du planlagt MR-undersøkelse i løpet av den neste uka? Ja Nei
5. Er du gravid? Ja Nei
6. Har du en kroppsvekt under 36,5 kg? Ja Nei
7. Har du svelgeproblemer? Ja Nei

Dersom du har svart Nei på alle spørsmålene over kan du delta i prosjektet.
Jeg bekrefter herved at jeg ønsker å delta i dette prosjektet og har lest informasjonsskrivet og fått muntlig informasjon på eventuelle spørsmål fra prosjektleder. Jeg er også klar over at jeg når som helst uten å oppgi grunn kan trekke mitt samtykke.

Sted og dato Deltakers signatur

Deltakers navn med trykte bokstaver

Jeg bekrefter å ha gitt informasjon om prosjektet

Sted og dato Forskers signatur

Rolle i prosjektet

Dette skjema skal fylles ut underskrives i to eksemplarer.
En kopi beholdes av forsøksperson og en av prosjektleder.

15.3 Consent Study III

Invitation to participate in a research project

You are invited to participate in a research project where the main goal is to examine how the body is affected in a combination of cold water swimming, cycling and running. You are asked to participate in this study, because you are an athlete starting in Isklar Norseman Xtreme Triathlon or Oslo Triathlon. This research project is a part of a PhD project at the University of Oslo, Oslo University Hospital and Vestfold Hospital Trust.

What is the study about?

The purpose of this study is to gain knowledge about how the body core temperature is affected by swimming in cold water, cycling and running. Your body core temperature is measured continually with a temperature sensor pill that you swallow before race start. (e-Celcius Performance, BodyCap, France) The sensor is in the shape of a small pill that will register your core temperature as long as it is inside your body. After the finish of the race, we can read out the data on the sensor pill by holding a measuring device near your body. You will not notice the pill at all during the race, and you can race as normal. It will disappear from your body with your faeces within a day or two. In addition, we will measure your body composition the day before the race, with a bioelectrical impedance method (InBody), and examine the relationship between changes in core temperature and body composition. We also ask you to fill out a short questionnaire, were we ask about your training and preparation for the race.

All the physiological tests and questionaries' will take about 20 minutes to finish the day before the race. Reading out the core temperature after finishing the race take about 15 minutes. You perform all measurements sitting or standing and this will not influence your race performance. If possible, we ask you not to drink and eat the last 2 hours before the body composition test.

All the data we collect will be stored so that you can't be identified. This means that you will be assigned a study number that is connected to all data that is registered about you. The data is stored at a secure research server at Oslo University Hospital. Your study numbers and name are stored at a separate list that is locked down at a secure place according to the Oslo University Hospital guidelines. If you want, you can have your results sent to you after the study is done.

Possible benefits and expected disvantages of taking part

This research project will give the researchers more knowledge about how the body core temperature are affected by exposure to cold water combined with cycling and running. The number of triathlon races are increasing, but there is very limited scientific research about how these races affect the athletes body and health. There are likewise no guidelines for organizers of these races that gives a lower water temperature limit. The results from this research project will contribute to more knowledge about this. You will also yourself have the opportunity to see how your body is affected by a hard endurance race. The temperature sensor pill you will swallow is tested by the manufacturer and are legal to use for studies like this. The temperature sensor pill has a size of a normal pill, e.g. like a pill of Paracetamol or similar. There are a few contraindications against using this core temperature sensor pill. These are listed at the end of this information letter, and you must sign this paper to state that you have none of these before you can be included in this study.

Voluntary participation and the possiblity to withdraw consent (Opt-out)
Participation in the study is voluntary. If you wish to take part, you will need to sign the declaration of consent on the last page. You can, at any given time and without reason withdraw your consent. If you decide to withdraw participation in the project, you can demand that your tests and personal health data be deleted, unless however, the personal health data and tests have already been analysed or used in scientific publications. If you at a later point, wish to withdraw consent or have questions regarding the project, you can contact Jørgen Melau, phone +47 91173629, Jorgen@melau.no

What will happen to your health information?
The information that is recorded about you will only be used as described in the purpose of the study. You have the right to access which information is recorded about you and the right to stipulate that any error in the information that is recorded is corrected.
All information will be processed and used without your name or personal identification number, or any other information that is directly identifiable to you. A study number connects your data through a list of names. This list is locked down at a secure place at Oslo University Hospital and is only reachable to the study group.
The Project Manager has the responsibility for the daily operations/running of the Research Project and that any information about you will be handled in a secure manner. Information about you will be deleted in 2027.

Transfer of information to others
The data from this project will not be shared with anyone outside our research group.

Follow-up study
We might contact you after the study for follow up questions.

Finance
You will not receive any financial compensation for participating in this study.

Approval
The Project is approved by the Data Protection Official at Oslo University Hospital ref.nr. 2017/8299

Consent for participating in the research project

There are some contraindications against the use of a core temperature sensor pill. For us to assure that it is safe for you to use the sensor we need you to answer the following;

(Circle your answer)

Do you have any form of obstructive gastro-intestinal disease?	Yes	No
Do you have a history of gastrointestinal surgery?	Yes	No
Do you have any electric implanted medical device in your body?	Yes	No
Do you have a scheduled MRI scan the next seven days?	Yes	No
Are you pregnant?	Yes	No
Do you weight under 36.5 kg?	Yes	No
Do you have any problems with swallowing?	Yes	No

If NO on all questions above you are cleared to participate in the study.

I am willing to participate in the research project:

Place and date	Participant's Signature

Participant's Name (in BLOCK LETTERS)

I confirm that I have given information about the research project

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Place and date	Signature

Role in the research project

15.4 Improvised Hypothermia Wrap

The Hypothermia wrap, with the "Burrito" method is a novel method for hypothermia prevention and prehospital treatment for laypersons. The technique is described in general by Dow et al. [122] In the following, we demonstrate this method with readily available outdoor gear. The Burrito wrap method consists of layers that can be improvised with different types of equipment. The photos describe how to achieve good hypothermia prevention. Still, we also give descriptions of additional equipment that can be used. The layers are from nearest to the patient and outwards: a vapor barrier layer, an insulation layer, and a vapor/wind layer. This can easily be achieved with the gear pictured below.

Improvised gear for a Hypothermia prevention kit. From left to right: a sleeping bag, a tarp, a sleeping mattress and large garbage bags.

A person with suspected hypothermia should be dry before packet in a hypothermia wrap. Wet clothes should be removed, and efforts should be taken to dry the skin if the patient is wet. In some exceptional circumstances, the removal of wet clothes is not feasible. Then, closest to the victim, a vapor proof layer can be used. This can be achieved with plastic garbage bags, like in the picture to the right. This can also be achieved with bubble wrap and other vapor proof layers. If the patient is dry, the vapor proof layer next to the victim can be considered skipped.

A plastic garbage bag. Make a hole for the head, and put it over the victim. A second bag is used for the legs.

The next layer is the insulation layer. In this demonstration, this layer is shown by packing the victim in a sleeping bag and then a mattress below the victim. The thicker the insulation layer, the better. A mattress below the patient is also beneficial in reducing the heat loss to the ground. Other materials can be used for insulation, like woolen blankets, duvets, the "Jerven" blanket, and much more.

Outside the insulation layer, we use a vapor proof and wind proof layer. This is to protect the patient from rain, splash and the wind chill. In this demonstration we use a tarp with size 3x3 meter. Other matherials can be used, like a tarpaulin, tents, buble wrap, sails and more. The patient is then wrapped as a burrito, hence the name "Burrito wrap".

In the end, the whole package is tightened up with bunge cords. Ropes, paracord, duct tape and bandages can also be used for this.

If a heat source like "Ready Heat" or warm water bottles are available, these should be placed inside the insulation layer. The best place for external heat is the area around the thorax, then the groin area. Be sure not to place the heating source directly onto the skin, as burn injures can occour.

All photos in this appendix by Kai-Otto Melau

14.5 Norsk sammendrag

Introduksjon

Kaldt vann er en utfordring for arrangører av svømmekonkurranser i åpent vann, samt for militære oppdrag som innebærer dykking eller andre aktiviteter i og ved sjøen. Det er derfor behov for mer kunnskap om hvordan kaldt vann påvirker menneskelig prestasjonsevne. Denne kunnskapen vil også være svært viktig i drukningsforebyggende arbeide samt for livreddende innsats hos både profesjonelle og lekmenn i og ved sjøen.

Mål

Hovedmålet for denne kappen er å undersøke de fysiologiske responsene til kaldt vann på personer som bruker våtdrakt eller tørrdrakt, enten i trening eller konkurransesammenheng eller i forbindelse med militære operasjoner.

Metode

Tre studier ble utført i forbindelse med dette arbeidet. I Studie I var deltagerne aktive triathlonutøvere, som svømte i 10°C vann med våtdrakt. Studien ble utført i åpent hav. I Studie II var deltagerne aspiranter under opptak i Marinejegerkommandoen. I denne studien svømte de 10000meter i åpent hav med tørrdrakt. Studie III ble utført på deltagere i en triathlon konkurranse, der datasamlingen ble gjort under og etter svømming. I alle studiene ble kjernetemperatur under svømming og kroppssammensetning av deltagerne målt. I Studie I og Studie II ble det i tillegg gjort målinger av hudtemperatur. I Studie II, inkluderte vi måling av spesifikke biomarkører (CK, CRP, Cortisol og Testosteron), reaksjonstid, fingerferdighet og styrke. Studie III ble gjennomført over tre år, der utøvere ble fulgt under en hard utholdenhetskonkurranse (Norseman Xtreme Triathlon)

Resultater

I Studie I, ble kjernetemperatur opprettholdt i de første 10 minuttene av svømmingen for alle deltagere. For hoveddelen av utøverne, sank kjernetemperaturen til under start temperatur i løpet av svømmingen. Gjennomsnittlig fall i kjernetemperatur var 0.9°C (SD 1.1). For alle deltagere der det ble observert fall i kjernetemperatur, ble det observert ytterligere reduksjon i kjernetemperatur etter svømmingen (afterdrop), med et gjennomsnittlig fall på 0.6°C (SD 0.3). I Studie II, var gjennomsnittlig fall i kjernetemperatur på 0.4°C i løpet av svømmingen. Afterdrop ble observert hos alle deltagere, med en gjennomsnittlig afterdrop på 1.1±0.3°C. Gjennomsnittlig fall i hudtemperatur var på 9.8±3.3°C under svømmingen. Det var en klar reduksjon i kraft, reaksjonstid, grepsstyrke og fingerferdighet umiddelbart etter svømmingen. Ved ny testing 24 timer etter svømming var de fleste målte verdiene tilbake til eller nært normale verdier. I Studie III målte vi kjernetemperatur under konkurranse og fant ingen sammenheng mellom kjernetemperatur etter svømming og svømmetid, kjønn eller BMI. Derimot var det en «outlier» som ble hypotherm under svømmingen, og dette funnet er vurdert til å være viktig.

Konklusjon

Hovedfunnet i denne avhandlingen er ulikhetene i responsen på kjernetemperatur på grunn av eksponering til kaldt vann. Selv om det er et klart mønster at deltagere som svømmer i kaldt vann har en gradvis reduksjon i kjernetemperatur, så er det også en klar tendens til at kjernetemperaturen blir opprettholdt de første 10-15 minuttene. Afterdrop opptrer hos mange deltagere som blir kaldere under svømming; derimot er det usikkert om dette har stor betydning. Et eventuelt fall i kjernetemperatur er primært avhengig av eksponeringstid. I denne avhandlingen, har vi ikke funnet noe som kan forklare dette annerledes. Derimot er et viktig funn i denne avhandlingen, at individuelle deltagere kan bli hypotherme, selv om det gjennomsnittlige fallet i kjernetemperatur er lite på gruppenivå.