COMPARISON OF HEAT DONATION THROUGH THE HEAD OR TORSO ON MILD HYPOTHERMIA REWARMING

by

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ABSTRACT

This study compared head vs. torso warming using a similar source of heat donation. Six subjects were cooled in 8˚C water to either a core temperature of 35˚C or for 60 min. They were then rewarmed by either shivering only, or charcoal heater applied to the head, or torso. There were no significant differences in rewarming rate between the three conditions. Head warming did not inhibit average shivering heat production resulting in greater net heat gain during 35-60 min of rewarming compared to shivering. Head warming is as effective as torso warming for hypothermic victims. Head warming could be a preferred method in some cases: extreme conditions in which removal of the insulation and exposure of the torso to the cold is contraindicated; excessive movement is contraindicated (e.g., severe hypothermia which has a risk of ventricular fibrillation, or potential spinal injury); or if emergency personnel are working on the torso.

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DEDICATION

To my mom and dad, for being present in times of happiness and achievements as well as in times when I needed support.

To my husband, for his constant support and encouragement and for flying more than 2000 km to be a part of my experiments.

To my sister, who motivated me to come to Canada for my graduate studies and supported me in every possible way until I achieved my goal.

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INTRODUCTION

Accidental hypothermia results from prolonged immersion in cold water. The rate of core cooling during immersion depends on variables such as water temperature, insulation, anthropometrics, amount of body surface area exposed to the water, sea state, body position and movement (19).

Skin cooling during cold-water immersion results in the initiation of shivering thermogenesis. This is an efficient protective mechanism as it increases the metabolic heat production up to five-six times the resting metabolic rate in mildly hypothermic individuals (1,13,44). Vigorous shivering prevents (43) or attenuates (64) the rate of core cooling during cold exposure. As well, a mildly hypothermic, vigorously shivering individual rewarms at a rate of 3-4˚C/hr (25). Inhibition of shivering results in a greater post-cooling fall in the core temperature ($T_{c;}$ afterdrop) and a reduction in the rate of rewarming (26). As shivering heat production can effectively rewarm a mildly hypothermic individual, application of external heat is not necessary but may still be beneficial as it helps conserve energy stores and decreases work of the heart. If there is no external heat source available, then shivering should be maximized by drying the patient and providing a vapour barrier and maximal insulation (25). However, external heat application is necessary when the shivering response is absent, as in the case of severe hypothermia (24).

Several methods of external rewarming have been studied in mildly hypothermic, shivering subjects, such as body-to-body contact (30), a charcoal heater (25), and forced-air warming (29). These rewarming methods increase skin temperature, reduce the stimulus for shivering, and thereby suppress shivering heat production. The rate of rewarming is consistently similar for external rewarming and shivering-only methods. Therefore, it is likely that the amount of heat donated by these external heat sources is approximately similar to the amount of shivering heat production that is inhibited (25,29,30).

A series of head submersion studies from our laboratory (Laboratory for Exercise and Environmental Medicine) demonstrated that with the body insulated or exposed in 17˚C water, immersing the whole head results in an increased rate of core cooling, with no additional increase in metabolic heat production (64,65). A surprising result of these studies was that the head-only immersion resulted in the same rate of core cooling to body-only immersion (0.7 ± 0.5˚C·h^{-1}) (64). Some of the possible explanations for these similar core cooling rates could be: 1) although there was less total heat loss in the head-only cooling condition, there was also a much smaller increase in shivering heat production compared to the body-only cooling condition (64); 2) the skin blood vessels in the scalp do not constrict in response to cold as they do in other body areas such as the torso, resulting in greater relative heat loss (18); and 3) if head-only cooling caused a greater overall peripheral vasoconstriction than body cooling (thus, reducing the mass of the tissue that is effectively perfused, i.e., the effective perfused mass), a given amount of heat loss from the head would have an exaggerated cooling affect on this reduced thermal core (80).

Although we have shown that head cooling is very effective in decreasing core temperature, less is known about warming the core through the head in a cold-stressed individual. Head warming could be more effective than torso rewarming if: 1) head warming does not suppress shivering; and/or 2) head warming does not increase the size of the effective perfused mass compared to torso warming. In that case, a given amount of heat donation through the head might be more effective in rewarming a hypothermic individual than heat donation through the torso.

First, since head cooling does not elicit a shivering response during cold exposure (64,65), then it is possible that head warming will not suppress shivering during warming. This could be possible on the basis of the following mechanism: cooling of the head results in minimal to no shivering heat production either due to: a) less or not enough decrease in the total mean skin temperature thereby, not providing enough thermal stimulus to elicit a shivering response; and/or b) direct inhibition of shivering. Similarly, warming the head in a cold individual could minimally reduce the thermal stimulus for shivering and/or remove shivering inhibition.

Second, as a result of cold-water immersion, there is a decrease in the general peripheral blood flow (peripheral vasoconstriction) thus; there is a reduction in the mass of perfused tissue. Torso warming increases the peripheral blood flow and the effective perfused mass. Head warming could be expected to induce a smaller increase in peripheral blood flow (and therefore effective perfused mass) than torso warming. Thus, the convective component of core temperature afterdrop would be less during head warming. Also, if head rewarming has less effect on increasing the effective perfused mass, then a given amount of heat donation to a reduced effective perfused mass will result in a greater rate of core rewarming compared to torso warming.

To date however, the effects of head warming following cold stress have not been determined. The purpose of the study is to compare the core rewarming effectiveness of the same amount of heat donation through the head or torso in rewarming mildly hypothermic individuals. It was hypothesized that heat donation through the head will be more effective than through the torso; and that compared to torso warming, head warming will result in greater shivering heat production, smaller afterdrop and greater rate of rewarming.

LITERATURE REVIEW

CONTROL OF BODY CORE TEMPERATURE

Despite a wide range of environmental temperatures, humans can maintain a near constant body core temperature (T_c, 37 ± 0.5˚C) (2). A balance between heat gain and heat loss is necessary to maintain this near-constant T_c.

The four mechanisms by which heat is lost from the body to the environment are: conduction, convection, radiation and evaporation (20). Conductive heat loss occurs when the body is in direct contact with a substance (i.e., solid or liquid) which is colder than the skin. Some substances have higher thermal conductivity than others; for example water has about 25 times greater conductivity than air at the same temperature (57). Therefore, a significant amount of heat can be lost by conduction by a person in cold water.

Convective heat loss occurs from the body when there is movement of fluid, which has a lower temperature than the skin temperature (T_{skin}), across the body surface. This fluid could be in liquid or gas form. Heat loss from the skin results in warming up of a still boundary layer of fluid adjacent to the skin. Convective heat loss occurs when the boundary layer of fluid is removed and a new boundary layer must be warmed. Convection is the major mechanism of heat loss in a windy cold air environment whereas, conduction is the primary mechanism of heat loss during cold-water immersion.

Radiative heat loss occurs from the human body through the air to solid objects and/or the atmosphere that have a lower temperature, mainly in the form of infrared radiation. Approximately 45 percent of heat is lost in the form of radiation in a thermoneutral environment (20) but the relative contribution decreases in a colder environment as total heat loss increases.

Evaporative heat loss occurs when a fluid changes from liquid to gaseous state. Since energy is required to change the state of a liquid to gas, evaporation cools the surface. For example, when 1 gram of water evaporates, it extracts 0.58 Kcal of heat in this process (20,82). Evaporative heat loss only affects the body if the fluid evaporates from the skin surface or the wet clothing which is in contact with the skin surface but, not if the fluid falls off of the skin surface to the ground.

Sources of heat gain are internal and/or external. The internal mechanism of heat gain is metabolic heat production which consists of resting heating production and muscle activity (voluntary or involuntary). Resting metabolic rate can be defined as the energy expended by an individual, who is resting quietly in a supine position (62). It is a sum of the metabolic processes occurring in the active cells to maintain the normal functions at rest (55). These processes occurring primarily in the liver produce about 1 Kcal of heat per kilogram of body weight per hour (20). In a resting adult, resting metabolic heat production ranges from 70 to 100 Watts (82). Heat production can be increased by voluntary and involuntary muscular exercise. During voluntary exercise, metabolic rate rises up to 20 times its resting value and approximately 80% of the energy used is given off as heat. At mild walking pace, heat production can go up to 280-350 W and during heavy exercise, it can be much greater than 1000 W (58). The body increases its metabolic heat production when it is under a cold-stress. Shivering heat production is an involuntary alternating contraction and relaxation of the skeletal muscles (20). This muscular exercise does no mechanical work but produces heat. It is a defence mechanism against body cooling and can increase the metabolic heat production up to 5-6 times the resting metabolic rate (1,13,44)

Heat can also be gained from the external environment when the ambient temperature is higher than T_{skin}. Heat gain can occur by conduction, convection, radiation, or condensation. Heat can be gained by conduction if skin is in contact with a surface of higher temperature (e.g., hot water bottles, heating pads, or when immersed in a hot-water tub (20). Convective heat gain occurs when a warmer fluid moves across the body surface, for example forced air-warming units have been studied for convectively rewarming mildly-hypothermic subjects (29). Warmer objects radiate heat to the skin in the form of infra-red radiation that can be absorbed by the body (e.g., solar radiation). Condensation is the process of conversion of a molecule from its gaseous state to a liquid state, with release of energy (77). In a hot and humid environment, it is possible that water vapour will condense onto the skin surface giving heat to the body.

Factors Affecting Heat Loss And Body Core Cooling

Various factors affect the rate of heat loss and core cooling during cold exposure. These factors include: environmental, intrinsic body factors, thermal protection, behavioral, and non-thermal factors.

Environmental factors

Medium of heat transfer. Rate of heat loss depends on the medium of heat transfer. Water is a medium of relatively high heat transfer in comparison to air (57). This is due to a difference in the thermal properties of the two. The specific heat of the water is about 4000 times greater and, thermal conductivity is about 25 times greater than that of the air at the same temperature (57).

Fluid movement. Core cooling rate depends on the sea-state (i.e., waves) and wind. Core cooling rate in rough seas is affected by the factors such as flushing of the garments with cold water, swimming in order to maintain airway free-board (32,36,57) and passive movements of the body by the waves (57). It has been shown that the core cooled faster when subjects were immersed in a wave tank as compared to calm water (35). Thus, in rough-seas, the convective heat loss due to blowing wind and waves will result in faster core cooling than in calm-seas.

Since most of the studies explaining effects of the various factors on the core cooling have been done in cold-water, these factors will be discussed primarily in relation to the cold water and not the cold air. In addition, these factors will affect the core-cooling in a similar manner irrespective of the medium except that the core-cooling will be much faster in the cold water than in the cold-air.

Temperature. There is an inverse linear relationship between the water temperature and the core cooling rate (36,39). Thus, the core cools faster in the colder water.

Intrinsic body factors

Body morphology (size and composition). A greater surface-area-to-mass ratio favours cooling of a body. Thus, children cool faster than adults, small sized adults cool faster than larger adults, and tall individuals cool faster than short individuals (19). Body composition also has an important effect on the body core cooling. Subcutaneous fat is an insulator against the heat loss and there is an inverse linear relationship between the core cooling rate and the mean skinfold thickness (48). Shivering thermogenesis, which is a primary defence mechanism against the core cooling is lower in people with higher fat content at a given skin temperature (48,50). In moderately cold-water, people with low and high fat have the same rate of core cooling because of the greater shivering thermogenesis in low fat people (19). However, at colder water temperatures (8˚C), insulation provided by the body fat results in attenuation of the core cooling rate (23).

Shivering. Shivering heat production increases with a decrease in the core and the skin temperature. Shivering can prevent (43) or attenuate (64) the rate of core cooling in a mildly hypothermic, vigorously shivering individual. If well insulated from the external environment, this individual can rewarm at a significantly high rate of 3-4˚C/hr by shivering thermogenesis only (25). However, shivering is inhibited in case of a severely hypothermic victim, resulting in a greater T_c afterdrop and a reduced rate of rewarming (26).

Thermal protection

Previous studies have shown that a wet-suit results in a higher rate of core cooling compared to a dry-suit (71). This could be due to the fact that a dry-suit does not allow contact between the skin and the water whereas; a wet-suit allows water to flush the skin during a cold-water immersion. Cooling rate also varies with the sea-state for a wet-insulated garment, with almost doubling for a rough sea compared to a calm sea. However, the cooling rate is not affected by sea-state for a dry-insulated garment (71).

Behavioural factors

Exercise. Generally, exercise is not advised during a cold-water immersion incident. This is due to the fact that the skeletal muscles provide insulation to the body and this insulation is reduced during exercise as the greater amount of blood flows to these muscles thus, causing greater conductive heat loss from the skin surface to the cold water. The increase in metabolic heat production due to exercise is not enough to offset the heat loss that occurs due to the reduced insulation (73). However, if enough external insulation is worn, the heat produced during exercise can be retained within this insulation, subsequently attenuating the rate of core cooling. In a study done by Faerevik and colleagues, 5-min leg exercise was performed intermittently (every 20 min) during a cold water immersion (water temperature 2˚C, air temperature of -2˚C, and wind speed of 5 $m \cdot sec^{-1}$) while wearing a neoprene survival drysuit. The intermittent exercise resulted in attenuation of core cooling as the heat produced was retained within the insulation (drysuit) (14). Thus, intermittent exercise can be beneficial if enough insulation is worn to retain the heat.

Behaviour and posture of the body in cold water. The major areas of heat loss during a cold water immersion are the lateral thorax, upper chest, back, and groin, identified using infra-red thermography (37). Little insulation (muscle and fat tissue) in these areas combined with the presence of major blood vessels such as femoral vessels, carotid arteries, and jugular veins resulted in a greater heat loss to the environment. In a study by Hayward and colleagues, it was demonstrated that maintaining a heat escape lessening posture (HELP) and the group huddle reduced the exposure of these high heat loss areas to the environment thus, significantly reducing the core cooling by 69% and 66%

respectively, in comparison to the control behaviour (38). Furthermore, behaviour of the victim during immersion can also affect the core cooling rate (37). It was seen that the swimming activity caused faster core cooling as there was an increased surface heat loss which was not compensated by the heat production due to the exercise. The two swimming behaviours- treading water, and drownproofing- increased the core cooling rates by 34% and 82% respectively in comparison to the control behaviour (38).

Amount and area of body immersed in the water. A greater amount of heat is lost from the body parts that are immersed in the water than those exposed to the air. Thus, it is recommended that the victim should try and reduce the amount of the body immersed in water as much as possible (20).

Head Immersion. Partial or complete submersion of the head into the water can have a significant effect on the core cooling. It has been shown that submersion of the dorsal head (51) or whole head (64) during a cold-water immersion increases the rate of core cooling. Even if the body is insulated from the water, submersion of the whole head into water can result in a significantly higher core cooling rate (64). This emphasizes the importance of keeping the head out of the water as much as possible during any cold-water activities.

Nonthermal factors

Several nonthermal factors such as nitrogen narcosis, hypoglycemia, hypercapnia, hypoxia, alcohol etc. affect the thermal regulation of the body thereby, influencing the rate of core cooling (19). Compressed air breathing during underwater activities such as diving or anaesthesia during surgery results in narcosis. This narcosis, which is induced due to inhalation of nitrous oxide, causes a reduction in the threshold for shivering and an increase in the core cooling rate (60). Similar effects on thermoregulation are seen during insulin-induced hypoglycaemia (59). Hypercapnia (46) and hypoxia (47) have been shown to lower the T_c threshold for shivering thus, accelerating the core cooling. In addition, hypoxia also lowers the T_c threshold for vasoconstriction (47). Alcohol consumption results in accidental immersions due to physical and mental impairment. Several studies have also shown that moderate doses of alcohol (blood alcohol levels of 50-100 mg/dL) can affect the thermoregulation during a cold exposure (17,45,54). Although it lowers the T_c threshold for vasoconstriction (a vasodilatory effect) during cool water immersion (28˚C), it does not affect the threshold for shivering or core cooling rate (45). However, in colder water (<28˚C), it has been shown to reduce the metabolic heat production by 10-20% with no significant increase in the core cooling rate (17,54). High doses of alcohol (>200 mg/dL) result in an impairment of the thermoregulatory system along with the motor and mental impairment. In this situation, the major threat will be from drowning in cold-water and not from hypothermia (19).

Body Thermoregulatory System

Various physiological mechanisms help in losing heat from the body when exposed to a hot environment and, in gaining heat and/or reducing heat loss in response to a cold environment. However, behavioural responses such as switching on a fan or a heater, putting on clothing etc. are seen before these physiological responses. These mechanisms are controlled by a primary thermoregulatory center at the base of the brain called hypothalamus (3). This center receives information from various peripheral and core sensors via afferent nerves which is then integrated to generate efferent responses. Therefore, thermoregulation occurs in three phases: afferent thermal sensing, central integration, and efferent (warm and cold) responses (2,68). The afferent thermal input is obtained by various peripheral receptors in skin surface and core receptors in deep central tissues, spinal cord, hypothalamus and other parts of the brain. There are distinct groups of receptors for detecting the cold and warm ambient temperatures. The thermal information from the cold receptors is carried via A-delta fibres and from the warm receptors by unmyelinated C fibres to the hypothalamus. Most of the thermal information reaches the hypothalamus via the spinothalamic tract.

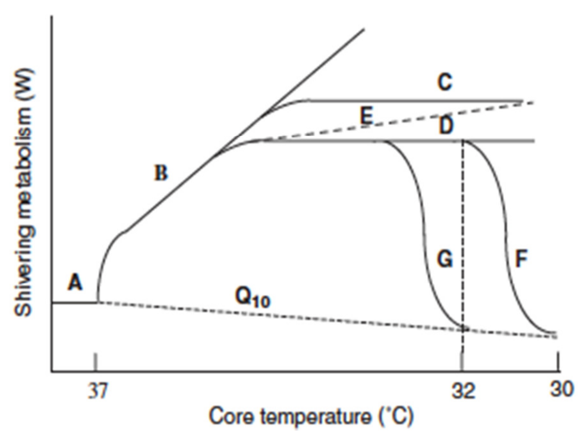
This information from both the central and peripheral core sensors is then integrated at the hypothalamus. The hypothalamus also acts as a comparator as it compares this integrated thermal signal with an adjustable set point (4). However, it was later established that it is not a set point rather a range of the core temperatures (56). Core temperature is maintained within this range solely by the vasomotor responses (i.e. vasoconstriction and vasodilation) and is bound on either side by the T_c thresholds for shivering and sweating. This range in which there is no sweating or shivering response and the T_c is maintained solely with vasomotion is called as 'Interthreshold zone' or 'Null Zone' or 'Thermoeffector threshold zone'(56). When there is an increase in the integrated thermal signal, as occurs during exercise or in a hot environment the following warm responses are initiated: (a) behavioural responses such as heat avoidance, switching on a fan etc.; and (b) autonomic responses that include vasodilation and sweating. Vasodilation of the peripheral blood vessels results in an increase in the blood flow (7) to the periphery, thus increasing heat loss primarily via radiation to the air environment. If the vasodilation is not enough to maintain the T_c within the interthreshold zone, the sweating response is initiated. Heat loss through sweating occurs primarily via evaporation of the fluid from the skin surface. On the other hand, in a cold environment the integrated thermal signal to the hypothalamus decreases and, the following cold responses are initiated: (a) behavioural responses such as cold avoidance behaviour, increasing insulation by putting on clothing, turning on the heaters etc.; and (b) autonomic responses that include vasoconstriction and shivering. Vasoconstriction of the peripheral blood vessels results in reduced blood supply to the periphery, thus decreasing the radiative heat loss to the environment (56,57,66). Further decrease in the integrated thermal signal with continued exposure to cold results in initiation of the shivering heat production (20). Shivering is accompanied by an increase in oxygen consumption, minute ventilation, heart rate, cardiac output, and mean arterial pressure (61). During a cold exposure, the secondary responses to tissue cooling are seen first i.e., shivering. If exposure continues for a longer duration then the primary responses of tissue cooling such as a decrease in tissue metabolism and neural inhibition are seen (61).

CONTROL OF SHIVERING

An early sign of cold-stress is the beginning of the shivering response. Initially during a cold-exposure, shivering begins in response to a decrease in T_{skin} even though the T_c is at 37˚C (23). This is due to the fact that the efferent responses are initiated in response to an integrated thermal signal and not the T_{skin} or T_c alone. As the T_{skin} decreases, there is an increase in shivering metabolism (M_{shiv}). At any given T_c, M_{shiv} follows a parabolic relationship with T_{skin} within the range between 33 to 10˚C, with maximum M_{shiv} occurring at about 17-20˚C (13,76). On the other hand, there is an inverse linear relationship between the T_c and the M_{shiv}. As the T_c decreases from 37 to 32˚C, there is an increase in $M_{shiv.}$ Subsequently, shivering diminishes and ceases at a T_c

of about 30˚C. A conceptual model for control of shivering has been developed in our laboratory (84) to predict thermoregulatory responses in humans to a long-term cold exposure (Figure 1). The primary response to tissue cooling is decreased metabolism according to the Q_{10} principle (a decrease in metabolism with every 10˚C decrease in temperature) (21). Initially however, the secondary response is an increased metabolism due to shivering. Shivering increases metabolism above basal values as T_c and T_{skin} decrease (Line A). As the T_c decreases from 37 to 32ºC, M_{shiv} is predicted to rise up (line B) to a theoretical maximum (line C). However, a submaximal shivering response is seen in most conditions (line D or E, compared to line C). At a T_c greater than 32ºC, a long-term cold exposure can eventually result in decreased M_{shiv} due to limited substrate availability (line G). But if the T_c falls below 32ºC, the decrease in the shivering metabolism is attributed to thermoregulatory inhibition resulting from global brain cooling and an impaired neural control (line F) (74).

Figure 1. Conceptual model for control of shivering intensity (84).



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MEASUREMENT OF HEAT EXCHANGE

Calorimetry

A calorimeter can measure the amount of heat dissipated or absorbed by the body and calorimetry can be defined as measurement of heat energy (66). A calorimeter can be a whole-body calorimeter or a suit calorimeter. A human whole-body calorimeter has been described (66,70) and used in various studies. Air is injected at a known constant flow rate into the calorimeter chamber and the area surrounding it. This is done in order to reduce any kind of thermal gradient across the chamber walls thus, making the heat flux across the walls negligible. The temperature and humidity difference of the inlet and outlet air reflects the heat dissipated by the subject (66,70). A water-perfused suit calorimeter works on the same basic principle as the whole-body calorimeter (49,81). However, unlike the whole-body calorimeter the subject can move around freely, exercise, eat meals, and sleep while the heat exchange gets measured continuously by the suit calorimeter. It consists of snugly fitting underwear that has a network of small vinyl plastic tubing that covers hands, arms, legs, tops of the feet, torso, and head excluding the face. The heat extraction (H_w) is calculated from the following measured variables- mass flow rate of water (m_w), and the temperature difference of water from inlet to outlet (T_{wo} - T_{wi}). H_w is given by:

$H_w = m_w . C_p (T_{wo} - T_{wi})$, where C_p is 1.0 for water.

Several layers of insulation are necessary over the suit calorimeter to reduce the heat flux gradient between the water tubes and the external environment and to reduce the heat loss from body to the environment.

Heat Flux Disc/Transducer

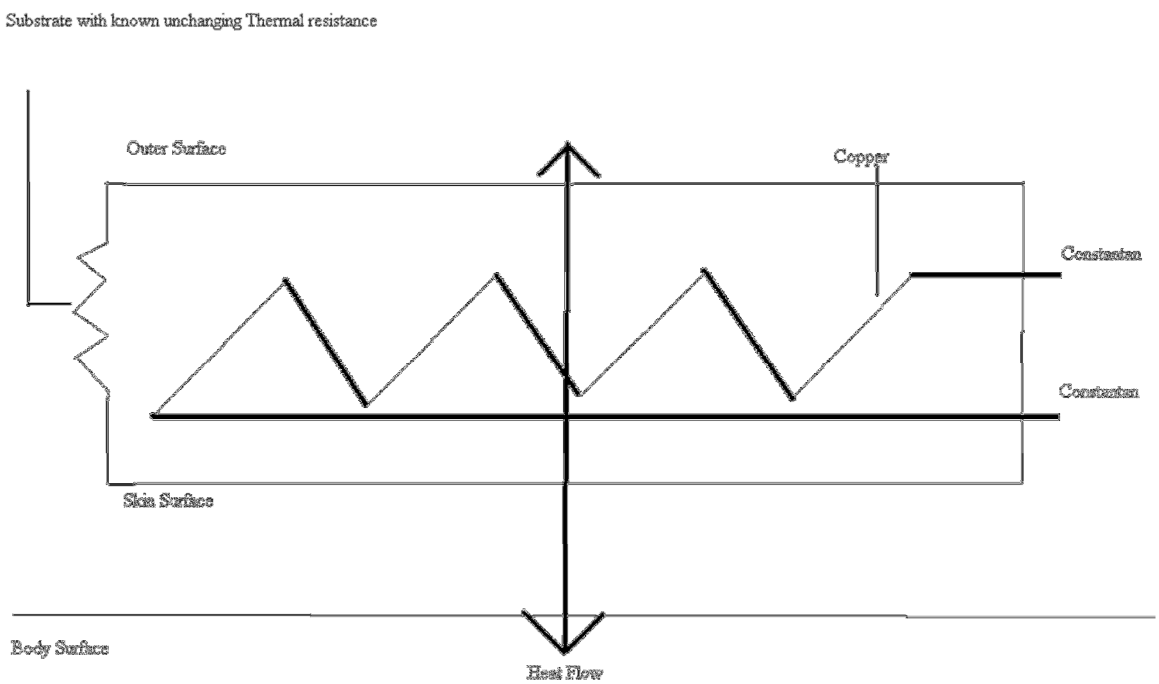
Heat flux discs or transducers are used extensively in thermoregulation studies to measure the heat loss or gain across the skin surface. These transducers consist of multiple thermocouples made up of two different metal alloys (conductors) such as a copper-constantan thermocouple, woven together in series across a substrate of known thermal resistance (Figure 2).

Each heat flux sensor has the shape of a flat disc, as shown in figure 2. In this figure, the outer surface refers to the surface that is exposed to air and skin surface refers to the opposite surface which is in contact with body surface. Within this disc, two different metals (copper and constantan) are arranged in series to form a thermopile. The two metals are arranged alternately in a zig-zag fashion such that thermocouple junctions (copper-constantan junctions) are formed alternately near the outer surface and near the skin surface of the disc substrate. The two sets of thermocouple junctions- one near the outer surface and one near the skin surface, generate separate electromotive forces (EMFs in mV) such that each EMF is proportional to the temperature (˚C) on their respective surfaces- T_{out} and T_{skin}. However, output of heat flux disc is a difference of the two EMF s (ΔEMF) which is proportional to the temperature difference across the two sets of thermocouple junctions. Heat flux across the disc (HF_{disc}) can be measured from the temperature difference across these thermocouple junctions (ΔT) and the known thermal resistance of the substrate (9,69):

$$HF_{disc}\,(W \cdot m^{-2}) = \Delta T\ (^{\circ}C)\ /\ \text{Thermal resistance}\ (^{\circ}C \cdot m^{2} \cdot W^{-1}).$$

It should be noted that there is a separate copper-constantan junction of a single thermocouple embedded in the middle of the heat flux disc on the skin surface (not shown in Figure 2).

Figure 2. Heat flow sensor with embedded thermopile (single thermocouple not shown).



This ΔEMF (mV) now travels through ISO-THERMIX and is eventually fed as an input to a PC Computer (DAYTEK) where, a software "Thermo program" converts it to HF_{disc} $(W \cdot m^{-2})$ using the following formula:

$$HF_{disc}\,(W \cdot m^{-2}) = C\,(W \cdot m^{-2})\,/mV * \Delta EMF\ mV$$

Where, $C\,(W \cdot m^{-2})\,/mV$, is a calibration constant, specific for a heat flux disc.

For example, if a disc has $C = 92.5\,(W \cdot m^{-2})/mV$ then, the Thermo program will calculate HF_{disc} as follows: $HF_{disc} = 92.5\,(W \cdot m^{-2})/mV * \Delta EMF\ mV$

Thus, the heat flux measured will be proportional to the ΔEMF (mV) which was proportional to the temperature difference between two sides of the disc.

These transducers can measure heat loss or gain that occurs via radiation, conduction and convection but not evaporation. Flux can be defined as positive when the heat traverses the skin towards the environment and negative when heat is absorbed by the skin from the environment. Heat flux is measured in $W \cdot m^{-2}$ from different skin sites such as the head, chest, abdomen etc. Heat flux is calculated for each site ($W \cdot site^{-1}$) as following:

HF_{site} ($W \cdot site^{-1}$) = HF_{disc} ($W \cdot m^{-2}$) * Body Surface Area (m^2) * Regional % of the site.

Body surface area (BSA) can be calculated by using the following equation (8):

$$BSA\ (m^2) = weight^{0.425}\ kg * height^{0.725}\ (m) * 0.007184$$

Layton et al. (49) has assigned regional % to different sites for example- forehead 4%, dorsum of the head 3%, chest 8.75%, abdomen 8.75%, back 17.5% etc.

Total heat flux from the body is calculated as a summation of heat flux from different sites:

$$HF_{body} = \sum HF_{site}$$

Metabolic or Shivering Heat Production

Shivering heat production can be calculated from the measured oxygen uptake ($l \cdot min^{-1}$) of the subject and the Respiratory exchange ratio (RER) using the following equation (80):

$$M\ (W) = VO_2 * 69.7 * \{4.686 + [(RER - 0.707) * 1.232]\}$$

Oxygen consumption can be measured with an open-circuit method from measurements of expired minute volume and inspired and expired mixed gas concentrations sampled from a mixing box. Another method of estimating or calculating heat production from VO_2 is by setting 1 litre O_2/min equivalent to 352 W (16).

CLASSIFICATION OF HYPOTHERMIA

During a cold-water immersion, the core temperature decreases gradually from its normal value of 37˚C. As the T_c falls below 35˚C, it can be clinically defined as mild hypothermia. Hypothermia can be classified into mild, moderate and severe on the basis of the T_c (19). In mild hypothermia (T_c = 35˚C to 32˚C), thermoregulatory mechanisms of the body are intact however, a person may develop ataxia, dysarthria, apathy and amnesia. In moderate hypothermia (T_c = 32˚C to 28˚C), there is a reduction in the effectiveness of the thermoregulatory system, the level of consciousness, and cardiac dysrhythimas may occur. In severe hypothermia (T_c = below 28˚C), the victim loses consciousness, does not shiver, develops acid-base disturbances and is at risk of ventricular fibrillation or asystole.

HEAT DONATION AND METHODS OF REWARMING A HYPOTHERMIC VICTIM

Prior to rewarming a hypothermic victim, it is imperative to stabilize the cardiovascular system, to stabilize or prevent further decline of the T_c, to transport the victim to a site of definitive medical care, and to establish a steady, safe rate of rewarming (11,32,75). Following cold-water immersion, choice of the rewarming method in the field and during transportation depends upon several factors such as level of hypothermia, the environmental conditions, rescuer's level of training, resuscitative equipment available, type of transportation, and time required for transportation to a site of definitive care (19). Rewarming methods can be classified into spontaneous/endogenous and exogenous, based on the source of heat production/donation. Spontaneous/endogenous rewarming includes shivering heat production and exercise; as the heat is actively produced by the body. Exogenous heat sources can be further classified into external (supplies heat primarily to the body surface) or internal (the heat is applied via invasive or non-invasive methods directly to the core) (21).

Warm Water Immersion: complete vs. partial

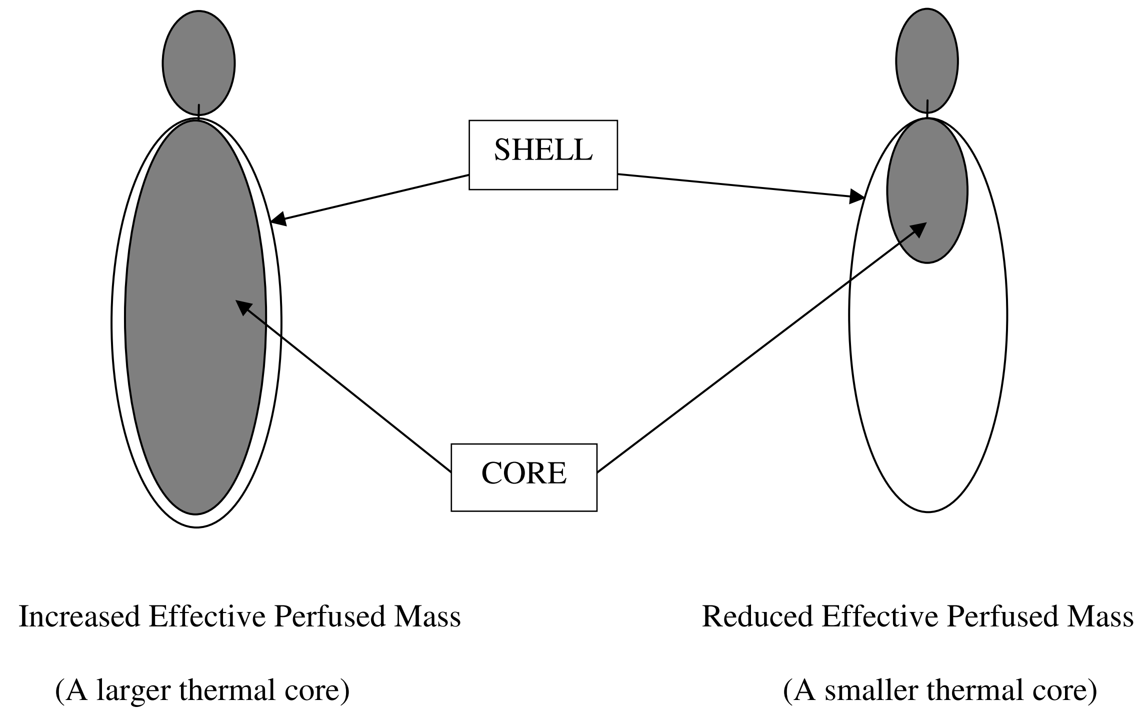
Complete or whole-body warm water immersion (40-43˚C) has been proven to be a very effective method of rewarming as the heat is donated to a large surface area. Rewarming with this method occurs at a much higher rate than the shivering only (5,6,53,67). T_c afterdrop (continued fall in T_c after removal from the cold water, until it starts to rise) has been shown to decrease (5,67) or remain same (6,53) as with shivering only. Note this is clinically unsafe as a victim may go into ventricular fibrillation or cardiac arrest.

Partial immersion of the body without extremities (trunk immersion) in warm water bath had a smaller T_c afterdrop and a higher rate of rewarming compared to the shivering only (6,33,41). It has also been compared to the complete body immersion in various studies. During complete warm water immersion, the opening up of the previously vasoconstricted peripheral vasculature in the extremities can result in convective cooling of the heart subsequently, increasing the T_c afterdrop. This effect was expected to be eliminated in case of partial immersion. However, the partial immersion did not have a smaller T_c afterdrop (6,33,41) and in fact had a lower rewarming rate than the complete immersion (6). This could be due to the fact that even though there is some peripheral vasodilation, the net heat gain is a lot higher during complete immersion.

Arm And Leg Immersion [Arteriovenous Anastomoses (AVA) Rewarming]

Arteriovenous anastomoses (AVA) are physical connections between the arteries and veins and are most abundant in the fingers and toes (20). These are usually open in a thermoneutral or a warm environment and the superficial veins in the forearm are filled with the blood returning from the periphery. However, these are closed in a cold environment in order to reduce peripheral blood flow and cutaneous heat loss, and the superficial veins are collapsed (78). Opening up of these AVAs in response to local heating (79) can greatly increase the blood flow to the periphery, thus increasing the heat exchange between the periphery and the environment. Rewarming of mildly hypothermic victims by donating heat through the AVAs was found to be a very effective method (80). It was demonstrated that immersion of the distal extremities (hands, forearms, feet, and lower legs) in warm water (42˚ or 45˚C) resulted in a smaller T_c afterdrop (0.4 ± 0.2˚C) as compared to the shivering only (0.6 ± 0.4˚C) (80). Interestingly, the rewarming rate was significantly greater with the distal extremities immersion in 45˚C water (9.9 ± 3.2˚C/hr) than 42˚C water immersion (6.1 ± 1.2˚C/hr) than shivering only (3.4 ± 1.5˚C/hr). Opening of the AVAs in response to the distal extremity immersion resulted in an increase in the heat delivery to the heart via the superficial veins in the forearms and lower legs. These superficial veins carrying the warm blood do not come in close contact with deeply situated arteries carrying cold blood, thus there was minimal counter-current heat exchange between the two. Although, it was established that AVA rewarming by this method is a source of high heat delivery, it might not be a practical method for pre-hospital or field treatment of the hypothermic victims.

Figure 3. Effective perfused mass- before and after cooling.



An interesting concept that emerged from this study was that of the "effective perfused mass" (80). Effective perfused mass or a thermal core can be defined as the mass of tissue that is effectively perfused (64). The size of this mass can change in different ambient conditions (Figure 3). According to a two-layer thermal model (72) the body has 2 layers- the core and the shell. The muscle, fat, and skin layers can be either part of the core or the shell, depending upon the state of vasomotion and whether the tissue is perfused. During a cold-exposure, the peripheral vasoconstriction reduces the size of the effective perfused mass (a smaller thermal core) as most of the blood from the periphery is directed to the core in order to conserve heat. The muscle, fat, and skin layers now become a part of the shell. On the other hand, massive vasodilation occurs in response to a hot environment and increases the size of the effective perfused mass (a larger thermal core). The muscle, fat, and skin layers now become a part of the core.

In AVA rewarming study (80), it was seen that during rewarming, the oesophageal temperature (T_{es}) and the aural canal temperature (T_{ac}) rose rapidly whereas the rectal temperature (T_{re}) was lagging behind, warming sluggishly. This indicated that T_{es} and T_{ac} represented the temperature of the reduced effective perfused mass and not the overall mean body temperature. On the other hand, T_{re} showed that there was still some abdominal tissue that was cold and unperfused, and acted as a cold sink.

The effective perfused mass was calculated in the study by using the standard heat transfer equation:

$$Q = \text{Mass} \cdot C_p \cdot \delta T$$

Where:

Q = heat transfer through the distal extremities

C_p of the body= 3.7 $Kj \cdot {}^{\circ}C^{-1} \cdot kg^{-1}$

δT = Rate of change of temperature in $^{\circ}C \cdot hour^{-1}$

Heating Pads

External heat can be applied to a hypothermic victim by using heating pads. Depending upon the source of heat production, these could be of various kinds such as- chemical heating pads, hot-water bottles, a charcoal heater etc. These rewarming methods have been studied extensively in mildly-hypothermic, vigorously shivering individuals (25,33). These methods increase the T_{skin}, reduce the integrated thermal signal for shivering, and thereby suppress the shivering heat production. Generally, the rate of rewarming has been shown to be similar for the external rewarming and shivering only methods. This could be due to the fact that the amount of heat donated by these external sources is just enough to compensate for the shivering heat production that is inhibited. However, they provide other advantages such as increased thermal comfort, preservation of energy stores and reduction of the cardiovascular stress. These sources will be beneficial (i.e., increase core rewarming) when there is no shivering heat production or shivering is inhibited. A few recent studies that used a human model for severe hypothermia (26) have shown that these sources are very efficient in rewarming the core of non-shivering, hypothermic individuals (42,52). Hot-water bottles and chemical heating pads provided high initial heat delivery to a large surface area thus reduced the amount and duration of the T_c afterdrop, whereas a charcoal heater that delivers heat to a relatively smaller surface area was effective in reducing only the duration of T_c afterdrop. The charcoal heater and hot-water bottles provided high continuous heat delivery, and thus had a steady core rewarming rate, whereas the chemical heating pad had a smaller core rewarming rate as it provided initial high heat delivery that gradually declined over time. All of these sources have been recommended for pre-hospital treatment of severely hypothermic victims.

Water Perfused Cover

A piped suit developed by Marcus (53) consists of a one-piece light cotton garment that carries a network of fine pipes perforated terminally near the skin. It allows for flow of warm water over the skin. The warm water that flows over the skin falls on to the floor, where it is collected by a floor drain. Its efficacy in rewarming hypothermic volunteers was tested (53). A vapour barrier was used on top of the piped suit to minimize the heat loss to the environment. The piped suit had a higher rate of rewarming compared to the shivering only. It was also compared to a warm-water bath and it had a smaller rate of rewarming than the warm water bath.

Forced-Air Warming (FAW)

This is a rewarming method in which the warm air is blown through a soft cover and exits via the holes on the patient's side of the covers, delivering the heat convectively. It has been shown that the soft FAW cover attenuates the T_c afterdrop by 30% as compared to the shivering-only condition (29) during rewarming of mildly-hypothermic, vigorously shivering individuals. However, it did not significantly increase the rewarming rate. This could be due to the fact that the peripheral rewarming inhibited shivering heat production and the heat provided was just enough to compensate for the decrease in shivering heat production.

FAW has also been tested for rewarming mildly and severely hypothermic volunteers in a simulated field condition (-20˚C air) (10). In the case of the mildly hypothermic volunteers, FAW suppressed shivering heat production by 30%, had no effect on the T_c afterdrop but almost doubled the rewarming rate compared to the shivering only condition. In case of severely hypothermic, non-shivering volunteers, it reduced the T_c afterdrop and increased the rate of rewarming compared to the control condition. In another study using the human model for severe hypothermia (26), FAW reduced the afterdrop by 30-40% and increased the rewarming rate by 6-10 fold as compared to the control condition (31).

A portable rigid force air warming cover (PORIFAC) was designed and evaluated in comparison to the conventional soft cover (26). Both covers delivered the same amount of heat to the hypothermic victims. The rigid cover was effective in rewarming the severely hypothermic volunteers as it attenuated the T_c afterdrop and provided a significantly higher rate of rewarming than the control condition (42).

HEAD COOLING

Heat can be lost from the head via conduction and/or convection (83). Conductive heat loss occurs when the heat is directly lost from the bone and the soft tissues to the environment, whereas the convective heat loss occurs from the blood that perfuses the scalp. A substantial amount of heat can be lost from the head as the blood flow to the scalp is high and the blood vessels in the scalp do not vasoconstrict in response to cold as do the surface blood vessels in other body areas (18). Contrary to these, one hypothesis predicts minimal heat loss from the dorsal head or the whole-head during cold-water submersion as it only involves 3-7 % more of the body surface area respectively (49).

A few studies from our lab determined the effect of dorsal or whole-head immersion on the core cooling when the body was either insulated or exposed to the cold water (27,51,63,64). These studies have been conducted with two different conditions i.e., with the shivering mechanism intact (51,64) or inhibited (27,63).

Lockhart and colleagues (51) determined the effect of dorsal head immersion in water (10˚C) on the body core cooling. A drysuit and two different kinds of personal floatation devices (PFDs) were used for the following three conditions- 1) a drysuit, kept the body insulated and the dorsal head immersed in the water, 2) PFD#1, kept the head and upper chest out of the water, and 3) PFD#2, kept the head and upper chest immersed in the water. In the drysuit condition, immersion of the dorsal head had no significant effect on the core cooling. However, when the dorsal head was immersed along with the whole body in the PFD#2 condition, the core cooling rate was 60% greater than with the body immersed and head out condition (PFD#1). These results were explained on the basis of following factors. First, a greater amount of surface area was exposed in the PFD#2 condition than in the PFD#1. Second, dorsal head cooling along with the body cooling (PFD#2) increased core cooling, whereas isolated cooling of the dorsal head (drysuit) had no significant effect, and this was explained on the basis of a reduced "effective perfused mass". In the dorsal head only condition, the body was not cold-stressed as it was insulated from the cold-water by the drysuit. Therefore, the extremities were relatively vasodilated so, the size of effective perfused mass was relatively large (a larger thermal core). Thus, any effect from the cooling of the scalp blood would likely have been dissipated in a larger volume of perfused tissue and would have had negligible effect on the core cooling. However, in the PFD#2 condition with whole body and dorsal head immersed, the extremities were vasoconstricted, thus reducing the effective perfused mass (a smaller thermal core). The cold blood returning from the scalp would have been distributed to this smaller volume of perfused tissue, thus having a significant effect on the net core cooling.

These conditions were repeated in another study by Giesbrecht et al (27), when the confounding effect of shivering was eliminated or minimized. Shivering was inhibited using meperidine and the subjects were immersed in water at 12˚C. Similar to previous results, dorsal head cooling with body insulated had no significant effect on the core cooling. However, there was a 39% increase in the core cooling when dorsal head was immersed along with whole-body cooling. This 39% increase in the core cooling was disproportionately greater than the 10% increase in the surface of heat loss (dorsal head and upper chest). Also, the heat loss from the head was not disproportionately greater than its contribution to the body surface area. Once again, it was explained that this exaggerated core cooling effect occurred as a result of moderate heat loss affecting a reduced effective perfused mass (a smaller thermal core).

Further studies were conducted by Pretorius et al. (63,64) to determine the effect of whole head-cooling on body core cooling with shivering intact or inhibited by meperidine and buspirone. The whole head and/or body were exposed to 17˚C water. Since two of these trials required submersion of the whole head under the water, the subjects breathed compressed air from scuba tanks that were kept at room temperature, in all the trials. When the body was cold-exposed, immersion of the whole-head increased the core cooling. Surprisingly, whole-head submersion with body insulated also increased the core cooling. Similar to previous dorsal head immersion studies, there was no proportionately greater heat loss from the head than would be expected from its contribution to the body surface area. Once again, additional cooling of the head increased core cooling proportionately more than its contribution to the total heat loss. This exaggerated core cooling effect was again explained as a result of a moderate increase in the heat loss affecting a reduced effective perfused mass (a smaller thermal core). The fact that immersion of whole-head only increased the core cooling whereas the dorsal-head only did not was explained by a greater vasoconstriction and a further reduction in the effective perfused mass when the face got stimulated during whole head submersion. This greater peripheral vasoconstriction could be a result of normal thermoregulatory mechanism and the dive-reflex, an oxygen sparing mechanism resulting from the stimulation of the trigeminal nerve. In addition, the whole head immersion with the body insulated or exposed results in greater core cooling with no additional increase in the metabolic heat production (64,65).

A very interesting finding of the whole-head immersion studies was that the core cooling rates were similar when the head only or the body only were immersed in 17˚C water, although there was a significantly greater heat loss with the body only immersion. Some of the possible explanations could be: 1) head cooling results in a greater overall peripheral vasoconstriction, therefore, a greater reduction in the effective perfused mass (a smaller thermal core) as compared to the body only. In this case, a given amount of heat loss from this smaller volume of perfused tissue will have an exaggerated effect on the core cooling, 2) although there was a greater total heat loss in the body only than the head only condition, there was also much greater shivering heat production in the body only immersion as compared to the head only immersion. Shivering might have attenuated the core cooling and increased the size of the effective perfused mass as blood flows from the core to the muscles to fuel shivering, 3) the skin blood vessels in the scalp do not constrict in response to cold as they do in other body areas (18). Thus, there could be substantial amount of heat lost from these dilated scalp blood vessels in comparison to the constricted blood vessels in rest of the body. These factors could have resulted in similar rates of core cooling for head only or body only immersion.

METHODS

SUBJECTS

A group of seven healthy and physically active volunteers (2 females) (aged 18-45 yrs) were tested. A list of participant inclusion interview questions were asked prior to recruiting the subjects to ensure they did not have Raynaud's Syndrome, or any other condition (including asthma) that could be aggravated by cold-water immersion. Subjects were asked to complete a Physical Activity Readiness Questionnaire (PAR-Q) to ensure the absence of any cardio-respiratory diseases. The protocol was approved by the Biomedical Research Ethics Board, at the University of Manitoba. A signed informed consent was obtained from each subject prior to participation.

One of the original six subjects experienced tingling and numbness in fingers and toes after the first trial. For precautionary reasons, this subject was excused from the study.

POWER ANALYSIS

Power analysis was done to determine the number of subjects required for the study, using the following equation (34):

$$n = (PI * \sigma/\mu_d)^2$$

Where:

n = number of the subjects,

PI = power index, determined from the desired power of the study.

In order to have 80% power to detect a difference between any two treatment methods:

$PI = 1.64$ (0.05 α, one-tailed) + 0.84 (0.20 β, one-tailed) = 2.48

μ_d = true mean difference between individual values for two treatment methods

σ = true standard deviation of the differences

This analysis was done with a goal of 80% power. A similar rewarming study (22) detected significant differences between T_c afterdrops of two treatment methods, with a mean difference = 0.25˚C and a standard deviation of the differences = 0.05˚C. Using this data for our power analysis, we wanted 80% power to detect a smaller difference between the T_c afterdrops of two treatment methods i.e., a true mean difference of 0.15˚C, and to allow for a higher variability between treatments i.e., a true standard deviation of 0.15˚C. Therefore, the number of subjects required was calculated as follows:

$$n = (2.48 * 0.15 / 0.15)^2$$

$$= 6.15$$

ANTHROPOMETRIC DATA

Height (m), weight (kg), age (yrs) and measurements of skinfold thickness (mm) at four sites (biceps, triceps, subscapularis, and suprailiac) were determined.

Body surface area (BSA, in m^2) was calculated by using the equation of DuBois & DuBois (8):

$$BSA\ (m^2) = weight^{0.425}\ (kg) * height^{0.725}\ (cm) * 0.007184.$$

According to Durnin and Womersley (12), body density (D_b) was estimated with an equation using the sum of four skinfolds and constants specific for gender and age group. For example, for males (17 to 19 yrs) - D_b (kg/l) = 1.1620 – 0.0630 . $\log_{base10}$ sum of four skinfolds (SFSF) (see Appendix I for different equations).

Percent body fat (% BF) was then calculated by using D_b in the Siri equation, as shown (12):

% BF = (4.95/ D_b - 4.50) * 100.

INSTRUMENTATION

Subjects wore a swim-suit and were then instrumented at an ambient temperature of ~22˚C. A single-channel electrocardiogram (ECG) was monitored continuously throughout the experiment for safety reasons and heart rate (HR) was measured and recorded at 30-sec intervals, with a Hewlett-Packard monitor/defibrillator (model 43100A). The electrodes were placed on the right and left shoulders and the left axilla. Core temperature was measured by a thermocouple inserted into the esophagus (T_{es}) to the level of the heart. This site provides the best non-invasive measure for intra-cardiac temperature (40) and is a standard procedure for our laboratory.

Skin temperature (T_{skin} in ˚C) and cutaneous heat flux (HF in $W \cdot m^{-2}$) was measured at 12 sites with thermal flux transducers (Concept Engineering, Old Saybrook, CT) which were taped to the skin according to the standard procedures used in our laboratory (49). The 12 sites were: forehead, right cheek, left temporalis, top of the head, dorsum of the head, anterior chest, anterior abdomen, upper back, left shoulder, right anterior forearm, right posterior thigh and left anterior calf. These sites were chosen in order to ensure that at least one site for both the head and torso, represents an area under: the charcoal heater (right cheek and anterior chest), ducts (forehead, dorsum of the head, top of the head, left shoulder, and upper back), and no active heating (left temporalis, anterior abdomen, right anterior forearm, right posterior thigh and left anterior calf). Note: The charcoal heater was chosen over a forced-air warming device for this study (see below). A light mesh hood was used to hold the transducers on top of the head and the dorsum snugly against the hair on the head.

Oxygen consumption ($\dot{V}O_2$ in $l \cdot min^{-1}$), carbon dioxide production ($\dot{V}CO_2$ in $l \cdot min^{-1}$), minute ventilation ($\dot{V}_E$ in $l \cdot min^{-1}$) and respiratory exchange ratio (RER) were determined with an open-circuit method from measurements of expired minute volume and inspired and mixed expired gas concentrations sampled from a mixing box (Vmax 229 by Sensormedics, Yorba Linda, Ca). Subjects wore a snuggly fitting mask, which had a one-way valve. The mask was connected to a flow transducer and the mixing box by a suitable length of light-weight, flexible tubing (29). Gas analyzers were calibrated against gases of known concentration prior to each session.

REWARMING METHODS

The active rewarming methods for this study were selected on the basis of the following criteria: 1) equal heat source applied to the head or the torso; 2) measurable heat delivery; 3) constant heat source; 4) realistic and practical; 5) comfortable; and 6) can cover the whole-head or the torso. Pilot studies were conducted to choose between a charcoal heater and a forced-air warming device as these fit all the above mentioned criteria.

Spontaneous Rewarming (Shivering Only)

In this control condition, the subject was placed inside a vapour barrier within a hooded sleeping bag. No external heat was provided and the subject rewarmed spontaneously with the heat produced from shivering. The subject inspired ambient air at room temperature (~22˚C).

Charcoal Heater To The Head (CH–Head)

A charcoal heater (HEATPAC Personal Heater, Emergco Tech. Solutions, Vancouver) consisted of a combustion chamber, an internal fan (powered by a 1.5 Volt D cell battery), a canister containing a charcoal fuel briquette, and a branched heating duct. The heater produces 250 W of heat with the briquette lasting 8–12 hours. The canister was placed inside the combustion chamber and the charcoal fuel was ignited. The heater comes with an insulated cover to prevent any thermal injury. Heated air was blown through the impermeable heating ducts by a fan within the charcoal heater above the combustion chamber. The subject was placed inside the vapour barrier within the hooded sleeping bag. Two different methods of applying the heater to the head were tried. First, the combustion chamber was placed on the dorsum of the head with ducts wrapping around the face covering most of the lateral portion of the face and top of the head. Second, the combustion chamber was placed on right side of the face with ducts wrapping around the dorsum of the head, top of the head, anteriorly over the forehead, nose, chin and the neck, not covering the eyes or the mouth (Figure 4). The heater was set to the "high" setting at least 15 minutes prior to applying it to the subject. Once the charcoal heater was applied, the subject's head was placed inside the hood of the sleeping bag. The subject inspired ambient air at room temperature (~22˚C).

Figure 4. Charcoal heater to the head (CH-Head)

Charcoal Heater To The Torso (CH–Torso)

The subject was placed inside the sleeping bag with the head inside the hood. The combustion chamber of the charcoal heater was placed on the subject's anterior chest (Figure 5). The flexible ducts were applied to the areas of high heat transfer, e.g., over the shoulders, neck, and then anteriorly under the axillae to cross over the mid anterior chest. The subject's hands were then placed on the combustion chamber. The heater was set to the "high" setting at least 15 minutes prior to applying it to the subject. The subject inspired ambient air at room temperature (~22˚C). Please note that the heater is applied to bare skin.

Figure 5. Charcoal heater to the torso (CH-Torso).

Forced-Air Warming To The Head (FAW–Head)

The forced-air warming unit consisted of a heater/blower and a rigid forced-air cover. The heater/blower (Bair Hugger 505 Heater/Blower, Augustine Med. Inc., Minn.) was small in size (30×30×30 cm, weight 4.5 kg) and produced 600 W. The rigid cover was made up of a cardboard box (39×30×25.5 cm) with a snug seal around the neck created by a neoprene collar. The cover (Figure 6) had one hole cut at the right bottom corner of the box (Inlet1, I_1), one hole right above the neck seal (I_2) and three holes on top (right above the forehead- I_3, nose- I_4 and mouth- I_5) that provided different options for attaching the hose from the heating unit. Each hole was 5.5 cm in diameter and all the holes were kept covered except the one that was being used for the heater hose. Two small openings on either side of the box served as an exhaust for exit of the warm air. The heater was set to the "high" setting. The subject was placed inside the same sleeping bag with the head outside the hood. The subject inspired warm air coming into the box from the heater/blower (~42˚C).

Figure 6. Forced-air warming cover for the head showing various inlet options.

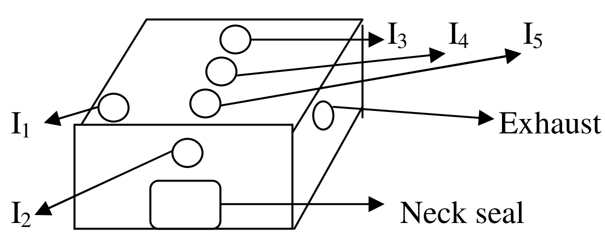


Figure 7. Forced-air warming to the head (FAW-Head)

Forced-Air Warming To The Torso (FAW–Torso)

The forced-air warming unit consisted of the same heater/blower as above and a portable rigid forced-air cover (PORIFAC) (28) (Figure 8). The rigid cover was a folding unit (93×62×3 cm when folded) made up of corrugated plastic. The unit was unfolded to fit over the subject's torso and the upper thighs. A snug seal was created around the head and the legs by neoprene_collars. The rigid cover has one hole cut in the head end and one above the abdomen that provided two options for attaching the hose from the heater/blower. Each hole is 5.5 cm in diameter and the hole above the abdomen was used. The heater was set to the "high" setting. The subject inspired ambient air at room temperature (~22˚C).

Figure 8. Forced-air warming to the torso (FAW-Torso).

PILOT STUDIES

Procedure

Four normothermic subjects participated in these pilot studies to subjectively compare forced-air warming and the charcoal heater. First, the head rewarming was carried out by using the charcoal heater followed by the forced-air warming, for all the subjects. Second, the torso warming was carried out by using the charcoal heater and the forced-air warming for one subject only.

For the CH-Head condition, two different methods of applying the heater were tried as described earlier (see Rewarming Methods). The second method with the combustion chamber on the right side of the face was determined to be more comfortable than the first method with the combustion chamber under the dorsum of the head.

For the FAW-Head condition, the heater/blower hose was attached to different air inlets. With the inlet on the right bottom corner of the box (I_1), it was found that the air escaped from the right side without spreading evenly over the rest of the face and was comfortable only for a short-time period. With the inlet above the neck seal (I_2), warm air was felt directly on to the nose and ears, with some air contacting the rest of the face. This location of the inlet was found to be uncomfortable by the subjects. With the inlet directly above the forehead (I_3), nose (I_4) and the mouth (I_5), it was found that the warm air spreads most evenly over the face in the I_4 condition. However, it was somewhat uncomfortable to breathe compared to the other two conditions.

Torso-rewarming with the charcoal heater (CH-Torso) and the forced-air warmer (FAW-Torso) was compared for one subject.

Choice Of Warming Device

The choice of the rewarming method for the study was based on the comfort and greater heat delivery. Subjects were asked to compare the two rewarming methods and comment on which feels more comfortable and/or warmer. The charcoal heater was found to be more comfortable than forced-air warming for the head condition by all of the subjects. However, there was no difference in the comfort level of the two methods for the torso condition. Two subjects found that the charcoal heater felt warmer than the forced-air warmer for the head condition, and two subjects were not able to comment on it. However, one subject who did the comparison for the torso condition felt that the forced-air was warmer than the charcoal heater for this condition.

The charcoal heater was chosen as the rewarming method for the study for several reasons. First, the charcoal heater can be used in a wider range of rescue efforts. It can be used for rewarming a hypothermic victim in the field and/or during pre-hospital transport whereas, the forced-air warmer can only be used during the pre-hospital transport as it requires a 120 Volt AC power supply. Second, a charcoal heater can be used by anyone in the field for example- the first responders, military personnel etc., whereas, a forced-air warming unit is only available to the emergency medical rescue personnel in their vehicles or the hospital. Third, the charcoal heater was found to be more comfortable than forced-air warming by all the subjects in our pilot studies. The discomfort associated with forced-air warming became evident after a while, when subjects found it difficult to keep breathing the warm air. In order to solve this issue, a larger forced-air warming cover was used so that the inlet was further away from the face. This was found to be more comfortable, however, predictably less warm. Last, there are some technical and/or scientific difficulties with forced-air warming for the head condition. In this condition, the subject breathes warm air which is similar to a real-life setting. However, inhalation of the warm air could be a confounding factor due to the following reasons: First, inhalation warming results in inhibition of the shivering heat production (67). This will be a limitation of the study, as the hypothesis of the study is that a similar heat source applied to the head will result in greater shivering heat production than heat donation through the torso. This could be solved if the subject is made to breathe ambient air by a hose from outside the box. However, this would not be a replica of real-life situation where a victim would likely prefer to breathe the warm air and not the ambient air from outside the box. Second, inhalation warming might add extra heat through the respiratory system which could be an additional advantage compared to the torso condition, where the subject is breathing ambient air. Due to these reasons, the charcoal heater was chosen as the rewarming method for the study.

PROTOCOL

Each subject was cooled on three different occasions, separated by at least 48 h. The experiments were conducted at the same time of day to control for circadian effects. Subjects were instructed to abstain from alcohol, medications or vigorous physical activity for a 24 hr period prior to the study. They were also instructed to have a small breakfast and no other food within 2-3 hrs prior to immersion. Instrumentation took about 45 minutes. The subjects then sat quietly and baseline measurements were taken for 10 minutes. With the help of an electrically isolated hoist, they were immersed to the sternal notch in a ~21˚C stirred water bath. The water temperature was then lowered to 8˚C over a period of 10 min by the addition of about 60 kg of ice. In all but the first four trials, the hands were kept out of the water by holding onto a bar placed above the water and feet were insulated with neoprene boots (see Results for explanation). Subjects remained in the water until one of the following criteria was met: T_{es} reached 35˚C, a time period of 60 min elapsed, a researcher advised exit for any reason, or the subject wished to terminate the immersion. None of the immersions was terminated due to either of the latter two reasons.

Subjects were towel dried and placed in a supine position, wrapped in a vapour barrier (2 m × 1.5 m plastic sheet) within a hooded sleeping bag. They were then rewarmed by one of the three treatment methods: 1) Spontaneous rewarming from Shivering only (Control); 2) Head warming with the charcoal heater (Head); and 3) Torso warming with the charcoal heater (Torso). The order of warming methods followed a balanced design. For the Control condition, no external heat was provided. For the Head and Torso conditions, external heat was provided by the charcoal heater, applied to the head or the torso respectively. In the Head condition trials, the collecting hose connected to the facemask was disconnected momentarily (~10 sec), to wrap the heating ducts around the face. Treatment continued for a period of 60 min or until T_{es} rose to 37˚C. Following that, subjects were transferred to a warm water bath (40-42˚C) until the T_{es} rose to 37˚C (if necessary) or they wished to exit.

Following their last trial, subjects were asked to compare the three rewarming methods based on warmth, comfort, and preference. They were also asked to provide any feedback related to the discomfort associated with any of the methods.

DATA ANALYSIS

The following variables were calculated for all three conditions:

Rate of core cooling (˚C·hr^{-1}) was calculated by linear regression for T_{es} data from the point of a steady decrease in T_{es} to exit from cold water.

Afterdrop (AD, ˚C) was calculated as the difference between T_{es} on exit from the cold water and its nadir.

Length of the afterdrop period (ADL, min) was calculated as the time difference between exit from cold water until T_{es} returned to the original exit T_{es}.

Rate of rewarming (˚C·hr^{-1}) was calculated by linear regression for T_{es} data from its nadir to 35 min of rewarming and from 35 to 60 min of rewarming.

Head skin temperature (T_{skHead}) was calculated from area weighted average of the forehead, right cheek, left temporalis, top of the head, and dorsum of the head sites according to the percentages described below. This described the area heated during the Head condition.

Upper torso skin temperature ($T_{skUTorso}$) was calculated from area weighted average of the anterior chest, upper back, and left shoulder sites according to the percentages described below. This described the area heated during the Torso condition.

Total skin temperature ($T_{skTotal}$) was calculated from area weighted average of all sites according to percentages described below.

The following regional percentages were assigned to these body sites based on, but adapted from, Layton et al. (49): forehead 3%, right cheek 1 %, left temporalis 0.5%, top of the head 0.5%, dorsum of the head 2% (Head total surface area = 7%), anterior chest 4.25%, anterior abdomen 8.75%, upper back 4.25%, lower back 13.25%, left shoulder 4.5%, right anterior forearm 19%, right posterior thigh 19.5% and left anterior calf 19.5%.

Metabolic heat production was determined from the oxygen consumption ($\dot{V}O_2$, $l\cdot min^{1}$) and respiratory exchange ratio (RER) by using the following equation (80):

$$M\ (W) = VO_2 * 69.7 * \{4.686 + [(RER - 0.707) * 1.232]\}$$

Respiratory heat loss was calculated in dependence of the metabolic heat production (15) as follows:

$$RHL\ (W) = 0.09 * M$$

Heat flux for each site ($W\cdot site^{-1}$) was calculated from flux values for each transducer ($W\cdot m^{-2}$) as follows:

$$HF_{site}\ (W\cdot site^{-1}) = HF_{disc}\ (W\cdot m^{-2}) * \text{Body Surface Area} * \text{Regional \% of the site}$$

Head heat flux (HF_{Head}) (W) = forehead + right cheek + left temporalis + top of the head + dorsum of the head.

Upper Torso heat flux ($HF_{UpperTorso}$) (W) = anterior chest + upper back + left shoulder.

Total cutaneous heat flux (HF_{Total}) (W) = HF_{Head} + $HF_{UpperTorso}$ + lower back + right anterior forearm + right posterior thigh + left anterior calf.

Net heat gain was calculated by subtracting the respiratory heat loss and total cutaneous heat flux from the metabolic heat production. Positive values of total heat flux indicated heat loss.

$$\text{Net heat gain}\ (W) = M\ (W) - RHL\ (W) - HF_{Total}\ (W)$$

Baseline data was analysed for the 10 minutes up to 30 sec before immersing the subject in the water, in order to exclude the 30 sec data with external movement.

At every 30-sec interval, the results were averaged for preceding 30-sec period, displayed graphically on the computer screen, and recorded in a spreadsheet format on a hard disk. Data for the three conditions were compared using repeated measures analysis of variance for all the variables except heart rate. Heart rate data were analysed using a two way repeated measures ANOVA to compare the three conditions amongst each other and over four periods (baseline, cooling, and the 0-35 min and 35-60 min rewarming periods). Post hoc analyses for significant differences between treatments was accomplished using Tukey's Post hoc test. Time to T_{es} nadir and time to maximum metabolic heat production were compared using paired *t*-test for each of the conditions; using a significance level of 0.017 (Bonferroni correction). Also, combined rewarming rates of the three conditions were compared for the two rewarming periods (nadir-35 min and 35-60 min) using a paired *t*-test. Results were reported as mean ± SD; $p < 0.05$ identified statistically significant differences.

Subjective data were classified based on warmth, comfort and preference; the data were then presented in tabular form. No statistical analysis was done for these data.

RESULTS

The six subjects (5 male, 1 female) who completed the study were (mean ± SD) 28 ± 5.1 years old, 172.8 ± 11.0 cm tall, weighed 72.5 ± 13.5 kg, had 1.9 ± 0.2 m^2 body surface area, and 19.5 ± 6.7% body fat (Table 1). The female subject was consistently studied in the early or late luteal phase.

Table 1. Descriptive data for six subjects.

Subject	Gender	Age (yr)	Height (cm)	Weight (kg)	BSA (m^2)	SFSF (mm)	%Body Fat
01	M	36.0	170.0	75.5	1.9	31.4	16.6
02	F	24.0	158.0	54.0	1.5	63.4	30.3
03	M	30.0	167.0	68.0	1.8	26.0	14.7
04	M	26.0	178.2	75.2	1.9	63.2	21.7
06	M	30.0	173.0	67.0	1.8	52.6	22.1
07	M	22.0	190.5	95.0	2.2	26.8	11.4
Mean		28.0	172.8	72.5	1.9	43.9	19.5
SD		5.1	11.0	13.5	0.2	17.9	6.7

CORE TEMPERATURE

Because of the mid-study change in cooling protocol (i.e., hands out of cold water, feet insulated) four subjects had one trial with hand and foot cold exposure, and two trials with hands and feet not cold-exposed. In order to determine that the change in protocol did not affect core cooling (i.e., faster cooling with hand and foot cold exposure), it was confirmed that the exposed cooling rates (3.1 ± 1.3°C·hr^{-1}) were not significantly different than the non-exposed rates (2.9 ± 1.2°C·hr^{-1}).

There were no significant between-condition differences in any core temperature parameters (Table 2, Figure 9). Baseline T_{es} was 37.2 ± 0.2 °C and the core cooling rate was 2.9 ± 1.0°C·hr^{-1}. Three subjects were immersed for the entire 60 min period (Table

3) whereas, the other three reached the target T_{es} 35°C before 60 min, and were therefore removed early, in one or all of the trials. There were no significant differences in exit T_{es} between conditions.

Following cooling, there were no effects of condition on either afterdrop amount or length (Table 2).

During the nadir-35 min and 35-60 min of rewarming periods, there were no significant between-condition differences in the rewarming rates for the Control (3.0 ± 1.3 ˚C·hr^{-1} and 1.2 ± 1.0˚C·hr^{-1} respectively), Head (3.1 ± 1.0˚C·hr^{-1}and 1.7 ± 1.0˚C·hr^{-1}), and Torso (2.6 ± 1.3˚C·hr^{-1}and 1.4 ± 0.9˚C·hr^{-1}) conditions (Table 2). The combined warming rate for nadir-35 min (2.9 ± 1.2˚C·hr^{-1}) was greater than for 35-60 min (1.5 ± 0.9˚C·hr^{-1}) ($p<0.001$).

Table 2. Core temperature responses during the baseline, cooling, and rewarming periods for the Control, Head, and Torso conditions (mean ± SD).

	Control	Head	Torso
Baseline Tes (°C)	37.3 ± 0.2	37.0 ± 0.2	37.2 ± 0.1
Rate of core cooling (˚C·hr^{-1})	3.1 ± 1.3	2.8 ± 0.8	2.8 ± 1.0
Afterdrop (°C)	0.53 ± 0.3	0.64 ± 0.2	0.71 ± 0.3
Length of the afterdrop period (min)	22.4 ± 7.4	26.8 ± 7.2	27.5 ± 4.6
Rate of rewarming - Nadir-35 min (˚C·hr^{-1})	3.0 ± 1.3	3.1 ± 1.0	2.6 ± 1.3
Rate of rewarming - 35-60 min (˚C·hr^{-1})	1.2 ± 1.0	1.7 ± 1.0	1.4 ± 0.9
Rate of rewarming - Nadir-60 min (˚C·hr^{-1})	2.0 ± 1.0	2.4 ± 0.9	1.9 ± 0.7

Figure 9. Mean change in esophageal temperature (˚C) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions; time 0 min and temperature 0˚C indicate exit from cold water. Not all immersions lasted for 60 min, ranging from 39.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=6 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 3 to 5.

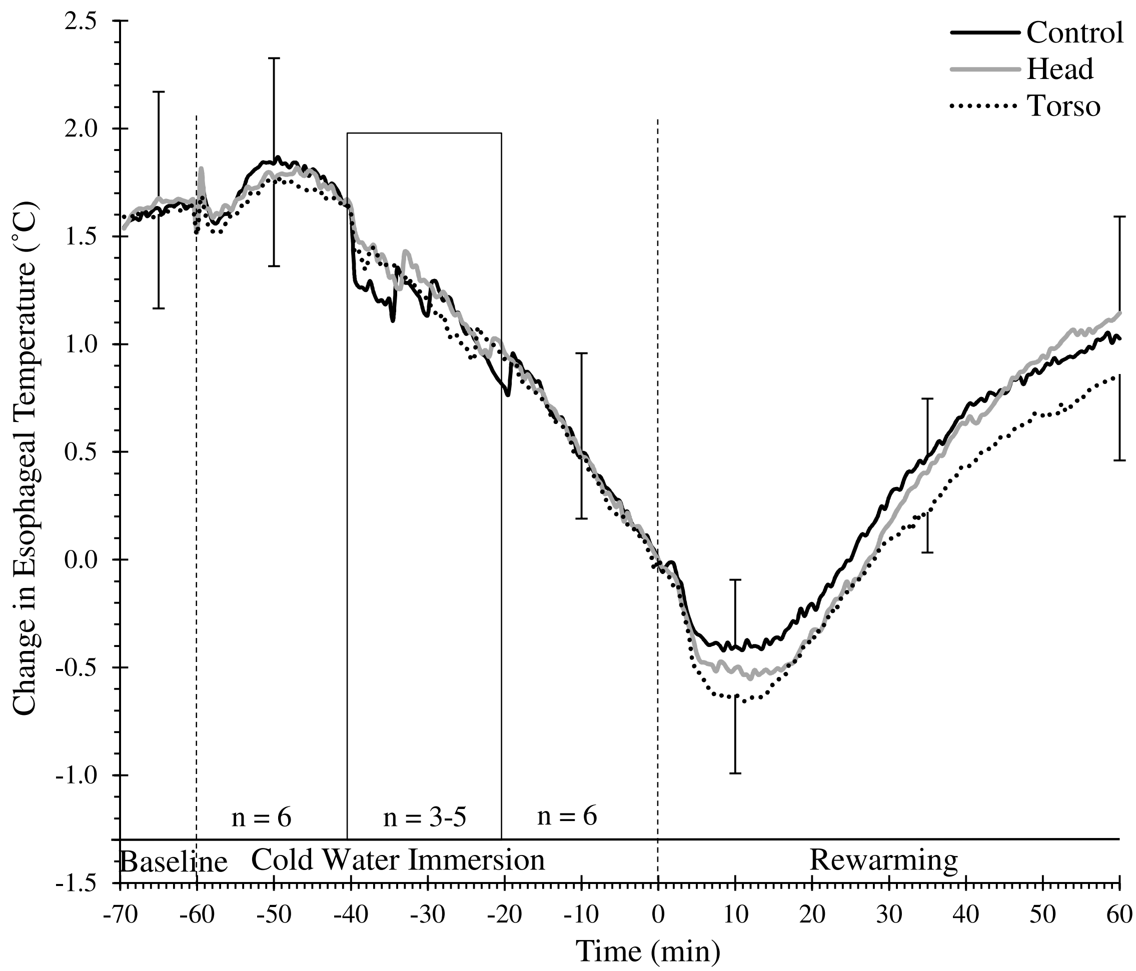


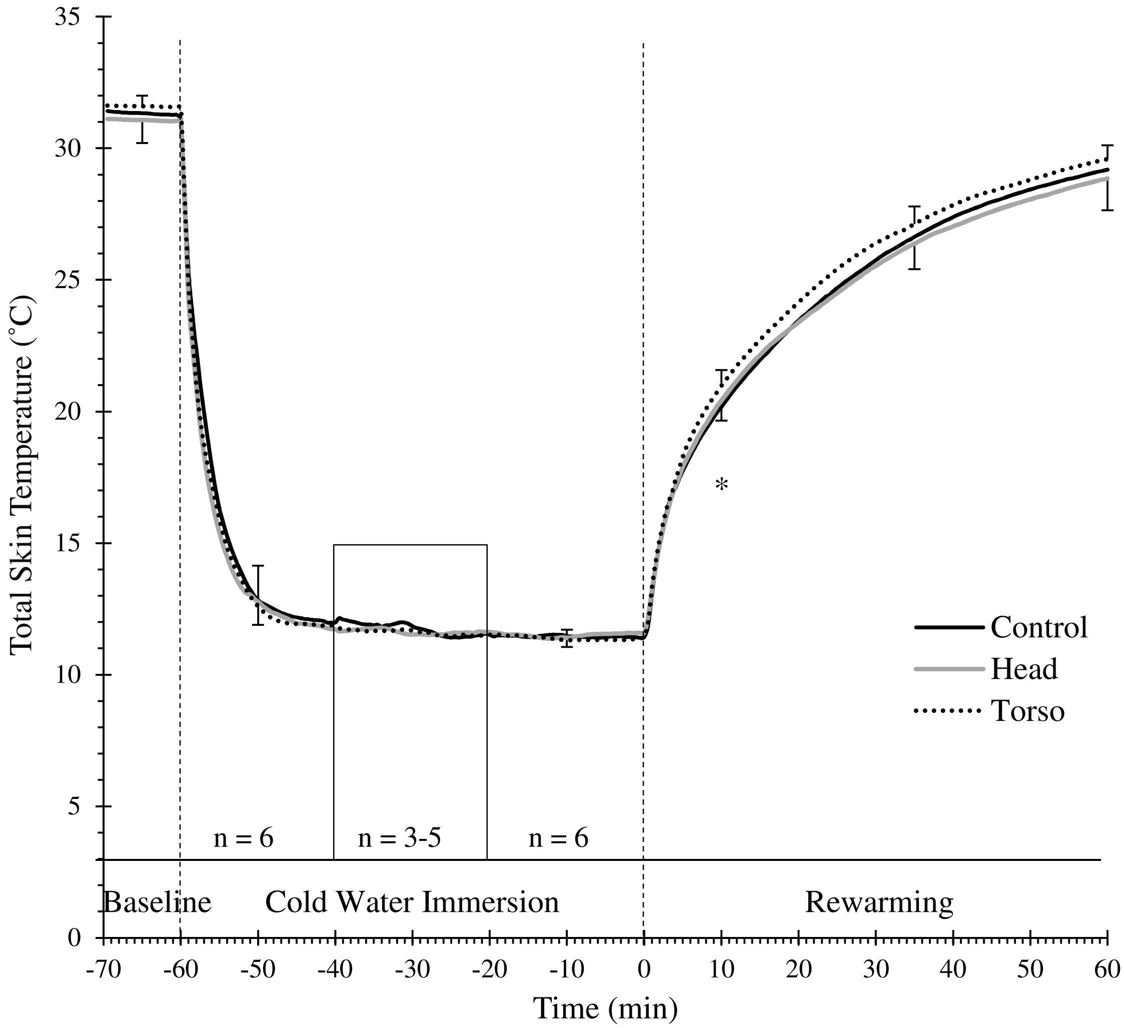
Table 3. Length of the immersion period (Submersion Time) and core temperature on removal from the cold water (Exit T_{es}) for each subject in the Control, Head and Torso conditions.

Subject	Submersion Time (min)			Exit T_{es} (°C)		
	Control	Head	Torso	Control	Head	Torso
01	60	60	60	35.9	35.6	36.0
02	54.5	60	60	35.0	35.2	35.6
03	39.5	42	44	34.9	35.0	35.0
04	60	60	60	36.8	36.6	36.2
06	60	60	60	36.3	35.0	35.9
07	50	53.5	58	35.0	34.8	34.9
Mean	54.0	55.9	57.0	35.6	35.4	35.6
SD	8.2	7.3	6.4	0.8	0.7	0.5

AVERAGE SKIN TEMPERATURE

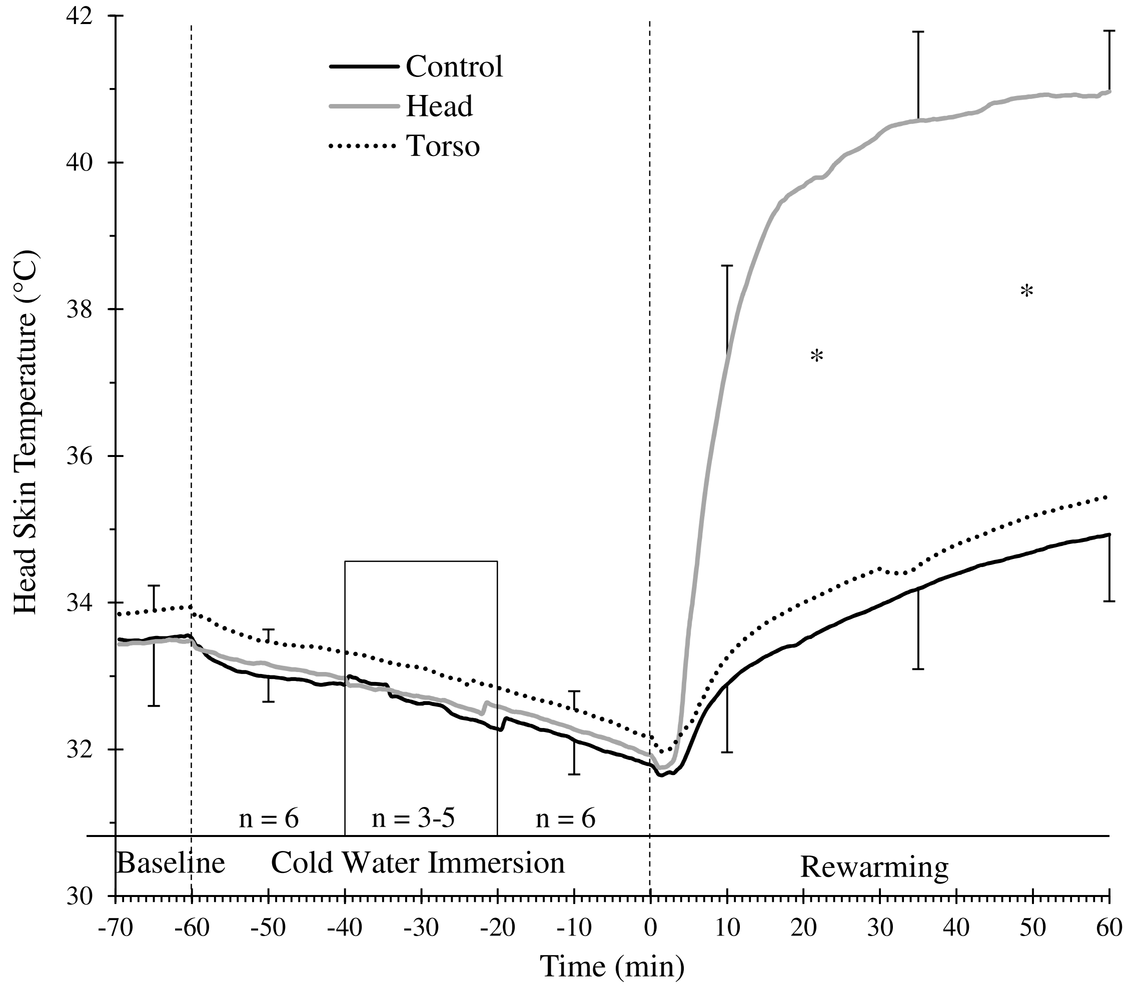
There were no significant differences between the three conditions for $T_{skTotal}$ during the baseline and cooling periods (Figure 10). $T_{skTotal}$ decreased rapidly from baseline values of 31.3 ± 0.6°C to 12.7 ± 1.0°C within the first 10 min of cooling and then, gradually reduced to 11.5 ± 0.3°C by the end of the cooling period. $T_{skTotal}$ was significantly higher at 10 min of rewarming in the Torso condition (21.0 ± 0.6°C) than the Control condition (20.2 ± 0.5°C) ($p<0.05$), but neither of these conditions were significantly different from the Head condition (20.4 ± 0.7°C). There were no significant differences in $T_{skTotal}$ between the three conditions at 20 min and 30 min of rewarming.

Figure 10. Total skin temperature (˚C) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions. Not all immersions lasted for 60 min, ranging from 39.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=6 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 3 to 5.
* Torso significantly greater than Control (p<0.05) at 10 min of rewarming.



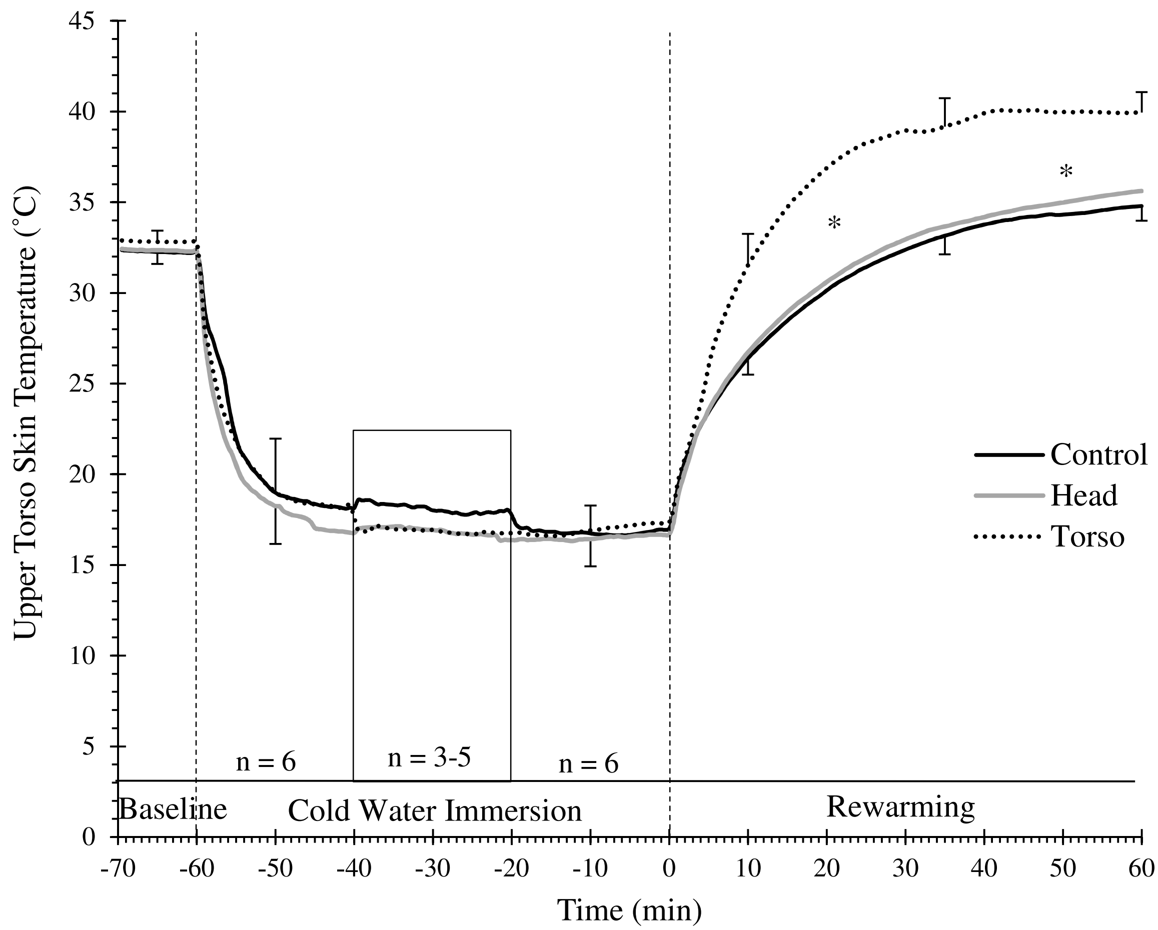
There were no significant differences between the three conditions for T_{skHead} during the baseline (33.6 ± 0.6°C) or cooling (32.8 ± 0.5°C) periods (Figure 11). T_{skHead} increased to 39.1 ± 1.5°C within the first 15 min of rewarming in the Head condition, whereas it returned to near baseline values in the Control (33.3 ± 1.0°C) and Torso (33.7 ± 0.5°C) conditions. T_{skHead} then continued to increase gradually in all the conditions with the average T_{skHead} during 0-35 min and 35-60 min of rewarming being significantly higher in the Head condition (38.0 ± 1.2°C and 40.8 ± 1.0°C respectively) than both the Control (33.2 ± 0.9°C and 34.6 ± 1.0°C) and Torso (33.6 ± 0.5°C and 35.1 ± 0.7°C) conditions ($p<0.001$). There were no significant differences for T_{skHead} between the Control and Torso conditions.

Figure 11. Head skin temperature (˚C) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions. Not all immersions lasted for 60 min, ranging from 39.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=6 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 3 to 5. * Significantly higher in the Head condition than the Control and Torso conditions (p<0.001).



There were no significant differences between the three conditions for $T_{skUTorso}$ during the baseline and cooling periods (Figure 12). $T_{skUTorso}$ decreased from baseline of 32.5 ± 0.7°C to 18.7 ± 2.3°C within the first 10 min of cooling and then, gradually reduced to 17.0 ± 1.4°C by the end of the cooling period. Following cooling, $T_{skUTorso}$ rapidly increased to 34.7 ± 1.6°C within the first 15 min of rewarming in the Torso condition whereas, it was still below the baseline values for the Control (28.5 ± 0.9°C) and Head (28.9 ± 1.6°C) conditions. $T_{skUTorso}$ then continued to increase in all the conditions, with average $T_{skUTorso}$ during 0-35 min and 35-60 min of rewarming being significantly higher in the Torso condition (33.5 ± 1.2°C and 39.9 ± 0.9°C respectively) than both the Control (28.3 ± 1.0°C and 34.2 ± 0.9°C) and Head (28.6 ± 1.4°C and 34.8 ± 0.9°C) conditions ($p<0.001$). There were no significant differences between the Control and Head conditions for these two rewarming periods.

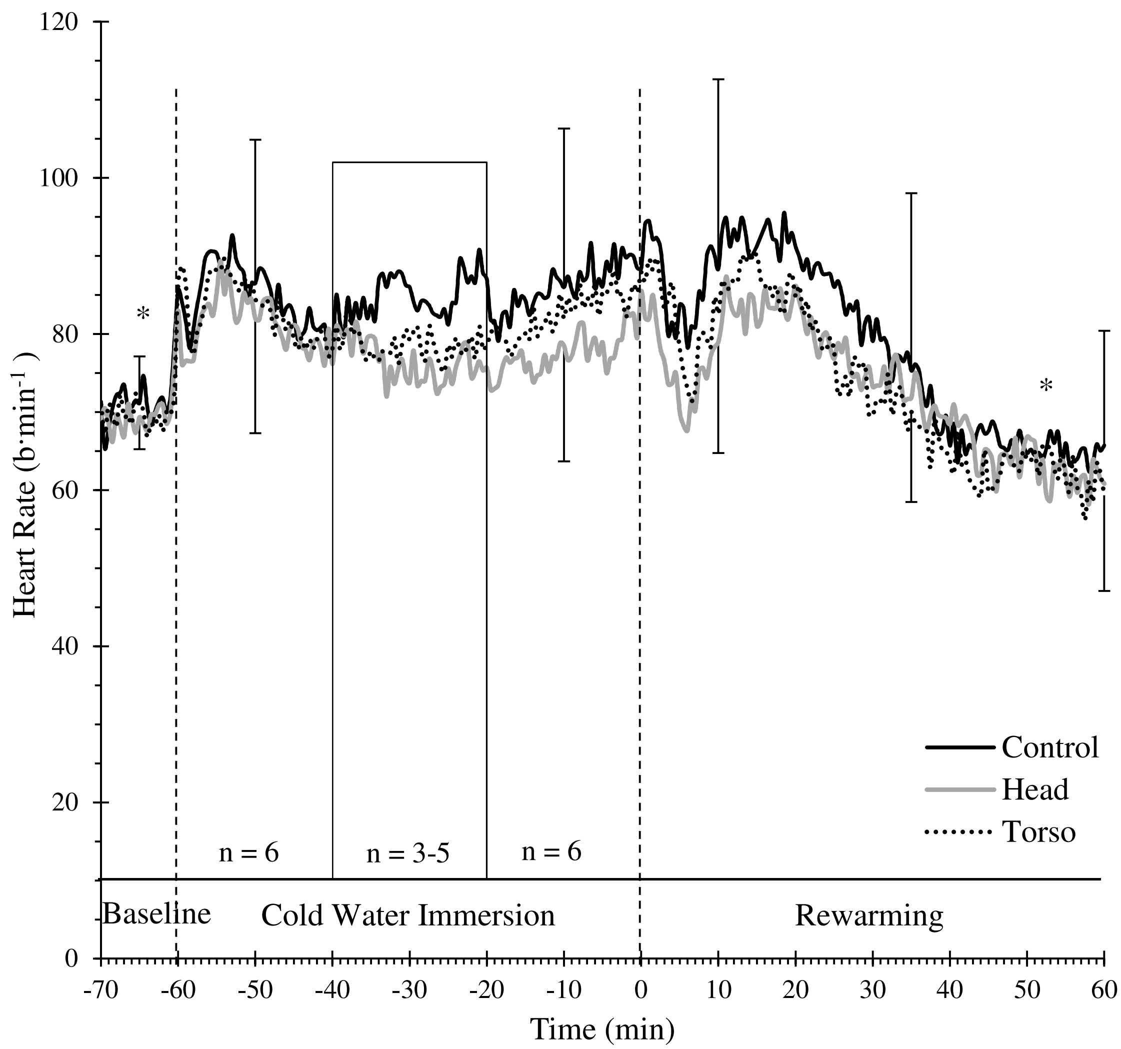
Figure 12. Upper torso skin temperature (˚C) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions. Not all immersions lasted for 60 min, ranging from 39.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=6 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 3 to 5. * Significantly higher in the Torso condition than the Control and Head conditions (p<0.001).



HEART RATE

There were no significant heart rate differences between the three conditions during baseline, cooling or the rewarming periods (Figure 13). On average, heart rate significantly increased from baseline 70 ± 5 $b \cdot min^{-1}$ to 81 ± 14 $b \cdot min^{-1}$ during cooling ($p<0.05$). Post-cooling, there was no significant change in the mean heart rate for 0-35 min of rewarming (82 ± 17 $b \cdot min^{-1}$) but then, it decreased significantly to 65 ± 12 $b \cdot min^{-1}$ in 35-60 min of rewarming ($p<0.05$).

Figure 13. Heart rate ($b \cdot min^{-1}$) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions. Not all immersions lasted for 60 min, ranging from 39.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=6 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 3 to 5. * Significantly different from adjacent period (p<0.05).

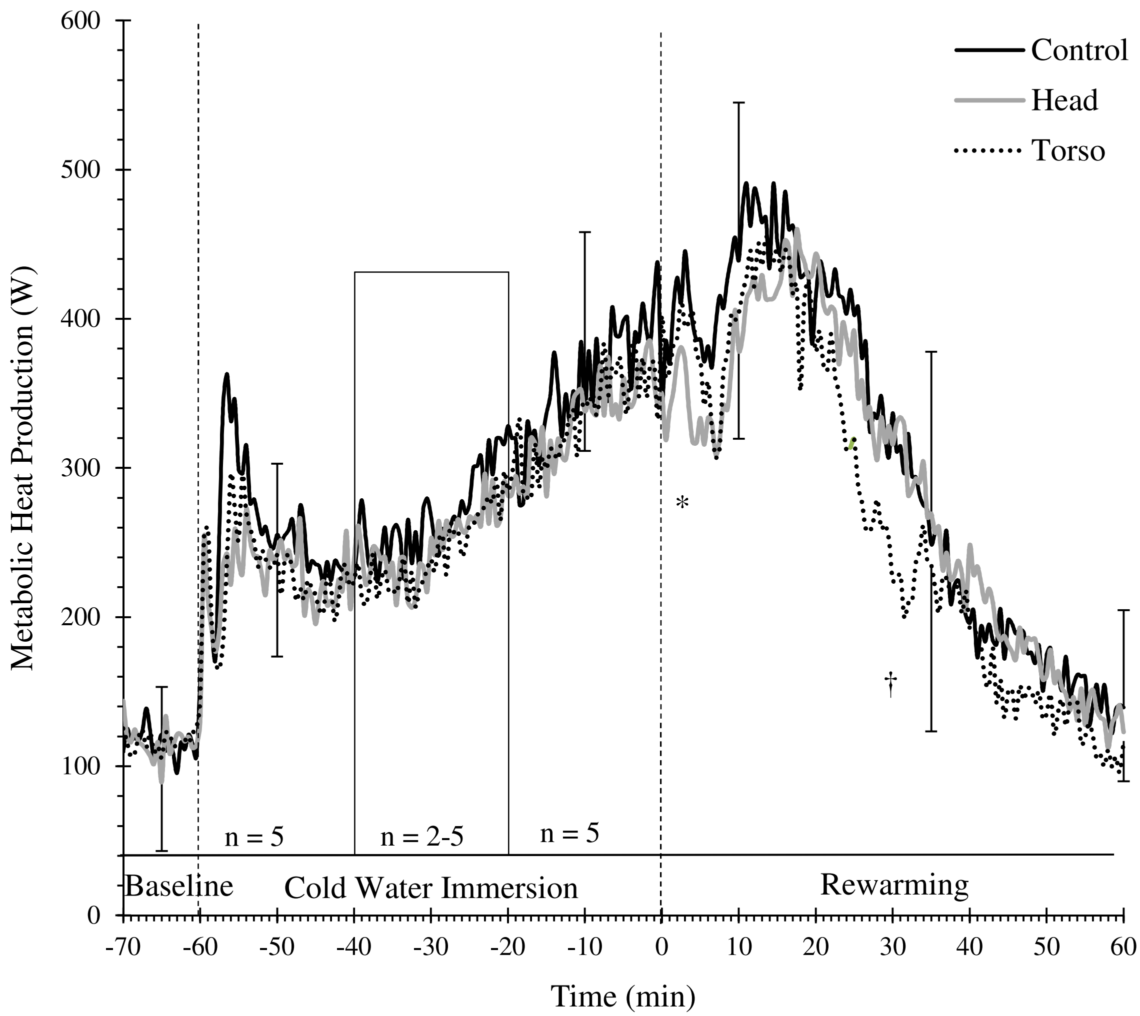


METABOLIC HEAT PRODUCTION

During one trial, the VMax computer shut down in the middle of the cooling period. In this trial, the metabolic heat production data was lost for the baseline and cooling periods. The VMax computer was restarted and data was successfully collected for the entire rewarming period. Metabolic heat production data for the baseline and cooling periods were subsequently removed for this subject for all three trials. Therefore, data analysis for metabolic heat production includes n=5 for the baseline and cooling periods and n=6 for the rewarming period (see Appendix 2).

There were no significant differences for metabolic heat production between the three conditions during the baseline and cooling periods (Figure 14). Values increased rapidly from baseline of 116.1 ± 18.7 W to 281.8 ± 112.6 W within first 3.5 min of cold-water immersion and then decreased to 228 ± 59.9 W over the next 15 min. From this point on, metabolic heat production gradually increased to 370.1 ± 85.1 W by the end of the cooling period. Post cooling, metabolic heat production continued to increase to maximum values of 521.5 ± 100.2 W in all three conditions within the first 14.0 ± 6.5 min of rewarming. In all three conditions, the time to T_{es} nadir (9.7 ± 3.8 min) was not significantly different from the time to maximum metabolic heat production (14.0 ± 6.5 min) (Appendix 3).

Figure 14. Metabolic heat production (W) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions. Due to the sudden shut down of the VMax computer in middle of the cooling period, data was lost for the baseline and cooling periods of one of the trials, but was successfully collected for the entire rewarming period. This subject's metabolic heat production data was eliminated for the baseline and cooling periods, hence n=5 for these periods and n=6 for the rewarming period (see Appendix 2). For the remaining five subjects, not all immersions lasted for 60 min, ranging from 53.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=5 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 2 to 5. * Significantly lower in the Head condition than Control ($p<0.05$) from 0-5 min. † Significantly lower in the Torso condition than Control ($p<0.05$) from 20-35 min and 0-60 min.



Metabolic heat production data were analyzed in smaller periods from 0-5 min, 5-10 min, 10-20 min, 20-35 min and 35-60 min (Table 4). There were no significant differences except during 0-5 min in Control vs. Head condition and during 20-35 min in Control vs. Torso condition. During 0-5 min, metabolic heat production was significantly lower in the Head condition (344.7 ± 68.7 W) than the Control condition (397.9 ±79.0 W) ($p<0.05$). During 20-35 min, metabolic heat production was significantly lower in the Torso condition (283.7 ± 62.3 W) than the Control condition (354.5 ± 104.7 W) ($p<0.05$). The average metabolic heat production during rewarming (0-60 min) was significantly lower in the Torso condition (268.0 ± 65.8 W) than the Control condition (306.6 ± 64.7 W) ($p<0.05$), but neither of these conditions were significantly different from the Head condition (289.7 ± 71.7 W).

0-5 min	**Control**	**Head**	**Torso**
HR01	453.4	458.5	429.7
HR02	255.2	258.8	275.7
HR03	409.6	298.2	383.2
HR04	382.7	331.7	387.3
HR06	402.5	375.2	407.5
HR07	483.9	346.1	437.8
Mean	397.9	* 344.7	386.9
SD	79.0	68.7	58.7
5-10 min	**Control**	**Head**	**Torso**
HR01	439.2	450.1	414.1
HR02	274.2	275.5	232.4
HR03	389.0	302.0	405.8
HR04	330.6	296.5	321.7
HR06	425.6	307.4	312.7
HR07	587.4	425.4	476.0
Mean	407.7	342.8	360.5
SD	107.4	74.7	87.7
10-20 min	**Control**	**Head**	**Torso**
HR01	473.3	458.5	405.8
HR02	350.5	314.4	313.6
HR03	537.3	430.0	484.2
HR04	365.8	312.1	330.0
HR06	464.4	421.1	425.5
HR07	531.0	611.0	589.9
Mean	453.7	424.5	424.8
SD	79.8	110.2	102.5
20-35 min	**Control**	**Head**	**Torso**
HR01	327.8	318.0	267.6
HR02	321.4	223.6	219.2
HR03	443.5	423.0	332.2
HR04	204.9	189.7	208.2
HR06	326.7	398.7	313.6
HR07	502.6	519.6	361.5
Mean	354.5	345.4	†283.7
SD	104.7	125.7	62.3
35-60 min	**Control**	**Head**	**Torso**
HR01	134.9	158.1	121.7
HR02	233.5	137.6	120.1
HR03	207.0	209.2	144.9
HR04	143.0	134.5	128.3
HR06	106.0	209.0	119.4
HR07	258.6	245.0	292.9
Mean	180.5	182.2	154.6
SD	61.1	45.3	68.5
0-60 min	**Control**	**Head**	**Torso**
Mean	306.6	289.7	† 268.0
SD	64.7	71.7	65.8

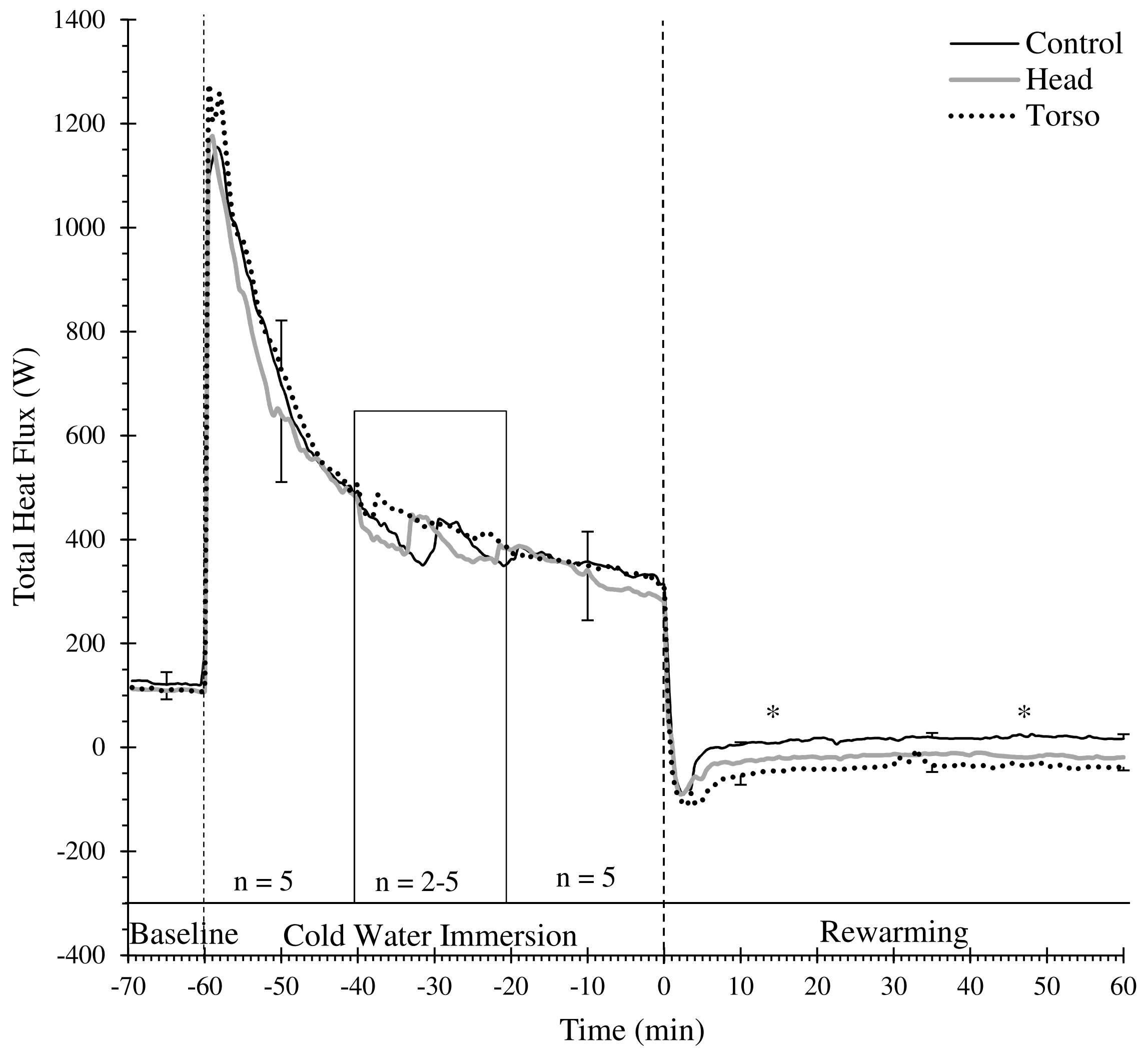
Table 4. Metabolic heat production (W) data for each subject during 0-5 min, 5-10 min, 10-20 min, 20-35 min, and 35-60 min, and group data for 0-60 min of rewarming in the Control, Head, and Torso conditions. * Significantly lower in the Head condition than Control ($p<0.05$).
† Significantly lower in the Torso condition than Control ($p<0.05$).

HEAT FLUX

During the very first trial of the study, heat flux discs for the chest and abdomen sites malfunctioned and did not provide accurate data for the entire trial. Therefore, we eliminated this subject's heat flux data for all three trials and data analysis for the entire experiment includes n=5 for HF_{Head}, HF_{UTorso}, and HF_{Total} (see Appendix 2).

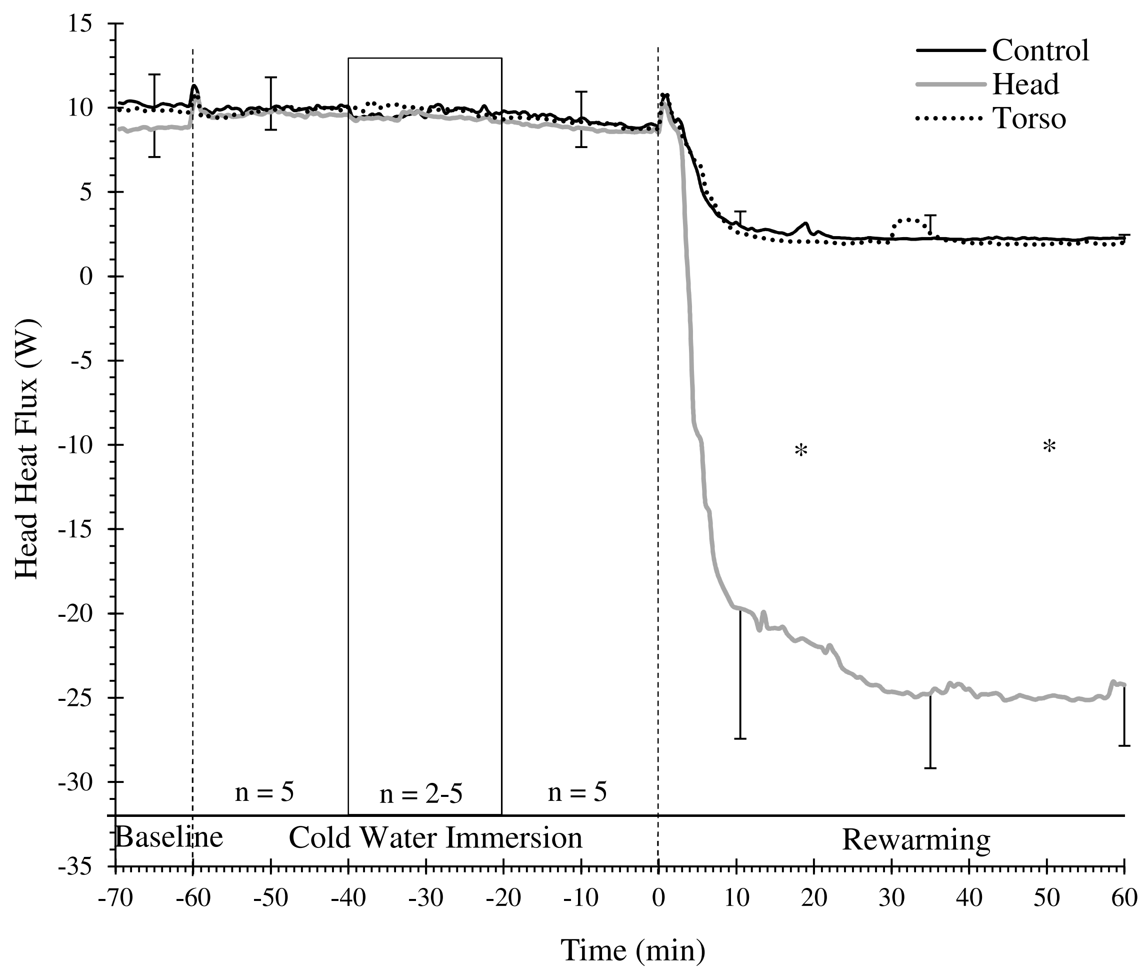
There were no significant differences for HF_{Total} between the three conditions during the baseline and cooling periods (Figure 15). Total heat loss increased from baseline values of 114.9 ± 20.1 W to a peak value of 1170.4 ± 241.9 W within 1 min of cold-water immersion. It then exponentially decreased to 302.6 ± 64.5 W by the end of the cooling period with an average of 510.7 ± 82.2 W during the entire cooling period. During 0-35 min and 35-60 min of rewarming, there was significantly less heat gain in the Control condition (10.9 ± 6.3 W and 19.1 ± 9.3 W respectively) than both the Head (-20.2 ± 15.0 W and -16.1 ± 14.6 W) ($p<0.05$) or Torso (-42.1 ± 10.0 W and -35.8 ± 12.1 W) ($p<0.001$) conditions. However, there were no significant differences between the Head and Torso conditions.

Figure 15. Total heat flux (W) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions. In the first trial of the study, the chest and abdomen heat flux discs malfunctioned and provided inaccurate data for the entire trial. This subject's heat flux data was eliminated for all three conditions, hence n=5 for the entire experiment (see Appendix 2). For the remaining five subjects, not all immersions lasted for 60 min, ranging from 39.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=5 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 2 to 5. * Significantly lower heat gain in Control than the Head (p<0.05) and Torso (p<0.001) conditions.



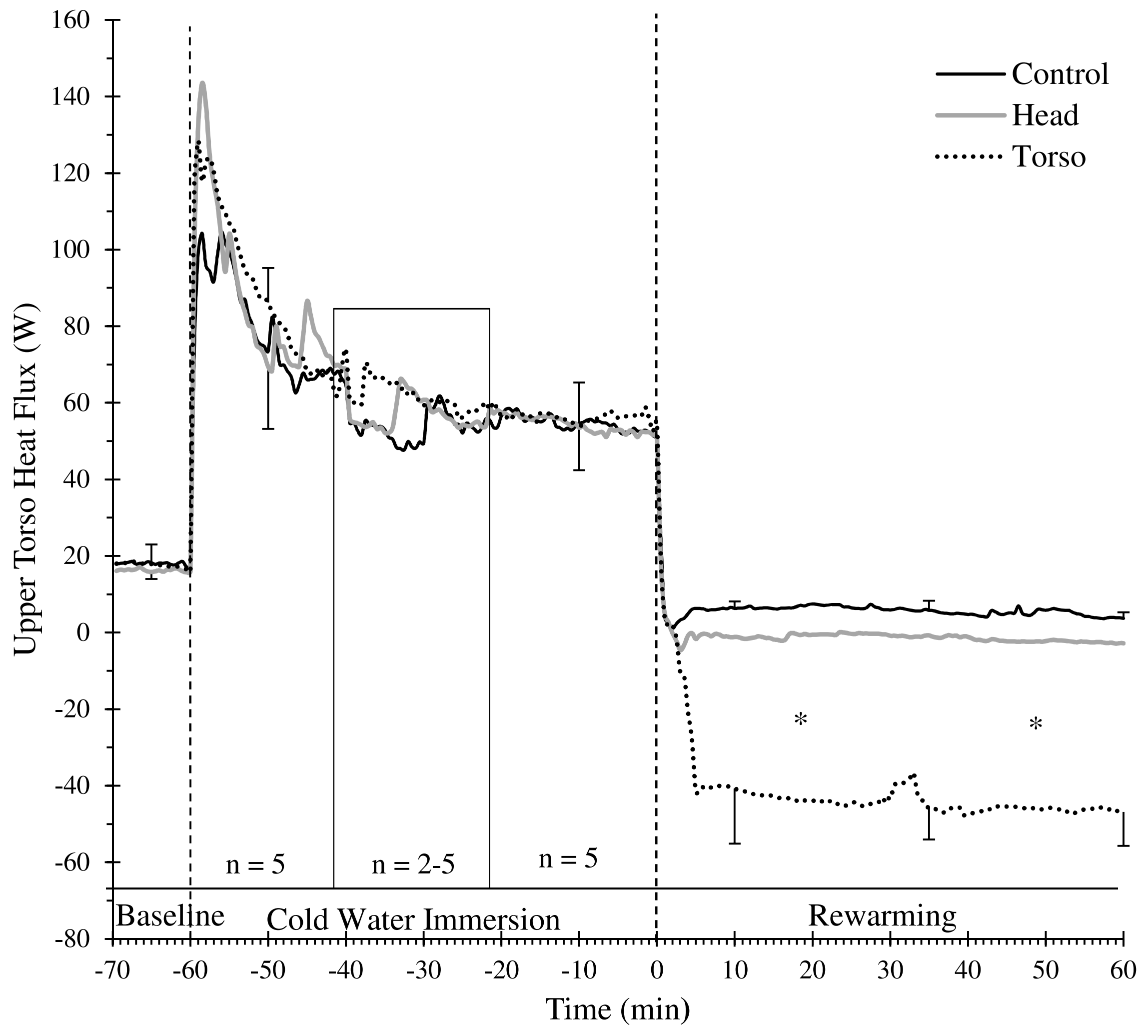
There were no significant differences between the three conditions for heat loss from the head during the baseline (9.6 ± 1.7 W) or cooling (9.5 ± 1.1 W) periods (Figure 16). Within the first 10 min of rewarming, head heat loss similarly decreased to 3.2 ± 0.9 W and 2.6 ± 0.5 W for the Control and Torso conditions respectively. Alternatively, the head actually gained heat in the Head condition (-19.7 ± 8.0 W). In the rest of the rewarming period, heat gain continued to increase gradually in the Head condition and heat loss decreased gradually in the other two conditions. During 0-35 min and 35-60 min of rewarming, there was significantly greater average heat gain from the head in the Head condition (-17.7 ± 4.8 W and -24.8 ± 4.4 W respectively) than in the Control (3.6 ± 0.9 W and 2.2 ± 0.6 W) and Torso conditions (3.5 ± 0.7 W and 2.0 ± 0.4 W) ($p<0.001$). There were no significant differences between the Control and Torso conditions.

Figure 16. Head heat flux (W) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions. In the first trial of the study, the chest and abdomen heat flux discs malfunctioned and provided inaccurate data for the entire trial. This subject's heat flux data was eliminated for all three conditions, hence n=5 for the entire experiment (see Appendix 2). For the remaining five subjects, not all immersions lasted for 60 min, ranging from 39.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=5 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 2 to 5. * Significantly greater heat gain in the Head condition (p<0.001).



There were no significant differences between the three conditions for HF_{UTorso} during the baseline and cooling periods (Figure 17). Heat loss from the upper torso increased rapidly from a baseline value of 17.3 ± 3.3 W to a peak value of 121.9 ± 30.1 W within first 1.5 min of cold-water immersion. It then decreased to 51.8 ± 10.6 W by end of the cooling period with an average of 67.2 ± 11.8 W during cooling. Following cooling, heat gain from the upper torso rapidly increased in the Torso condition (-41.7 ± 16.3 W) within first 5 min of rewarming and then, gradually increased to -46.8 ± 8.9 W by the end of the rewarming period. During 0-35 min and 35-60 min of rewarming, there was significantly greater heat gain from the upper torso in the Torso condition (-36.5 ± 8.4 W and -46.2 ± 8.2 W respectively) than the Control (7.0 ± 2.1 W and 4.9 ± 2.2 W) and Head (0.2 ± 4.3 W and -2.0 ± 3.8 W) conditions ($p<0.001$). There were no significant differences between the Control and Head conditions.

Figure 17. Upper Torso heat flux (W) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions. In the first trial of the study, the chest and abdomen heat flux discs malfunctioned and provided inaccurate data for the entire trial. This subject's heat flux data was eliminated for all three conditions, hence n=5 for the entire experiment (see Appendix 2). For the remaining five subjects, not all immersions lasted for 60 min, ranging from 39.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=5 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 2 to 5. * Significantly greater heat gain in the Torso condition ($p<0.001$).



NET HEAT BALANCE

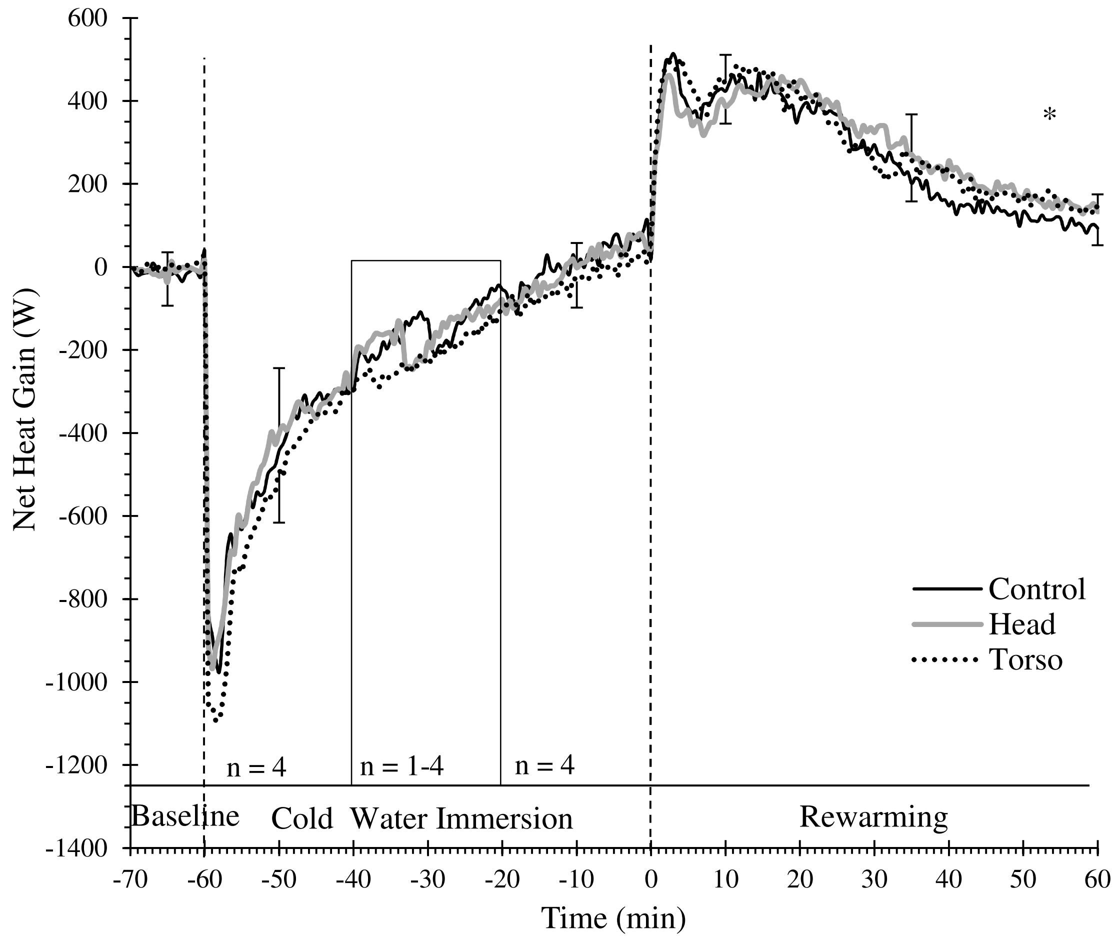
Heat flux data were available for only five subjects (see Heat Flux section above) for all three conditions. Out of these five subjects, the metabolic heat production data for one of the subjects was eliminated during the baseline and cooling periods (see Metabolic Heat Production section above). Therefore, net heat balance calculation and analysis for all three conditions included n=4 during the baseline and cooling periods and n=5 during rewarming.

There were no significant differences between the three conditions during the baseline and cooling periods (Table 5, Figure 18). During baseline there was a net heat loss (-7.8 ± 16.5 W) which increased rapidly to a peak value of -983.4 ± 170.7 W within the first 2 min of cold-water immersion. Net heat loss then decreased exponentially for remainder of the cooling period with an average net heat loss of -236.1 ± 96.6 W during the cooling period. Post-cooling, there was a net heat gain which increased rapidly for all three conditions; however, there were no significant differences between the Control (364.8 ± 71 W), Head (373.4 ± 70.8 W), and Torso (376.7 ± 63.4 W) conditions during 0-35 min of rewarming. During 35-60 min of rewarming, net heat gain in the Head condition (190.1 ± 31.2 W) was significantly greater than the Control condition (135.5 ± 50.9 W) ($p<0.05$); however neither of these conditions were different from the Torso condition (182.7 ± 62.2 W).

Table 5. Net heat gain (W) during baseline, cooling, and the rewarming periods (0-35 min and 35-60 min) for the Control, Head and Torso conditions. Heat flux data was eliminated for subject 02 for the entire experiment and the metabolic heat production data was eliminated for subject 03 for the baseline and cooling periods (see Appendix 2), therefore, n=4 during baseline and cooling periods, and n=5 during rewarming periods for the net heat gain calculations. * Significantly greater than Control ($p<0.05$).

Net Heat Gain (W)	Control	Head	Torso
Baseline (n=4)	-14.3 ± 24.0	-9.3 ± 11.2	0.2 ± 12.1
Cooling (n=4)	-218.5 ± 120.0	-219.3 ± 111.7	-270.5 ± 70.4
Rewarming 0-35 min (n=5)	364.8 ± 71.0	373.0 ± 71.5	376.7 ± 63.4
Rewarming 35-60 min (n=5)	135.5 ± 50.9	* 190.1 ± 31.2	182.7 ± 62.2

Figure 18. Net heat gain (W) during baseline, up to 60 min of immersion in 8˚C water, and during 60 min of rewarming in the Control, Head, and Torso conditions. Due to instrument failure, heat flux data was lost for Subject 02 for the entire experiment, and metabolic heat production data was lost for Subject 03 for the baseline and cooling periods (see Appendix 2). Heat flux data was thus, eliminated for the subject 02 for the entire experiment and metabolic heat production data was eliminated for the baseline and cooling periods for the subject 03. Thus, n = 4 during the baseline and cooling periods, and n=5 during the rewarming period. For the remaining four subjects, not all immersions lasted for 60 min, ranging from 53.5 to 58 min (see Table 3). In order to show what the whole group did at the beginning and the end of immersion, data for trials <60 min are presented for the first 20 min, with the remainder adjusted so that the exit time is lined up for everyone at time 0. As a result, n=4 for data from -60 to -40 min and from -20 to 0 min. In the area between -40 and -20 min, n ranges from 1 to 4. * Significantly greater net heat gain in the Head condition than Control (p<0.05) from 35-60 min.



SUBJECTIVE EVALUATION

Four out of the six subjects found the torso condition to be most comfortable, one subject felt that the head condition was the most comfortable and one subject found both the torso and head conditions to be equally comfortable; three subjects actually found the head condition to be uncomfortable (e.g., unnatural, claustrophobic) (Table 6). Three subjects stated that the charcoal heater felt warmer on the torso than on the head, two stated that the heater felt warmer on the head than on the torso, and one subject rated the heater on the head and torso felt equally warm. Four out of the six subjects preferred torso warming as the method of choice and two subjects preferred head warming (Table 7).

Table 6. Subjective evaluation of the three treatment methods by each subject based on comfort and warmth.

Subject	Control	Head	Torso
HR01	uncomfortable	uncomfortable	most comfortable, warmest
HR02	worst	not uncomfortable	most comfortable, warmest
HR03		uncomfortable, equally warm	comfortable, equally warm
HR04	worst	unnatural, warmest	comfortable
HR06	not that bad	most comfortable, warmest	comfortable
HR07	not that bad	equally comfortable	equally comfortable, warmest

Table 7. Preferred rewarming method indicated by each subject following completion of the final trial.

Subject	Control	Head	Torso
HR01			✓
HR02			✓
HR03			✓
HR04		✓	
HR06		✓	
HR07			✓

DISCUSSION

This was the first study to compare the effectiveness of a similar source of heat donation through the head or torso for rewarming hypothermic individuals. On three different occasions, subjects were immersed in 8˚C water for a period of 60 min or until they reached the target T_{es} of 35˚C. They were then rewarmed with one of three methods: shivering only, head warming or torso warming. As we expected, heat donation in the torso condition resulted in an increase in skin temperature, inhibition of shivering heat production and thereby, a similar net heat balance as the shivering only condition. Therefore, consistent with our previous studies, torso warming provided a similar afterdrop and rate of rewarming to shivering only.

We hypothesized that compared to torso warming, head warming would result in greater shivering heat production, a smaller afterdrop, and a greater rate of rewarming. Our results did not support these hypotheses, as there were no differences between the head and torso warming conditions for any of these variables. However, unlike torso warming, head warming did not inhibit average shivering heat production during rewarming (0-60 min).. During the last 25 min of rewarming, there was greater net heat gain in the Head condition than the Shivering only condition.

Four out of the six subjects felt that torso warming was most comfortable and three of these subjects actually found the head warming to be uncomfortable. Half of the subjects felt that torso warming felt warmer than head warming and four of six subjects preferred torso warming over head warming as their method of choice.

RELATION TO PREVIOUS LITERATURE

We expected that torso warming would result in a similar afterdrop and rate of rewarming as shivering only. Similar results have been seen in other rewarming studies (25,29,30). Heat donation through the torso caused an increase in peripheral skin temperature and lower shivering heat production. The amount of heat donated was only enough to compensate for the shivering heat production that was inhibited, thus, the torso warming resulted in a similar afterdrop and rate of rewarming as shivering only.

Similar to our protocol, Giesbrecht et al. (25) applied a charcoal heater to the torso for rewarming mildly hypothermic, vigorously shivering subjects. They also reported no differences in afterdrop or the rate of rewarming between shivering only and torso warming. Torso warming with other external rewarming methods such as body-to-body warming (30) and forced-air warming (29) also resulted in similar afterdrop and rewarming rate as shivering only, with the exception that forced-air warming decreased afterdrop by about 30% (29). Whether the rewarming method resulted in cutaneous heat gain of only 60 W greater than shivering (30), or as high as 213 W greater than shivering (29), the relative results remain the same.

In our study, torso warming with a charcoal heater resulted in an afterdrop of 0.7 ± 0.3˚C and a rewarming rate of 2.6 ± 1.3˚C·hr^{-1}. However, Giesbrecht et al. (25) reported a lower afterdrop (0.3 ± 1.1˚C) and a higher rewarming rate (3.8 ± 1.4˚C·hr^{-1}) for torso warming with a charcoal heater. Afterdrop (0.5 ± 0.3˚C) and the rewarming rate (3.0 ± 1.3˚C·hr^{-1}) seen in our study for the shivering subjects are similar to the afterdrop (0.6 ± 0.3˚C) and the rewarming rate (3.0 ± 1.2˚C·hr^{-1}) reported by Giesbrecht et al. (29) for the shivering subjects in their forced-air warming study.

Head warming was as effective in rewarming the core as torso warming when a similar source of heat donation was used in both the conditions. Head warming inhibited shivering heat production for a short time period during the first 5 min of rewarming. This result was expected on the basis of the head cooling studies done in our lab (64,65) in which head cooling did not stimulate shivering (see Potential Mechanisms section below).

POTENTIAL MECHANISMS FOR THE RESULTS

Torso warming has consistently resulted in similar rates of rewarming compared to shivering only (25,29,30). An increase in skin temperature during torso warming reduced the thermal stimulus for shivering, thus inhibited shivering heat production. Since the amount of heat donated through the torso (~40 W) was similar to the amount of shivering heat production that was inhibited (~38 W), the net heat balance was not different between these two conditions during early or late periods of rewarming (0-35 and 35-60 min). Torso warming, therefore, provided no rewarming advantage over spontaneous rewarming (shivering only) in rewarming mildly hypothermic, vigorously shivering individuals. However, lower metabolic heat production, if it persisted could provide some other benefits such as a decrease in cardiac workload and preservation of energy stores. As well, active warming could provide some psychological support.

Head warming had similar net heat gain to Control during the first 35 min of rewarming but, during 35-60 min of rewarming, head warming had significantly greater net heat gain. This is because during the last 25 min of rewarming, head warming had significantly greater cutaneous heat gain (~26 W) than Control, but similar shivering heat production.

Although total heat flux for the Head (-18.6 ± 13.9 W) and Torso (-39.5 ± 7.6 W) conditions were not significantly different during rewarming, there was a tendency for the total heat flux to be higher in the Torso condition. This is consistent with the values of heat flux from the upper torso (-40.5 ± 7.9 W) in the Torso condition and heat flux from the head (-20.6 ± 4.5 W) in the Head condition. The lack of significant differences between the Head and Torso conditions for total heat flux could be due to a Type II error. There was a trend for total heat flux to be greater in the Torso condition than the Head condition for all subjects except one (Subject 04), who had less total heat gain in the Torso condition (-27 W) than in the Head condition (-43 W). Two factors could have contributed to this error: 1) In the Torso condition for Subject 04, the heater was warming up slowly in the beginning (~17.5 min) which resulted in a lower total heat flux value in this condition; and 2) In the head condition for Subject 04, there was heat gain not only from the head but also from rest of the body. It is possible that some heat could have escaped from underneath the hood to the torso, subsequently resulting in a higher total heat gain value in this condition.

Even though the same heat source was applied to the head and the torso, there was less heat gain from the head (-20.6 ± 4.5 W) in the Head condition than from the upper torso (-40.5 ± 7.9 W) in the Torso condition. This could be because in the Head condition, some overlap of ducts of the charcoal heater was likely to increase heat loss to the environment, even though the head was insulated. As well, the hood edges of the sleeping bag provided an opening for heat escape which was not available in the Torso condition.

When a similar heat source was applied to the head, warming proved to be as effective in rewarming the core of a hypothermic individual as the traditional method of torso warming. This could potentially be explained based on no differences in either the shivering heat production or the size of the effective perfused mass between the Head and Torso conditions.

First, unlike what we expected, head warming did not result in a greater shivering heat production than torso warming. Although head warming resulted in significantly lower shivering heat production than Control for the first 5 min of rewarming, it did not inhibit the average shivering heat production during the entire rewarming period. This could be because head warming does not provide enough increase in the skin temperature to reduce the thermal stimulus for shivering. We expected this result based on the previous head cooling studies done in our lab (64,65). Pretorius et al. (64) determined the effect of whole-head cooling on the core cooling with body insulated or exposed to 17°C water. They reported that additional cooling of the head with or without body cooling increased the rate of core cooling with no additional increase in shivering heat production. In another study by Pretorius et al. (65) whole-head cooling resulted in core cooling with no significant increase in shivering heat production. As cooling of the head in these previous studies resulted in core cooling with no stimulation of shivering heat production; head warming in our study resulted in core rewarming with a short-term inhibition of the shivering heat production.

As mentioned in the Literature Review, during cold stress there is a generalized decrease in the peripheral blood flow and thus, a reduction in the size of the effective perfused mass (80). We expected that compared to head warming, torso warming would result in a greater increase in the peripheral blood flow and thereby, in the size of the effective perfused mass. Therefore, a given amount of heat donation through the torso would dissipate into a larger volume of the perfused tissue resulting in a lower rewarming rate than the Head condition if the same amount of heat was added to a smaller mass of perfused tissue. Also, the convective component of afterdrop was expected to be greater during torso warming. However, this increase in the size of the effective perfused mass in the Torso condition might have been counterbalanced by a decrease in the muscular blood flow due to inhibition of shivering. Therefore, the size of the effective perfused mass might not be different for the Head and Torso conditions; thus, no differences would be seen in the afterdrop or rewarming rates. Further work is required to quantify the effective perfused mass in these two conditions.

PRACTICAL IMPLICATIONS

In mildly hypothermic vigorously shivering subjects, heat donation through the torso did not provide a rewarming advantage compared to shivering only. However, it may have other benefits such as decreased cardiac work, preservation of energy stores and increased physical and psychological comfort. This study shows that head warming is equally effective in rewarming a shivering hypothermic individual, therefore, an external source of heat donation could be applied to either the head or the torso with the same results.

Although torso warming was generally a more comfortable and preferred method than head warming in our study, head warming could be more useful and practical in several situations. First, in a field-situation where a victim is already wrapped up and insulated by a first-responder, heat could easily be applied to the head instead of the torso in order to avoid exposure of the torso to the cold-environment, especially in extreme weather conditions such as a storm or blizzard. Second, head warming may be an advantage over torso warming in conditions where minimal movement of the victim is prescribed, for example, in the case of a severely hypothermic victim who is at risk of ventricular fibrillation, or a victim with a potential spinal injury (with appropriate caution to minimize neck movement). Third, if emergency medical personnel are working on the victim's chest (for example carrying out cardiopulmonary resuscitation), heat could be given simultaneously through the head.

LIMITATIONS

The charcoal heater used in this study did not function reliably. In many of the trials, we had to light several charcoal briquettes before one worked properly. In one of the trials, the heater was slow to warm up in the beginning of the experiment and in one of the trials, the heater was replaced after 17.5 min of rewarming with another heater unit that was functioning properly. Even then, we had two trials in which the heater did not work fully throughout the rewarming period. These trials were therefore repeated. Since these experiments were conducted in a laboratory, innumerable charcoal heater briquettes were available and time could be spent on finding a briquette that worked properly. It was only discovered after this study was started, that there is a world-wide problem with the manufacture of these briquettes. Therefore, although there is present and historical evidence to show the value of the charcoal heater (25,42,52), it can not be recommended for use until the problem is rectified. In fact, the supervisor of this thesis has recommended that the distributor of this product take it off the market until such a time.

CONCLUSION

When a same heat source was applied to the head or the torso, the heating was equally effective in rewarming the core of a mildly hypothermic individual. Although there were no differences between torso and head warming in shivering heat production, afterdrop or rate of rewarming, compared to Control, head warming briefly inhibited shivering heat production and eventually resulted in a greater net heat gain than shivering only. We recommend that torso or head warming could be used in a field-situation for rewarming a mildly hypothermic victim. However, if a victim is already wrapped up and insulated by a first-responder in extreme weather conditions, opening this insulation may be contraindicated and a charcoal heater may be directly applied to the victim’s head. Head warming could be a choice of method for victims in whom movement should be avoided for example, severely hypothermic victims or a victim with potential spinal injury. Head warming could also be useful in rewarming a hypothermic victim when emergency medical rescue personnel are working on the victim’s torso. Although this study was conducted on mildly hypothermic vigorously shivering individuals, these results could be extrapolated to severely hypothermic individuals in whom shivering response is reduced or absent. We recommend that a similar rewarming study should be done to compare the effectiveness of head and torso warming in non-shivering hypothermic subjects. This could be done using a human model for severe hypothermia (26) in which shivering in mildly hypothermic subjects is inhibited with meperidine. A similar rewarming study using a forced-air warming device is recommended to compare head vs. torso warming. Since the heater/blower during forced-air warming produces more heat (650 W) than a charcoal heater (250 W), head warming with forced-air warming may decrease shivering heat production. In addition, the effect of head and torso warming on effective perfused mass should be studied and quantified.

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APPENDIX 1

Equations for calculating the body density for different age groups and gender by using the constants and equations given by Durnin & Womersley (12).

Body Density Equations for different age groups of Males

Age (Yrs)	Density, D_b (kg/l) = *c – m . log*$_{base10}$ *sum of four skinfolds (SFSF)*
17-19	D_b (kg/l) = *1.1620– 0.0630 . log*$_{base10}$ *sum of four skinfolds (SFSF)*
20-29	D_b (kg/l) = *1.1631 – 0.0632 . log*$_{base10}$ *sum of four skinfolds (SFSF)*
30-39	D_b (kg/l) = *1.1422 – 0.0544. log*$_{base10}$ *sum of four skinfolds (SFSF)*
40-49	D_b (kg/l) = *1.1620 – 0.0700 . log*$_{base10}$ *sum of four skinfolds (SFSF)*
50+	D_b (kg/l) = *1.1715 – 0.0779 . log*$_{base10}$ *sum of four skinfolds (SFSF)*
17-72	D_b (kg/l) = *1.1765 – 0.0744 . log*$_{base10}$ *sum of four skinfolds (SFSF)*

Body Density Equations for different age groups of Females

Age (Yrs)	D_b (kg/l) = *c – m . log*$_{base10}$ *sum of four skinfolds (SFSF)*
16-19	D_b (kg/l) = *1.1549 – 0.0678 . log*$_{base10}$ *sum of four skinfolds (SFSF)*
20-29	D_b (kg/l) = *1.1599 – 0.0717 . log*$_{base10}$ *sum of four skinfolds (SFSF)*
30-39	D_b (kg/l) = *1.1423 – 0.0632 . log*$_{base10}$ *sum of four skinfolds (SFSF)*
40-49	D_b (kg/l) = *1.1333 – 0.0612 . log*$_{base10}$ *sum of four skinfolds (SFSF)*
50+	D_b (kg/l) = *1.1339– 0.0645 . log*$_{base10}$ *sum of four skinfolds (SFSF)*
16-68	D_b (kg/l) = *1.1567 – 0.0717. log*$_{base10}$ *sum of four skinfolds (SFSF)*

APPENDIX 2

DATA PROBLEMS

Data problems encountered during the experiments can be classified into the following four types: measurement/instrument failure; heater failure; heater placement; and subject condition. Depending upon the problem, we took one or more of four actions: keep the data as it is; extrapolate to replace inaccurate data; eliminate the inaccurate data; or repeat the trial.

Measurement/Instrument Failure

1. Subject 02 Control condition

   This was the first trial of the study during which we determined that the chest and abdomen heat flux discs malfunctioned and did not provide accurate data throughout the entire trial. Therefore, we eliminated this subject's heat flux data for all three trials, and data analysis for the entire experiment included five subjects (n=5) for HF_{Head}, HF_{UTorso} and HF_{Total}. These problems were fixed after this trial: 1) the electrical connection for the chest heat flux disc was repaired; and 2) the abdomen heat flux disc was replaced with another disc.

2. Subject 03 Head condition

   During the cooling period, the heat flux disc for the head dorsum site showed incorrect readings for heat flux but, correct temperature readings. While the subject was still in the water a second disc, which only measured heat flux, was added near the first disc to measure heat flux. Thus, correct heat flux and temperature data were available for the rewarming period for this trial. Subsequently, these two heat flux discs were applied to the head dorsum site- one for measuring temperature and the other for measuring heat flux. Although data was successfully collected for the rewarming period, this condition had to be repeated for another reason (see Heater Failure below).

3. Subject 03 Torso condition

   In this trial, the VMax computer shut down in the middle of the cooling period. The VO_2 and RQ data; which are required to calculate metabolic heat production were lost for the baseline and cooling periods. The VMax computer was restarted and data was successfully collected for the entire rewarming period. Therefore, this subject's metabolic heat production data was excluded from the group data analysis for the baseline and cooling periods (n=5) but, was used for analysis during the rewarming period (n=6).

   As the VMax computer also records and stores the heart rate data, we also lost the heart rate data for baseline and the first 26 min of the cooling period. However, the heart rate data was also being manually recorded in a lab book at 5 min intervals during these periods. The recorded value at every interval was extrapolated for each 5 min interval. Therefore, data analysis for heart rate includes n=6 for the entire experiment.

4. In several trials, 30 sec average readings of VO_2 and RQ showed extremely high (inaccurate) values. These were corrected by taking an average of the values 30 sec before and after these time points.

5. In several trials, extreme mechanical artifact from the ECG leads resulted in extremely high heart rate values at some time points. These artifacts were

corrected by taking an average of the heart rate values 30 sec before and after these time points.

6. Subject 06 Control condition

   In this trial, the subject was shivering vigorously which resulted in extreme mechanical artifacts in heart rate for more than half of the cooling period (42.5 min). As expected, heart rate for each subject was similar during cooling for all three conditions. For subject 06, heart rate during cooling was likewise similar for the Head and Torso conditions. Since this pattern would be expected in the Control condition, heart rate data for the first 42.5 min of cooling in this condition was replaced with this subject's heart rate data from the Torso condition.

Heater Failure

A. Complete/Whole failure

   In two of the trials- Subject 02 Torso condition and Subject 03 Head condition, the charcoal heater did not work fully throughout the warming periods. Therefore, these trials were later repeated (see Replacement Trial).

B. Partial failure

1. Subject 03 Head condition (Second trial)

   The charcoal heater did not work fully in the beginning of the rewarming period and was therefore, replaced with another heater after 17.5 min of rewarming. The second heater functioned properly for the remaining 42.5 min of the rewarming period.

2. Subject 02 Torso condition (Second trial)

   In this trial, the heater may not have worked optimally with mean heat gain from the upper torso -26.6 W vs. -37.2 W for Subject 01 and 03. This trial was not repeated because we did not want to conduct a 6th trial for this subject as two trials had been repeated for this subject, therefore, a total of five trials had already conducted (see Replacement Trials below).

3. Subject 04 Torso condition

   In this trial, the heater was slow in warming up and took 17.5 min to increase the upper torso heat gain to -38.2 W, which was then comparable with a heat flux value of -40.6 W for Subject 01 and 03 in their Torso conditions. This trial was not repeated as the heater was functioning properly for the remaining 42.5 min of rewarming period.

4. Subject 06 Head condition

   In this trial, the heater may not have worked optimally as the mean heat gain from the head was -16.6 W vs.-19.4 W for Subjects 02 and 07 for the entire rewarming period.

Heater Placement

1. During rewarming, there were short periods of time when the duct of charcoal heater was not directly over the heat flux disc, therefore the disc showed less heat gain compared to the times when the duct was in full contact with the disc. Whenever this was noticed during the experiment, the duct was positioned correctly. Later, this data error was corrected by extrapolating data from the times before and after when the duct was in full contact with the heat flux disc.

Subject Condition

1. Subject 01 Control condition

   In this trial, unbeknownst to the researchers the subject had worked vigorously in a warm environment on a hot summer day. During the cooling period, initially his T_{es} started to rise and it was not until later (after 15 min) that his core temperature started to drop. After 55 min of cooling, his T_{es} was 37˚C. Finally, the drop in T_{es} (ΔT, ˚C) by the end of the cold-water immersion was less than in his other two trials (0.9˚C vs. 1.6 and 1.4˚C). Therefore, this trial was later repeated on a day when the subject did not have a similar work/temperature condition prior to the experiment.

2. Subject 02 Head condition

   This trial was conducted during the mid-luteal phase of the menstrual cycle (Day 20 of the menstrual cycle). In order to be consistent with the other two trials which were conducted either at the beginning or the end of the luteal phase (Day 17 and Day 26 of the menstrual cycle respectively), this trial was repeated in the early luteal phase (Day 17 of the menstrual cycle).

3. Subject 07 Torso condition

   In this trial, the subject need to get out of the sleeping bag in the middle of the rewarming period to urinate. During this short time period of about 6 min, the heat flux data showed an increase in heat loss from all the sites and the temperature data showed a drop in the skin temperature from all the head and body sites. This data was not altered and was included in the analysis.

REPLACEMENT TRIAL

The following trials were repeated for the given reasons:

1. Subject 02 Torso condition and Subject 03 Head condition

   In these two trials, the charcoal heater did not work fully throughout the experiment (complete failure); therefore, the net heat gain was much less in these conditions when compared with the other subject's torso and head conditions respectively.

2. Subject 01 Control condition

   In this trial, the drop in T_{es} (ΔT, 0.9˚C) by the end of the cold-water immersion, was lower than the ΔT (˚C) in the other two trials (1.6 and 1.4˚C). Therefore, the trial with a lower ΔT (˚C) could not be compared with the other two trials with a greater ΔT (˚C). This is because a lower core temperature will provide a greater stimulus for shivering heat production. In order to eliminate any differences between the three conditions other than the rewarming method used, we repeated this trial.

3. Subject 02 Head condition

   See previous section (Subject Condition).

APPENDIX 3

Time to T_{es} nadir and to maximum metabolic heat production from the start of rewarming period (0 min) for each subject in the Control, Head, and Torso conditions.

Subject	T_{es} Nadir Time	Control	Head	Torso
01	12	10.5		
02	6.5	15		
03	13	16		
04	5	12		
06	14	12		
07	5.5	25.5		
Mean	9.3	15.2		
SD	4.1	5.5		
01	5		12.5	
02	14.5		11	
03	16		20.5	
04	11		2.5	
06	5.5		20.5	
07	7.5		17.5	
Mean	9.9		14.1	
SD	4.7		6.9	
01	11			3.5
02	5			17.5
03	11.5			17
04	7			2.5
06	10.5			22
07	13.5			13.5
Mean	9.8			12.7
SD	3.1			8.0

APPENDIX 4

UNIVERSITY OF MANITOBA | BANNATYNE CAMPUS
Research Ethics Boards
APPROVAL FORM

P126 - 770 Bannatyne Avenue
Winnipeg, Manitoba
Canada R3E 0W3
Tel: (204) 789-3255
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Principal Investigator: Dr. G. Giesbrecht
Sponsor: NSERC

Ethics Reference Number: B2012:024
Date of REB Meeting: February 27, 2012
Date of Approval: May 24, 2012
Date of Expiry: February 27, 2013

Protocol Title: Effectiveness of heat donation through the head or torso on mild hypothermic rewarming

The following is/are approved for use:

- **Protocol, Version dated Feb. 13, 2012**
- **Research Participant Information and Consent Form, Version dated 12/05/22**
- **Questionnaire PAR-Q & YOU, Revised 2002**
- **Participant inclusion interview questions, Version dated Feb. 13, 2012**
- **Script to be read out loud, Version dated Feb. 13, 2012**

The above was approved by Dr. Lindsay Nicolle, Chair, Biomedical Research Board, Bannatyne Campus, University of Manitoba on behalf of the committee per your letter dated May 22 and electronic mail of May 24, 2012. The Research Ethics Board is organized and operates according to Health Canada/ICH Good Clinical Practices, Tri-Council Policy Statement, and the applicable laws and regulations of Manitoba. The membership of this Research Ethics Board complies with the membership requirements for Research Ethics Boards defined in Division 5 of the *Food and Drug Regulations of Canada.*

This approval is valid for one year from the date of the meeting at which it was reviewed. A study status report must be submitted annually and must accompany your request for re-approval. Any significant changes of the protocol and informed consent form should be reported to the Chair for consideration in advance of implementation of such changes. The REB must be notified regarding discontinuation or study closure.

This approval is for the ethics of human use only. For the logistics of performing the study, approval should be sought from the relevant institution, if required.

Sincerely yours,

L. Nicolle

Lindsay Nicolle, MD, FRCPC
Chair,
Biomedical Research Ethics Board
Bannatyne Campus

Please quote the above Ethics Reference Number on all correspondence.
Inquiries should be directed to the REB Secretary **Telephone:** (204) 789-3255/ **Fax:** (204) 789-3414

www.umanitoba.ca/medicine/ethics

Name : _____________

PARTICIPANT INFORMATION AND CONSENT FORM

PART I: *INFORMATION FOR PARTICIPANTS*

1. Dr. Gordon Giesbrecht is studying/comparing the effectiveness of heat donation through the head or the torso in rewarming a mildly hypothermic individual. Either a rigid forced-air warming cover or a charcoal heater will be used for the head or torso rewarming. Similar torso rewarming studies using these rewarming methods have been conducted extensively in our lab previously over the past 26 years. The information obtained from this study will give a better understanding of the heat-transfer mechanisms in the human body. This might help in the ongoing research in pre-hospital treatment of cold patients. Through this form, you are being asked to participate in this research study.
2. You will be asked to participate in three cold-water immersion trials, separated by at least 48 hours. Each trial will last about 4 hours (1 hour for setup, 1 hour for cooling, and 2 hours for rewarming and removal of instrumentation). Thus, your total commitment will be about 4 hours per visit and three total visits within a period of 3-4 months.
3. On each of the three trials, you will undergo immersion to the level of the sternal notch in a tank of 21°C water. The temperature will then be quickly (~5-10min) lowered to 8˚C – by the addition of about 60 kg of ice – with a total immersion time of 60 minutes. You will then exit the water, be dried off and lie in a hooded sleeping bag where one of the three warming procedures will be administered for 60 minutes or until core temperature returns to normal values (~36.5-37˚C). At this point you will be allowed to sit in a tank of warm water (40-42°C) until you feel ready to leave the lab.
   The three warming methods are as follows:
   A. Spontaneous rewarming (Shivering Only) - In this control condition, no external heat will be provided and you will rewarm spontaneously with the heat produced from shivering.
   B. Head Warming (Head): One of the following rewarming methods will be used:
      - Forced-Air Warming to the Head (FAW-H) - A modified rigid forced-air warming cover will be placed over your head. Warm air (~43˚C) will blow into the cover through an inlet on top of the cover and will escape from the bottom of the cover. You will be breathing warm air (~43˚C).
      - Charcoal Heater to the Head (CH-H) - A charcoal heater will be placed on right side of your face/head (the heater itself is insulated to prevent burning the skin) with ducts wrapping around the dorsum of the head, anteriorly over the forehead, nose, chin and the neck, not covering the eyes or the mouth. You will be breathing ambient air (~22˚C).

C. Torso Warming – One of the two rewarming methods will be used:

- o Forced-Air Warming to the Torso (FAW-T) - A specially designed portable rigid forced-air cover (PORIFAC) will be placed over your torso and the upper thighs. Warm air (~43˚C) will blow into the cover through an inlet above the abdomen and will escape from the bottom of the cover. The participant will be breathing ambient air (~22˚C).
- o Charcoal Heater to the Torso (CH-T) - The charcoal heater will be placed on your anterior chest; the heater will be insulated to prevent skin burning. The flexible ducts will be applied to the areas of high heat transfer i.e. over the shoulders, neck, and then anteriorly under the axillae to cross over the lower anterior chest. You will be breathing ambient air at room temperature (~22˚C).

After 60 minutes of warming, you will be placed in a warm water bath (40-42˚C) until you are comfortable and core temperature returns to normal values (~36.5-37˚C).

The study will include the following specific procedures:

- You will be asked to complete a PAR-Q-Activity questionnaire prior to participating.
- You will be asked supplemental questions regarding your medical fitness for the study.
- Anthropometric data will be collected and recorded. This includes age, height, weight, and measurements of skin fold thickness at four sites- biceps, triceps, subscapularis, and suprailiac. This is used to calculate your body surface area and % body fat.
- The testing session will involve cooling of the skin. Your heart rate and electrocardiogram will be monitored continuously throughout this period. You will be asked several times throughout the study if you would like to stop.

You will be instrumented as follows:

- o 12 heat flux disks (2 cm in diameter) will be taped to the skin on the legs, arms, torso, and head to measure skin temperature and heat transfer from the skin.
- o Three ECG leads will be affixed to the skin.
- o Core temperature will be measured with a disposable esophageal thermocouple. A sterilized thin, flexible tube will be inserted through the nose, to midway down the esophagus at the level of the heart. There is a slight risk of a sore throat or a minor nose bleed. If this occurs, direct pressure will be applied to the nostrils until bleeding stops. The esophageal probe will be inserted by Dr Giesbrecht. You will have your own thermocouple that will not be used by anyone else.
- o Oxygen consumption will be continuously measured; you will be asked to wear a face mask which will collect the expired breath, during the cooling period. The mask will be replaced with a mouth-piece

during the rewarming period and a nose-clip will be placed on the nose. You will be able to speak and communicate with the investigators throughout the study.

Protocol:

You will be submersed in 21˚C water up to the level of the sternal notch. The water temperature will be lowered to 8˚C over a period of 5-10 min by addition of ~60 kg of ice. You will remain in the water until either:

1) You wish to exit;
2) The investigator advises stopping for safety or other reasons;
3) Your core body temperature decreases to 35˚C; or
4) 60 minutes of immersion elapses, whichever comes first.

After the experiments you will be warmed by one of the three rewarming methods (mentioned above). Treatment will continue either for a period of 60 minutes or until your core temperature returns to normal values (~36.5-37˚C). Following that, you will be actively rewarmed by entering a warm water bath of 40-42˚C.

4. Dr Giesbrecht has an experience of 26 years, with > 40 studies involving over 100 subjects who participated in a total of more than 300 hypothermia immerisons.
5. – NA
6. The cooling sessions may involve risks that are currently unforeseeable, although to date in our many similar immersions, we have not seen any untoward effects caused by the cold stress itself. The rewarming treatments do not present any risks as they are commonly used in relevant clinical situations. There are other minimal risks, which will be explained below.

7. Some known risks or discomforts may be:

A. Hypothermia: - The study in which you have been asked to participate involves lowering of body core (esophageal) temperature by a maximum of 2.0ºC (to a minimum of 35.0ºC). Submersion in cold (8°C) water may result in an unpleasant, cold sensation and may cause a transient increase in breathing; this will soon subside; these responses are greatly blunted by our protocol which gradually decreases the water temperature from 21 to 8°C. As well, you may experience vigorous shivering, which is a natural response. The criterion for stopping cooling is a maximal decrease in core temperature to the upper threshold of clinical/mild hypothermia – 35.0ºC. Therefore, cooling will be terminated before you become clinically hypothermic. The investigators have previously conducted many cooling studies of this type and no complications were experienced as a result of the change in core temperature. Serious complications including death due to heart rhythm abnormalities do not occur in the range of core temperatures to be experienced in this study. A core temperature below 28.0˚C is necessary to produce dangerous effects to the heart.

B. Core temperature measurement – You will have your own sterilized disposable esophageal thermocouple probe. The insertion of the esophageal probe may invoke some gag reflexes but our technique has been well tolerated by all but a few subjects (who had a pronounced gag reflex) for 26 years. There is a slight risk of minor nose bleed. If this occurs, direct pressure will be applied to the nostrils until bleeding stops. Rarely it is also possible that the probe could enter the wind pipe (trachea). This will not cause any damage but would be uncomfortable. This can be identified by difficulty in talking. If this occurs the probe will be removed and another attempt will be made if the participant is willing.

<u>C. Skin numbness</u> – On rare occasions, extended exposure of toes and fingers to 8˚C water can cause short-term skin numbness on these areas. Although this rare problem will resolve itself (normally within a few days), this problem will be prevented by insulating the feet (with neoprene boots) and having the subject keep their hands out of the water (by holding on to a bar placed above the water).

8. The investigator may learn about the effects of heat donation through the head in rewarming hypothermic subjects (this method has a theoretical basis to be an advantage over torso warming). This will help in the ongoing research on pre-hospital treatment of cold patients.

9. Any significant new information, which becomes available during the research, which may relate to your willingness to continue participation, will be provided to you.
10. NA
11. You understand that participation is voluntary, you may refuse to participate, and you have the right to withdraw from the study at any time without prejudice. You can inform the investigators in any way you like- i.e., phone, e-mail, in person etc.
12. Your participation may be terminated by the Investigator without your consent in cases such as- you are not able to cope with the cold stress, any of the procedures was causing unexpected negative reactions or adverse events, or there are problems with data acquisition or protocol adherence were detected which nullified the value of collected data..
13. You will be instructed to abstain from alcohol, medications or vigorous physical activity for a period of 24 hour prior to the study. You will also be instructed to have a small breakfast and no other food 2-3 hours prior to the immersion. You will be required to come to the laboratory at the same time of the day for all 3 trials.
14. NA
15. NA
16. NA
17. NA
18. NA
19. NA
20. NA

COMPENSATION

21. Because this study involves your time and some discomfort, you will be reimbursed $100 for each immersion. Payment will be in the form of a cheque mailed after the last experiment with a delay of 3 to 6 weeks.
22. Once you start any immerison you will be reimbursed whether you complete the trial or not. If there are any adverse events you should inform Dr. Giesbrecht at 474-8646 (office) or 995-6599 (cell).

23. You are responsible for your own parking – if applicable – during your laboratory visits.

CONTACTS FOR PARTICIPANTS

24. Signing this document indicates that you have talked with Dr. Giesbrecht about this study and your questions have been answered to your satisfaction. If you have any other questions or feel distressed in any way after leaving the laboratory, you may call Dr. Giesbrecht at (204) 474-8646 day, (204) 269-5685 evening or (204) 995-6599 cell phone.
25. The research has been approved by the Biomedical Research Ethics Board (BREB) at the University of Manitoba. Any questions regarding your rights as a participant or any complaints regarding this study may be reported to The University of Manitoba Bannatyne Campus Research Ethics Board at (204) 789-3389.

CONFIDENTIALITY FOR PARTICIPANTS

26. Any information obtained in connection with this study that can be identified with you will remain confidential and will not be disclosed without your permission. Data will be coded and names will not be revealed at any time. Only group data or coded individual data will be presented or exposed. Any data that can be specifically identified as yours will be stored by the Dr. Giesbrecht in secure file cabinet in archives indefinitely, or until instructions to shred the information is received from the University of Manitoba Health/Biomedical Research Ethics Board. Experimental results, which cannot be specifically identified as yours, will be kept permanently in paper and/or digital form. The University of Manitoba Health/Biomedical Research Ethics Board will have access to your confidential records but they are committed to confidentiality as well. Your identity will be protected, but due to access from this group, it cannot be guaranteed. You will not be identified in any written reports or publications, your identity will be treated as confidential in accordance with the Personal Health Information Act of Manitoba and the information will only be used for research purposes.

102 Frank Kennedy Centre
Winnipeg, Manitoba
Canada R3T 2N2

UNIVERSITY OF MANITOBA | Faculty of Kinesiology and Recreation Management

PART II: INFORMED CONSENT FOR CLINICAL TRIALS

RESEARCH PARTICIPANT INFORMATION AND CONSENT FORM

Title of Study: Comparison of heat donation through the head or torso on hypothermic rewarming efficacy.

Protocol number: NSERC Discovery Grant (2010-16)
Principal Investigator: Gordon Giesbrecht
211 Max Bell Centre, University of Manitoba,
Winnipeg, MB - R3T 2N2
Phone: 474-8646
Co-Investigator: None
Sponsor: NSERC 350 Albert Street, Ottawa, ON – K1A 1H5

You are being asked to participate in a Clinical Trial (a human research study). Please take your time to review this consent form and discuss any questions you may have with the study staff. You may take your time to make your decision about participating in this clinical trial and you may discuss it with your regular doctor, friends and family before you make your decision. This consent form may contain words that you do not understand. Please ask Dr. Giesbrecht or his study staff to explain any words or information that you do not clearly understand.

The Principle Investigator (Dr. Giesbrecht) is receiving financial support (from the Natural Sciences and Engineering Research Council) to conduct this study.

Public registration of the study

A description of this clinical trail is available on http://ClinicalTrials.gov. This website will not include information that can identify you. At most, the website will include a summary of the results. You can search this website at any time.

Purpose of Study

This Clinical Trial is being conducted to study rewarming methods for mild hypothermia. You are being asked to take part in this study because you have fulfilled the criteria of being a healthy adult between the ages of 18-45 years with no adverse responses to cold exposure nor any cardiorespiratory disease. A total of eight participants will participate in this study.

The purpose of this study is to compare the core rewarming effectiveness of the same amount of heat donation through the head or torso in rewarming of mildly hypothermic individuals.

This research is being done because currently the effectiveness of head warming in rewarming mildly hypothermic individuals is not known.

Study procedures

The order of experiments will follow a randomized balanced design. The order of the three rewarming methods will be randomly assigned to each participant so that all participants have a different order of treatments. This design allows the researchers to ensure that all participants do not undergo the experiments in an exactly same order.

Neither you nor the study staff will be blinded to the treatment groups.

If you take part in this study, you will have the following tests and procedures:

You will be asked to participate in three experimental trials on three separate occasions, separated by at least 48 hours. On each of the three trials, you will be submersed in 21˚C water up to the level of the sternal notch. The water temperature will then be lowered to 8˚C over a period of 5-10 min by addition of ~60 kg of ice. You will remain in the water until either:

You wish to exit;

The investigator or physician advises stopping for safety or other reasons;

Your core body temperature decreases to 35˚C; or

60 minutes of immersion elapses, whichever comes first.

You will then exit the water, be dried off and lie in a hooded sleeping bag, where one of the three warming procedures will be administered:

Spontaneous rewarming (Shivering Only) - In this control condition, no external heat will be provided and you will rewarm spontaneously with the heat produced from shivering.

Head Warming (Head): Either of these rewarming methods will be used:

Forced-Air Warming to the Head (FAW-H) - A modified rigid forced-air warming cover will be placed over your head. Warm air (~43˚C) will blow into the cover through an inlet on top of the cover and will escape from the bottom of the cover. You will be breathing warm air (~43˚C).

Charcoal Heater to the Head (CH-H) - A charcoal heater will be placed on right side of your face/head (the heater is insulated to prevent skin burning) with ducts wrapping around the dorsum of the head, anteriorly over the forehead, nose, chin and the neck, not covering the eyes or the mouth. You will be breathing ambient air (~22˚C).

C. Torso Warming – Either of these rewarming methods will be used:

Forced-Air Warming to the Torso (FAW-T) - A specially designed portable rigid forced-air cover (PORIFAC) will be placed over your torso and the upper thighs. Warm air (~43˚C) will blow into the cover through an inlet above the abdomen and will escape from the bottom of the cover. Participant will be breathing ambient air (~22˚C).

Charcoal Heater to the Torso (CH-T) - The charcoal heater will be placed on your anterior (the heater is insulated to prevent skin burning). The flexible ducts will be applied to the areas of high heat transfer i.e. over the shoulders, neck, and then anteriorly under the axillae to cross over the lower anterior chest. You will be breathing ambient air at room temperature (~22˚C).

Treatment will continue either for a period of 60 minutes or until your core temperature returns to normal values (~36.5-37˚C). Following that, you will be placed in a warm water bath (40-42˚C), until you are comfortable and core temperature returns to normal values (~36.5-37˚C).

If you take part in this study, you will have the following procedures:

You will be visiting the laboratory 3 times in a period of up to 4 months. You will be required to visit at same time of the day, during weekdays.

You will be asked to complete a PAR-Q-Activity questionnaire prior to participating. An example of questions asked in PAR-Q is**:** Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor? You will also be asked a series of verbal questions to determine if you have any cardiorespiratory disease or any conditions that are stimulated by cold exposure.

Either males or females between the ages of 18-45 years can participate in this study. There is no other screening procedure other than the PAR-Q and verbal questionnaires.

You will be instructed to abstain from alcohol, medications or vigorous physical activity for a 24 hour period prior to the study.

You will be instructed to have a small breakfast and no other food 2-3 hours prior to the immersion.

Anthropometric data will be collected and recorded. This includes age, weight, height, and measurements of skin fold thickness at four sites- biceps, triceps, subscapularis, and suprailiac. This will be used to calculate your body surface area and % body fat.

Each testing session will involve cooling of the skin. You will be submersed in 21˚C water up to the level of the sternal notch. The water temperature will then be lowered to 8˚C over a period of 5-10 min by addition of~60 kg of ice. Your heart rate and electrocardiogram will be monitored continuously throughout this period. You will be asked several times throughout the study if you would like to stop. The trial will be stopped when:

You wish to exit (you can communicate by either asking to be removed or giving a thumbs-up hand signal);

The investigator advises stopping for safety or other reasons;

Your core body temperature decreases to 35˚C;

Or 60 minutes of immersion elapses, whichever comes first.

You will be instrumented as follows:

12 heat flux disks (2 cm in diameter) will be taped to the skin on the legs, arms, torso and head to measure skin temperature and heat transfer from the skin.

Three ECG leads will be affixed to the skin.

Core temperature will be measured with a sterile disposable esophageal thermocouple. A thin, flexible tube will be inserted through the nose, to midway down the esophagus at the level of the heart. The esophageal probe will be inserted by Dr Giesbrecht. You will have your own thermocouple which will not be used by anyone else.

Metabolic rate will be continuously monitored; you will be asked to wear a face mask which will collect the expired breath, during the cooling period. The mask will be replaced with a mouth-piece during the rewarming period and a nose-clip will be placed on the nose. You will be able to speak and communicate with the investigators throughout the trials.

After the experiments you will be dried off and lie in a hooded sleeping bag with the head inside the hood where you will be warmed by one of the three rewarming methods: A. Spontaneous rewarming; B. Head warming; and C. Torso warming. Treatment will continue either for a period of 60 minutes or until your core temperature returns to normal values (~36.5-37˚C). Following that, you will be actively rewarmed by entering a warm water bath of 40-42˚C.

You will be asked to participate in three experimental trials. Each trial will last about 4 hours (1 hour for setup, 1 hour for cooling, and 2 hours for rewarming and removal of instrumentation). Your trials will be at least 48 hours apart and the three tests will be completed within three-four months (April-July). Thus, your total commitment will be about 4 hours per visit and three total visits within a period of 4 months. Same procedures will be carried out for each visit except the rewarming treatment method.

Participation in the study will be for a period of up to 4 months, until you have visited the laboratory 3 times.

The researcher may decide to take you off this study if you are not able to cope with the cold stress, any of the procedures causes unexpected negative reactions or adverse events, or there are any problems with data acquisition or protocol adherence are detected which nullifies the value of collected data.

You can stop participating at any time. However, if you decide to stop participating in the study, we encourage you to talk to the study staff first.

If you are interested, we will provide an electronic copy of a summary report of the study once it is completed.

Risks and Discomforts

While on the study, you are at risk for certain side effects .

1) Hypothermia – The study in which you have been asked to participate involves lowering of body core (esophageal) temperature by a maximum of 2.0ºC (to a minimum of 35.0ºC). Submersion in cold (8°C) water may result in an unpleasant, cold sensation and may cause a transient increase in breathing; this will soon subside. As well, you may experience vigorous shivering, which is a natural response. The criterion for stopping cooling is a maximal decrease in core temperature to the upper threshold of clinical/mild hypothermia – 35.0ºC. Therefore, cooling will be terminated before you become clinically hypothermic. The investigators have previously conducted many cooling studies of this type and no complications were experienced as a result of the change in core temperature.

2) Core temperature measurement – You will have your own sterilized disposable esophageal thermocouple probe. The insertion of the esophageal probe may invoke some gag reflexes but for our technique has been well tolerated for 26 years. There is a slight risk of minor nose bleed. If it occurs, direct pressure will be applied to the nostrils until bleeding stops. Rarely it is also possible that the probe could enter the wind pipe (trachea). This will not cause any damage but would be uncomfortable. This can be identified by difficulty in talking. If this occurs the probe will be removed.

3) Skin numbness – On rare occasions, extended exposure of toes and fingers to 8˚C water can cause short-term skin numbness on these areas. Although this rare problem will resolve itself (normally within a few days), this problem will be prevented by insulating the feet (with neoprene boots) and having the subject keep their hands out of the water (by holding on to a bar placed above the water).

Benefits

By participating in this study, you will be providing information to the study investigators that will show the effects of head vs. torso warming for the treatment of mild hypothermia . There may or may not be direct medical benefit to you from participating in this study. We hope the information learned from this study will benefit accidental victims of mild hypothermia in the future.

Costs

You will be responsible for your own parking while in the study. There will be no other expenses for you as a result of participation in this study.

Payment for participation

You will be given $100 per completed study visit to a maximum of $300 upon termination of your participation in this research study.

Payment will be in the form of a cheque mailed after the last experiment with a delay of 3 to 6 weeks.

Alternatives

Not Applicable

Confidentiality

Information gathered in this research study may be published or presented in public forums, however your name and other identifying information will not be used or revealed. All study related documents will bear your initials, date of the experiment, and the name of the experiment. Despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed.

The University of Manitoba Biomedical Research Ethics Board may review research-related records for quality assurance purposes.

All records which can be identified as yours will be kept in a locked secure area and only those persons identified will have access to these records. If any of your medical/research records need to be copied to any of the above, your name and all identifying information will be removed. No information revealing any personal information such as your name, address or telephone number will leave the University of Manitoba.

Voluntary Participation/Withdrawal From the Study

Your decision to take part in this study is voluntary. You may refuse to participate or you may withdraw from the study at any time. Your decision not to participate or to withdraw from the study will not affect your other care at this site. If anyone from the investigation team feels that it is in your best interest to withdraw you from the study, they will remove you without your consent.

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

Adverse Events or Medical Care for Injury Related to the Study

In case of any adverse event due to this study or if you are distressed in any way after leaving the laboratory, you will inform Dr Giesbrecht (business – 474-8646; residence – 269-5685; cell – 995-6599) for assistance. All adverse events and unanticipated problems will be reported to the Bannatyne Campus Research Ethics Board as described on the following website: http://umanitoba.ca/faculties/medicine/ethics/Adverse%20Event%20Reporting%20and%20Safety%20Information.html. Once you start any immersion you will be paid an amount of $100 for that trial, irrespective of whether you complete the trial or not.

You are not waiving any of your legal rights by signing this consent form nor releasing the investigator(s) or the sponsor(s) from their legal and professional responsibilities.

Questions

You are free to ask any questions that you may have about your treatment and your rights as a research participant. If any questions come up during or after the study or if you have a research-related injury, contact the study investigator and the study staff: Dr. Gordon Giesbrecht at 474-8646.

For questions about your rights as a research participant, you may contact The University of Manitoba Biomedical Research Ethics Board at (204) 789-3389

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

Statement of Consent

I have read this consent form. I have had the opportunity to discuss this research study with Dr. Gordon Giesbrecht and or his/her study staff. I have had my questions answered by them in language I understand. The risks and benefits have been explained to me. I believe that I have not been unduly influenced by any study team member to participate in the research study by any statement or implied statements. Any relationship (such as employee, student or family member) I may have with the study team has not affected my decision to participate. I understand that I will be given a copy of this consent form after signing it. I understand that my participation in this clinical trial is voluntary and that I may choose to withdraw at any time. I freely agree to participate in this research study.

I understand that information regarding my personal identity will be kept confidential, but that confidentiality is not guaranteed.

By signing this consent form, I have not waived any of the legal rights that I have as a participant in a research study.

I would like to receive a summary report of this study once it is completed.
Yes No
If yes, please provide your e-mail address:___________________________

I am willing to be contacted regarding participation in future studies of this type.
Yes No
If yes, please provide your e-mail address and phone no.

E-mail address: ___________________________________

Phone no: ________________________

Participant signature_____________________ Date __________________
(day/month/year)

Participant printed name: ___________________________

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has knowingly given their consent

Printed Name: Dr. Gordon Giesbrecht Date __________________
(day/month/year)

Signature: ___________________________

Role in the study: Primary Investigator

Relationship to study team members:_________________[eg. teacher/professor or family member.]

APPENDIX 5

Faculty of graduate studies
University of Manitoba

Faculty of Graduate Studies
500 University Centre
Winnipeg, Manitoba
R3T 2N2

PERMISSION TO USE COPYRIGHTED MATERIAL

Date: 16-02-2013

Student name: Bhupinder Jit Kaur Sran

Student address: 2 Emily Street, Apartment no-510, Winnipeg, MB. R3E 1Y7

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Title of article / book / website:	Thermoregulatory model for prediction of long-term cold exposure.
Page numbers / URL:	287-298
Title and number of image:	Conceptual model for control of shivering intensity. Figure 1.
Print / Web publisher and date of publication:	Elsevier Ltd. 2005.
Journal name and issue number:	Computers in Biology and Medicine. 35.

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