The effects of elapsed time after a warm-up on physiological and performance responses during rowing and running in a cold environment.

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CHAPTER ONE
INTRODUCTION

Background

Competitive rowers and other athletes such as runners, often compete in relatively cold environmental conditions (as low as 5°C). A pre-competition warm-up is a standard procedure in all sports, and athletes complete it in order to increase the temperature, and therefore, the function of the tissues. In a rowing regatta, the race structure usually is such that following the warm-up, a considerable amount of time may elapse before a race actually begins. Because this delay may allow the beneficial effects of the warm-up to dissipate, rowers may face a combination of environmental temperatures and race conditions that can negatively alter physiologic, metabolic, and mechanical responses and thereby impact their performance.

Since rowing regattas sometimes consist of many different events, the duration of time between races differs depending on the organization of the regatta, timeliness of crews to the starting line, false starts, and unfavorable weather conditions such as high winds, and large waves. Because of these factors, crews that have already warmed up before the race could spend a large amount of time sitting near the starting line and become exposed to the environmental conditions while forced to be at rest. Quick starts following this rest period do not allow time for additional warm-up; therefore, performance during the race may be affected. Most races are 2000 meters and are completed at an intensity that is at or above maximal aerobic capacity (VO₂max), lasting about 6 to 8 minutes. This combination of intensity and duration does not give the body enough time to benefit from gradual warm-up effects that occur during the first few minutes of exercise at a lower intensity.

Research shows that performing a proper active warm-up before exercise can positively impact metabolic responses in subsequent performances (2, 19, 20). A warm-up will increase peripheral blood flow to the exercising muscles and can improve perfusion of these muscles, which will enhance oxygen delivery and will allow an individual to reach higher levels of aerobic metabolism more quickly during a subsequent performance (2, 19, 20, 29, 34, 45). Increased muscle temperatures will also enhance oxygen
use and mitochondrial functioning simply due to the fact that biochemical reactions occur more rapidly at higher temperatures (26). Along with the enhanced aerobic metabolism, there is evidence that warm-up will activate the glycolytic process, which may acutely cause an elevated blood lactate, but will then ultimately decrease the lactate accumulation during the subsequent performance (9,20,29,34,45). Burnley et al. (9), found improvements in a 7-minute performance cycling trial when preceded by a moderate or heavy warm-up regimen causing blood lactate concentrations to be between 1 and 4 mM at the onset of the time trial. This was compared to cycling trials that were preceded by either no warm-up or high-intensity sprints that elevated lactate levels to above 5mmol. Gray and Nimmo (19) suggest that when an active warm-up precedes a performance, a blunted response of lactate concentration may be due to an increased rate of lactate clearance and uptake of lactate in the blood from the muscles during the recovery time following the warm-up. Robergs et al. (45) showed that immediately after a supra-maximal swim performance lasting about two and a half minutes, blood lactate concentrations immediately after trials preceded by a warm-up did not differ from those observed in trials without a warm-up. After two minutes of recovery, lactate was found to be significantly lower in the trial with a warm-up. To also note, in this study the authors also compared arterialized bicarbonate concentrations as well as venous concentrations of hydrogen ions (H+) (45). After warm-up and before the swim performance, bicarbonate concentrations were lower compared with not warming up, but this difference was reversed after the performance with significantly higher concentrations observed after the warm-up. H+ concentration was significantly lower after swim performance in the warm-up trial, as well as after 5 minutes of recovery. A warm-up before a supra-maximal swim performance was beneficial in reducing the accumulation of H+ in venous blood (45). The researchers suggest that the mechanism for this change is that increased muscle temperature may activate the muscle’s buffering capacity against the decline of intracellular pH, showing that a warm-up could positively affect the buffering capacity during subsequent exercise (29,45). The measurement of blood pH and H+ may be better indicators of the metabolic conditions in the muscle that could alter performance (45).
Although there is a considerable amount of evidence demonstrating the benefits of performing a specific, proper, active warm-up before an exercise performance, there is no consensus as to how long the effects will last in order to still benefit from the warm-up. As the amount of time between a warm-up and performance increases, it is logical to assume that the benefits of the warm-up will decrease. In the majority of studies that examine the effects of several different types of warm-up protocols, a 5-minute time period between the warm-up and subsequent time trial has been used (2, 9, 19, 20, 34). It is said that this duration will negatively affect high-intensity performance and that increased muscle temperatures caused by warm-up are maintained in this period of time, which is beneficial for optimal performance (19). Accelerated heat loss may occur with colder ambient temperatures and the decay in the beneficial effects of a warm-up with an increased lag prior to performance could be accentuated. There is little research to date that has examined the impact of varying the amount of time between a warm-up and performance exercise with varying ambient temperatures.

In sporting events or competitions that take place in lower temperatures, a proper warm-up may be even more important for optimal performance than in neutral or warm environments because of the increased rate of heat loss. Core temperature reflects heat balance, or thermoregulation, and is simply the balance between body heat production and loss. Exchange of heat between the body and the surrounding environment occurs through evaporation, convection, conduction, and radiation. These mechanisms can be altered by environmental factors such as cold temperatures and wind which may significantly affect thermal gradients between the air, skin, and muscle so that there is a potential for significant body heat loss (56). In rowing, cold and windy conditions can increase convective cooling and there is an increased chance of getting wet, which, with exposed skin, can increase heat loss via conductive, convective, and evaporative mechanisms. Even when an athlete wears proper clothing in a cold condition, if enough sweat is produced from high-intensity exercise to saturate the clothes, the clothing then loses insulating value (48).

Skin temperatures are the first to reflect the effects of cold ambient conditions. When skin temperatures fall below about 35°C, vasoconstriction will occur in order to help defend core temperature,
thus reducing convective heat transfer between the core and the skin, subcutaneous fat, and skeletal muscle (10,56). As a result of the heat-preserving responses, there can be decreases in blood flow to peripheral exercising muscles which can significantly decrease variables such as oxygen delivery and lactate clearance. A reduction in oxygen delivery will decrease the reliance on aerobic metabolism which may, in turn, negatively impact exercise conducted at a high percentage of VO2max.

Resting in the cold for a significant amount of time may decrease core temperatures and when exercise is completed in cold environments, the normal rise of core temperature that occurs with increasing physical activity is blunted (54). Core temperatures may not drop to pre-exercise values during the rest period; however, there may be an accelerated decrease compared with a warmer environment. Similar with core temperature, it would be unusual for muscle temperature to drop below pre-exercise levels, but lower than normal muscle temperatures can alter muscle metabolism via reduced enzyme activity and altered contractile function (47). Studies have shown detrimental effects on performance when muscles were cooled either by ambient temperature or by water immersion. And researchers concluded that decreases in body temperature induce an increase of catecholamines in the blood, which then enhances glycogenolysis (1,5). As a result of the reduced physiological function when performing exercise in the cold, an individual may be unable to maintain high levels of intensity for a long duration, which can decrease metabolic heat production which will, in turn, affect regulation of core temperature (56).

Although their study was not specifically designed to study the lasting effects of a warm-up, the findings of Castellani et al (10) can be applied to the current research question since they examined thermoregulatory changes during cold exposure after exercise. In the study, core temperatures were raised either via submaximal exercise for 60 minutes, or warm-water immersion, followed by a 120-minute rest period in a cold-air chamber set at 5°C. After the exercise condition, core temperatures decreased at a faster rate during the cold exposure compared to the passive warming condition. The authors suggest that this change may have been due to the persistent increased post-exercise blood flow which continued to increase convective heat transfer from the core to the periphery. The exercise may
have also caused a blunted vasoconstrictive response during the cold exposure, which the authors term, “thermoregulatory lag” (10). This study provides insight into the thermoregulatory responses that would be present during the post-warm-up/pre-competition period that would be present in the rowing regatta scenario. Because of the accelerated heat loss following active heating, when an athlete competes in a cold environment, the time in between the active warm-up and performance could become crucial for an optimal thermoregulatory response.

It is evident that warming up prior to a maximal exercise bout can enhance performance through many mechanisms such as increased blood flow, core and muscle temperatures, and metabolic efficiency. It is less known as to how long the positive effects can last in order to still receive gains in a later performance. Effects of increases in core and skin temperature may be negated with an increased amount of time in-between warm-up and subsequent performance; this effect may be accentuated by lower ambient temperatures.

**Purpose**

The purpose of this study was to examine the effects of varied durations of post warm-up periods on the metabolic, thermoregulatory, and performance responses during subsequent high intensity rowing or running in a cold environment. Specifically, core and skin temperatures, cardiovascular function, metabolic responses, and 2000 meter rowing performance or 1.5 mile running performance were measured after rest periods of 5 minutes and 30 minutes following a standardized warm-up in two different environments.

**Hypotheses**

It is hypothesized that: 1) after a full-body active warm-up, a prolonged (30-min.) duration of rest in a cold environment will negatively affect 2000-meter performance, or 1.5 mile running performance, compared to a short (5-min.) rest period. The impaired performance will be evident via an increase in performance times in these trials; 2) decreased core and skin temperatures will be seen in the cold
environments compared to the temperate and that the prolonged duration of rest in the cold environment will produce the lowest body temperatures before the time trial; 3) blood lactate concentrations should increase after warm-up in both conditions, should increase before the time trials in cold compared to the temperate environment, and should be similar after the time trials in both environments.

Project Significance

No studies to date have examined the effects of a prolonged time between warm-up and performance in a cold environment. Studies also have not examined to what extent an active warm-up in a cold environment will positively affect physiological and mechanical variables before a subsequent performance. Determining the effects of cold-stress on the body after an active warm-up can help an athlete’s preparation before competition in less than desirable conditions.
Exercise physiology researchers have extensively examined the effects of environmental conditions on variables associated with exercise performance. There can be many effects on the body from external environmental differences separate from, or in addition to exercise. Exposure to and exercising in the cold can affect thermoregulation and can alter the effectiveness of a pre-performance warm-up.

Colder temperatures can cause different changes in the body’s normal thermoregulatory capability and have physiological and mechanical effects before, during, and after exercise. In extreme cases, shivering can occur, furthering these changes. Warm-up is a well-studied parameter of exercise and if adequate, can benefit exercise performance. Environmental changes may impact how an athlete performs a warm-up exercise and may alter the effects that are normally associated with warm-up. Research shows that intensity is an important factor in a warm-up, and affects changes in blood metabolites such as lactate (2, 3, 9, 19). Lastly, time between warm-up and performance is important, especially with variable outside temperature and thermoregulatory changes occur. The following literature will discuss evidence relevant to these issues and their applicability to the current research question of how the effects of varied durations of post-exercise resting periods can affect physiological and performance parameters in a cold environment.

Exercise in the Cold

Thermoregulation/Heat Balance

Thermoregulatory processes act in order to maintain a normal core temperature (Tc) by controlling the rate of the body’s heat production and heat loss. The temperature control center is located in the hypothalamus, which initiates physical and chemical processes in order to maintain core temperature (40). When ambient temperature is greater than skin temperature, the body gains heat, and
with exercise, metabolic heat production may cause the core temperature to rise. These changes cause the hypothalamus to react, bringing about numerous hormonal and physiological changes that help the body lose the excess heat via thermoregulatory methods. Core temperature reflects the balance between the production and loss of body heat and the mechanisms by which thermoregulation occurs are radiation, conduction, convection, and evaporation.

Heat gain or loss via radiation occurs through electromagnetic waves; gain occurs primarily via the transfer of heat from the sun’s rays to an object, while loss occurs when there is a favorable gradient for energy dissipation. The human body usually receives radiant heat and radiates heat at the same rate; thus, the amount of heat exchanged via radiation varies as a function of the environment and exercise parameters. Conduction is the transfer of heat between two objects in contact with one another, such as muscle and skin tissues. Exercise causes increased heat generation in the working muscles that subsequently causes superficial heat transfer so that skin temperature increases. Heat transfer via convection occurs between a stationary object and a moving substance such as air or water. Increased blood flow to the periphery during exercise represents a form of internal convection whereby energy is carried from the muscle to the skin due to blood flow from the muscle to the subcutaneous vessels, thus increasing the temperature of the skin. The skin then loses heat via convection, radiation or evaporation to the ambient air, with radiation occurring only if the air temperature is lower than that of the skin (8). Evaporation is the most common form of thermoregulation in the human body and is especially important for heat loss during exercise. For each liter of sweat that evaporates, almost 600 kcal of energy are dissipated, showing that sweating is the most important effect to increase heat loss by means of evaporative cooling.

Gradients of temperature exist between ambient air and skin, between skin and muscle, and between muscle and core. There are small conduction gradients within internal body tissues; however, heat transfer becomes more apparent when the outside environment changes, which will initially increase the gradient between air and skin. While a person is at rest in colder environments, decreased air temperature prompts the initial gradient between air and skin to increase, favoring heat from the skin to
move to the air and resulting in a net loss of body heat via primarily radiation or convection; the latter if there is wind present. Because of this process, skin temperatures are the first to decline during cold exposure, and if one remains at rest in this condition, heat loss continues so that temperatures will decrease slowly in muscle tissue and then the core.

In a normal environment, increased metabolic heat production from exercise will typically cause increases in core temperature over time, but these changes can vary with relative workload and environmental temperature (44). In a cold environment, exercise and metabolism produce body heat and the body may store some of this heat with the help of insulation from body fat and clothing. This storage of heat helps maintain normal core temperature; however, colder ambient temperatures along with increased body temperature from exercise will create a thermal gradient between the body and air that favors heat loss. Rintamaki and Rissanen (44) define cold strain as when mean skin temperatures decrease below 27°C, even if core temperatures remain normal. In the cold, the body must preserve heat when needed and facilitate heat loss as needed (44). If strain occurs from temperature and exercise, the body reacts and initiates vasoconstriction or vasodilation.

Heat Gain/Vasoconstriction

Vasoconstriction is a thermoregulatory response initiated by signals coming from thermoreceptors located on the skin and in the core (18). During cold exposure while the body is at rest, peripheral vasoconstriction decreases blood flow to the limbs in order to maintain the internal temperature of organs and working muscles, and will decrease the amount of heat being lost convectively between the core and skin (17, 48, 54, 57). Castellani et al. (10) argue that this response is reflective of sympathetic nervous system activation and helps defend core temperature. During longer durations in this environment, vasoconstriction can cause decreased skin temperatures, and in extreme cases can affect simple motor skills and comfort.

Heat Loss/Vasodilation
Flouris et al. (17) indicates that responsive cold-induced vasodilation (CIVD) causes an increase in local blood flow and a consequent increase in local skin tissue temperature. This process acts to dissipate heat from the muscle to the skin and will then lower mean body temperature. Vasoconstriction, which is simultaneously occurring to defend core temperature, may inhibit CIVD and could become a problem when an athlete exercises in the cold. Vasodilation is also a response to exercise when increased heat production causes body temperature to rise above normal and leads to increased heat loss (17, 57). At higher exercise intensities and warmer ambient temperatures, Tc increases at a faster rate, and exercise-induced vasodilation occurs sooner compared to normal conditions (44). This is an important thermoregulatory mechanism for athletes who compete in warmer environments; however, it may be overlooked by those who compete in colder weather.

Exercise increases metabolic heat production, and at a high enough intensity can overcome any heat loss from the cold, but the concurrent body movement also increases convective heat loss from the body surface, and when sweating occurs, even more heat dissipates. Evaporative cooling via sweating can still occur in individuals who are exercising in the cold, depending on the core and skin temperatures. Several studies have proven that this mechanism occurs when core temperatures increase above about 37°C while skin temperatures fall below 26°C and the body is under cold strain (44).

In the cold, the body’s thermoregulatory processes go back and forth in their attempts to either help increase or decrease Tc. Vasoconstriction occurs when an athlete is in a cold environment in order to shunt heat back to the core to preserve heat, while vasodilation occurs during exercise in order to increase heat loss. Intensity and duration of exercise, as well as environmental conditions of temperature and wind speed, all have variable effects on thermal balance. Thermoregulation could be compromised in cold weather situations, especially if an athlete is unprepared for colder temperatures and must compete at their highest intensity.
Core Temperature

Core temperature reflects internal heat balance and is important to understand when drastic temperature changes occur due to exercise or via changes in ambient temperatures. Initial decreases in Tc during exercise result from a redistribution of heat and the shunting of cooler peripheral blood into the core. This change termed “after-drop,” occurs parallel to increased heat production and when the body is re-warming during exercise after being cooled (12). In cold, this decrease is even more pronounced and research proves that core temperatures during exercise in cooler temperatures are significantly lower compared to warmer temperatures (44). This effect may be due to the increased radiative heat loss from the warmer body to the cooler ambient air, and convective heat loss from increased blood flow from exercise (57). The literature does not address how an athlete in a colder environment may be affected at the beginning and during an exercise performance, if core temperature is lowered.

Post-exercise cold exposure

Exercising at a high enough intensity in a cold environment is not dangerous for an athlete. Some sports may subject athletes to a resting period in the cold, which may alter thermoregulatory functions and the variables that can then affect a subsequent performance.

According to Castellani et al. (10), higher-intensity exercise could cause “thermoregulatory fatigue,” which may blunt the shivering responses and reduce the normal vasoconstrictive response when a person is exposed to cold after a bout of exercise (10, 11). Thermoregulatory fatigue describes what occurs from post-exercise cold exposure, when there may be a delay in the body’s thermoregulatory response to preserve heat. This delay may result from exercise-induced hyperemia and redistribution of heat to the active limbs, which can continue to favor conductive heat loss. In cases of extreme cold exposure for long durations, the impaired thermoregulatory system could delay the shivering response and vasoconstrictor responses that normally act to defend the body’s temperature (11, 44). Evidence suggests that if this extreme were to occur, it would do so after hours of strenuous exercise, followed by long bouts of resting in a cold environment (11).
Castellani et al. (10) reported that when individuals exercised before cold exposure, their body temperatures cooled at a faster rate post-exercise when compared to those who rested prior to exposure. This evidence would indicate that in a subsequent bout of exercise, an athlete may lose the beneficial warm-up effect of increased body temperature. Researchers have not proved as to whether or not this cooling affects performance or if a significantly longer resting time after a warm-up and before competition could impact changes in Tc and then optimal performance (10).

Even with increased post-exercise heat loss, Kenny et al. (32) states that a person’s core (esophageal) temperatures may remain elevated for up to an hour after exercise, while skin temperatures return to baseline or below. The increases in Tc could result from endocrine changes, metabolic byproducts, or baroreflex activity that can cause residual thermoregulatory effects (32, 44).

**Effect of cold exposure on exercise performance**

Effects of cold on exercise performance vary depending on intensity and duration of exercise as well as the actual ambient temperature. Cold temperatures can have effects on certain physiological and mechanical aspects of athletic performance. Acute significant cold exposure alone can increase metabolic rate and change the energy cost of exercise. Because of these changes, maximal and submaximal exercise capacity can be negatively affected by decreases in blood and stroke volume along with increased heart rate at any given intensity of submaximal exercise (37, 49). Beelen et al. (1) found increased VO2 in men during steady-state exercise in the cold compared to room temperature. They suggested that while decreased blood flow could have impaired oxygen delivery, the increased VO2 actually may have been the additional energy cost associated with metabolism and removal of the greater concentrations of accumulated lactate. This removal occurs when lactate is used as a substrate to help produce more energy through oxidation in the heart, muscles, brain and kidneys (1). Both of these conclusions would negatively affect many parameters of exercise performance.

With longer durations in a colder environment either before, during, or after exercise, there can be other significant effects on the body. Thermal gradients continue to favor heat loss from the body,
especially during and after exercise, and this effect will continue to cause decreases in core and skin temperature. Shepard (49) states that with every 10°C decrease in local tissue temperature, the rates of enzymatic reactions and resting metabolism are reduced about 2- to 3-fold. Decreased metabolism and reduced blood flow during rest can then cause underperfusion of muscles and increased reliance on anaerobic metabolism during subsequent exercise. This effect may cause increased accumulation and peak concentrations of lactate and an increased energy cost, which can diminish performance (1, 3, 21, 23, 37).

Significant body heat loss from exercising in colder ambient temperatures can also increase body strain due to impaired neuromuscular functioning, which may result in a decrease in the mechanical efficiency of muscles working together to co-contract (37, 49). Research by numerous authors has shown that considerable decreases in temperature of muscle tissue can impair power output and force production during exercise via decreased nerve impulse frequency, activation of motor units and contraction of antagonist muscles (3, 13, 39, 48). Comeau et al. (13) also implies that decreased force production may result from decreased metabolism of muscle tissue, decreased rates of calcium release and absorption, altered coordination, and impaired reflex activity. Compared to exercise in warm environments, exercising in a cold setting can increase the overall strain on a person’s body, as seen with evidence in cardiovascular and mechanical effects.

Other specific variations of environment, in addition to colder temperatures, can also impact physiological changes. Windy conditions can increase heat loss convectively, especially with direct exposure of the skin to air and when an athlete is moving fast, such as rowing in a boat or running during a race. During vigorous exercise, sweat can accumulate on exposed skin or can saturate the clothes an athlete is wearing to the point where he or she may lose insulation value, and increase heat loss via evaporation (37).
Shivering

Shivering is an involuntary and simultaneous contraction of muscles as a response to decreased body temperatures (23, 49). Shepard (49) states that at rest, shivering can start after a 3 to 4°C decrease in Tc, which represents the body’s attempt to increase resting metabolic rate; however, this response can cause lactate accumulation and muscle fatigue. Shivering can become an ineffective method of heat production because the body movements that occur and continuous muscle contraction can both increase convective heat loss.

Even at low intensities, shivering will increase resting metabolism and is fueled mainly by lipids. Over time, stored muscle glycogen becomes the dominant source of fuel and as shivering intensifies with longer cold exposure, glycogen stores can become the dominant source of heat (23, 24). Research on the topic displays a discrepancy between whether carbohydrate (CHO) or lipid oxidation is the main provider of energy and heat production during cold exposure. Some studies show CHO providing more energy and some show that lipids are the body’s primary energy source and can compensate for any changes in glycogen stores; however, these studies have been done using different experimental protocols, which may account for the variable results (21, 23, 49).

Increased metabolism during shivering is evident from elevated concentrations of blood lactate. Shepard (49) indicated that after 90 minutes of resting in a cold environment, lactate concentrations increased 1.8-fold, with slight increases seen even after 30 minutes of rest. There were also significant increases in VO2, VE, and non-significant decreases in RER, suggesting a trend of lipid metabolism during shivering. The body’s use of glycogen stores during shivering in the cold may play a role in a subsequent bout of exercise and it seems that shivering should be prevented if possible, before a competition (49).

Evidence (49) indicates that exercising in a colder environment can have the potential to cause irregular changes in the body’s thermoregulatory mechanisms. Exposure to the cold before, during, or after exercise can directly affect parameters such as core, muscle and skin temperature. Metabolic and mechanical body processes may then be altered which may affect the body’s fuel supply and changes in
performance. The evidence discussed shows that it is important for an athlete to consider environmental conditions when preparing for a competition because of negative effects that may occur on the body and possibly result in diminished performance. Research has not yet determined the greatest contributor to significantly impacted performance in less than ideal conditions.

**Warm-up**

Studies have established the many benefits of performing a proper active warm-up (WU) before an intense bout of exercise. Primarily, WU can increase core and muscle temperatures, muscle blood flow, metabolism, nervous system function and enzyme activity (2, 3). Mechanically, increases in muscle temperature from warming up can reduce muscular stiffness and resistance during contraction (3). These effects become more important for athletes who exercise in a cold environment since the air temperature may decrease skin and core temperature.

Relating to oxygen kinetics, warm-up can be a preparatory stimulus for systems involved in O2 transport and utilization that can allow an individual to reach a high level of aerobic metabolism more quickly during a subsequent task (2). Exercise will cause increased oxygen delivery to the muscles from vasodilation of the blood vessels and a rightward shift in the oxyhemoglobin dissociation curve (3). This change may reduce initial O2 deficit and allows the anaerobic system to contribute to energy supply for a greater period of time before the aerobic system is needed (2, 9, 46). Specific athletic performances of shorter duration and higher intensity that rely on anaerobic metabolism for energy can benefit from this “sparing”, and there can be increases in time to exhaustion (3). Increased peripheral circulation from a prior warm-up also contributes to enhanced O2 delivery and mitochondrial function, which can improve the circulatory and respiratory system’s response to the onset of subsequent exercise (26, 46).

Another WU effect is increased muscle temperature, which increases blood flow to the working muscle and consequently increases aerobic contribution to energy metabolism at the onset of subsequent exercise (19). The change of core and muscle temperature may activate buffering capacity against a
decline of intracellular pH, which can also add to enhanced aerobic and anaerobic capacity as well as performance (29). An active, sport-specific WU of proper intensity is most desirable because it increases the temperature of specific muscles, which the athlete will use in subsequent, more strenuous activity (30).

Intensity

Studies suggest WU can significantly affect performance; however, athletes need to take into consideration the proper intensity and mode of exercise (2, 9). Inadequate WU does not improve performance and WU that is too intense can impair performance (26, 46). There are also physiological benefits to performing an active, specific WU compared to passively warming up the core and muscles via sitting in a warm water bath or chamber. Gray and Nimmo (19) compared exercise performance when preceded by either an active WU consisting of 5 minutes at 40% VO2max followed by four short sprints at 120% VO2max, or a passive WU where participants sat in a warm environmental chamber. While the study found no differences in time to exhaustion between the trials, it did find increases in total VO2 along with a blunted lactate response in the exercise preceded by active rather than passive WU. This result may not show absolute performance benefits of time to exhaustion. It is discussed, however, that the physiological differences could have been influential on peak and total power output, which can also be an indicator of performance depending on the task (19). Several other studies conclude that when exercise is preceded by a low-intensity active WU (30-60% VO2max), maximal peak power and exercise time to exhaustion are enhanced, compared to passive WU or WU of 70-100% intensity (19). Similarly, Stewart and Sleivert (52) observed that, compared to not performing WU, there were significant increases in run to exhaustion time when the exercise was preceded by a 15 minute WU at 60-70% intensity. I can be hypothesized that an optimal warm-up of around 10 minutes in duration and at about 60-70% VO2max intensity could enhance performance, as this is sufficient time for VO2 kinetics to reach a steady state and for muscle temperatures to increase to a beneficial level (3).
Authors studying WU discuss improvements that are attributed to the consequential effects on metabolism and the resulting changes in blood lactate, blood hydrogen ions (H+)/pH, and bicarbonate (HCO3-) (2,9). Exercise will induce increases in H+, which will decrease blood pH, which is continuously buffered by HCO3-. Burnley (9) found that prior exercise that results in a slight elevation of lactate levels at the onset of subsequent exercise can improve mean power output and overall performance. Others suggest that metabolic increases in H+ from a WU can be beneficial because of its vasodilatory effects, which result in better perfusion of working muscles and oxygen delivery via improved capillary-to-mitochondria diffusional gradient for oxygen (2, 3).

Several studies state that a specific WU before maximal performance contributes to a lowered total accumulation of lactate and a decreased concentration of blood H+ (9, 20, 30, 46). This response is due to increased blood flow that facilitates the transport of lactate out of the muscles and increased oxygen supply to muscles, decreasing reliance on anaerobic glycolysis during the performance (19, 20, 30, 35).

On the other hand, a very intense WU can cause significant acidemia and lactate accumulation, which may impair supramaximal performance via inhibition of anaerobic glycolysis, interference with contractile processes, and reduction of muscle contraction force (2, 14, 30). In two studies, Bishop (2, 3) states that the increases in H+, such as from a WU performed at greater than 75% VO2max, could inhibit release and uptake of calcium, causing decreases in muscle contraction intensity and possibly performance. When a WU of proper intensity is performed, positive effects may occur. Burnley et al. (9) showed performance improvements after athletes completed a WU and blood lactate concentrations were between 1-4mM after the WU. The authors concluded that an overly intense WU may cause lactate concentrations to increase above 5mm and either not benefit or diminish performance (9).

Overall, researchers have shown WU to decrease lactate accumulation acid-base disturbance, muscle glycogen use, and the time needed for cardiovascular adjustments during subsequent exercise (9,
Athletes should consider the type of and intensity of WU when preparing for a competition or event, especially when in less than ideal environmental conditions.

**Time between WU and Performance**

Performing a proper warm-up has proven to be necessary for optimal performance; however, the beneficial effects of exercise, such as increased core and muscle temperatures, do not last for a significantly long period of time. Few studies have been conducted to examine exactly how long the specific effects of a warm-up will last, but several studies do show that after exercise lasting approximately 15 minutes, a resting period while exposed to the cold can either cause no changes or slight decreases in skin and core temperature even within 30 minutes (10, 30, 33, 54). Kenny et al. (31) indicated that for participants who had exercised in a cool environment, there were drops (about .2°C) in esophageal temperatures during the first 5 minutes of the recovery period followed by a plateau in temperature throughout the entire 20 minute recovery period. In this protocol, the environment was 20°C and is not directly relevant to the current research question. Castellani et al. (10) found changes in both core and skin temperatures after a bout of exercise and during a rest period in about 5°C. After 10 minutes, rectal and skin temperatures decreased about .25°C and 3.5°C, respectively, followed by further decreases of .5°C and 5.5°C after 30 minutes, respectively. There are no findings that have determined if this drop in core temperature after about 30 minutes affects performance in a subsequent bout of exercise.

Several studies have used a 5-minute period between a warm-up and exercise performance trial and the authors suggest that this amount of resting time is optimal for maintaining the effects of warm-up for subsequent performance (2, 9, 19, 20, 35). Gray and Nimmo (19) suggest that this duration of recovery period does not affect a successive high-intensity performance and that the body maintains muscle temperature through the time period. They found that maximal peak power during a time-to-exhaustion test is improved with a recovery time of 5-6 minutes between a high-intensity WU and exercise (19). Other studies focus specifically on the recovery period after a warm-up and the effects on phosphocreatine restoration, which is an indicator for anaerobic energy recovery. Bishop (3) found that
PCr stores can be completely restored within a 5-minute period, which can contribute to improved short-term, high-intensity performance. Dawson et al. (15) and Harris et al (25) also found that power output can be improved because of the full restoration of PCr stores that occurs within 5 minutes of rest.

Depending on intensity and duration of WU, as well as environmental conditions, muscle temperature can significantly drop after about 15 minutes post WU, and so researchers have suggested that optimal recovery time after WU should be between 5 minutes and 15-20 minutes (3). A proper, active warm-up followed by an ideal recovery time is important for an athlete to get the most out of his or her performance, and this factor becomes even more important when an athlete performs in settings with less-than-ideal weather conditions.

Rowing

Most rowing events are 2000 meter races that can last anywhere from 5.5 – 9 minutes. The body uses both aerobic and anaerobic pathways to derive energy for these sprint races, and laboratory studies of athletes exercising on an indoor rowing ergometer show that the relative amount of anaerobic energy used for racing is anywhere from 21%-35% (14, 27, 43). Because of the large amount of energy derived from anaerobic metabolism, glycolysis and high-energy phosphate breakdown become important processes during these rowing races (43). It would seem important that a rower performs a proper active warm-up in order to prepare the energy systems for a high-intensity race. Unfavorable weather conditions and regatta delays could affect the adequate preparation of a rower before a performance.

Running

There is a lack of consensus from the research on energy contributions to middle-distance running; however, evidence suggests that the anaerobic energy system contributes anywhere from 13-50% during a 1500 meter run (16). Duffield et al. (16) examined energy system contribution in 1500 meter and 3000 meter runs. Results of the study concluded that during the 3000 meter run, the anaerobic
energy pathway may contribute anywhere from 6-14%, which is a lower percentage than what has been found in athletes who row in a 2000 meter race (16).

Summary

Because of the nature the sport of rowing, many external factors play a role in how well a rower performs during a race. Environmental conditions, such as variable temperatures, wind speed, and delays in race starts can all affect physiological variables of an athlete’s performance. These situations may also affect runners who perform shorter to middle distance track events. Researchers have studied the effects of cold temperatures on exercise performance, as well as the beneficial effects of a proper warm-up. It is not specifically known as to how colder ambient temperatures, and delayed rest periods after a warm-up, can alter physiological variables that impact subsequent performance.
CHAPTER THREE
METHODS

Participants

Rowers

Five participants, 1 female and 4 males, aged 22-43 years were recruited from the Dallas-Fort Worth area by contacting local rowing clubs and collegiate rowing teams, and via informational flyers and word of mouth. Inclusion criteria included having at least one year of competitive rowing experience and being able to perform a maximal intensity 2000 meter trial on a rowing ergometer.

Runners

Five participants, 2 females and 3 males, aged 22-25 years were recruited from the TCU campus by word of mouth. Inclusion criterion was to be involved in frequent and high-intensity training with running being the primary mode of exercise.

All participants completed a university-approved informed consent and medical history questionnaire. The medical history questionnaire included basic background information regarding conditions that are contraindications to strenuous exercise.
<table>
<thead>
<tr>
<th></th>
<th>Age</th>
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<th>Weight</th>
<th>Body Fat</th>
<th>VO2max</th>
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</thead>
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<tr>
<td></td>
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<td>%</td>
<td>L/min</td>
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<tr>
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<tr>
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<td>16.73</td>
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</tr>
<tr>
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<td>8.46</td>
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<td>14.13</td>
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</tr>
<tr>
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<td>7.94</td>
<td>10.63</td>
<td>12.57</td>
<td>5.8</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Table 1. Participants 1-5 were rowers, consisting of one female and four males, and participants 6-10 were runners consisting of two females and three males.

**Experimental Design**

This experiment was conducted using a repeated measures, three factor, condition by environment by time design. A total of four experimental trials were completed by each participant in a randomized, counterbalanced order. Each trial was performed on a rowing ergometer or treadmill and included a standardized warm-up, followed by a period of rest, and then a subsequent 2000 meter time trial on the rowing machine or 1.5 mile time trial on the treadmill. The rest periods were either 5 minutes or 30 minutes and trials were performed in the environmental chamber in the cold or at room temperature (Table 2). At certain time points throughout the trial, blood samples, and core (Tc) and skin (Ts) temperature responses were taken. From the blood samples, lactate, pH and bicarbonate (HCO3-) was measured.
Preliminary Testing

Participants reported to the Exercise Physiology Laboratory on the preliminary test day and completed all documents (medical history questionnaire and informed consent), along with preliminary anthropometric measurements. If there were no contraindications to exercise, participants completed a VO2max test on the rowing ergometer (Concept II Model C) or treadmill (JAS Systems Trackmaster). The Concept II wind resistance braked rowing ergometer is the most widely used ergometer for training purposes in the sport of rowing, and allows standardization of testing compared to studying rowers on the water (14, 49). Either on the same day or on a subsequent day, participants completed an acclimation trial in order to become familiar with the warm-up protocol and environmental chamber.

**Anthropometric Measurements.** Height and weight were measured for all participants to determine body mass index (BMI). In addition, to assess percent body fat, a 7-site skinfold test was used with measurements taken from the chest, midaxillary, triceps, subscapular, abdominal, suprailiac, and thigh regions. The average of three attempts was recorded for each region and placed into the Jackson and Pollock equation to determine body density and percent body fat (28). This measurement was made for basic anthropometric information, and also to assess any differences in percent body fat with thermoregulatory changes.

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>POW</th>
<th>Pre2K/1.5m</th>
<th>PO2K/1.5m</th>
</tr>
</thead>
<tbody>
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<td>22.7</td>
<td>23.8</td>
<td>23.7</td>
<td>24.2</td>
</tr>
<tr>
<td>30 cold</td>
<td>3.6</td>
<td>6.8</td>
<td>5.3</td>
<td>6.2</td>
</tr>
<tr>
<td>5 cold</td>
<td>4.0</td>
<td>6.7</td>
<td>6.7</td>
<td>7.6</td>
</tr>
<tr>
<td>30 room</td>
<td>22.5</td>
<td>23.6</td>
<td>23.3</td>
<td>24.2</td>
</tr>
</tbody>
</table>

Table 2. Average temperatures during all trials; temperatures are in °C.
For the rowing participants, a VO2max test protocol was performed on the rowing ergometer interfaced with a monitor which allows participants to see their split times and stroke rates per minute. Runners performed a standard graded exercise test on the treadmill. Participants wore a Polar heart rate monitor (Polar Electro E600, Finland) around their chest, and were fitted with a mouth piece in order to collect and analyze respiratory gas exchange. VO2max was measured in order to determine a submaximal intensity for participants to exercise at during their warm-up in each trial.

Modified from a study by Cosgrove, et al (14), each stage of the rowing test lasted one minute with ten seconds in between each stage in order for the ergometer to collect data for each interval. Participants were told to maintain a certain 500 meter split time throughout the duration of each stage and were asked to try and keep their strokes per minute rate as constant as possible. The first stage began with a split time of 2:30 and decreased by 5 second intervals for each stage of the test until the participant reached exhaustion or could not maintain the split time required.

The VO2max test on the treadmill began with a three minute stage at 5.5 mi/hr at 0% incline, followed by increases in speed and incline in the stages thereafter until participant reached exhaustion.

Oxygen consumption was measured continuously via on-line gas analysis (TrueOne 2400 Metabolic, Parvo Medics, Inc, USA) while subjects breathed via a mouthpiece and one-way valve (2700 Series, Hans Rudolph, Inc, USA). Heart rate was collected continuously and a valid VO2max was determined by achieving two or more of the following criteria: 1) Heart rate equivalent to 220-age; 2) RER> 1.1; 3) a plateau in VO2. Data collected from the rowing ergometer in each stage included the number of meters rowed, average watts, average strokes per minute, and actual average 500 meter split time.

Acclimation. Following the VO2max test, an acclimation trial was completed inside the environmental chamber which was set at a temperature of 5° C. Participants entered the chamber and rested in a seated
position for 5 minutes before performing a 15-minute standardized exercise protocol similar to what was going to be performed during the experimental trials.

**Experimental Testing**

Participants reported to the laboratory at least one week following the acclimation trial. Four surface probes were placed on the triceps, chest, thigh and calf to measure mean skin temperature. Then, after a 5 minute supine rest, a catheter was inserted into the antecubital vein and a baseline blood sample was drawn. All participants wore a Polar heart rate monitor around their chest for continuous measurement of heart rate. An esophageal thermistor connected to a digital telethermometer (Model 8502-12, Cole Parmer, Illinois, U.S.A.) was inserted through the nasal passage to a depth corresponding to 25% of the participant’s height. The thermistor remained in place throughout the trial to obtain continuous temperature measurements. Baseline temperatures were recorded and participant entered the environmental chamber and began their experimental trial. Rowers performed a 15-minute standardized warm-up on the rowing ergometer, consisting of a 10 minute steady state at a split time of about 60-70% of maximal time achieved during the preliminary testing, followed by five, 30 second sprints with 30 seconds of active recovery in between. On the treadmill, runners performed a 10 minute steady state at about 60-70% VO2max, followed by five, 30 second self-paced sprints with 30 seconds of passive recovery. A resting period of either 5 or 30 minutes occurred immediately following the warm-up, in which participants remained in a seated or standing position in the environmental chamber. During this time, participants were allowed to drink water ad libitum, so as to not have any consequences of dehydration impact subsequent performance. Immediately after the rest period, rowing participants performed a 2000 meter trial and runners completed a 1.5 mile self-paced time to completion trial in which they all were instructed to do so as fast as possible. The digital monitor on the rowing machine was covered up so that participants could only see how many meters have been rowed along with their stroke rate. On the treadmill, time and speed were both covered so that only distance could be seen.
Blood Analysis. Blood samples were obtained from the antecubital vein at five different time points during the trial: before and after the standardized warm-up then before, after, and 3 minutes after the 2000 meter or 1.5 mile time trial. Samples obtained from all participants were analyzed for lactate, and in rowers, blood was also analyzed for pH, bicarbonate, and electrolytes. Lactate concentration was assayed using an enzymatic spectrophotometric reaction. Blood pH and bicarbonate levels were assessed using a blood gas and electrolyte analyzer (ABL 77 Series Radiometer, Copenhagen).

Statistical Analysis

Data from the experimental trials were analyzed using either a two-factor or a three-factor repeated measures analysis of variance (ANOVA). The first factor was “duration of rest period” and had two levels: 5 minutes and 30 minutes; the second factor was “environment” and also had two levels: cold and room temperature; and for variables that were sampled multiple times within a condition, the third factor was “time” with a variable number of levels depending on the sampling frequency. A Newman Keuls post hoc analysis was used to isolate the location of differences detected by the ANOVA. Pearson correlations were conducted between key dependent variables; for example, between time trial performance and core temperature, and trial performance and blood lactate concentration. An alpha level of $p<.05$ was accepted as significant.
CHAPTER FOUR
RESULTS

Five rowers and five runners volunteered and completed the experimental trials. Their descriptive statistics are shown in Table 1 of the methods section. Experimental trials are abbreviated as: 5-R = 5 room; 30-C = 30 cold; 5-C = 5 cold; 30-R = 30 room.

Performance Times

There was no learning effect was observed in 2000 meter time trials in any of the rowers or in 1.5 mile time trials in any of the runners.

<table>
<thead>
<tr>
<th></th>
<th>Row</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(min ± SD)</td>
<td>(min ± SD)</td>
</tr>
<tr>
<td>5 room</td>
<td>7.34 ± .69</td>
<td>9.29 ± .78</td>
</tr>
<tr>
<td>30 cold</td>
<td>7.42 ± .60</td>
<td>9.85 ± 1.08</td>
</tr>
<tr>
<td>5 cold</td>
<td>7.33 ± .61</td>
<td>9.57 ± .86</td>
</tr>
<tr>
<td>30 room</td>
<td>7.32 ± .64</td>
<td>9.65 ± 1.06</td>
</tr>
<tr>
<td>Room</td>
<td>7.31 ± .66</td>
<td>9.47 ± .95</td>
</tr>
<tr>
<td>Cold</td>
<td>7.34 ± .61</td>
<td>9.71 ± .98</td>
</tr>
<tr>
<td>5 rest</td>
<td>7.30 ± .65</td>
<td>9.43 ± .83</td>
</tr>
<tr>
<td>30 rest</td>
<td>7.35 ± .62</td>
<td>9.75 ± 1.07</td>
</tr>
</tbody>
</table>

Table 3. Mean performance times in all trials. Mean time (min ± SD) of each condition is shown, along with means comparing the different environments and different rest times.

There were no significant differences in performance times during the rowing trials nor running trials; however, there was a tendency of trial 30-C resulting in the slowest times compared to the rest of the trials. There was also a trend showing the fastest times in the running trials was in 5-R, compared to 5-C and 30-R, however, this was not a significant difference.
After combining the performance data from the rowing and running trials, no significant differences were found in performance times between trials; however, there is a trend seen in the slowest times being performed in 30-C and the fastest times in 5-R.

**Blood Variables**

Blood was drawn and lactate was analyzed in all participants (n = 10). pH and HCO3- were only analyzed in rowers (n = 5). Blood catheter issues lead to only two out of the five rowers having complete samples drawn in all four trials. Data for blood variables are presented as means and since statistical analyses were not performed on rower data for pH and HCO3-, only descriptive data from the graphs will be discussed.
As seen in Figure 2, absolute blood pH levels decreased similarly between trials during the warm-up, increased during the resting period, dropped during the 2000 meter performance (2K), and then increased again 3-minutes-post exercise. Changes of pH are shown in Figure 3, and it can be seen that a trend of larger changes occurred in the 30-minute trials compared to 5-minutes.

Resting pH values were similar between trials, as well as values seen immediately after the warm-up (POW). During rest, pH tended to increase the most in trials which had 30 minutes of rest (seen at Pre2K), and reached pre-exercise values. Compared to the control trial (5-R), pH values tended to be lower after the 2K, and remained lower 3 minutes post-2K. It should be noted that during 5-R, there was a trend that pH did not decrease as low as the other trials. Also, this is a descriptive analysis and no statistics are applied.
Similar changes in blood pH occurred during WU between all trials. During the rest period, there was a tendency for greater changes in pH to occur during trials that included a 30-minute rest period. During the 2K time trial, larger decreases in pH occurred in trials with 30-minute rest compared to those with 5-minute rest. Changes occurring 3-minutes post-exercise were similar between all trials.

*Bicarbonate (HCO3−)*

Figures 4 and 5 show absolute levels of and changes of HCO3−, respectively. Compared to changes in pH, there was more separation in the responses of HCO3−. Similar decreases occurred between trials during warm-up, but larger increases occurred during the 30-minute resting period compared to 5-minutes, and this increase was the largest with 30-C. Interestingly, during 2000 meter performance, HCO3− levels decreased to similar values and remained similar through 3-minutes post-exercise.
Figure 4. Mean absolute bicarbonate (HCO3-) levels during rowing trials.

Between all trials, pre-exercise HCO3- values were similar and then decreased similarly after the warm-up. HCO3- increased and returned to near pre-exercise values after 30 minutes of rest, and concentrations continued to fall with only 5 minutes of rest. After the 2K, concentrations decreased to similar values, regardless of which trial it was, and then decreased similarly even more so 3 minutes post-exercise. It should be noted that similar to pH responses, 5-R was different than the other trials resulting in what may be significantly smaller changes as well as absolute level of HCO3- during the rest and 2K performance. As with pH, this is also a descriptive analysis and statistics are not applied.
Figure 5. Mean changes in HCO3- during rowing trials.

Similar to absolute concentrations of HCO3-, the largest changes were seen during the 30-minute rest period and in the cold. There was a tendency for large decreases in HCO3- to occur during the 2K time trial during the 30-minute trials as well, including the largest drop seen in the cold. Changes after 3 minutes-post exercise were similar between all trials.

Blood lactate

Figure 6. Mean concentrations of blood lactate in the rowing vs. running trials (n = 10).
Overall concentrations of blood lactate were higher throughout the rowing trials compared to the running trials. Changes in blood lactate concentration were larger during the rowing trials for the warm-up, resting period, and performance trial, compared to the running trials (Table 2).

<table>
<thead>
<tr>
<th>Row</th>
<th>WU</th>
<th>Rest</th>
<th>2K</th>
<th>3 min</th>
<th>Run</th>
<th>Rest</th>
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<th>3 min</th>
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<tr>
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</tr>
<tr>
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<td>-4.80</td>
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<td>0.41</td>
<td>±0.52</td>
<td>6.12</td>
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Table 4. Changes in blood lactate concentrations in rowing and running trials. Data is presented as mean ± SD.

![Figure 7. Mean concentration of blood lactate in all trials.](image)

Statistical analysis found no significant interactions between environment or resting time conditions; however, at the Pre2K/1.5 time point, there was a trend for decreased concentration of lactate after the 30-minute trials compared to the 5-minute trials. Blood lactate returned to pre-exercise values in the trials that included a 30-minute rest period in both cold and room temperature.
No significant differences were found in average changes of blood lactate concentration when combining data from all trials. There was a tendency, however, for lactate to decrease more during the 30-minute resting periods compared to 5-minute resting periods.

Core Temperature (Tc)

Both absolute Tc and change of Tc had significant duration of rest by environment by time point interactions (p = 0.000). It was observed in all trials that Tc increased during the warm-up exercise and there was a notably larger increase in the cold trials compared to trials in room temperature, as seen in Figure 9. Changes of Tc are shown in Figure 10, and as expected, the 30-minute rest period induced larger decreases in Tc when compared to the 5-minute rest periods. The greatest changes were seen in the 30-minute rest period in the cold (-.85°C), and was significant compared to changes in 5-C (p < .05). Subsequent performance trials (2K row/1.5 mile run) induced secondary increases in Tc, in which the 30-C trial showed a significantly smaller change of Tc (.56°C) compared to the other trials (5-R: 1.48°C; 5-C: .92°C; 30-R: 1.25°C). Tc then remained lower during the time trial and was found to be significantly lower at the end of the trial, compared to all of the other trials.
Figure 9. Mean core temperatures in all trials (n = 9). WU represents the peak Tc recorded during the warm-up; End Rest represents the average Tc during the rest period; 2K/1.5 represents Tc at the end of the performance trial. The α indicates a significant difference between trial 5-C and all other trials. The # indicates a significant difference between trial 30-C and all other trials.

A significant duration of rest by environment by time interaction (p = 0.001) was found for Tc.

Post-hoc analyses indicated significant differences at the end of rest between 5-C and all other trials and after performance (2K/1.5) between 30-C and all other trials.

Figure 10. Mean change in core temperature in all trials (n = 9). The * indicates a significant difference between 5-C and 30-C. The α indicates a significant difference between trial 5-R and 30-C and 30-R (p < .05).
Changes in core temperature during the warm-up were similar in all trials. Trials including a 30-minute rest period induced larger, and significant decreases (in cold trials but not room temperature) in Tc during rest compared to trials with a 5-minute rest period. During performance (2K/1.5), Tc significantly increased more in 5-R compared to 30-C and 30-R (p < .05).

*Skin Temperature (Tsk)*

Figure 11. Mean change in skin temperature in the rowing and running trials (n = 10).
Figure 12. Mean skin temperatures in all trials (n = 10). The * indicates a significant difference between trials in room temperature and trials in cold. The α indicates a significant difference between 5-R and all other trials. The θ indicates a significant difference between 30-C and 5-C (all p < .05).

A duration of rest by environment by time point interaction (p = 0.000) was found and post-hoc analyses were performed. During warm-up during the trials in room temperature, Tsk stayed about the same between the two environments, which was significantly different from the large (about 6°C) decreases seen during trials in the cold (p < .05). During the resting period in the cold, Tsk continued to drop, and significantly dropped during the 30-minute rest. Tsk in the cold trials remained significantly different from each other after the performance time trial. Through the trials, Tsk remained significantly different between environmental conditions.
Similar to absolute Tsk, a significant duration of rest by environment by time point interaction (p = 0.000) was found and post-hoc analyses were performed. During warm-up in the cold trials, significantly larger decreases occurred in Tsk compared to trials in room temperature. Tsk increased during the rest period in 5-R, but this was not significantly different from all of the other trials in which Tsk decreased. Also at this time point, the largest decreases in Tsk occurred significantly in 30-C (p < .05). During performance, there was a trend of the smallest decreases in Tsk occurring during 30-C.
Figure 14. Mean heart rate during all trials (n = 10). The * indicates a significant difference between 30-C and 30-R. The α indicates a significant difference between with 5-minutes rest and 30-minutes rest. The # indicates a significant difference between 30-C and all other trials.

A significant duration of rest by environment by time point interaction (p = 0.000) occurred and post-hoc analyses found differences at each time point. Peak HR during warm-up in 30-C was significantly lower compared to 30-R. Trials including a 5-minute rest period had significantly higher HR during rest compared to trials with a 30-minute rest period. Peak HR during performance was significantly lower during 30-C compared to all other trials.
CHAPTER FIVE
DISCUSSION

The current investigation was conducted in order to determine the physiological and performance effects of a prolonged time between warm-up and performance in a cold environment. The experimental design was set up to analyze: 1) rowing and running performance in a cold environment (5°C) vs. room temperature (22°C), 2) effects on the body from a longer (30 minutes) vs. shorter (5 minutes) rest period after a warm-up, and 3) the effects on metabolic variables associated with performance from the combination of different temperatures and rest times. It was hypothesized that after a full-body active warm-up, a 30-minute duration of rest in a cold environment would negatively affect 2000-meter rowing performance, or 1.5 mile running performance, compared to a 5-minute rest period in either cold or room temperature. The primary findings in this study were that: 1) when warm-up was followed by a 30-minute resting period in the cold, rowing and running performances were the slowest; however, because this difference was not significant, the findings do not support the first hypothesis; 2) in the cold environment, skin and core temperatures were significantly lower throughout the trial compared to the trials in room temperature; thus, these findings support the second hypothesis, and 3) there were no significant differences in the change of blood lactate concentrations between environments, a finding that is contrary to the third hypothesis.

Performance Time

To analyze the differences in performance times, data from both the rowing and the running trials were combined, but it should be noted that average 2000 meter rowing trials was about 7.5 minutes while 1.5 mile running trials was about 9.5 minutes. There was a tendency for overall performance times to be slower in 30-C, in comparison to 5-R, but this was not significant. A further tendency was observed in that runners were more affected by the colder temperature, as well as the 30-minute resting time, showing slower times in the two 30-minute trials combined compared to the two 5-minute trials combined. These tendencies are most likely the outcome of the additive effect of a variety of physiological mechanisms.
These variables will be discussed in further sections; however, a brief analysis suggests that the thermoregulatory effects had a greater impact on the outcomes than the metabolic variables such as pH and lactate. Split times at each quarter of performance were recorded in the rowing trials, but not all of the running trials. There was no statistical significance when analyzing the pacing strategy during the rowing trials, nor were there trends seen in the split data of the runners. It might be assumed that the effects of the environmental and duration manipulations may have had an initial impact on performance that would then dissipate after the first several minutes; however, the similarity in pacing results suggests that this was not the case.

**Blood Lactate Responses**

It was hypothesized that blood lactate concentrations would increase after WU in all conditions, remain higher in cold trials compared to room temperature during the rest, and be similar after performance and 3-minutes post-performance. When comparing all data, 30 minutes of rest induced more clearance of lactate, which would be expected due simply to the fact that more lactate can be removed with more recovery time. This response was followed by a slightly larger, accumulation of lactate during the subsequent performance. The tendency for a smaller accumulation of blood lactate during performance in trials with 5-minute rest, although not significant, is in agreement with what other authors have found as a beneficial effect of performing a proper warm-up (2, 9, 19, 30, 46). The 5-minute rest period allowed lactate concentrations to remain within about 1 mmol of post-warm-up concentrations, followed by less accumulation of lactate after the performance trial. This finding is similar to what Burnley et al. (9) reported in cyclists who performed a warm-up that increased lactate concentration up to 4 mmol, followed by a smaller accumulation of the metabolite during performance, along with, an improved performance time. Similar findings by Jones et al. (29) lead to suggestions that blood acidosis from warm-up may increase muscle vasodilation to allow increased perfusion and lactate clearance during exercise.
There were notable differences in blood lactate response between the rowing and running trials. The warm-up protocol induced larger increases in lactate concentrations in the rowing trials and did not have much of an effect in the runners. It has been shown that about 6-14% of energy used during middle distance running comes from anaerobic pathways compared to 21-35% in rowing, which may explain higher lactate concentrations in the rowers, since lactate is a primary end product of this energy pathway (14, 16, 27, 43). Another reason for this difference could be the different recovery methods during the warm-up: the protocol was set to be equal between both modes of exercise, the 10-minute steady state being set at 60-70% of the participants VO2max, followed by 5 high-intensity, 30-second sprints, with 30-seconds recovery in between. Despite these similarities, the rowers were able to have an active recovery during the sprint phase of the warm-up, while runners jumped to the side of the treadmill and had a passive rest. This difference may account for decreased heart rate as well as increased lactate clearance during passive recovery, compared to an active recovery, which includes continuous muscle use and increased heart rate. The intensity of the active recovery for the rowers would be an issue in this interpretation since low intensity recovery (40-50% VO2max) has been shown to facilitate clearance; thus, if the recovery mode were responsible for the differences, it would have to have been due to a relatively high intensity active recovery that prevented the facilitated clearance. The overall fitness level of the runners was significantly higher than that of the rowers, which may also account for the lack of response.

There were large increases in lactate concentration following both the 2000 meter and 1.5 mile performance trials; however, the two different subsets of participants responded differently depending on which condition they were in. In the rowing trials, there was a larger change in concentration after the 2K in 30-C and 30-R compared to 5-C and 5-R. This was due to the larger decrease that had occurred during the 30-minute rest period in these trials. The runners, whose lactate concentrations did not increase as much during the warm-up exercise compared with the rowers, showed the largest increases in concentration after the 1.5 mile run in room temperature trials, compared to those in the cold. In this subset population during room temperature trials, there was a .57 mmol increase in lactate after warm-up,
compared to the .38 mmol increase in the cold. The slight build-up of lactate after the warm-up did not cause any decreased accumulation of lactate during the time trial, rather concentrations were higher post-time trial in room temperature compared to cold. Research shows that increasing lactate up to about 4 mmol during a warm-up can help reduce later accumulation, and the current study found that rowers exceeded this amount after warm-up (7-8 mmol) and runners did not reach this level after warm-up (1.8-2.4 mmol). In any case, there were no significant differences in any lactate increases after the warm-up compared to changes that occurred after the time trial, which is different from previous research. Since warm-up protocols were performed at the same intensity with each trial and there were no differences in lactate concentrations after the warm-up and after the time trials, it can be concluded that environment alone most likely has no direct effect on changes in blood lactate concentration.

Recovery times after the warm-up, on the other hand, showed to have an effect on blood lactate responses, showing increased rates of clearance during 30-minute recovery times (-3.04 mmol) compared to 5-minutes (-1.12 mmol). There was no difference seen during recovery between environments, as was true in comparing changes after the time trial. After performance, there was a trend of larger amounts of lactate to accumulate after 30-minutes rest compared to 5-minutes. This comparison may prove that after 30-minutes there was a reduction in the beneficial effect of the warm-up exercise to slightly increase lactate, which has been shown to delay fatigue and improve performance (9, 29).

The lowest absolute lactate concentrations were seen in the 30-C trial after the resting period, after performance, and after the 3-minute post-exercise recovery period. This may have been due to decreased rates of enzymatic reactions and metabolism due to decreased core and skin temperatures (49). Core and skin temperatures will be discussed later; however, there may be a competing effect of lower temperatures since, in addition to the blunting effect on metabolic reactions, they may also cause underperfusion of muscles and increased reliance on anaerobic metabolism during exercise. Because it was found that absolute concentrations tended to be lower in the cold condition, the reduction in enzymatic rates and metabolism during subsequent exercise may be the more powerful effect. Since lactate is a metabolic byproduct, it makes sense that we would see lowered concentrations if there is
decreased rate of energy production via glycolysis. In conclusion, the current findings suggest that environment may have had a slight impact on blood lactate responses, but did not affect performance in rowers nor runners.

*pH and HCO3- Responses*

Because of time constraints and supply cost, blood pH and HCO3- were only analyzed in participants of the rowing trials (n = 5) and due to issues with the blood catheters, only two participants have complete sets of pH and HCO3- data for all of their trials. Statistical analysis could not be completed for this data; however, there were some tendencies seen between certain trials. Increased anaerobic metabolism during any type of exercise will increase the amount of lactic acid, a glycolytic byproduct, present in the blood. According to Robergs et al. (45), during exercise, once the production of H+ exceeds that of the body’s buffering capacity, the decreased blood and muscle pH ultimately contributes to fatigue. Decreases in pH occurred between all trials during the warm-up (-.164) and after the 2K time trial (-.369) due to the nature of the high-intensity exercise. Similar decreases in pH that occurred during warm-up in all experimental conditions shows that we successfully controlled for comparable warm-up intensities between all trials. As expected, pH increased slightly after 5-minutes of rest and returned to near pre-exercise values after 30-minutes. This response then accounted for larger drops in pH during the 2000-meter performance in the trials with the longer resting period.

Concentration of bicarbonate (HCO3-) is an indicator of the blood’s ability to buffer acidic byproducts of metabolism. HCO3- neutralizes the H+ that are produced during exercise and concentrations will decrease during exercise as it is used (8). These responses were seen in the current findings and there was more separation in HCO3- responses between the rowing trials compared to what was seen with levels of pH. Similar decreases occurred during warm-up due to increased metabolism, and larger increases occurred during the 30-minute resting period compared to 5-minutes, and this increase was larger in the cold. Similar to blood lactate responses, 30-minutes allowed the HCO3-buffering system to work to reduce blood acidosis for a longer amount of time. Interestingly, during the
2000-meter performance, HCO3- levels decreased to similar absolute values and remained similar through 3-minutes post-exercise. This result may show that environment and rest time affected buffering capacity during the resting period, but not during the high-intensity exercise. It should be noted that similar to pH responses, bicarbonate levels in trial 5-R were different than the other trials resulting in what may be significantly smaller changes as well as absolute level of HCO3- during the rest and 2K performance. It may be interpreted that during 5-R, expected metabolic responses during exercise and recovery occurred, but since either resting time or environment was changed in comparison to this trial, these conditions may have altered responses of these variables.

Robergs et al (46), reported enhanced swimming times when athletes warmed up compared to no warm-up. They analyzed blood H+, HCO3- and lactate and reported lower concentrations of HCO3- in swimming performance preceded by a warm-up compared to no warm-up. These authors also found that performing a warm-up resulted in decreased lactate accumulation, smaller increases in H+ (smaller decreases in pH), and smaller decreases in HCO3- after swim performance, all when compared to not warming up (46). These findings suggest that warm-up can prevent decreases in pH by enhancing the buffering capacity. These results are similar to what we found in the rowers during the current study when we consider the effects of a warm-up are present in trials with 5-minutes rest and minimally present in trials with 30-minutes of rest. Rowing performance was only slightly slower in the trials with the 30-minute resting period so the effects of these blood variables probably are not a cause of diminished performance in the current study. Contrary to this general conclusion, during the 2K time trial pH decreased much less (through observation) in 5-R compared to the other trials. Rowing performance in these trials were similar to 5-C and 30-R, but was faster compared to 30-C. While no direct relationship can be established between pH and performance for the current sample, it seems that with more data, we might be able to infer relationships or correlations between blood pH, HCO3-, and lactate. To better understand if and how these variables may affect performance, it would be valuable to include warm-up protocols of varied intensities to induce different changes in the metabolites, and then examine performance times.
Core Temperature ($T_c$) Responses

Esophageal temperature is a widely used measure of internal temperature because it rapidly reflects heat balance changes within the body (36). Exercise and increased metabolism usually will result in an increase in $T_c$, but changes vary with different intensities and durations of an exercise bout, as well with varied environmental conditions. This normal body heat production and loss is thought to be altered when in a colder environment, especially during a resting period following a bout of exercise. In the current study, we saw increases in $T_c$ during the warm-up exercise that were similar between trials in the cold and room temperature. As expected, there were larger decreases in $T_c$ during the 30-minute resting period compared to the 5-minute resting period. There were no significant differences in the change of $T_c$ during the resting period between conditions, but greater decrease in 30-C compared to 30-R is what would be expected based on the longer duration in the colder environment and increased temperature gradients between air, skin, and core. This result coincides with what has been found in other studies examining exercise and cold exposure (36). There was a separation of $T_c$ responses during the subsequent time trial, which is an indicator that environment and rest-time probably had an effect on $T_c$. The “after-drop” phenomenon was only seen in 30-C, when $T_c$ dropped about .23°C from the end of the 30-minute rest to when a recording of $T_c$ was made after the first quarter of the time trial. This physiological effect occurs when one recommences exercise after being cooled and is due to increased circulation of cold blood in the periphery into the core (12). It is likely that both the lower $T_c$ before the time trial and the “after-drop” effect played a role in $T_c$ remaining significantly lower throughout the time trials compared to the other conditions. This result is also similar to what Kenny et al. (33) found in participants who exercised in a variety of ambient temperatures. Significantly smaller changes in $T_c$ occurred during an 18-minute bout of exercise in a cooler environment compared to temperate or warm environments (33). After exercise, thermoregulatory mechanisms continue to activate heat loss via vasodilation and increased blood flow to the periphery, and when in the cold, this can cause a delay in the body’s secondary attempt at heat conservation (10). Castellani et al. (10) reported that exercise could
create a “thermoregulatory fatigue” during a subsequent exposure to cold by decreased vasoconstriction and blunted shivering responses. While the current study most likely did not include resting durations long enough for these responses to occur, this effect is important for athletes who train and perform in colder environments. During longer durations where a more accentuated version of the Tc responses seen during the 30-C trial could occur, it may be possible to observe the phenomenon reported by Castellani et al. (10). While this “thermoregulatory fatigue” may have been evident during the 30-minute rest, it is not clear as to why Tc remained lower throughout the performance trials. It can be speculated that since the trials were only about 7.5-9.5 minutes in duration, this may not have been enough time for Tc to elevate back to levels achieved during the initial warm-up exercise. Skin temperature responses likely played a significant role in the lowered Tc since the colder ambient environments affect the temperature gradients between skin and core. The relationship between these two variables and the current findings will be discussed in the next section. Overall skin temperatures were decreased in the cold trials compared to room temperature and while it was seen to possibly affect 30-C, it may have also impacted 5-C, in which there was also a significantly smaller increase in Tc during the performance when compared to 5-R, indicating that the cold temperature did have an effect on this subsequent increase in Tc.

The current results show that the cold environment played a significant role in the responses of Tc during the subsequent time trial, as there were significantly smaller increases in Tc during the cold trials compared to room temperatures. There was an additive effect of the longer resting time in the cold on the response of Tc, causing Tc to remain lower throughout the performance. In trial 30-C, performance times were the slowest and Tc responses were the most affected, showing that there may be a relationship between these two variables. This is potentially a paradoxical interaction between Tc responses and performance since it has been shown that increased Tc and altered thermoregulation can cause fatigue, compared to the current findings that show decreased performance with lower Tc. Because participants were able to determine their own pace during the time trials, decreased time to completion most likely occurred as a result of slower starts to the trials in 30-C compared to the other conditions. Participants also noted that they felt colder, that their muscles were more “stiff” and had an overall sense of not
feeling as ready to perform their best during the time trial compared to the other conditions. In order to determine if there is a direct relationship between $T_c$ and performance, it would be necessary to use a series of graded initial $T_c$ levels to determine where the threshold exists above or below which performance is negatively impacted.

Skin Temperature Responses

Skin temperature responds first to any changes in ambient conditions since skin has the closest contact with air. Young and Castellani (57) state that during exercise, heat is lost from the body surface faster than it is replaced, resulting in decreased temperatures of the skin tissue. This would especially be true if athletes are not wearing clothing that covers their limbs, such as in the current study, allowing a greater surface area of heat loss to occur. During the warm-up phase, average $T_{sk}$ in the room temperature did not significantly change from pre-exercise values, but, in the cold trials, $T_{sk}$ decreased about 6°C, which was found to be significantly different from trials in room temperature. According to Young and Castellani (57), when $T_{sk}$ falls below about 31°C, there is a maximal rate of peripheral vasoconstriction as a response to defend temperature in the core. Because of this thermoregulatory mechanism, blood from the periphery is shunted back into the core, and $T_{sk}$ decreases further. Small changes occurred in $T_{sk}$ during trials with 5-minutes rest, while during the 30-minute resting period, $T_{sk}$ in 30-C decreased more (about 2.3°C) and stayed lower throughout the performance trial. This resulted from the continuous heat loss resulting from exercise and also convective heat loss via limb movement and evaporative heat loss via sweat that may have accumulated on the skin.

In several participants, shivering occurred during 30-C after about 20 minutes into the rest period. Two participants began shivering when their $T_{sk}$ decreased below 23°C and mean body temperature ($0.67 * T_c + 0.33 * T_{sk}$) had dropped about 1°C from the end of the warm-up. Haman (23) states that when shivering commences, body heat loss can increase even more because of the continuous involuntary muscle contractions. Several authors (21, 23, 24, 49) found that shivering can significantly increase
metabolic rate, leading to increased muscle fatigue, metabolite (lactate) accumulation and possibly glycogen depletion. These studies included protocols with participants shivering for long periods of time (> 60 minutes); therefore, the absolute results cannot be directly related to the current study. It should be noted, however, that shivering may be a factor in affecting a subsequent exercise performance.

Such drastic responses in Tsk occurred in the cold because participants wore short sleeved t-shirts and shorts, thus producing larger changes in skin temperature; compared to if the participants were wearing clothes to cover more surface area of skin. We wanted the significant changes to occur in Tsk so we could fully analyze any effects the changes had on other variables, especially Tc. After analyzing data from both core and skin temperature responses during the trials in different conditions, it can be concluded that the longer rest period in the cold environment significantly affected both Tc and Tsk, which in turn, may have been either a direct or indirect factor in affecting time trial performance.

Heart Rate (HR) Responses

During all of the trials, heart rate responded similarly, but an interaction was found when comparing trials. The significantly lower average heart rate during the rest period in trials with 30 minutes of rest compared to those with 5 minutes of rest was due simply to the longer recovery time. The slightly lower HR in the colder trials compared to those in room temperature are in general agreement with the findings of Oksa et al. (37) and Kenefick et al. (17) who both recorded significantly lower heart rates in individuals who were exercising in colder temperatures (-10-4°C) compared to temperate conditions (20-25°C). These findings along with what was found in the current study are evidence as to the physiological changes that occur to a person in a cold environment. The cold-induced peripheral vasoconstriction leads to increases in central blood volume, which then causes increased blood pressure and possibly increased stroke volume and decreased heart rate (8). While the colder trials in the current study did not induce significantly lower heart rates during rest, peak HR during performance was found to be significantly lower in 30-C compared to all of the other trials, showing that the 30-minute cold exposure had some affect on cardiovascular function during the time trials. An additional possible reason
for reductions in cardiorespiratory performance may have been due to the decreased metabolism and its byproducts. Heart rate will increase in order to send more oxygen in the blood to working muscles, as well as when the blood becomes more acidic. As mentioned previously, lactate was lower during time trials in the cold compared to room temperature, showing that there may be a link with decreased byproduct production leading to decreased chemoreceptor activation to increase heart rate during the time trials. Because heart rate did not increase as high during 30-C compared to the other trials, it seems the athlete was affected enough by the environment that their maximal performance capacity could not be attained, as this was seen in slower time trials.

**Overall Conclusions**

The current study was successful with inducing significant changes in body temperatures during trials in the cold environment. The trial that included a 30-minute resting period after the warm-up and before the performance time trial in the cold, as hypothesized, had the greatest impact on the tendencies observed in physiological changes and performance. The cold caused significant decreases in skin and core temperature throughout the rest, and these values, along with heart rate, remained lower throughout the performance. Responses of blood pH and HCO3- are difficult to interpret in relation to overall performance because of their lack of complete data, but no relationships were seen between these variables and performance. Blood lactate changes, however, responded differently between conditions, and in 30-C, accumulated the least during performance, likely due to a slowed metabolism from decreased body temperature from the cold environment. These physiological changes either separate or combined, may be responsible for the tendency toward slower times that were rowed or run during 30-C. Participants noted that they felt they were most uncomfortable during 30-C and that the cold temperature had affected them. These comments, along with the participants lack of enthusiasm for not being able to wear warmer clothing, may allude to a psychological component that played a role in diminished performance as well. Overall, the primary hypothesis was not proven in that performance was altered, but not significantly, in 30-C, compared to the other trials. It can also be interpreted that a combination of
physiological events due to temperature and prolonged resting time directly affected the performance times. Also evident from these findings is the importance of performing an adequate warm-up before a subsequent bout of exercise. The increases in overall body metabolism from the warm-up were seen in tendencies for differences in blood lactate, pH and HCO3- responses, along with increased core temperature. Within 5 minutes after the warm-up exercise, residual effects of these responses were still present in the body, which differed from the 30-minute resting trials in which most of these effects had dissipated. We saw tendencies for improved performance in 5-C and 5-R compared to 30-C and 30-R, demonstrating that the positive effects from the warm-up exercise were diminished with the longer resting period, and even more so in the cold environment.

**Strengths and Limitations**

This experimental design was successful in creating a real-life scenario that could take place during a rowing event; however, it was not as applicable to middle-distance running events. A rower in a boat would probably not have the ability to warm-up again immediately before a race if the situation had them unable to move their boats around on the water; whereas, a runner would most likely have the ability to move their body around on land right before a race. An important difference to note was that not enough rowers could be recruited for this study, and since a subset population of runners was added, trial protocols had to be altered to fit the population. It was thought that a 1.5 mile run would be comparable in duration to a 2000 meter row; however, performance times were actually about 2 minutes longer in the running trials. A strong limitation is that we cannot compare results between the groups because of the small sample size, and we also cannot generalize the overall results since two different populations were used. Even though there was less applicability of this study protocol to the runners, similar changes were seen in responses to the longer duration of rest time in the cold. Another limitation was that even after a preliminary acclimation trial, the runners who participated were not accustomed to performing a 1.5 mile time trial on a treadmill without being able to see their instant speed. All rowers who participated had previously performed many 2000 meter time trials on the rowing ergometer and were familiar with the
exercise. In addition, the warm-up protocol in the running trials did not induce changes in blood lactate similar to the changes seen in the rowing trials. Speed during the warm-up was set at 60-70% of the maximum speed attained during the VO2max test; however, in the runners, this did not induce much change in concentration of lactate. The warm-up did, though, induce similar changes in skin and core temperatures, compared to the rowers.

Applications and Future Directions

While this experiment overall did not find any novel physiological differences in exercising while in different environments, the results can be applied externally for athletes who perform in cold conditions. The participants in the current study were not allowed to wear the same clothing they would normally wear in colder temperatures, which is unrealistic in a competitive scenario. Wearing garments that covered more surface area of skin might have resulted in different changes of skin and possibly core temperature, which may have shown less change in performance in 30°C. Future studies could compare trials in a cold environment similar to the current study, but with participants wearing short-sleeved clothes or clothes they would normally compete in if temperatures were around 5°C.

In the current study, the warm-up protocol was adequate in preparing the participants for maximal subsequent performance. The trials with 30-minutes of rest after the warm-up, especially in the cold, also resulted in showing how the positive effects seen with the exercise were diminished with a recovery that was too long. This situation of a delayed resting time after a warm-up can be applied to the sport of rowing because of the constraints of other environmental conditions such as wind and water movement, and it is also interesting to put application of this situation to other athletic events. In running events, even if a proper warm-up is performed and there is a delay in the start of a race, an individual can still perform stationary movements in order to keep their body temperature elevated before the start of a race and so it is harder to apply the current results to those events. In shorter-distance cycling races, however, a warm-up can be performed and then delays might occur at the starting line where cyclists are lined up and there is no space for further warm-up before the race begins. Other sports which involve intermittent
activity such as football, could also take these results into consideration, however, sport-specific studies should be performed to receive the most worthwhile information for each individual event. The current findings are meant to portray what occurs during a rowing regatta and can therefore be applied to the sport.
REFERENCES


17. Flouris AD, Westwood DA, Mekjavic IB, Cheung SS. Effect of body temperature on cold induced vasodilation.


Figure 15. Mean changes occurring during rest period. (in order to see the changes of pH and to compare to other variables, 1 was added to each value) (pH & HCO3- n = 5; La n = 10).

Figure 16. Mean changes occurring 3-minutes post-exercise. (in order to see the changes of pH and to compare to other variables, 1 was added to each value) (pH & HCO3- n = 3; La n = 8).
ABSTRACT

The effects of elapsed time after a warm-up on physiological and performance responses during rowing and running in a cold environment.

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Background: Competitive rowers among other athletes, compete in relatively cold environmental conditions. A warm-up is a standard procedure in all sports, and athletes complete it in order to increase body metabolism and tissues. Delays that occur before races can force rowers to be constrained to their boat and lose the effects of the warm-up. Quick racing starts following long delays do not allow time for additional warm-up; therefore, performance during the race may be affected, which is important since rowers perform supramaximally for about 6 to 8 minutes. This combination of intensity and duration does not give the body enough time to benefit from gradual warm-up effects that occur during the first few minutes of exercise at a lower intensity. Purpose: The purpose of this study is to examine the effects of varied durations of post warm-up periods on the metabolic, thermoregulatory, and performance responses during subsequent high intensity rowing or running in a cold environment. Method: Five experienced rowers (1 female; 4 male) and five trained runners (2 female; 3 male) completed four trials consisting of a standardized warm-up followed by: 5 minutes of rest in room temperature (5-R); 5 minutes of rest in the cold (5°C) (5-C); 30 minutes of rest in room temperature (30-R); 30 minutes of rest in the cold (30-C). After the resting period, rowers performed a 2000 meter time trial on a rowing ergometer and runners performed a 1.5 mile time trial on a treadmill. Blood samples were collected pre-exercise, post-warm-up, pre- and post-time trial and 3 minutes post-time trial and were analyzed for lactate concentration in all participants, and pH and bicarbonate (HCO3-) in the rowers. Core temperature (Tc) was measured via an esophageal probe, skin temperature (Tsk) was measured via surface probes on four sites of the body, and heart rate (HR) was measured via a Polar monitor. These variables were measured every five minutes during the warm-up and resting period, and every quarter of the time trial. Results: In performance times, there were no interactions found between conditions; however, there was a tendency for slowest times to be completed in 30-C and the fastest times in 5-R. Statistical analysis could not be performed for pH and bicarbonate responses due to the lack of complete data. These variables both returned to pre-exercise values after 30 minutes of rest and the smallest changes after the time trial occurred in 5-R. No significant interactions were found in blood lactate concentrations; however, there were increased rates of clearance following 30 minutes of rest, smaller changes after the time trial in 5-R, and slightly lower concentrations in the cold trials. A significant rest time by environment by time point interaction was found for Tc (p=0.00). At the end of rest, average Tc was significantly greater in 5-C and during performance, peak Tc was significantly lowest in 30-C, both compared to all other trials. A similar interaction was found in Tsk (p=0.00) and during warm-up, Tsk significantly decreased in cold trials compared to room temperature. Also, at the end of rest, Tsk was significantly lower in 30-C compared to the rest of the trials and remained lower throughout the time trial. HR was significantly lower after performance in 30-C compared to all other trials (p < .05). Summary: We found significantly colder core and skin temperatures during the trials in the cold and significant differences in variables when comparing 30 minutes of rest to 5 minutes. Even though performance was not significantly slower in 30-C, it would seem that there was a combination of physiological events due to temperature and prolonged rest time that may have affected performance. From the results, we can conclude that performing an adequate warm-up and maintaining core temperature, especially in the cold, is important for preparation before a high-intensity bout of exercise, and that athletes should consider this information when performing in colder environments.
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△ Education

Bachelor of Science: Exercise Science
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Ithaca College, Ithaca, NY
August 2002 - May 2006

Candidate for Master of Science: Applied Exercise Physiology
University of Illinois-Chicago, Chicago, IL
August 2006-May 2007

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△ Work Experience

Lifeguard and Swim Instructor, Apachi Day Camp, Summer 2002-2008
Northbrook, IL

TCU Campus Recreation, Fort Worth, TX Fall 2007-Present

Internship, Gatorade Sports Science Institute, Summer 2005
- mentored by Dr. Jeff Zachwieja
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- Assisted with compiling and analyzing research data during on-going studies
- Designed research project which involved collecting and analyzing physiological data

Kinesiology Department Graduate Assistant, Fall 2007-Present
- advised under Dr. Joel Mitchell
TCU, Fort Worth, TX
- Instructor: Jogging (Spring 2008-9)
- Teaching Assistant: Personal Fitness (Fall 2007-Spring 2008)
- Research assistant for ongoing projects in physiology lab
Projects and Research Papers

- “Studying the difference in technique, muscle activity, and efficiency of a rowing stroke between an experienced and novice rower”
  *Ithaca College, Spring 2004*

- **Innovative Paper**, “A Training Solution to Prevent Shoulder Instability in Younger Swimmers”, *Ithaca College, Fall 2004*

- “Effects of warm-up and stretching on vertical jump”
  *Ithaca College, Spring 2005*

- “Relationships between blood lactate, heart rate, and rate of perceived exertion in three different modes of exercise”
  *University of Illinois-Chicago, Fall 2006*

- “Effect of exercise and environment on immune response”
  *Texas Christian University, Fall 2007*

- “Effects of post-endurance exercise carbohydrate ingestion prior to sprint performance in the heat”
  *Texas Christian University, Fall 2007*

Laboratory and Data Collection Experience

- **Exercise Capacity Testing**
  - VO2max: Douglas Bag and Metabolic Cart
  - Wingate test

- **Blood and Tissue Procedures**
  - Phlebotomy
  - Hematocrit and Hemoglobin
  - Lactate and Glucose
  - ELISA
  - Blood centrifugation and storage
  - Adipose tissue processing

- **Other Laboratory Assessments**
  - Body composition analysis
    - Bod Pod
    - Skin folds
    - BIA
    - NIR
  - Environmental chamber
  - Esophageal core temperature probe insertion
Professional Affiliations and Current Certifications

American College of Sports Medicine Member, 2005-Present

American Red Cross: Lifeguarding, CPR for the Professional Rescuer, AED

Extracurricular Activities

Women’s Varsity Crew, Ithaca College, 2002-2006
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Hillel, Jewish Student Organization Board Member, Ithaca College, 2002-2004

Indoor Rowing Club Treasurer, Ithaca College, 2004

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