

THE EFFECTS OF BASE LAYER CLOTHING DESIGNED FOR COLD WEATHER  
ENVIRONMENTS ON ATHLETE CORE TEMPERATURE

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## ABSTRACT

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Synthetic material clothing has become an extremely large market for athletes and athletic departments alike. While these materials were originally designed to keep an athlete cool and dry in hot conditions, there have also been products designed to keep athletes warm and dry in cold conditions. While numerous studies have examined the effect of synthetic material clothing on individuals in warm climates, very few have examined the effects in cold environments. Of those few, virtually none have examined strictly the effect of specific base layers on body temperature without additional clothing. The purpose of this study was to determine to what extent these materials affected body temperature in cold weather environments without additional clothing to aid in the maintenance of body temperature

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# CHAPTER 1

## INTRODUCTION

### 1.1 Overview of the Problem

In athletics, there has always been a goal to minimize bulk when it comes to clothing in competition. The least amount of clothing that can be worn while still protecting the athletes from environmental elements is of great concern, especially when considering sports that take place in cold weather environments. The days of wearing a long sleeve cotton shirt underneath a uniform have long since come and gone. In today's competitive world and more specifically, competitive sports, every coach, player and team are looking to get a leg up on the competition.

Synthetic material base layers have been used for over a decade. The first major brand, Under Armour, began to do so in 1996 with the idea of creating a material to wick sweat from the body and allow for continued sweating to cool the body. This moisture-wicking material caught on fast and before long, every major sports equipment company had their own line. In the beginning, it was all about keeping athletes cool, doing whatever possible to prevent overheating and heat related illness. Over the past decade, companies have begun to look at not only how to keep the body cool in hot environments, but also how to keep athletes warm in cold conditions. Therefore, the goal of this study was to compare the body's reaction to cold weather while wearing no base layer, regular cotton shirts, and base layers designed for cold weather to determine the extent to which these materials effect on body temperatures.

While the original goal of moisture-wicking garments was to help remove sweat from the body, thereby allowing the body to cool via conduction, the same can be true for keeping athletes warm. The idea being that this new ColdGear would provide a soft inner layer that would help distribute heat while still having an outer layer to help wick away moisture (ua.com, 2012).

When sweat builds on the body and is absorbed by a cotton shirt, this moisture stays on or close to the skin. While exercising in cold conditions, this cold air hits the moisture causing a cooling effect, ideal for trying to keep body temperatures low, but in cold weather, the opposite effect is desired. By wicking moisture away from the skin in a cold weather environment, you give the body a chance to maintain skin and core body temperature by diminishing the amount of moisture directly on the skin and transferring this moisture to the outer layers where it can evaporate (Castellani, Young, Ducharme, Giesbrech, Glickman & Sallis, 2006).

While it is important for the athletes to have full movement during their sport, it is also important to maintain body temperature, which is the aim of synthetic base layers. The Mayo clinic defines hypothermia as any time the body's core temperature drops below 95 degrees fahrenheit (Mayo Clinic, 2011). That's a 3.6 degree drop from normal body temperature. Effects of hypothermia generally happens when a person is exposed to cold weather or immersed in cold water. If the individual continues to be exposed, and does not seek treatment, hypothermia can lead to total failure of the cardiovascular and respiratory systems and eventually, death (Mayo Clinic, 2011).

Although most sports performed in cold weather environments often have equipment or layering associated with them, such as ice hockey, biathlon, skiing, snowboarding etc, these layers and equipment aid in the body's effort to maintain body temperature. The focal point of this study was to determine the base layer's ability itself to maintain body body temperature without the aid of outer layers. If companies were able to construct base layer materials, which could maintain body temperature by itself, it would revolutionize sports. Skiers, snowboarders, endurance athletes, even recreational athletes would be able to enjoy the benefit of not having to put on layer after layer to keep warm in the cold. They could minimize the bulk and maximize



comfort in participating in their chosen sport or event.

Houghton, Dawson, and Maloney (2009) completed a study, which compared cotton shirts to synthetic material shirts to determine any significant difference in skin or core body temperature. In this study, “ten match-fit field hockey players” performed four interval exercise sets in a “temperate climate” on the same day. Each interval lasted 15 minutes. Results revealed no significant difference in core temperature between a cotton shirt and the synthetic material worn by athletes. However, the specific synthetic material was not discussed or named. While all major companies have their own brand of cold weather synthetic material clothing, and all companies claim their product will keep athletes warm in commercials and advertising, no company has anything in writing stating that their products affect either skin or core body temperature. Due to this lack of published evidence, it leads one to believe that the effects acknowledged by athletes are more psychological rather than an actual physiological fact.

## **1.2 Significance of the Problem**

According to Yahoo’s financial center report, athletic apparel has become a multi-billion dollar industry, with the top performer (Nike) earning more than \$10 billion in 2012 (yahoo.com, 2013). With that just being the top performer, and dozens of companies joining in, it has become clear that everyone in the athletic community realizes the importance of undergarments worn during competition. However, there is currently very little published research on the topic of synthetic material base layers and their effect on body temperature in cold conditions. While research is abundant in the realm of warm and mild temperature climates, it appears very few research studies have examined the environment once the temperature drops below 50 degrees Fahrenheit.

### 1.3 Purpose of the Study

The purpose of this study was to determine to what degree synthetic material clothing effected body temperature in physically active individuals while exercising in cold weather.

### 1.4 Hypotheses

H1: There will be no difference in body temperature among individuals wearing synthetic material, cotton shirt or no base layer while exercising in cold weather.

H2: There will be no difference in weight loss among individuals wearing synthetic material, cotton shirt or no base layer while exercising in cold weather.

### 1.5 Operational Definitions of Key Terms

**Base Layer** - The layer closest to the skin in any layering situation.

**Chilblains** - A painful inflammation of blood vessels in the skin that result of re-warming cold skin too quickly.

**ColdGear** - Under Armour product designed specifically to keep athletes warm and dry in cold weather environments

**Frostbite** - The freezing of skin and underlying tissues.

**HeatGear** - Under Armour product designed specifically to keep athletes cool and dry in hot environments.

**Homeostasis** - The body's method for maintaining a stable state of temperature and pH levels where normal body functions can take place.

**Hypothermia** - Hypothermia is a state in which the body loses heat faster than it can produce. Hypothermia is a medical emergency that can be fatal if left untreated. A hypothermic state is referred to when the body core temperature drops below 95 degrees Fahrenheit.

**Raynaud's Phenomenon** - Condition where a response to cold blocks blood flow to the fingers,

toes, nose and ears.

**Synthetic Material** - Clothing made from man-made fibers, rather than natural fibers. Including but not limited to polyester, acrylic, kevlar, spandex, nylon, and elastane.

**Thermoregulation** - The body's method of maintaining temperature through modes such as convection, conduction, radiation, and evaporation.

**Wick** - An action performed by material which removes moisture from the skin. Rather than absorbing this moisture, it is transferred across the fabric thereby preventing build-up in the same areas.

## **CHAPTER 2**

### **REVIEW OF LITERATURE**

#### **2. Introduction**

This review examined the current literature pertaining directly to this thesis project. This literature includes thermoregulation, hypothermia, common cold-related illnesses, synthetic base layers and literature pertaining to clothing worn in cold environments.

#### **2.1 Overview of Thermoregulation**

Thermoregulation is the body's method of regulating core temperature in order to maintain homeostasis. Homeostasis is the state at which the body is fully functioning at maximum efficiency. The body's goal is maintain a core body temperature between 97.7 and 99.5 degrees Fahrenheit (Vella & Kravitz, 2004). The portion of the brain responsible for temperature maintenance is the hypothalamus. Thermoreceptors throughout the body constantly relay information back to the brain regarding temperature changes in and around the body. Based on this received information, the hypothalamus decides whether or not a change needs to be made. Upon signs of the body being cold, several efforts will be made to produce heat internally before "emergency action" must be taken. People notice these efforts almost every time they enter a cold environment. The first and probably most common is "goose bumps". Cold environments initiate a response which simulates the erector pili muscles of hair follicles, causing the hair to stand on end and the skin to raise. This reflex is in place to create an extra layer of insulation to help maintain body temperature in mammals (Bubenik, 2003).

Another response is for the body to attempt to generate heat. The body can do this in two separate ways, non-shivering thermogenesis and shivering thermogenesis. Non-shivering thermogenesis is defined as an increase in metabolic heat production from a source outside of

muscle contraction (Cappaert, Stone, Castellani, Krause, Smith & Stephens, 2008). Non-shivering thermogenesis is generally considered a minor factor in heat production (Cappaert, Stone, Castellani, Krause, Smith & Stephens, 2008). Shivering thermogenesis is an involuntary response to create heat using muscle activity. Vigorous shivering can use as much energy as riding a bike or shoveling snow (Saunders, 2003). In prolonged exposure to cold, the body's final response will be to pull blood from the extremities to the core to maintain temperature of vital organs. The body will begin to pull blood from the extremities when the skin temperature drops between 95.0 and 93.2 degrees Fahrenheit, and is at its maximum capacity when skin temperature drops to or below 87.8 degrees Fahrenheit (Cappaert, Stone, Castellani, Krause, Smith & Stephens, 2008). In the case of body temperature dropping significantly, if submerged in cold water, or being exposed to a cold environment with inadequate layering, for example, hypothermia becomes the primary cause of concern.

### **2.1.1 Overview of Hypothermia**

When core body temperature drops below 95 degrees Fahrenheit, it is said to be in a hypothermic state (Castellani, Young, Ducharme, Giesbrech, Glickman, Sallis, 2006). When in a hypothermic state, the body is losing heat at a rate faster than it can produce heat. When the body reaches these temperatures, the lack of heat affects the brain making it difficult to concentrate, think clearly, and physically move (CDC, 2011).

Hypothermia affects people in three different stages, mild, moderate and severe. Mild hypothermia is when the core body temperature drops between 98.5 and 96 degrees Fahrenheit. Signs of mild hypothermia include involuntary shivering, inability to perform complex motor functions (i.e. winter sports), and beginning numbness in extremities due to vasoconstriction. Moderate hypothermia presents when temperatures drop between 95 and 93 degrees Fahrenheit.

The signs include dazed consciousness, loss of fine motor movements (particularly in fingers due to decreased blood flow), and slurred speech. The individual may also present with violent shivering, irrational behavior, and an apathetic attitude. The individual may begin removing clothing as they are unaware they are cold. Severe hypothermia is an immediate life threatening condition. Severe hypothermia takes place when the core temperature drops between 92 and 86 degrees Fahrenheit (Curtis, 1995).

Severe shivering comes in waves until the body recognizes it is no longer producing heat to counteract the dropping core temperature. The body then shuts down shivering to save glycogen stores (Curtis, 1995). The person will fall to the ground and go to the fetal position to conserve heat. Muscle rigidity develops due to reduced blood flow to the extremities and a build up of lactic acid and CO<sub>2</sub> (Curtis, 1995). The skin becomes pale and the pupils dilate and pulse rate decreases. When core temperature reaches 90 degrees Fahrenheit the body attempts to enter hibernation by eliminating peripheral blood flow and slowing breathing and heart rates (Curtis, 1995). At 86 degrees, the body is in a “metabolic icebox” form, where the individual appears dead, but is still alive (Curtis, 1995).

### **2.1.2 Methods of Thermoregulation**

In the body's constant battle against hypothermia in cold environments, the different forms of thermoregulation must be taken into consideration. The body regulates temperature using a variety of methods, both internal and environmental. The main internal method of keeping the body warm is the aforementioned shivering. Environmental conditions include evaporation, conduction, convection, and radiation. The four environmental conditions can sometimes work in conjunction to heat and cool the body.

Evaporation uses the body's sweating to release heat from the body. Evaporation uses the conversion of liquid to gas (water to sweat) to cool the body (Vella, Kravitz 2006). Conduction is the body's method of regulating temperature through direct contact with another object (Vella, Kravitz, 2006). For example, if one was cold, they could get a warm drink and hold on to the cup. Through conduction, their hands would become warmer, simply because of the heat given off by the warm liquid in the cup.

Convection is the process of losing or gaining heat by the movement of air around the body (Vella, Kravitz, 2006). A person standing outside in the wind will experience convection, and notice a difference in temperature when the wind is blowing and when the air is still.

Radiation is the use of infrared rays to heat a surface without any physical contact that is seen in conduction (Vella, Kravitz, 2006). The prime example of this would be a person sunbathing, that person will feel warmth from the sun, even though they are not making any direct contact with the sun itself.

## **2.2 Overview of Other Cold Illnesses**

Aside from hypothermia, other conditions can arise from prolonged exposure to cold conditions. The most common of these would be chilblains and frostbite. Another common condition is known as Raynaud's phenomenon.

### **2.2.1 Chilblains and Frostbite**

Chilblains is a condition that is brought about by warming skin that was previously exposed to cold conditions too rapidly (Mayo Clinic, 2012). Chilblains is an inflammation of small blood vessels in the skin (Cappaert, Stone, Castellani, Krause, Smith & Stephens, 2008). Chilblains can present with a variety of symptoms, such as, redness, itching, swelling and blistering on the extremities, particularly on the fingers and toes. (Cappaert, Stone, Castellani,

Krause, Smith & Stephens, 2008). While not an overly severe issue, if blisters become infected, chilblains can lead to severe and permanent damage.

Frostbite is the actual freezing of any soft tissue, most commonly the skin. This is caused by prolonged overexposure to cold temperatures. Different signs of frostbite can be white or grey-yellowish skin, along with very cold and hard skin. As the skin begins to warm it can itch, burn, and even go numb. Severe frostbite can result in blistering or permanent hardening. Some severe cases of frostbite will require amputation to remove the dead tissue from spreading any possible infection to the rest of the body.

### **2.2.2 Raynaud's Phenomenon**

Raynaud's phenomenon is a problem of blood flow to the extremities. Primary Reynaud's has no known cause, but secondary Reynaud's can be caused by other diseases, medications, smoking and frostbite to the area. The body restricts blood flow to the hands and feet, or previously traumatized areas, causing them to feel cold and/or numb.

## **2.3 Overview of Synthetic Material Base Layers**

Since synthetic base layers burst onto the scene in 1996, every major sports brand, along with most smaller companies produce some sort of synthetic material base layer clothing. Under Armour was the original producer of synthetic material base layers. Still to this day they are arguably the most popular brand for base layer clothing. Shortly after their successful start, companies such as Nike, Adidas, and Reebok also began to produce synthetic base layer clothing.

Under Armour was founded by a former Division-1 football player, Kevin Plank, from the University of Maryland (ua.com, 2012). After playing collegiate football in a hot, humid climate for several years, he had the idea to produce a material that would help wick moisture away from



the skin and allow the body to maintain a reasonable body temperature to avoid overheating and heat illness. Under Armour has come a long way since their original ideal of creating a base layer to help keep athletes cool. They now offer a variety of base layers to keep athletes cool, dry, and warm depending on the conditions in which the individual will experience during their particular activity. After the introduction of the base layer for warmth, the terms ColdGear® and HeatGear® were coined. ColdGear® is designed specifically for cold weather and to keep athletes warm. HeatGear® has the opposite design and is to keep body temperature down and keep athletes cool.

ColdGear® products are comprised of 89-93% polyester and 7-11% elastane (ua.com, 2012). Although the inside of shirts has a fleecfeel, it is still comprised of polyester. HeatGear® shirts that are not compression types are comprised of 100% polyester. Shirts with a compression aspect range anywhere from 13-19% elastane, with the remaining material being polyester (ua.com, 2012).

Soon after Under Armour's success, Nike developed their dri-fit® material. Following the example set by Under Armour, they too offer different designs for differing conditions. Nike offers the largest variety and has arguably advanced the field further than any other company, including Under Armour. Their latest innovations are their "hyper-warm" and "hyper-cool" lines. Hyper-warm products generally consist of 88% polyester and 12% spandex (nike.com, 2013). Hyper-cool products tend to consist of approximately of 84% polyester and 16% spandex (nike.com, 2013).

Adidas and reebok have also joined in the synthetic material race with products of their own. While not as publicly recognized as Nike or Under Armour, these products also have claimed to maintain body temperature in hot and cold conditions.

## **2.4 Overview of Literature Pertaining to Cold Illnesses**

Injuries sustained from the cold have a wide range of effects on the human body. Specifically, an individual can endure painful re-warming of the skin from being in the cold, to freezing of the skin and other tissues, or even the body steadily shutting down in an attempt to keep an individual alive. Because it would be considered immoral and cause harm to humans to actually experiment with cold injuries such as hypothermia, the vast majority of the published material are case studies, reviews of reported injuries and position statements for various organizations.

In 2004, Ulrich and Rathlev published a report on the history of hypothermia and localized cold injuries. The study goes as far back as the American Revolution which showed that 10% of George Washington's troops perished due to the cold weather in 1777 and 1778 (Danzl, Pozos, Hamlet 1995). While their other historical references show astronomical amounts of cold illness casualties to military personnel, in recent years the majority of hypothermia and cold illness cases come from three categories: the homeless, outdoor enthusiasts and those who participate in winter sports.

The report shows the most relevant predisposing factors to sustaining different cold illness include: extreme age, old or young, major trauma, hypothyroidism, and hypoglycemia (Ulrich & Rathley, 2004). While all of these factors could play a role in one sustaining a cold-related injury, the biggest factor will always be the amount of time exposed to the conditions. If the exposure time is not monitored or protected against the risk of sustaining an injury cold illnesses increase exponentially.

Ulrich and Rathley (2004) discuss several treatments for rewarming affected areas. When it comes to hypothermia, a common method of rewarming is passive external warming. In

this scenario, the individual removes all wet clothing and is placed in a warm dry environment and covered in blankets. This method is used for mild hypothermia and will generally cause an increase in core temperature of 0.5 to 2.0 degrees Celsius per hour. Another form is active external warming. This technique employs heating blankets and heat lights or a heated air system to help the individual increase body temperature and is used for moderate hypothermia. Active core warming is the most effective technique, however, it is only used in severe hypothermic cases. In this situation, cardiopulmonary bypass is used to heat the blood in the pump and have this warmed blood pumped back through the body in order to increase full body temperature (Ulrich and Radley, 2004). This technique can see instant results of 1-2 degree Celsius increases every 5 minutes.

For freezing injuries, the best treatment is rapid external rewarming. Immersing the affected area in warm water (104-108 degrees Fahrenheit) and circulating the water to maintain temperature for 15-30 minutes to maintain temperature. Dry or excessive heat is potentially harmful because it can cause liquefaction necrosis which could cause further bacterial infection. Aggressive/intravenous analgesia usually accompanies rewarming due to the intense pain caused during the thawing process.

In 1999, Sallis and Chassay discussed how to recognize and treat common cold-induced injuries in outdoor sports. In this report, many of the treatments and protocols are the same or very similar to what Ulrich and Rathlev (2004) reported. However, Sallis and Chassay go further in discussing prevention techniques for cold-induced injuries.

They state prevention of cold injuries should include maximizing heat production through physical activity, shivering and consuming food. Individuals should also prevent as much heat loss as possible by proper layering of clothing. Clothing should be added or removed as the

weather dictates. If these measures are insufficient for maintaining body temperature, an external heat source should be introduced, or shelter of some sort should be sought.

The National Athletic Trainer's Association developed a position statement in 2008 about environmental cold injuries. This statement is to provide certified athletic trainers and other health care professionals the problem-solving skills to address environmental cold injuries when they are encountered. While Ulrich and Rathlev (2004) listed internal factors which could predispose individuals to cold injuries, the NATA position statement also lists non-environmental risk factors that could play a role in one sustaining a cold environment injury. Some of these factors include individuals with a previous cold injury. For example, if a person has sustained a previous cold injury they are 2-4 times more likely to sustain that injury in the affected cold area again (Ulrich & Rathlev, 2004). Low caloric intake, dehydration, fatigue can play a role because if insufficient fuel is present in the body, metabolism is decreased thereby decreasing heat generated by the body (Ulrich & Rathlev, 2004). Moreover, when combined with a decreased metabolism, fatigue can lead to faulty decision making which could make one susceptible to cold injury. Nicotine, alcohol and drug use can increase vasoconstriction and increase the possibility of sustaining frostbite or other cold injuries to the peripheries.

Body size and body composition play key roles in maintaining body temperature. Both high proportions of body fat and muscle mass are vital in maintaining core body temperature when exposed to cold weather for prolonged periods of time. Regardless of clothing, those with higher muscle and fat mass maintain core temperature better than less fit counterparts (Cappaert, Stone, Castellani, Krause, Smith & Stephens, 2008). Aerobic fitness level and training seems to play a minor role in thermoregulation, however, more fit individuals would be able to sustain longer bouts of physical exertion and thereby produce more metabolic heat than a less fit person.

Finally, clothing's role in preventing cold injuries is based on its ability to reduce the amount of heat loss and also protect against the build-up of moisture close to the skin. The NATA position statement (2008) recommends a three layer system where the first layer is comprised of a moisture wicking material, the second layer being an insulating material to protect against heat loss, and the outer layer comprising vents to allow moisture to evaporate into the environment.

## **2.5. Overview of Literature Pertaining to Synthetic Material**

Since the creation of synthetic material shirts in the mid-1990's, numerous studies have been published to support the use of these materials to maintain body temperature in warm weather conditions. However, very few studies have been performed to observe the affects these materials have on the body in cold weather environments. Particularly without the assistance of other layers being present which would assist in keeping the individual warm.

In 2013, Smith and colleagues studied the physiological and perceptual responses to different base layers on firefighters under their personal protective equipment. Ten healthy, male participants were chosen and medically cleared to participate. These 10 participants underwent four multiple exercise routines with rest periods intermixed of varying lengths. The exercises were different amounts of time walking on a treadmill at varying degrees of incline. This study compared four different clothing materials: 1) cotton, 2) modacrylic, 3) wool blend, and 4) phase change material. The phase change material was a mix of modacrylic, rayon, p-aramid and spandex. The phase change material was the most advanced and had properties such as the ability to absorb, store and release heat. The results showed no significant difference in core body temperature based on the base layer material either during exercise or during rest periods.

This study concluded that none of the base layers had a significant effect on perceptual or physiological responses during exercise and rest periods.

Another study by Ciesielska, Mokwinski, and Orelowska-Majdak (2009) aimed to determine if a material fabric or synthetic fabric would be more comfortable during rest periods and physical activity. Twenty medical school students (6 females, 14 males) between 21 and 29 years of age performed two 15-minute treadmill tests. The first treadmill test they were wearing 100% wool clothing and the second test the participants wore 100% acrylic clothing. All tests were performed at a temperature between 17-23 degrees C (62-73 F). Between each 15 minute exercise period, the participants rested for 30 minutes. The physiological tests conducted were heart rate and blood pressure. The results revealed that participants wearing wool clothing had a significantly lower heart rate, but also a significantly higher blood pressure. In addition, participants felt more uncomfortable post exercise when wearing the acrylic clothing compared to the wool clothes. The authors concluded that, the clothing worn by individuals during exercise should be decided upon by the participant themselves.

In 1996, Gavhed and Holmer studied physiological and subjective responses to thermal transients of exercising subjects dressed in cold protective clothing. The purpose of the study was to determine if fiber type, wool or synthetic, affects individuals dressed in winter clothing during exercise in changing cold temperatures. The study used 20 men, mean age 26, in two separate groups. All participants wore multiple versions of multi-layer clothing during the experiment. One group wore four different versions of clothing, while the other wore only two. The versions of clothing each group wore was not specifically discussed, however, the different variations of clothing were identified in general. These ensembles were divided into two groups, synthetic and wool based with two variations of each. The first synthetic version was comprised

of 100% polypropylene briefs, ankle length underwear, and a long sleeve crew-neck undershirt as a base layer. The middle layer was a fiber pile jacket and pants, comprised of 100% polyester. The outer layer is an overall and jacket comprised of 52% cotton and 48% nylon. The second synthetic material version is the same inner and middle layers but with a high insulative parka and overall (fiber composition was not specified).

Both wool variations were comprised of the same briefs and inner layers as the synthetic variations, however, the clothing was 100% wool instead of polyester. The middle layers were fiber pile jackets and pants comprised of 75% wool and 25% polyester. The first wool group wore a overall and jacket comprised of 52% cotton and 48% nylon. The second group wore a highly insulative parka and pants with no specified composition. Another ensemble was put on a mannequin to measure the heat generated from insulation on an object at rest. Heart rate, skin temperature, skin humidity, and core temperatures were all taken before, during and after exercise. This study concluded that skin temperature increased with higher insulation during steady-state exercise. Skin temperatures were slightly higher in the wool ensembles, but no other significant temperature changes were present.

A study completed by Noonan and Stachenfeld (2012) examined the effects of undergarment composition worn beneath hockey equipment during high-intensity intermittent exercise. The purpose was to determine the undergarments' effect on thermal homeostasis and power output on a cycle ergometer. This study examined eight men in their mid-20's and compared body temperatures and power outputs. In addition, it examined if synthetic material or cotton had a differing effect on homeostasis or power output when worn under full hockey equipment. The participants alternated 25-second activity periods with 50-second rest periods to simulate a hockey game. There was no statistical difference in core and skin temperatures

between the two test groups. It was noted that there was essentially no difference found in the power outputs of either the synthetic material or the cotton material base layer group. The total power output between the groups was only 0.5W different. The study concluded that any advantage that could be observed by the synthetic material was masked by the fact that the equipment provides such an impediment to the body's ability to cool itself.

In 2011, Kicklighter and colleagues reviewed the current literature on moisture wicking garments with the purpose to investigate the perceptions and physiological effects attributable to the garments worn during exercise in hot and cold environments. The review examined a wide array of companies and their products including Nike, Under Armour, Adidas, Starter, Champion and Russell. Most brands use their own blend of synthetic material. With the shirts designed for warm weather, all companies used polyester and/or spandex. There is a bit more variety with the cold weather gear as all shirts contains polyester, spandex, nylon, or filament silk. While the review has plentiful examples of studies being performed which look at the relationship between different materials and the body's response in warm weather, they state: "To date, no research has been published that documents the effects of various moisture-wicking fabrics on body temperature during exercise in a cold environment; however clothing construction has been shown to affect thermoregulation during and following exercise in cold conditions." They concluded that, while very marketable and appealing to athletes and consumers alike, these products do not show a significant effect on body temperature in hot or cold environments.

## **2.6. Overview of Literature Pertaining to Weight Loss due to Sweating**

The American College of Sports Medicine (2011) has several guidelines and suggestions for combating water loss due to exercise. One guideline is how to monitor how much water is lost due to exercise. The simplest way to do so is to weigh yourself before and after exercise.



Individuals can determine how hydrated they have stayed during exercise based on the amount of weight lost. A decrease in body weight generally indicates a certain level of dehydration. If the individual's weight has fluctuated 1% of their total body weight up or down, they have stayed well hydrated. If the loss is between 1% and 3% of their body weight, this indicates minimal dehydration. A loss of 3% to 5% indicates significant dehydration and greater than 5% indicates serious dehydration reference.

In 2012, Goulet found that the current literature was misleading when it came to endurance-trained athlete, but there was no reason his findings would not translate to recreationally-trained athletes. Goulet found that decreases in athletes' body weight of up to 4% loss did not decrease time trial performance and drinking to the demands of thirst maximized endurance performance. Goulet (2012) lists three of his new guidelines for hydration in endurance athletes. The first guideline is to make sure to be well hydrated prior to exercise. The best way for athletes to do this is to monitor their own thirst. A calculable way is to determine the amount is to drink 5-10 mL of water per kilogram of body weight in the 2 hours prior to exercising. The second guideline says to drink only according to your thirst sensation: no more, no less. He states that athletes drinking less than the amount to suppress thirst decreased performance significantly. Athletes who drank more than enough to suppress thirst had their performance decrease non-significantly. Furthermore, it is suggested that it is not the body weight which should be regulated as much as plasma osmolality. Drinking to thirst will maintain plasma osmolality in athletes; therefore, thirst is the ultimate determining factor in the amount of water consumed by athletes during performance. The final guideline is that fluid intake should be limited if high-intensity exercise is only going to last around 1-hour. In high-intensity workouts mid-length levels of time, trying to replenish fluid amounts can lead to gastrointestinal

problems which will degrade athletic performance. He concludes that the new guidelines focus on the athletes' thirst level which means athletes must develop their own hydration strategies in order to maximize their own performance.

In 2011, Nolte, Noakes and van Vuuren performed an experiment looking at total-body water content in soldiers exercising in cool weather. The soldiers performed a 14.6 km march in 57 degree fahrenheit weather. The soldiers were allowed to drink as they felt necessary throughout the data collection. They found that there was no significant changes in total body water or urine specific gravity despite an average body mass loss of 1.3 kg. They noted core temperature rises when intensity increased but this was not related to any body mass changes. These findings suggest that changes in mass do not accurately predict the amount of body water lost. It further suggests that body mass loss during exercise include losses other than water or, the body itself contains an endogenous water source that does not need to be replenished during exercise, or both. Finally, they found that water replacement between 65%and 70% of water lost maintained safe levels of hydration throughout the experiment.

## **2.7 Summary**

While much research has been done on cold illness and synthetic material in maintaining body temperature in warm weather, there has been very little research on synthetic material's effect on body temperature in cold environments. Therefore, the purpose of this study was to determine the extent of which synthetic material clothing effects body temperature while exercising in cold environments.

## **CHAPTER 3**

### **METHODS**

#### **3.1 Research Design**

A randomized, counterbalanced, within-subject experimental design was used to determine if base layers effected an athletes' body temperature and weight loss. The independent variable was by group (synthetic, cotton, no base layer). The dependent variables were body temperature and weight loss.

#### **3.2 Sample Population and Participant Selection**

Twelve subjects participated on a volunteer basis to determine their body temperature while exercising in cold weather environment. Participants had to meet the inclusionary criteria for physically activity based on the American College of Sports Medicine recommendations (Garber et al., 2011).

##### **3.2.1 Inclusionary criteria**

The participants had to meet the following basic recommendations: 1) Cardiorespiratory exercise—at least 150 minutes of moderate intensity exercise (4.8-7.1METs and PRE 12-13) or 75 minutes of vigorous intensity exercise (7.2-10.1 MET and PRE 14-17) per week. One continuous session and/or multiple shorter sessions of at least 10 minutes per session are both acceptable to accumulate the desired amount of exercise. Participants should have met at least one of the two recommendations: 2) Resistance Exercise—two to four sets of 8-12 repetitions on major muscle group such as chest, shoulders, back, hips, legs, trunk, and arms two or three days week using a variety of exercises and equipment, 3) Neuromotor exercise—two or three days per week of exercises that involves motor skills (balance, agility, coordination and gait). Multifaceted physical activities such as tai chi and yoga involve variety combinations of

neuromotor exercise, resistance exercise, and flexibility exercise. The ACSM recommends 20-30 minutes per day to be sufficient for neuromotor exercise.

### **3.3 Instrumentation**

#### **3.3.1 Base Layer - Synthetic material**

Males and females wore a synthetic material shirt designed to keep athletes warm in cold weather environments. The participants wore a HyperWarm shirt designed by Nike. These shirts were designed to be form fitting and sat close to the skin. The fabric composition of the shirts was 88% polyester and 12% spandex. These shirts were specifically designed to wick moisture away from the body to keep the athlete comfortable, while an insulating layer was designed to maintain body temperature in cooler conditions.

#### **3.3.2 Base Layer - Cotton Material**

The cotton shirts were standard 100% cotton, plain white, short sleeve undershirts.

#### **3.3.3 Base Layer - No Base Layer**

Males participated in the session with no shirt, while women wore a sports bra only. All participants wore gym shorts and compression shorts on their lower body.

#### **3.3.4 Body Temperature**

Body temperature was determined with an oral thermometer. Participants had their temperature taken prior to their warm-up period and immediately following the workout.

### **3.4 Exercise Intervention**

Each participant will perform an interval spin workout for 30 minutes each session. The participants will bike at varying levels of resistance and varying levels of time for a duration of 30 minutes. Starting at a level 1 resistance, the athlete will warm-up at a comfortable pace for five minutes. Following the warm-up, the interval training will begin. A playlist of songs of

varying genres will be selected. The participants will be informed that during each verse of songs, they will ride in a seated position with the current resistance. During each chorus, the resistance will be increased by 2 full turns, and the participant will stand and pedal as hard as they can. This will continue for approximately 20 minutes. After the workout has concluded, the participants will perform a five-minute cool down period of resistance set at level zero. By exercising for 30 minutes, participants will maintain aerobic exercise similar to cold weather athletes. The entirety of the spin workouts will be monitored and directed by one data collector. To decrease the incidence of error and to remove the inter-rater reliability, the same person will collect all data from all sessions.

### **3.5 Procedures**

Prior to data collection, this study will be approved by the Institutional Review Board (IRB) at Michigan State University. Each participant will complete an informed consent and health history questionnaire prior to participating in this study. Participants will then be weighed to determine if they lose weight during this workout. All sessions will be held in an ice rink with temperatures near or at 40 degrees Fahrenheit. Participants will be randomly assigned to one of the three groups for session 1. Participants will then swallow the capsular thermometer and make sure the computer is reading it accurately prior to the start of the spin workout. Participants will complete the spin workout which will be monitored by a certified athletic trainer in case medical issues arise during the workout. At the end of the session, participants weighed again to determine weight loss. Once complete, the next two sessions will be arranged for testing. All readings will be compiled and analyzed electronically.

### **3.6 Statistical Analysis/Data Management**

Participants were recruited through word of mouth in kinesiology and athletic training classes along with flyers posted around campus and in each athletic training room. Descriptive and inferential statistics were used to analyze the data for this study. A 3 base layer group (cotton, synthetic, no base) x 2 time (pre, post) repeated-measures analysis of variance (ANOVA) will be performed to assess differences on body temperature. Another 3 base layer group (cotton, synthetic, no base) x 2 time (pre, post) repeated-measures analysis of variance (ANOVA) will be performed to assess differences on weight loss. Data were analyzed using Statistical Package for Social Sciences (SPSS) version 19.0. Significance level for all analyses was set at prior to  $p < 0.05$ .

## CHAPTER 4

### RESULTS

#### 4.1 Overview

This research was conducted to determine to what degree synthetic material clothing affects body temperature in physically active individuals while exercising in cold weather. The following chapter will describe the demographics of the sample, and discuss the results for the pre- and post-tests for body temperature and weight loss among the three clothing groups.

#### 4.2 Demographic Data

##### 4.2.1 General Demographics.

A total of 12 (6 females, 6 males) participants began the study with 10 (6 females, 4 males) finishing the study by completing all three test sessions. One male dropped out of the study after the first session and the second male dropped out of the study after the second session. The average age of the participants was  $22.50 \pm 1.51$  years old. The average weight was  $154.58 \pm 23.27$  pounds and the average height was  $68.58 \pm 4.80$  inches.

#### 4.3 Results of Body Temperature Data

Due to issues with the Phillips equipment, we changed from core temperature readings to body temperature readings using oral thermometer.

*H1: There will be no difference in body temperature among individuals wearing synthetic material, cotton shirt or no base layer while exercising in cold weather.*

This hypothesis was supported as results of the repeated measures ANOVA revealed that there were no differences in body temperature between the groups [ $F_{(2,27)}=.342$ ,  $p=.713$ ] or the interaction between time and group [Wilks'=.880,  $F_{(2,27)}=1.84$ ,  $p=.177$ ]. However, there was a significant difference for time [Wilks'=.721,  $F_{(1,27)}=10.50$ ,  $p=.003$ ]. Specifically, when you

combined all three groups together the pre spin workout body temperature ( $M=98.637\pm.081$ ) was higher than the post spin workout body temperature ( $M=98.340\pm.061$ ). However, clinically this is not a significant drop in body temperature as the mean change was less than .50 degrees. See table 4.1 for body temperature means and standard deviations.

Table 4-1

Means and Standard Deviations for Pre- and Post-Test Body Temperature for synthetic, cotton and control groups (N=10)

Group	Pre-Test	Post-Test
Synthetic	98.60 $\pm$ .54	98.28 $\pm$ .30
Cotton	98.51 $\pm$ .46	98.44 $\pm$ .27
Control	98.80 $\pm$ .32	98.30 $\pm$ .41

#### 4.4 Results of Weight Loss Data

*H2: There will be no difference in weight loss among individuals wearing synthetic material, cotton shirt or no base layer while exercising in cold weather.*

This hypothesis was also supported as results of the repeated measures ANOVA indicated that there were no differences in weight loss between the groups [ $f_{(2,27)}=.005$ ,  $p=.995$ ] or the interaction between time and group [Wilks'=.975,  $f_{(2,27)}=.347$ ,  $p=.710$ ]. However, there was a significant difference for time [Wilks'=.540,  $f_{(1,27)}=22.99$ ,  $p=.000$ ]. Specifically, when you combined all three groups together the pre spin workout weight ( $M=154.01\pm22.38$ ) was higher than the post spin workout weight ( $M=153.57\pm22.44$ ). Although, it would appear that this would not be a significant clinical finding as weight loss only dropped .05 pounds after the 20 minute spin workout. See table 4.2 for means and standard deviations for body weight pre- and post-test.



Table 4-2

Means and Standard Deviations for Pre- and Post-Test Weight for synthetic, cotton and control groups (N=10)

Group	Pre-Test	Post-Test
Synthetic	154.41 $\pm$ 22.73	154.00 $\pm$ 22.97
Cotton	154.12 $\pm$ 23.09	153.76 $\pm$ 23.03
Control	153.50 $\pm$ 23.76	152.96 $\pm$ 23.77

#### 4.5 Summary of Results

Overall there were no significant differences from pre-test to post-test for both the body temperature and weight loss measures. However, it did indicate that there was an overall main effect for time for both body temperature and weight loss indicating that the spin workout did cause a change in body temperature and weight loss.

## **CHAPTER 5**

### **DISCUSSION**

#### **5.1 Introduction**

This chapter will provide an overview of the results for body temperature and weight loss found in the present study and discuss them in relation to the relevant literature focused on different clothing materials. This chapter will also discuss clinical implications as it relates to clothing material in cold weather, limitations, future research and conclusions.

#### **5.2 Summary of Research Findings for Body Temperature**

Based on the results of this study, no statistical significant differences were found in body temperature for the three base layer groups. These findings are similar to earlier studies, which examined body temperature with synthetic base layers underneath protective equipment (Noonan & Stachenfeld, 2012) and winter clothing (Smith et. al., 2013). Similar to this study, Noonan and Stachenfeld also had participants performed a spin workout. Both studies were in climates colder than 50 degrees Fahrenheit, and both were looking to determine the effect of different base layers on body temperature in that environment. However, in contrast to the current study, Noonan and Stachenfeld modeled their entire study around hockey players. On top of the base layers, their participants wore full hockey equipment. They also modeled their workout to simulate a hockey game, switching between 25 second sprint periods, and 50 second rest periods. Also, Noonan and Stachenfeld were examining skin temperature, rather than internal body temperature. Despite the similarities and differences, both studies found no statistical differences between the different base layer groups. Noonan and Stachenfeld did note that any difference that could have been noticed was nullified by the fact that the participants were also wearing full hockey equipment.

Like Noonan and Stachenfeld, In 2013, Smith et al conducted a study looking at different base layer under firefighter personal protective equipment. This study observed four different types of base layers under the protective equipment and studied physiological and perceptual responses to each. The physiological responses monitored were heart rate and core temperature. Much like Noonan and Stachenfelds study, no statistaical differences were noted in body temperature either during rest or activity. Smith's study did note that one perceptual difference was common in that participants preferred a wool-blend material to the cotton in terms of comfort. In our study, several participants anecdotally mentioned the synthetic material to be more comfortable than the cotton once they began to sweat.

In 1996, Gavhed and Holmer conducted a study similar to that of Noonan and Stachenfeld. Rather than using ful hockey equipment, Gavhed and Holmer used differing combinations of cold protective clothing. Heart rate, skin temperature, skin humidity and core temperature were all monitored before, during and after exercise. The study concluded that skin temperatures were higher in the clothing combinations with more insulation, but no other significant findings were noted. Similar to Noonan and Stachenfeld, one would believe that any possible findings from synthetic material would be lost due to the fact that there are other pieces of clothing assisting in the same objective as the synthetic materials.

The findings of the current study are in line with the study it is modeled after. In 2009, Houghton performed a study on “match-fit” field hockey players, examining the difference in body temperature between synthetic material shirts and cotton shirts. The athletes were put through interval tests in mild temperatures for 15 minutes. Houghton found no significant difference in body temperature between the two materials. The findings are also in line with Kicklighter's 2011 review of the current literature available on synthetic materials' effect on

athletes in hot and cold environments. He concluded that while marketable and appealing to athletes, there exists no evidence that synthetic materials have a significant effect on body temperature in hot or cold environments.

The present study's findings did demonstrate a main effect for time across all groups for body temperature. The results showed that body temperature will drop while exercising in cold weather, no matter the base layer worn. Despite the fact that the participants were wearing base layers, these results showed that more layers are needed to maintain a body temperature in climates around 40 degrees Fahrenheit. While earlier studies did not find any significant differences in body temperature, none noted a drop in temperature for all base layers reference. One can only conclude that this is due to the fact that all other studies also included some sort of protective equipment. This drop in body temperature warrants further research to determine if the drop in temperature seen in our study is due to the lack of protective equipment, the base layers themselves, or simply from the measuring methods.

### **5.3 Summary of Research Findings for Body Weight**

Similarly to body temperature, there were no statistically significant findings in weight loss in relation to the base layer worn. All three groups showed very similar weight loss from pre-test to post-test. In 2011, Nolte, Noakes and van Vuuren performed an experiment examining total-body water content in soldiers exercising in cool weather. They found that there were no significant changes in total body water or urine specific gravity despite an average body mass loss of 1.3 kg. Similarly, in our study, participants tended to lose some amount of weight, despite some participants verbally noting they "did not sweat at all".

In 2012, Goulet found that current literature was misleading when it came to water loss during exercise for endurance athletes. He went on to note that there was no reason this

literature could not also relate to recreational athletes. It was noted that endurance athletes losing up to 4% body weight during exercise did not decrease in time trial performance, and drinking to he demands of thirst maximized performance. From the current literature, Goulet devised three guidelines by which athletes should abide. First, athletes should hyper-hydrate prior to exercise. Second, athletes should only consume water according to thirst, no more, no less. Finally, fluid intake should be limited if exercise is only going to last one hour or less. Goulet's guidelines show that there is no perfect way to determine hydration levels by looking at weight lost. While One person could lose 2% body weight and be dehydrated, another could lose up to 4% and be perfectly fine. Essentially, it is up to the athletes to monitor their hydration levels and drink accordingly. The participants in our study all tended to lose weight during their trials, but none complained of thirst or feeling dehydrated.

Nolte, Noakes, and van Vuuren noted core temperature rose when intensity increased but this was not related to any body mass changes (2011). These findings suggest that changes in mass do not accurately predict the amount of body water lost. It further suggests that body mass lost during exercise includes losses other than water or, the body itself contains an endogenous water source that does not need to be replenished during exercise, or both. Unfortunately, with our temperature measuring methods, it was not possible to monitor body temperature during different aspects of the exercise interventions. This would be an excellent source of data to observe in future research.

#### **5.4 Clinical Implications**

The results of this study indicate that synthetic base layers designed for cold weather do not have a significant impact on body temperature when exercising in cold weather. While a cotton shirt seems to keep an individual just as “warm” as the synthetic material, there are still

several reason why one would choose to wear a synthetic shirt in lieu of a cotton shirt, including comfort, tight fit, and advertising. As far as athletic trainers are concerned, it is still important to recognize risk factors for cold injuries when recommending clothing options to athletes. While there were no statistical differences in body temperature between base layers that does not mean cotton t-shirts are a better choice for cold weather environments. Having exposed skin is still a risk factor for cold injuries; therefore, synthetic material shirts designed for cold weather could still be a better choice for that reason alone. If an athletic director were to inquire as to what materials to purchase, the budget would be the big determiner of that decision. If the budget allows for the materials, then it may be the best choice for its ability to cover skin, sit close to the skin, moisture wicking abilities, and athlete moral.

## **5.5 Limitations**

There were several limitations to this study. First, the sample size was quite small. Due to a lack of time, the sample size was decreased from originally planned of 20 participants, yielding 60 total trials, to 12 participants yielding 36 total trials. However, with participant mortality also being a limitation, we finished with ten full participants, yielding 30 usable data points.

Another limitation was the inability to use core temperature as a measurement. With multiple complications and equipment failures, we were forced to use a different and less effective means of recording body temperature. While oral thermometers are less effective at measuring body temperature, particularly in this care, the environment plays a big role. Because this was an aerobic workout, participants began to breath heavily through their mouths, constantly inhaling core air. This may have played a role in their body temperature readings, especially in the post-workout readings. While this study showed no significant results in body

temperature, there is a possibility that core temperature itself could have been affected differently than oral temperature.

Finally, only using college students is another limitation. College students are busy and it was quite difficult to schedule times for participants to complete their trials. Also, college students are not the only group of individuals who participate in athletic competition in cold weather. A larger group of NCAA athletes may be a better indication of how these materials affect their body temperature, as they are the ones for whom these materials are designed.

## **5.6 Future Research**

Due to the minimal number of studies done on synthetic materials in cold weather, future research is warranted. It would be important in the future to examine the impact of the materials themselves on the body, without assistance from protective equipment or other cold weather attire. Core temperature is the big key to determining the true effectiveness of these materials. All other forms of measuring body temperature have one flaw or another which make them far less valid than core temperature, taken rectally, or from the GI tract. Increasing the sample size would also be an improvement. Along with the size of the sample, it would be important to include more than college age individuals. Anyone from the ages of 12-40 or older should be included. Companies who produce these products produce them for all ages, not just 18-25 year olds.

Another future study should examine intramuscular temperature. This technique is very invasive, but could show true effectiveness of these materials. In theory, core temperature should always stay around a homeostatic temperature in cold weather because blood will be pulled from the extremities to maintain it. However, if these materials were efficient enough at

maintaining core temperature, the extremities would not have to spare their blood to protect the core, and could continue to operate at their maximum potential.

Finally, for future research, it would be important to continue to monitor the trends of synthetic materials. Even from the time this research began, there has already been a small shift from purely synthetic material clothing to a combination of synthetic and natural fibers, such as wool. If these materials begin to become more popular, perhaps they could perform better at maintaining core temperature in cold environments.

## **5.7 Conclusion**

Based on the statistical significance for body temperature and weight loss, this study indicates that synthetic material clothing, cotton base layers and no base layers, all performed equally when it comes to maintaining body temperature. The results did indicate that no matter the base layer, all groups lost body temperature to about the same degree over time. This shows that while exercising in cold environments, no matter the base layer worn, body temperature will eventually drop.



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