AN ABSTRACT OF THE THESIS OF

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Title: The Effect of Textiles on Perceived Physiological Comfort While Backpacking in the Cold

Abstract approved:

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Clothing is the primary means that wilderness backpackers have to protect themselves from injuries and illnesses that can occur while hiking in the cold. The current method of layering clothing may not meet backpackers' needs for both thermal insulation and heat dissipation, particularly in areas of the body that produce greater sweat, and during times of high physical exertion. No previous studies have addressed backpackers' needs for thermal and moisture comfort in different body areas within a single layer garment. The purpose of this study was to design and evaluate a single-layer garment of different textiles, to improve the physiological comfort of male backpackers hiking in cold winter weather conditions. The objectives of this study were to identify the physiological comfort needs of male backpackers hiking in the cold, to design a prototype

backpacking shirt to improve comfort, and to evaluate the comfort and performance of the prototype over time, in comparison to a control.

Male backpackers were recruited from a wilderness therapy company in Bend, Oregon, where subjects' employment duties included regularly backpacking in the cold. Qualitative data was collected by interviewing the subjects about their physiological comfort needs, types of garments and materials worn, dissatisfactions and preferences with hiking clothing, and locations on the body that need better attention to thermal and moisture comfort. Information provided by the qualitative interviews was used to develop design criteria. From the guarded hot plate and moisture management testing, results were used to select one thermal insulation, moisture management, and control fabric for the garment design. Based on the design criteria, a prototype shirt was developed. A prototype garment was constructed using the combination of the thermal, moisture, and control fabrics; while a control garment was constructed in an identical style using only the control fabric. The prototype and control garments were worn and tested by subjects while they backpacked. Additionally, comparisons of thermal insulation data between the prototype and control garment were collected on a thermal manikin.

Major findings from the qualitative interviews were that subjects preferred base layer shirts made with synthetic fibers and style features that helped retain body heat. Subjects preferred to have greater thermal insulation in the chest and the arms, and less thermal insulation in the underarms and upper back area. Additionally, subjects were concerned about durability. A polyester fleece pile-knit was selected for the thermal insulation fabric and located in the arms and chest of the prototype. The moisture management fabric selected was a polyester fiber mesh knit fabric and was located in the upper back, underarms, and side seams of the garment. The control fabric was a brushed polyester double knit fabric and was located in all other body areas of the prototype and in the entire control garment.

The wear test data indicated that both the control and prototype garments were perceived to be comfortable. The prototype had slightly better overall comfort than the control, and there were significant differences found between the prototype and the control in the areas of overall comfort, combined thermal comfort, and combined moisture comfort. The prototype did not consistently have better comfort performance than the control in each trial and for each subject. It was found that the prototype and control shirts could be worn without additional layers when the temperatures were above 35 °F and 40 °F, respectively. Thermal manikin testing results confirmed that the overall thermal insulation of both test shirts was equal, but that the prototype had greater or less thermal insulation than the control in specific body areas, depending on the placement of the thermal insulation or moisture management fabric.

In summary, the prototype shirt designed in this study has accomplished the goal of providing backpackers' physiological comfort needs identified in the qualitative interviews. The design prototype, when worn alone, is able to keep backpackers comfortable when hiking in cold conditions, particularly in temperatures above 35˚F. Although not intended to be worn as part of a layer system, the prototype also keeps backpackers comfortable when they are wearing multiple clothing layers. The use of different fabrics in different body areas satisfies the backpackers' needs of both retaining and dissipating body heat with changes in physical activity. Although both the prototype and the control shirts were found to have good thermal, moisture, and overall comfort, the prototype had slightly higher overall comfort ratings than the control. In addition, both the prototype and the control were perceived to be better than the subjects' own base layer shirts, and all subjects were willing to recommend the shirts to other hikers.

The Effect of Textiles on Perceived Physiological Comfort While Backpacking in the Cold

by

Lynn M. Rau

A THESIS

Submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 4, 2012

Commencement June 2013

Master of Science thesis of Lynn M. Rau

presented on June 4, 2012

APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Lynn M. Rau, Author

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my advisor and committee members who have been vital in the completion of this project. My advisor, Dr. Hsiou-Lien Chen, has provided me with ideas, wisdom, and feedback, and has encouraged me to strive for goals I never thought possible. Without her, my thesis would not have been possible. My other committee members, Dr. Brigitte Cluver, Dr. Kathy Mullet, and Dr. Larry Roper have also been instrumental in this process. I am in great debt to both Dr. Cluver and Dr. Mullet, who have shared additional time and knowledge with me in their areas of expertise. My Graduate Committee Representative, Dr. Roper, has lent his feedback and support, for which I am truly grateful.

Additionally, I would like to thank the Department of Design and Human Environment, for providing me with such a wonderful opportunity to learn.

Lastly, my heartfelt thanks goes to my parents and my significant other, Jonathan. Without the continual encouragement, listening, and support of these individuals, I would not have pursued or survived graduate school education.

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THE EFFECT OF TEXTILES ON PERCEIVED PHYSIOLOGICAL COMFORT WHILE BACKPACKING IN THE COLD

THE EFFECT OF TEXTILES ON PERCEIVED PHYSIOLOGICAL COMFORT WHILE BACKPACKING IN THE COLD

CHAPTER I

INTRODUCTION

Wilderness hiking and backpacking are enjoyed by many people as a fitness activity, an escape from daily routine, or as an educational experience. The popularity of wilderness backpacking, in particular, is growing dramatically. More than four times as many backpackers completed long thru-hikes, such as the Appalachian Trail, in 2010 than in 1980 (Appalachian Trail Conservancy, 2011). Due to the fact that this activity often occurs in a location far from modern conveniences and emergency aid, wilderness backpackers must carry gear to provide their own shelter, food, and first aid in unpredictable weather and trail conditions. Consequently, injuries and illness while wilderness backpacking occur frequently and are of great concern. A study of backpackers on The Long Trail in Vermont found that nearly 70% of participants sustained some type of illness or injury during trip. These complaints ranged from musculoskeletal, to blisters, to hypothermia (Gardner & Hill, 2002). Among the illnesses or injuries confronting wilderness hikers, the body's ability to respond to heat or cold exposure is particularly concerning, as humans must maintain body temperatures within a narrow range for the body to function correctly. According to Makinen (2007), cold exposure can cause discomfort and distraction, which can lead to an increased risk of accidents. An unprepared individual spending prolonged time in the cold due to accidents or otherwise, can face more severe problems like unconsciousness, hypothermia, and eventual heart failure (Parsons, 2003).

Clothing is a primary means for backpackers to protect themselves from temperature and weather extremes. Clothing designed for outdoor sports can protect the individual from rain, provide thermal insulation, wick moisture from the body, block ultraviolet (UV) radiation, or repel insects. Currently, clothes designed specifically for backpacking are typically single-layer garments intended to be combined in a 3-layer system, consisting of a base layer, thermal insulation, and a windproof/waterproof shell (Bramel, 2005). This system is effective in that it allows the backpacker to continually adjust the level of protection in response to changes in temperature, precipitation, or activity. However, in certain backpacking conditions, such as during vigorous or uphill hiking, combinations of layers may not be effective in meeting the comfort needs of the backpacker. Combining layers can reduce the breathability and moisture-wicking capabilities of the garments while the wearer is moving, leaving sweat moisture on the base layer, and causing discomfort and a chilling effect when the hiker stops (Yoo & Kim, 2008) and/or removes the outer layers. Additionally, different parts of the body have different clothing needs, depending on the movement of the body and where heat or sweat is generated. This is particularly true in backpackers, where the backpack can cause greater sweat accumulation and temperature on the hiker's back when hiking in the cold (Byers, McCormick, & DeVoe, 2006). A garment worn as a single-layer, with varying thermal, moisture-wicking, and breathability properties, depending on the body area, would be ideal to meet the complex thermal and moisture requirements for physical activity in the cold.

In addition to the layering design or construction, materials play a significant role in the overall comfort of the garments. Textile parameters such as fiber content, fabric structure, and fabric treatment can be modified to give different function and comfort properties. Especially, textile materials used for garments for backpacking must be durable in several aspects of functional performance such as resistance to abrasion, sunlight, and perspiration, as well as frequent laundering.

Problem Statement

Upper body garments for backpackers currently available on the market are designed to be worn as part of a 3-layer system, which do not address the backpacker's comfort needs for various parts of the body during vigorous movement in cold conditions. This is due to the fact that during rigorous activity, combing layers of garments presents the problem of breathability and moisture trapping inside the clothing system when layers are used together, and even when the shell layer and/or the insulation layer are removed, the base layer alone does not provide sufficient insulation for certain parts of the body. Related studies have been focused on fiber content, thermal properties, moisture management, and garment openings in general outdoor wear. However, no previous studies on the design of a single garment layer specifically for backpacking to meet the various comfort needs of the body have been found. Therefore, there was a need to study how a single-layer garment might better accommodate a backpacker's varying comfort needs in cold weather. The overall purpose of this study was to design and evaluate a single layer garment, consisting of different types of textiles, to improve the physiological comfort of wilderness backpackers in cold conditions. The study was conducted through the following specific objectives:

Objective 1: To identify the physiological comfort needs of male wilderness backpackers in cold weather conditions.

Objective 2: To design one prototype single-layer backpacking shirt for improved physiological comfort of male wilderness backpackers.

Objective 3: To determine the effectiveness of the design solution by conducting wear tests of the prototype shirt to assess physiological comfort and garment performance over time, in comparison to a control.

Significance

Clothing is the primary means of protection that humans have against the environment. For backpackers, this means of protection is particularly important due to their remoteness from shelter or emergency services. Cold-related illness and injury can lead to discomfort, distraction and accidents, or even hypothermia and death (Parsons, 2003). Accumulation of sweat in clothing during body movement can contribute to this risk, especially when the backpacker stops moving (Yoo & Kim, 2008). It was expected that the design of a single-layer upper body garment with varying textiles would better meet the comfort needs of backpackers hiking in cold weather than a garment worn as part of the 3-layer system. It was predicted that the benefits would be in the areas of sweat accumulation, thermal protection of the limbs, and overall physiological comfort. The design of a single-layer garment was intended to improve the well-being and safety of backpackers, reducing risk of cold-related injury or hypothermia.

Assumptions of the Study

1. That male backpackers want a single-layer garment that can meet their physiological comfort needs while hiking in the cold.
2. That participants used in the qualitative interviews had a basic knowledge of outdoor clothing.
3. That participants used in the garment evaluation were physically fit and able to complete the required physical activity.
4. That participants were able to perceive, remember, and record changes in comfort.
5. That participants followed wear test instructions and answered the questionnaire honestly.
6. That backpackers have multiple comfort needs that specific textiles are able to meet.

Limitations

1. The physiological comfort needs cannot be generalized beyond the participants in the study.
2. Results of the wear tests are only directly applicable to the design prototype tested and the participants and conditions under which they complete the tests.
3. That the designs will not be able to meet all possible comfort needs of the wilderness backpacker in all types of environmental conditions, due to the inability of textiles to meet certain competing needs due to their physical and chemical structures.
4. That the textiles used in the designs will be limited to those currently available on the market.

Definitions

Backpacker: (Wilderness Backpacker) A person who hikes with the intention of spending at least one night in the wilderness, and who consequently must carry items of food, clothing, and shelter.

Base layer: A garment layer worn closest to the skin to wick moisture from the body to the outer clothing layers and to provide thermal protection (Holmér, 2005).

Breathability: The ability of the fabric to allow moisture vapor to pass from the skin to the fabric surface.

Cold Conditions: For this study, defined as temperatures of -1°C (30°F) to 7°C (45°F).

Comfort: "A state of physiological, social-psychological, and physical balance among a person, his/her clothing, and his/her environment" (Branson & Sweeney, 1991, p. 99).

Evaporative Resistance: The ability of clothing to resist the transfer of heat, caused by moisture evaporation and moisture vapor transfer through the clothing layers (Holmér, 2005).

Exercise: Body movement or muscle activity that disrupts the homeostasis of the body (Winter & Fowler, 2009). To be defined as exercise, the activity must be "planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective," (Caspersen, Powell, & Christenson, 1985, p. 128).

Hypothermia: Body core temperature at 35°C or below (Parsons, 2003).

Moisture Management: The moisture-wicking and breathability properties of a textile that allow liquid and moisture vapor to be transferred away from the skin.

Moisture-Wicking: The transfer of moisture from the skin to the outer surface of the fabric that occurs on the surface of the fibers (Kadolph, 2010).

Physical Activity: Body movement or muscle activity that disrupts the homeostasis of the body (Winter & Fowler, 2009). Unlike exercise, participants engage in physical activity without the intention of improving physical fitness.

Physiological/Perceptual Comfort: The state of balance between the body, clothing, and environment that can be both physically measured by skin temperature, sweat rate, heart rate, etc. and subjectively indicated based on the subject's interpretation of their own body responses to the clothing and environment (Branson & Sweeney, 1991).

Three-layer System: Clothing layers consisting of a base-layer garment, and second-layer insulation garment, and an outer layer garment to protect from wind and precipitation (Bramel, 2005).

Thru-hike: An end-to-end hike that can take several weeks up to several months to complete.

Upper-Body Garment: A garment worn to cover the torso, shoulders, and arms, such as a shirt, sweater, or jacket. It may also cover all or part of the neck.

CHAPTER II

REVIEW OF LITERATURE

It is estimated that in 2009, approximately 34% of the U.S. population participated in hiking, and that approximately 12.3% of the U.S. population participated in wilderness backpacking (National Sporting Goods Association, 2011). The popularity of outdoor sports has risen steadily since mid-20th century, with over 4 times as many people participating in backpacking trips currently, such as the 3,380 km Appalachian Trail, than in 1936 (Appalachian Trail Conservancy, 2011). This increase in number of backpacking participants has resulted in a growing market for outdoor clothing, and increasing knowledge and interest in designs to meet the comfort and protection needs of backpackers. This review of literature will examine backpacker injuries; the body's physiological responses cold and physical activity; the role of clothing, textiles, garment construction, and garment layers in thermoregulation; perceived clothing comfort; clothing design criteria; and the current outdoor clothing market.

Backpacker Injuries

A backpacking trip can be 1-2 days or up to several months in length and may cover up to several thousand miles. In wilderness backpacking, the participant typically hikes in a remote area and has limited access to shelter, retail stores, technology, or emergency services. The backpacker must carry gear, such as a tent, sleeping bag, clothing, food, and cooking equipment, to meet his or her basic needs while hiking. Backpackers can be at risk for many types of injury on the trail, including blisters, insect bites, musculoskeletal injuries, gastrointestinal illness, and heat/cold related illness (Gardner & Hill, 2002).

In a study of hikers completing the 270-mile Long Trail in Vermont, 70% of participants sustained some type of injury or illness during their trip (Gardner & Hill, 2002). Hikers who completed the trail responded to a questionnaire about injury occurrence and severity, prior physical conditioning, prior backpacking experience, and type of trip (thru hike or section hike). Differences in injury frequency and severity were noted between two sub-groups: thru hikers (those who complete the entire trail in one trip) and section hikers (those who complete the trail in several trips by hiking one section at a time). Overall, musculoskeletal pain was the most common injury, affecting 46.6% of thru hikers and 37.5% of section hikers. Thru hikers had a higher frequency of gastrointestinal illness than section hikers (10.7% versus 3.8%), whereas section hikers had a higher frequency of hypothermia than thru hikers (7.5% versus 0%). The authors suggested that greater frequency of hypothermia in section hikers may have been attributed to less preparedness for weather conditions. As the thru hikers were planning to spend anywhere from 14 to 42 consecutive days on the trail, they would have been more likely to prepare for a variety of weather conditions to ensure comfort and safety. The section hikers, on the other hand, were planning for fewer days of hiking and may not have been as willing to carry additional gear. The authors suggest that backpackers could have greater comfort and less injury by anticipating conditions and carrying sufficient supplies, such as clothing for changing weather conditions.

Similarly, Crouse and Josephs (1993) researched the healthcare needs of Appalachian Trail hikers. One hundred eighty hikers who completed the 3,380 km Appalachian Trail in 1987 and 1988 responded to a questionnaire about injury occurrence. Like Gardner and Hill, the researchers concluded that musculoskeletal pain was the most common injury, affecting 62% of the respondents. Other injuries included fractures, lacerations and abrasions, gastrointestinal illness, skin complaints, blisters, and infections.

On the other hand, Pugh (1964; 1966) has studied more severe consequences of hiking injury in his research on cold-related deaths and accidents among hikers. In a case study of 23 incidents of hikers' cold exposure in the United Kingdom, 25 cold-related deaths occurred, and 18 cold-related injuries occurred that required medical treatment (Pugh, 1966). Victims' ages, victims' hiking experience, and the time of year the hikes took place varied, but in each case, cold and wet weather played a factor. The researcher found that most accidents could be explained by: unexpected weather changes, lack of visibility, unexpected overnight stays, wet or insufficient clothing, exhaustion, or inexperience. In many incidents of injury or death, the participants became fatigued while hiking, and suffered falls down slopes, became lost, or failed to find shelter in bad weather. It's suggested that fatigue may have caused poor judgment and mental impairment leading to such accidents. Falls, becoming lost, and severe fatigue often resulted in the victims being stranded overnight, for which they did not have sufficient gear, supplies, and clothing, leading to hypothermia and death in some incidents. Some victims appeared to have walked to the point of collapse without having found shelter. In most of the fatal incidents, victims were found with wet-through clothing, which could have led to hypothermia.

In Pugh's (1964) related study of cold-exposure in a hiking race, three deaths occurred due to hypothermia. In the 72.4 km (45 mile) hiking competition, 22 out of the initial 240 participants were able to complete the hiking race in anywhere from 9 ½ to 22 hrs. Temperatures during the competition ranged from 4°C to 7°C (39°F to 45°F) with early rain leading to strong wind, sleet, and snow later in the day. Of the three deaths that occurred, two deaths were related to the fact that the victims became lost while seeking shelter in bad weather. The victims' ages ranged from 19-21 and all were experienced hikers in good physical condition. All three victims suffered from hypothermia due to cold exposure, resulting in eventual heart failure. The hikers were purportedly dressed in light clothing, despite the wet and cold weather conditions and the victims' experience with outdoor hiking. It's suggested that the victims were unprepared for the weather because of the need to travel lightly and quickly in a race, with little extra gear weight.

The Body's Physiological Responses to Cold and Physical Activity

In the least amount of harm, cold exposure can cause discomfort, distraction, and reduced physical and mental performance (Makinen, 2007). Each of these, consequentially, can increase the risk of accidents and injury in hikers. Prolonged exposure to the cold can cause more severe dangers, like hypothermia, loss of consciousness, and death.

Occurrence of Heat Loss The body loses heat by *conduction, convection, radiation, sweat evaporation,* and *respiration* (Havenith, 2003; Pascoe et al., 1994). By definition, *conduction* is the transfer of heat from a warm object to a cold object that occurs when the objects are in direct contact (Kholiya & Goel, 2007). Heat always transfers from the warmer object to the colder object, and with greater difference between object temperatures, faster heat transfer occurs (Watkins, 1995). Body heat is conducted directly from the warm muscles and body tissues through the skin to the cool air surrounding the body (Young, 1990). Conduction, in turn, facilitates the loss of heat by convection. *Convection* is defined as heat loss through a moving medium, such as blood or air. When blood circulating in the body moves through exterior areas exposed to the cold, like the skin and extremities, the heat is transferred from the warm blood to the cooler tissues by conduction, and the blood looses heat. The cooled blood then circulates to the head and trunk of the body, cooling the body core. Convection can also occur with the movement of air around the body. As cool air surrounding the body is heated by conduction, warm air rises away from the body to be replaced by cooler air. This flow can be increased by body movement or wind, allowing greater heat to be lost from the body. Another way the body may lose heat is by *radiation*, which occurs when electromagnetic waves produced by the body's heat warm the environment independently of the presence of air or other environmental effects. Objects produce electromagnetic waves according to temperature. Higher temperatures, like that of the sun, result in visible waves, and lower temperatures, like those produced by the human body, result in invisible waves. Radiation occurs when there is a difference between the temperature of the surface of the body and the temperature of another surface. As noted by Hardy and DuBois (1938), at temperatures below 22°C, radiation can cause up to 70% of heat loss. In the cold, clothing shields the body surface, providing a barrier between the body and the environment, and preventing heat loss by radiation (Fourt & Hollies, 1970). *Moisture evaporation* can cause the additional 30% of heat loss. The body continuously loses moisture as both insensible and sensible perspiration. Insensible perspiration is moisture that always being lost as the body "dries out," and can be up to .7L to .95L (1.5 to 2 pints) per day for a human at rest (Watkins, 1995). When the body becomes overheated, high blood temperature causes the hypothalamus to activate the sweat glands, producing sensible perspiration in the form of liquid sweat on the skin. Liquid sweat transforms into water vapor by the application of heat. In this case, the body heat fuels the change of the liquid to gas, dissipating heat from the body and cooling the skin (Havenith, 2003). When liquid sweat wets the clothing, the evaporation can approximately double the rate of body cooling (Fourt & Hollies, 1970). The final cause of the body to lose heat is by *respiration* when cool air is inhaled. The body transfers heat to the cool air entering the body, then it loses heat as the warm air is exhaled.

Body Prevention of Heat Loss To limit heat loss, three main physiological responses occur in the body: *peripheral vasoconstriction, metabolic heat production,* and *shivering thermogenesis* (Parsons, 2003; Castellani et al., 2010; Young, 1990). When skin temperature is less than 35˚C, *vasoconstriction* causes the veins located in the skin and the body extremities to constrict. This limits the blood flow to the areas that are first exposed to the cold, preventing the blood stream from cooling when passing through these areas, and preventing cold blood from re-circulating to the body core (Young & Castellani, 2007). Vasoconstriction causes lower temperatures in the extremities, since these areas are dependent on blood flow to stay warm (Doubt, 1991).

While vasoconstriction conserves existing body heat by preventing the blood from losing heat, both *metabolic heat production* and *shivering thermogenesis* are functions that the body uses to generate heat (Sawka & Young, 2006). Metabolic heat production involves tensing of the muscles and voluntary increase in body movement to create heat. Shivering thermogenesis consists of muscular vibrations and occurs after greater exposure to the cold than metabolic heat production alone. Both methods create heat to replace that which is lost to the environment. Shivering can increase the metabolic heat production rate of the body by 5-6 times the heat production rate when the body is at rest (Stocks et al., 2004).

When these body responses are not sufficient to preserve and generate heat in the cold, the body core temperature may drop. Normal human body core temperature is 37°C. A core temperature lower than 36°C is considered severe, and hypothermia occurs at core temperatures of 35°C or below (Parsons, 2003). With the onset of hypothermia, the muscles stiffen, blood viscosity increases, movements get clumsy, and there can be changes of consciousness, confusion, and sensory problems. At a core temperature of 30-31°C the person loses consciousness and there is a higher risk of death from heart failure. At 15°C the heart stops pumping blood.

Physical Activity in the Cold Physical activity in the cold can contribute to the risk for cold-related injury. While physical activity increases the body's metabolic heat production, it also increases the rate of heat loss. With muscle movement, the metabolic rate increases, and the body produces heat energy at a higher rate, which is lost to the environment at a higher rate (Holmér, 2005; Young, 1990). Blood flow increases to the working muscles in the body extremities, increasing heat loss by conduction and by convection. As blood flow increases to the working muscles and extremities, the difference between the body temperature and the outside air temperature becomes greater, so more heat flows from the warm body to cool environment. Concurrently, with the increased blood flow, a greater amount of blood is exposed to the colder body extremities than would be allowed by vasoconstriction. As a result, the blood loses heat, which then re-circulates back to the head and trunk of the body and cools the core (Parsons, 2003; Doubt, 1991; Young & Castellani, 2007). Additionally, physical activity increases natural convection that occurs around the outside of clothing and through spaces between skin and clothing layers (Fourt & Hollies, 1970). Air convection is constantly occurring. Around the outside of the clothed body exists an air layer that is disrupted when the body moves as body parts displace the air. The wearer perceives this air movement as a breeze. Within the clothing, air movement increases with body movement. Air trapped between the clothing and the body is warmed by heat from the wearer's skin, creating an insulation layer. During physical activity, the warm air rises out of the clothing ensemble in a chimney effect. As body movement increases the circulation of air around the skin surface, more warm air is drawn up and away from the body than would occur when the person is sedentary. Each of these effects of physical activity can result in a net loss of heat over the period of activity and can cause the athlete's core temperature to fall when the activity stops (Doubt, 1991).

According to Weller et al. (1997), the amount of additional heat lost due to physical activity depends on the intensity of the movement. With low intensity walking, researchers concluded that there was greater heat loss than with high intensity walking. A possible explanation is that when participating in high intensity physical activity, subjects were able to generate enough heat to offset that lost due to the cold and physical activity effects (Weller et al., 1997).

Additionally, sustained exercise in the cold can inhibit the body's thermoregulatory system (Young & Castellani, 2007). After strenuous exercise, particularly over several days of exertion, researchers have found that the vasoconstriction and heat production reactions to cold can be impaired (Castellani et al., 1999). With vasoconstriction impaired, blood flow is not as restricted to the skin and extremities, causing greater loss of heat. When shivering becomes impaired, the body is less able to generate heat. Both of these factors cause a greater risk of hypothermia (Young & Castellani, 2007; Castellani et al., 2010).

Physical Activity and Sweating During physical activity, liquid sweat is produced by the body as a means of lowering the body's core temperature. The movement of muscles generates heat, warming the blood, which then circulates to the brain. The hypothalamus detects changes in the blood temperature as it enters the brain, and acts as a thermostat to maintain a constant internal body temperature of about 37˚C

(McHardel, 2001). When a rise in blood temperature is detected, the hypothalamus triggers vasodilation and sweat production to dissipate heat.

The body's surface is covered with approximately 2-4 million sweat glands, which produce sweat at different rates, depending on the location on the body. Some research has been conducted to determine which body areas produce more or less sweat, however, little has been concluded about the number of active sweat glands or the sweat rate per sweat gland (Machado-Moreira et al., 2008).

In their study of regional sweat rates, Smith and Havenith (2011) mapped the sweating locations on the bodies of 9 male runners. The subjects ran on a treadmill for 90 minutes, while wearing absorbent pads either on their head or body. The researchers concluded that the back torso had the highest sweat rates on the body aside from the forehead. Low rates of sweat production were found on the sides of the chest, on the body extremities, and on the inner thighs of the participants. The skin temperatures in different body areas were not found to be related to the sweat rates. The researchers suggest that differences in sweat rates in body areas may be attributed to differences in the sweat gland production.

Machado-Moreira et al. (2008) cited similar results when mapping the sweat rates on subjects' torsos. Ten male athletes were first warmed with a water-perfusion suit while resting. The subjects then removed the warming suit and cycled on an ergometer. Ventilated capsules were attached to the torsos of the subjects in different areas to record the sweat rates. The subjects did not wear shirts while cycling. The greatest sweat production occurred on the backs of the subjects, particularly on the lower back. The least sweat production occurred on the sides of the chest.

Nielsen and Endrusick (1992) also concluded that higher sweat levels occur on the back than on other body areas while cycling. In their study of a layered ensemble worn during alternating periods of cycling and rest, subjects had the greatest water vapor pressure increase and the highest amount of sweat accumulation on their backs. Likewise, the skin temperatures were higher on the upper back than on the arms or lower back. The researchers suggested that while the subjects had a higher accumulation of sweat on their backs, the skin temperatures were also higher in this area because the evaporative cooling produced by the sweat was not sufficient to prevent the temperature from rising.

The Role of Clothing in Thermoregulation

The primary means for humans to regulate body temperature is through behavior: clothing can be removed or added, a person can seek shade in the heat of the day, or stay sheltered in the cold (Parsons, 2003). Clothing helps provide thermal balance and protection from the environment that the physiological responses of the human body cannot sustain alone. Clothing can be used for thermal insulation, to keep out precipitation, and to block wind in cold conditions.

Clo Value and Thermal Insulation Clothing provides thermal insulation by trapping air between the fabric and the human body or between layers of fabric in a space termed the thermal microclimate (Kinnicutt et al., 2010). The greater the ability of the clothing to trap air, the better the insulation, and the higher the thermal protection against the cold. The thermal insulation of a clothing ensemble can be measured by Clo value. Clo value indicates the amount of thermal insulation needed to keep a person at rest in thermal balance at various temperatures. A measurement of 1 Clo, for example, is the thermal value of typical business suit, and will keep a sedentary person comfortable at 21°C (Parsons, 2003). Table 1 provides additional examples of Clo values for individual clothing items. Should the temperature decline, clothing with a higher Clo value and greater thermal insulation will be needed to keep the sedentary person in thermal balance. The thermal insulation and measurement of Clo value is affected by wind speed, body movement, natural convection "chimney" effect of clothing, water vapor transfer, and moisture wicking factor (Gavin, 2003):

1. Wind speed: Wind causes forced convection by pushing cool air around the body and disrupting the insulative air layer between the body and the environment. As cool air enters the clothing, the thermal insulation value is reduced, and the body loses warmth by transfer to the cold air.
2. Body Movement: Forced convection occurs with body movement. During exercise, moving arms and legs increase air and moisture flow around the body, disrupting the trapped air layer. The thermal insulation value of the clothing lessens as heat transfers from the body to the cool, circulating air.

Table 1: Clo Values of Individual Clothing Items (Olesen and Dukes-Dubos, 1998)

Garment Description	Thermal Insulation, clo (I_{clu})	Garment Description	Thermal Insulation, clo (I_{clu})
Underwear		Thin sweater	0.20
Panties	0.03	Sweater	0.28
Underpants with long legs	0.10	Thick sweater	0.35
Singlet	0.04	Jackets	
T-Shirt	0.09	Light summer jacket	0.25
Shirt with long sleeves	0.12	Jacket	0.35
Panties + Bra	0.03	Smock	0.30
Shirts—Blouses		High Insulative, Fiber-pelt	
Short sleeves	0.15	Boiler suit	0.90
Light weight, long sleeves	0.20	Trousers	0.35
Normal, long sleeves	0.25	Jacket	0.40
Flannel shirt, long sleeves	0.30	Vest	0.20
Lightweight blouse, long sleeves	0.15	Outdoor clothing	
Trousers		Coat	0.60
Shorts	0.06	Down jacket	0.55
Light weight	0.20	Parca	0.70
Normal	0.25	Fiber-pelt overalls	0.55
Flannel	0.28	Sundries	
Dresses—Skirts		Socks	0.02
Light skirt (summer)	0.15	Thick ankle socks	0.05
Heavy skirt (winter)	0.25	Thick long socks	0.10
Light dress, short sleeves	0.20	Nylon stockings	0.03
Winter dress, long sleeves	0.40	Shoes (thin soled)	0.02
Boiler suit	0.55	Shoes (thick soled)	0.04
Sweaters		Boots	0.10
Sleeveless vest	0.12	Gloves	0.05

3. Chimney Effect of Clothing: Passive convection ventilates warm air upward through loosely-fitting clothing. This effect is increased by body movements when the wearer is exercising, acting as “bellows” to force the warm air up and out through clothing openings. By this means, the clothing system will lose warm air and moisture from the insulated air layer through openings in the upper of the garment, and cool air will fill the clothing system to replace it.

4. Water Vapor Transfer: When a wearer is engaging in physical activity, moisture vapor created by body heat and perspiration passes from the skin to the garment. The moisture may then wick to the outside of the clothing where evaporation takes place, which helps to cool the body. When water vapor

concentration inside the clothing system is greater than the saturation concentration level, moisture will condense inside the clothing, making the wearer uncomfortable (Wang et al., 2007). Since the moisture is unable to evaporate, heat will not dissipate, and the wearer may feel hot.

5. Moisture Wicking: Liquid sweat is transferred away from the body along the surface of the fibers through pores or capillaries in the fabric or fibers to the outside of the clothing. The liquid then evaporates from the fabric, rather than from the skin, so there is less cooling effect felt than when sweat evaporates directly from the body. Clothing with good moisture wicking ability (evaporative clothing) is more able to retain body heat because sweat evaporates from the clothing, rather than from the body (Gavin, 2003).

How the clothing responds to each of the above factors is, in turn, dependent on individual clothing factors, such as textile fiber and fabric structure, garment construction and fit, and layering.

Role of Textiles in Thermoregulation

Thermal Insulation of Textiles Air that is trapped within a clothing system provides thermal insulation for the wearer. Because air has lower heat conductivity than solid materials, trapped air will not as readily transfer cold from the outside to the skin as a textile alone (Lee, Hong, & Hong, 2007). However, too much air within the clothing system will cause air convection, reducing the degree to which the clothing system can provide insulation, and cooling the wearer. Textile fibers or fabric structures that allow air between the fabric and the skin feel warmer to the wearer. When wearing a very smooth fabric that sticks to the skin, for example, the wearer is more likely to perceive the fabric as cold, due to the fact that there are no air gaps between the skin and the textile, so the fabric readily transfers the cold to the skin (Fourt & Hollies, 1970). The surface of textile fabrics can be specifically engineered to form small spaces that trap air within the clothing, thereby increasing thermal insulation (Watkins, 1995).

Knit fabrics are constructed of interlooping yarns, which form air gaps in the fabric and provide thermal insulation. Study has shown that fabrics with knit-in raised geometric shapes (knit 3-D mapping) provide better regulation of temperature in a cold environment than fabrics without 3-D mapping (Kinnicutt et al., 2010). This is due to the fact that raised shapes in the fabric structure change the thermal microclimate of the clothing by creating small air gaps between the wearer's skin and the spaces between the raised shapes.

Wetting and Moisture Wicking in Textiles When fabric comes into contact with liquid sweat, wetting and/or wicking may take place. The wettability of the fabric depends on the contact angle of the liquid with the fabric. A rounded drop of liquid water forms a contact angle with the fabric surface, which is measured as the angle between the tangent of the liquid drop/air boundary and the liquid drop/fabric boundary (Figure 1) (Kissa, 1996). Fabrics with a high contact angle with liquid are less able to be wetted, while fabrics with a contact angle close to zero can easily be wetted. The contact angle is dependent on the molecular structure of the textile fiber, the fiber surface, the fiber geometry, and the fabric roughness. When the fabric comes into contact with a liquid, wetting must occur before moisture wicking can take place (Kissa, 1996). Moisture wicking refers to the flow of a liquid along the surface of a fiber (Kadolph, 2010). Moisture wicking will occur if there are capillary pathways on the fiber surface or between fibers in a fabric structure. The ability of fabric to wick moisture depends primarily on the size and number of capillaries in the fiber, fabric, or yarn, and the liquid surface tension (Fangueiro et al., 2010). Synthetic fibers, such as olefin, nylon, and polyester, can be manufactured with modified cross-sectional shapes to have capillaries on the fiber surface, rather than round cross-sections (Figure 2).

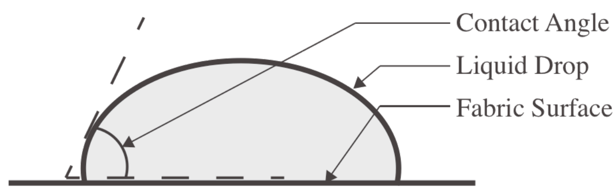


Figure 1: Contact Angle, As Defined by Kissa (1996)

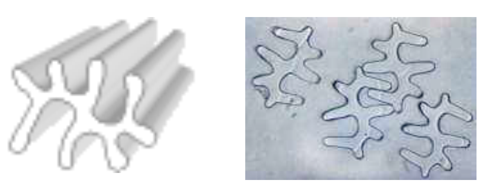


Figure 2: Examples of Fibers with Modified Cross-Sectional Shapes
(Fiber Innovation Technology, Inc., 2011).

The capillaries on the fiber surface and the spaces between the irregularly shaped fibers produce forces that pull liquid into the capillaries. The liquid then travels along the fiber surface to the outside of the fabric for evaporation. Non-absorbent fibers generally have better wicking capability than absorbent fibers (Kadolph, 2010). This is due to the fact that when absorbent fibers become saturated with water, they swell, closing capillaries and spaces where wicking would occur (Fangueiro et al., 2010).

Moisture Vapor Transfer in Textiles Moisture vapor transfer differs from moisture wicking in that it relates to the fabric's ability to transfer a gas, rather than a liquid substance. Moisture vapor is created from perspiration and body heat during physical activity, and it passes through the clothing to evaporate and cool the wearer. Researchers have found that the moisture vapor transfer of clothing is dependent on the air permeability and the cover factor of the fabric (Zhang et al., 2002). Fabrics with higher cover factor and with few spaces between yarns, have less air permeability and are less able to transfer moisture vapor.

Moisture Wicking and Moisture Vapor Transfer Properties of Fibers Absorbent fibers, such as wool and cotton, have a low contact angle with liquid, and can be wetted. Wool is a hygroscopic fiber, having the ability to absorb moisture without feeling wet, and the ability pass moisture vapor from the skin, through the clothing to the environment (Zhou et al., 2007). Because of the tendency to transfer moisture, wool also dries quickly. Cotton fibers have high moisture absorption, and are comfortable for wear in situations of light or moderate sweating. However, cotton fibers are hydrophilic and have a tendency to retain moisture, leaving wearers to cite two moisture management complaints when exercising: fabric drying time, and a cold feeling after sweating (Wallace, 2002). If garments are saturated with sweat after physical activity, moisture evaporation may continue to take place, causing a chilling feeling (Gavin, 2003). Synthetic fibers, on the other hand, have a high contact angle with liquids and do not; therefore, easily become wetted or absorb moisture. Because of their lack of ability to absorb moisture, synthetic fibers that are not engineered to have moisture wicking capillaries can feel uncomfortable when a person sweats. Synthetic fibers generally dry more quickly than cotton fibers due to their lack of absorbency. Synthetic fibers engineered for wicking are often noted as feeling more comfortable than absorbent natural cellulosic fibers in a cold, wet environment, due to their ability to transfer, rather than absorb moisture, and to dry quickly (McCormick & DeVoe, 2004). When physical activity takes place in the cold, synthetic wicking fibers will transfer moisture away from the skin, allowing it to evaporate more readily. Consequently, the wearer feels cool while moving. After the activity is complete, synthetic wicking fibers will have less moisture available to evaporate than cellulosic fibers, so evaporation cooling will subside, preventing the wearer from becoming chilled.

Moisture Management Research in Fibers In a previous study by McCormick and DeVoe (2004), cotton and synthetic wicking fabric garments were compared for comfort while backpacking in the cold. Subjects completed trials wearing shirts of each fiber in a cold climate-controlled chamber. They wore backpacks and walked on an inclined treadmill while researchers exposed them to simulations of outdoor wind conditions. The subjects indicated greater perceived comfort while wearing the synthetic fiber shirts than while wearing cotton shirts. There were also higher values for sweat accumulation and rate of sweat evaporation in the synthetic shirts. The researchers concluded that the synthetic shirts tested had better thermal comfort properties for cold temperatures than the cotton shirts (McCormick & DeVoe, 2004).

With the goal of producing a cotton fabric with less moisture absorbency for the active wear market, Wallace (2002) investigated the absorbency of cotton with a durable water-resistant finish. Water repellent fluorocarbons were printed in a pattern on 100% cotton fabrics, allowing 50% of the fabric to be moisture absorbent, and 50% of the fabric to be moisture repellent. The importance of maintaining absorbent spaces in the fabric was to ensure moisture could be absorbed from the wearer's body. When tested, the cotton fabrics treated with the water repellent fluorocarbons had a significant decrease in water absorption and faster drying time in comparison to a 100% cotton control fabric.

In a related study, the wicking abilities and the drying rates of polyester and polypropylene fibers were compared (Fangueiro et al., 2010). The researchers developed two sets of plated knit fabrics for testing, controlling the face yarn for each set and varying the back yarn in each individual fabric. One set was composed of 100% polyester trilobal fibers on the face of the fabrics, and the second set was composed of 100% polypropylene round fiber on the face of the fabric. Between the two different face fabrics tested, the polyester trilobal fiber exhibited better wicking ability than the polypropylene. In terms of evaporation, the round polypropylene fiber had a higher water evaporation rate than the polyester trilobal fiber. The higher water evaporation rate of the polypropylene was due to the low moisture regain of polypropylene fiber (close to zero), and the lower weight of the polypropylene yarn used in the study in comparison to the polyester yarn.

Wool is a commonly recommended fiber choice for use in outdoor garments due to the ability of the fiber to provide both thermal insulation and moisture management properties. These characteristics allow for thermal and moisture comfort during physical activity in a cold and possibly wet environment. Warm weather and base layer wool garments are becoming increasingly available with the use of fine knit wool fabrics. Zhou et al. (2007) examined the water distribution and absorbency rate of six different knit wool fabrics in a variety of blends and knit structures. In comparison to a plain knit jersey 100% wool, to a plated wool/polyester blend, and to a plated wool/Coolmax® blend; a plated wool/cotton blend fabric was found to have the best overall moisture management capacity on the basis of moisture absorption, one-way moisture transport, and drying speed. The wool/cotton blend had the highest one-way moisture transport between the top and bottom of the fabric than the other fabrics tested.

Moisture Management Research in Fabrics In addition to the fiber type, the moisture management ability of fabrics also depends on the volume of pores/capillaries in the fabric or fiber, and the fabric thickness. In Crow and Osczevski's (1998) study of the water absorbency of fabrics with different structures, thicknesses, and fiber contents, a positive relationship was found between the amount of water absorbed by the sample fabric and the fabric thickness. It was also noted that the fabrics had an absorbency limit affected by the size of pores in the fabric. The capillary force of the pores is inversely related to the diameter of the pore; smaller pores in a fabric will have greater force, and will fill with liquid before larger pores. Fabrics submerged in water stopped absorbing liquid after pores of a certain size had been filled.

Likewise, Wang et al. (2009) found fabric structure to be related to moisture wicking in their study of the moisture wicking abilities of synthetic fibers. Polyester fibers were developed with honey comb-like pore structures to aid in moisture transfer. The new fibers were then used in plain and twill weave fabrics with different cover factors and fabric counts, and were tested for water transport rate and moisture vapor transmission. It was concluded that fabrics with higher cover and with tighter woven structures resulted in less liquid wicking ability and less moisture vapor transmission.

Similarly, Prahsarn et al. (2005) concluded that moisture vapor transport is affected by fabric thickness. In their study of 14 polyester fiber fabrics with different weights, thicknesses, knit structures, and fiber cross-sectional shapes, there was a correlation between fabric thickness and moisture vapor transmission rate.

Waterproof fabrics exhibit lower moisture vapor transmission rates than absorbent or wicking fabrics, depending on the waterproofing application used, making them a possible discomfort during high exertion activities. Oh and Cho (2005) studied the moisture vapor transfer rate of 4 different waterproof breathable fabrics in comparison to 4 knit fabrics. The waterproof breathable fabrics included a nylon warp-knitted fabric coated with polyurethane, a polyester woven microfiber fabric, a nylon woven fabric coated with polyurethane, and a nylon warp-knitted laminated fabric with a PTFE membrane. Overall, the moisture vapor transfer rates were higher in the knit fabrics than in the waterproof breathable fabrics. Between the waterproof breathable fabrics, the researchers concluded that the polyester woven microfiber fabric had the highest moisture vapor transfer rate, followed by the PTFE laminated nylon knit fabric.

The Role of Garment Construction in Thermoregulation

The design of a garment, from a construction perspective, can also affect the thermal comfort properties of a garment. Heat transfer can be incorporated into the design of a garment through fit and venting features. Loosely fitting garments, for example, will allow natural convection effects to move heat outward through the garment. According to Fourt and Hollies (1970), any area where the garment is cinched, such as the waist or cuffs, reduces the ability of air movement. Additionally, vents in the upper portions of the garment can allow heat and moisture to escape when air is forced upward by a “chimney” effect and body movement acting as “bellows.”

In Ruckman’s (1999) study of rain jacket openings, he lists two main types of jacket venting features: pit zips, which are used in the side and underarm seams and can be opened to allow ventilation; and venting pockets, which are typically across the chest or back of a garment and consist of a flap with mesh. In the study, Ruckman tested different locations of pit zips in wear trials, monitoring skin temperature and sweat accumulation. Pit zips that spanned the underarm sleeve seam and side seam performed the best in terms of temperature and sweat accumulation, in comparison to zips in only the underarm sleeve or in only the side seam. This result was expected, and was due to the fact that the underarm/side seam combination zips had a larger opening than the other two zip options, so they allowed greater dissipation of heat and moisture (Ruckman, 1999).

Similarly, mesh venting panels can be incorporated into active wear to allow heat and moisture dissipation by a “chimney” effect when the wearer exercises. In a study of t-shirts with mesh panels and uncovered openings, 10 shirt designs were tested on a thermal manikin for thermal and moisture vapor retention (Ho et al., 2008). Six of the shirts featured mesh openings in different body locations, three shirts had uncovered openings in different body locations, and one shirt served as a control with no openings. The researchers concluded that the mesh and uncovered openings placed at the side seams of the t-shirts provided the least amount of thermal and moisture vapor retention, allowing greater thermal comfort when the wearer is exercising. Openings placed across the chest or back provided the more thermal and moisture vapor retention, which may be due to the fact that the openings across the back and chest were flat against the manikin’s skin, not allowing warm air and moisture to escape as effectively. At the side seams there was more space between the manikin body and the garment, allowing more air and moisture flow through the openings. These findings are consistent with Nielsen et al.’s (1989) comments about the fit of a garment, looser fitting garments allowing more heat dissipation than tight fitting garments. This is due to the fact that if fabric is flat against the skin, heat transfer and convection are limited, because there is less air flow around the body.

The Role of Garment Layers in Thermoregulation

Combinations of clothing layers can also contribute to the thermal comfort properties of a clothing ensemble. For outdoor activities, a common recommendation is to dress in layers, which can be added or removed according to the level of activity. This system generally consists of three layers: a base layer that sits next to the skin and provides moisture wicking to keep the body dry, an insulation layer that traps air next to the body to preserve heat, and an outer shell layer that may be wind or waterproof (Holmér, 2005). Additionally, it's advised to clothe the head to maintain the heat balance of the entire body (Fourt & Hollies, 1970). In temperatures of -15 °C, approximately ¾ of the body heat may be lost through the head. Although layers of clothing allow flexibility for comfort in various activity levels in the cold, layers can act as a barrier to sweat evaporation and cooling of the body during physical activity. According to Nagata (1978), the greater the amount of clothing on the body, the lower the evaporative sweat rate. When exercising in a cold environment, thermal comfort can be a challenge, because the body is generating heat and sweat. The use of layers reduces the moisture permeability of the clothing, causing sweat to condense in clothing during physical activity. This can cause thermal discomfort when the wearer stops moving, particularly in a cold environment, and the moisture may even freeze (Yoo & Kim, 2008).

In a study of layered clothing ensembles worn in cold conditions, researchers found that moisture management properties of outer clothing layers affect the ability of the base layer to transfer moisture (Wang et al., 2007). The researcher conducted wear trials of wool/cotton blend long underwear base layers under two different clothing ensembles: 1. A “typical” clothing system of waterproof polyester and nylon layers, and 2. A system designed specifically for moisture management with waterproof breathable cotton/wool blend and polyester layers. Wear trials were conducted on exercising subjects at -15° C. The researcher found that the “typical” ensemble had higher levels of humidity inside the clothing and had higher perceived moisture ratings than the ensemble selected for moisture management properties. In the “typical” ensemble the base layer became saturated with moisture during exercise, because the moisture was not able to transfer from the base through the outer clothing layers.

Perceived Clothing Comfort

Many contrasting views of the definition of comfort and the best method to measure clothing comfort exist. As evidenced in the articles cited previously, there are differences among researchers as to whether comfort should be assessed by objective measurements or by subjective responses from the subject. These measurement techniques relate directly to definition of comfort the researcher has chosen to apply.

Branson and Sweeney (1991, p. 99) defined clothing comfort as “a state of physiological, social-psychological and physical balance among a person, his/her clothing, and his/her environment.” As part of this definition, Branson and Sweeney proposed a model that includes a physical dimension triad, a social-psychological dimension triad, and a physiological/perceptual response, which all influence the individual in his or her comfort judgment (Figure 3). The physical dimension triad is composed of person, clothing, and environmental attributes that can be objectively measured, including age, sex, clothing fibers, and outdoor temperature. Social-psychological dimensions, on the other hand, are less concrete and can be difficult to measure. These are composed of person, clothing and environmental attributes, such as the individual's personality or religious beliefs (personal); the clothing aesthetics and appropriateness (clothing); and the situation of the wearer (environmental). The third important aspect of the model is the individual's physiological/perceptual response to both the physical and social-psychological dimensions. Since the physical and social-psychological dimensions will not be identical for any two individuals, responses and comfort judgments will be different.

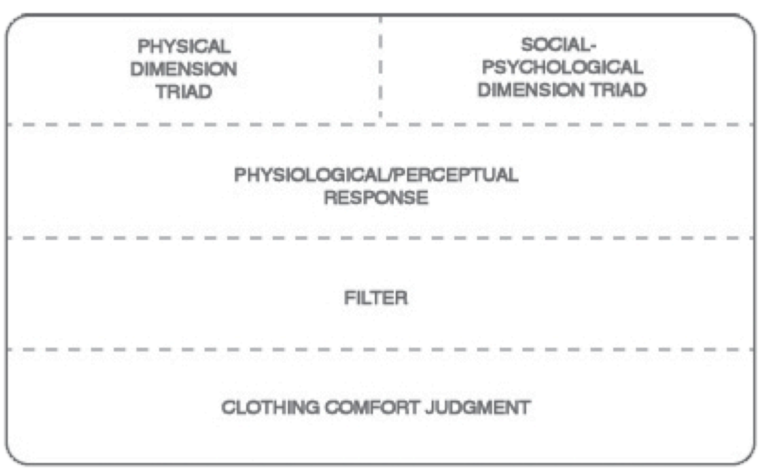


Figure 3: Clothing Comfort Model (Branson & Sweeney, 1991)

Hollies et al. (1979) developed a measurement system for subjects to indicate perceived comfort. By examining past research where subjects described comfort sensations they were experiencing, the researchers developed a list of comfort rating terms: snug, loose, heavy, light weight, stiff, staticy, sticky, non-absorbent, cold, clammy, damp, clingy, picky, rough, and scratchy.

Previous studies of functional clothing have utilized both Branson and Sweeney's (1991) clothing comfort definition and Hollies' et al. (1979) comfort scale, focusing on the measurable physical dimension attributes. Horridge et al. (2002), for example, evaluated the comfort of fabrics for Texas state trooper uniforms on the basis of physical characteristics; comparing fabric wear, physical person attributes, and physical environmental factors of perceived comfort. Hollies' 15 comfort terms were used for subjects to indicate their perceived comfort sensations. The authors concluded that both the wear of fabrics and perceived comfort varied based on the individual's person characteristics (namely body weight and age) and environmental characteristics (length of work shift uniform was worn, temperature, humidity, time of day).

Past researchers have also sought to determine if perceived comfort responses can be predicted based on other responses or objective measurements of comfort. In a study of the relationship between perceived comfort sensations and overall perceived comfort, researchers used an artificial neural network to predict comfort sensations (Wong et al., 2003). Twenty-two athletes tested three different sportswear garments while cycling for 90 minutes in a controlled laboratory. The subjects rated the comfort of the clothing overall, and the comfort in10 of the sensory categories developed by Hollies. The researchers found that through a neural network, the 10 sensory perception ratings could be used to predict the overall comfort rating of the subject.

In a study of the relationship between perceived comfort and physiological measurements, Li (2005) concluded that subjects' perception of dampness was related to the measured humidity inside clothing and the skin temperature. Twenty subjects tested sweaters while walking on a treadmill in a climatic chamber during periods of dryness and simulated rain. The subjects were polled on their perceptions of wetness, warmth, and overall comfort. Physiological measurements of the skin temperature and the humidity inside the clothing were taken during the exercise. The overall perceived comfort of the subjects correlated to the perceived dampness and the perceived warmth of the clothing. When comparing the subjects' perceived comfort ratings and the physiological measurements, the researcher concluded that higher ratings of perceived dampness correlated with lower skin temperatures and higher measured humidity levels.

Likewise, Fan and Tsang (2008) applied Branson and Sweeney's definition of comfort to determine if physical measurements and perceptions of thermal comfort could be compared. Five clothing ensembles were tested on a sweating thermal manikin for thermal insulation value, moisture vapor resistance, and moisture accumulation within clothing. Five volunteers were also dressed in the clothing ensembles and tested the garments while playing badminton. Subjects rated their perceived comfort sensations in 8 categories as well as their overall comfort. The researchers found that the subjects' overall comfort sensation ratings were strongly related to the thermal and moisture measurements from the thermal manikin. Thus, the researchers concluded that for thermal attributes of comfort, the thermal manikin may provide a comparable assessment of comfort, and the "perception" aspect of Branson and Sweeney's model may not be essential for accurate comfort measurement.

Design Criteria

The design of performance sportswear garments requires a basic understanding of anatomy and physiology, as well as detailed information about the needs of the particular sport (McCann, 1998). McCann developed a model outlining considerations in the design of performance sportswear (Figure 4). Main considerations include the functional needs of the body and the activity, the form of the garment, and commercial realities. Functional considerations for the body take into account thermal and moisture-management needs, ergonomics of the moving body, and tactile feeling. The design for these needs must be addressed differently in sportswear than in fashion garments. Traditional construction of fashion garments, for example, are designed to fit an erect body or dress form, and do not consider the body movement that would be needed in a garment for sports (McCann, 1998). Functional sportswear design must also consider the comfort and safety of the wearer, which requires knowledge about the duration and intensity of the physical activity and the physical activity environment. Design aesthetic needs for performance sportswear garments are also different from those of fashion garments, and are often dependent on the culture of the particular sport. Snow boarders, for example, have different style preferences than mountaineers, who might be wearing a similar amount of clothing in a mountain environment. Colors, styles, and regulations for team sports need to be taken into account when considering garment aesthetics. Market outlook must also be considered in the design of performance sportswear. This includes acknowledgement of the garment's position within the market, the price point, and branding. Sportswear consumers are exposed to branding information about textiles through garment tags, print advertising in sports magazines, and the use of such textiles by popular sportswear companies. This consumer awareness should be accounted for when the designer selects textiles for the garment, deciding whether the use of a trade name will be more successful than a generic name textile of the similar function.

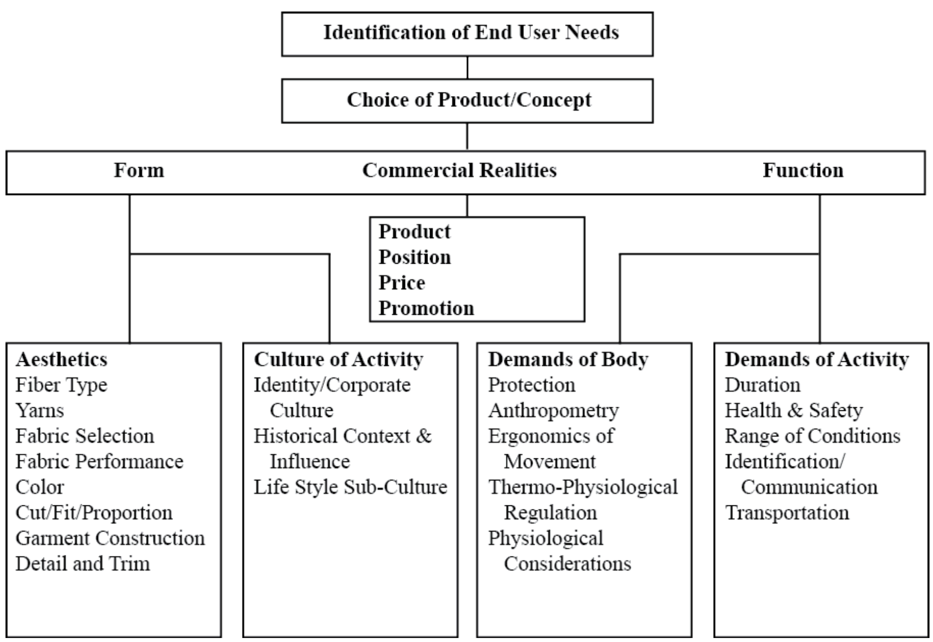


Figure 4. Performance Sportswear Considerations (McCann, 1998)

Current Outdoor Clothing Market

Upper-body garments designed for hiking and backpacking can be grouped into several categories of use, features, and textile composition. Many backpacking and hiking garments comply with Holmér's (2005) description of a 3-layer clothing ensemble for outdoor use. This system consists of a next-to-skin base layer, an insulation layer, and a weather resistant shell. Some garments, such as shirts for warm weather hiking, are designed to be worn as a single layer.

Base Layers First, multiple styles and weights of upper-body base layers for hiking are currently available. Of eight upper-body base layers reviewed, some are categorized as lightweight, midweight, or expedition weight, depending on the backpacker's thermal needs. Most lightweight base layers weigh from 96 to 170 g, and are designed specifically to wick moisture away from the body. Construction features of lightweight bases may include a crew neck or a stand collar with a front zip, short or long sleeves, gusseted sleeves for arm movement, and flat lock seams rotated away from movement areas to prevent skin abrasion. Textiles used are mostly knit fabrics, and fiber contents include polyester, polyester/elastane blends, nylon/elastane blends, cotton/polyester blends, polypropylene, and merino wool. Some lightweight base layers have finishes beneficial to the hiker when wearing the base layer by itself in warm weather, such as anti-microbial odor prevention, UV protection, and insect protection. Example textiles include Dri-Balance, Omni-Freeze®, Capilene, and Advance™.

The midweight and expedition weight base layers reviewed range from 218-311 g in weight and, in addition to the moisture-wicking abilities of the light base layers, offer insulation and softness. Some expedition-weight base layers are designed with careful consideration of the body movement, incorporating stretch, raglan sleeves, and underarm panels for mobility. Chafing of the skin against backpack straps is also a consideration, so shoulder seams maybe offset to the front and back of the shoulder by incorporating a yoke across the top of the shoulder. Flat lock seams may also prevent abrasion and can be rotated away from movement areas. Additional features may include a high collar with a full or partial-length zipper for warmth and ventilation, thumb-holes at the sleeve cuff to keep hands warm, and pockets. Expedition-weight base layers tend not to have insect and UV protection, but may have finishes to prevent odor build-up. Textiles used are most commonly double knit fabrics or double knit/pile knit fleece structures. Fiber compositions include polyester, polyester/spandex blends, merino wool, or wool/polyester blends. Examples include Polartec® Power Dry®, Polartec® Power Stretch®, and Polartec® Pure Wool™. Some mid and expedition baselayers have incorporated polyester knit mesh panels for breathability in areas of perspiration.

Thermal Insulation Layers The insulation category of the 3-layer hiking ensemble can include a variety of weight garments, depending on the backpacker's need. Of the garments surveyed, weights ranged from 238 to 649 g. Many of the tops surveyed include moisture wicking and breathability as main functions. Design features may include a stand collar with a 1/4-length or full-length front zip for warmth and ventilation, a hood, and a drawstring at the hem to retain heat. Pit zips may also be used for thermal ventilation. Side seam pockets or chest “Napoleon” pockets are offered in some designs. The materials used in insulation layers can vary considerably, depending on the hiking use. Jackets surveyed included the following textiles: polyester pile knit fleece, wool jersey knit, and nylon woven fabric with down or synthetic fiber fill. The insulation layer does not typically include treatments for insect, UV, or odor protection. Some insulation layers, however, may be used as a combination insulation and outer clothing layer, having windproof or water resistant properties. This can be achieved, for example, by using WindStopper® Technical Fleece, that combines microfleece layers with a windproof membrane layer. Some insulation layers have water resistance properties for more flexibility of use with a DWR (Durable Water Repellent) finish on woven nylon fabric.

Shell Layers Next, the outer shell layers worn in the outdoors to protect hikers from the elements can be categorized as hard shells or soft shells. Hard shell jackets for hiking are water and/or windproof and, ideally, breathable. Like the insulation layers surveyed, shell jackets can also vary considerable in weight, from 121 to 482 g. Protection features generally include a hood with a brim, draw strings at the hood and hem, and elasticized/Velcro sleeve cuffs to keep water away from the skin. Body movement is considered in some designs, with the incorporation of articulated elbows or gusseted underarms. Ventilation is important in waterproof jackets, which can lack the breathability of non-waterproof fabrics. Features like pit zips or mesh ventilation pockets in the torso are offered in some shell jackets to allow moisture vapor and heat to escape before condensing within the jacket. Jacket hoods may have the convenience of being stowed in a zippered pocket in the collar when not needed for protection. Zippered hand pockets, map pockets along the center front zipper, and interior pockets may also be included. Pocket placement for backpackers is sometimes given special consideration, since hip-level pockets cannot be easily accessed while wearing the waist-belt of a backpack. Pockets may be, instead, placed on the chest or at mid-torso level where hands can easily access them if resting on the backpack straps. Specialized jacket construction techniques can be used to reduce weight and bulk, such as 1.6mm micro seam allowances and sonic-welded seams. Textiles frequently used in hard shell jackets are laminated 2 or 3-layer moisture-permeable membrane fabrics or coated, moisture-permeable fabrics. Laminated fabrics consist of an outer woven nylon fabric, an inner membrane layer, and a woven scrim fabric closest to the skin to protect the membrane. Coated fabrics are composed of a nylon outer layer and an inner plasticized coating layer. These fabrics have small pores in the membrane or coating layer that allow moisture vapor generated from the body to transfer to the outside air but are small enough to prevent the liquid water from rain or snow to penetrate the fabric (Ruckman, 2005). Waterproof jackets may be treated with a DWR finish in addition to the waterproof membrane or coating, so that water beads up and rolls off the fabric surface.

Soft shell jackets, on the other hand, are not designed to be waterproof, but may be water-resistant and windproof. This type of shell offers greater mobility for the wearer and is suitable for a variety of conditions, rather than for weather extremes. In addition to providing protection from wind and rain, soft shell jackets are typically breathable and moisture-wicking, allowing for better physiological comfort than a hard-shell jacket. Design features may include a full-length zipper, articulated sleeves for mobility, hand or chest pockets, and a draw-string hem. Textiles used in soft shell jackets are typically double weave fabric structures in polyester/spandex blends for stretch, and microfleece linings in 100% polyester. Some soft shell jackets reviewed also included a thermal insulation lining of pile knit polyester fleece, combining the benefits of layer system in one jacket. Water resistance in soft shell jackets is achieved by applying a DWR finish.

Single Layer Shirts In contrast to garment designs for use in a 3-layer system, for warm-weather backpacking, some garments are designed to be worn primarily alone. This category of backpacking garments includes front-button collared shirts. They offer moisture wicking, breathability, stretch, insect protection, and sun protection. Comfort features may include ventilation panels, seams rotated away from the shoulders to prevent chafing from backpack straps, and button plackets to roll up and fasten sleeves. This type of shirt may also have pockets. Textiles used are generally plain-weave fabrics, combined with knit-mesh in venting areas. Fiber composition for the woven fabrics can be nylon/spandex or nylon/polyester blends. Knit-mesh fabrics are often 100% polyester.

CHAPTER III

METHODS AND PROCEDURES

The purpose of this study was to design and evaluate a single layer garment to improve the physiological comfort of male wilderness backpackers in cold conditions. Physiological comfort was defined in this study as a state of balance between a person's body, his or her clothing, and the environment. The following are objectives of this study:

- To identify the physiological comfort needs of male wilderness backpackers in cold conditions.
- To design one prototype single-layer backpacking shirt, using various textile materials, for improved physiological comfort of male wilderness backpackers.
- To determine the effectiveness of the design solution by conducting wear tests of the prototype shirt to assess physiological comfort and garment performance over time, in comparison to a control.

The methods chapter outlines the procedures and protocols used to meet the above objectives, by describing the subjects, study procedures, questionnaire development, and statistical analysis.

Subjects

The subjects that participated in the study were male wilderness backpackers, recruited from the staff of Second Nature wilderness therapy program in Bend, Oregon, who hiked or had hiked within the past year for their profession. On average, each subject hiked or had hiked professionally for 2+ hours at a time, carrying supplies needed for an eight-day work shift in the wilderness, including food, shelter, and clothing. Employees from this program were recruited for this study, in particular, due to the frequency of the employees' backpacking trips, the proximity of Bend to Corvallis, Oregon, and the cold weather conditions in Bend during the winter and spring, where and when hiking for the study took place.

As required by their work, the field staff typically backpacks 2-4 times over the period of an 8-day work shift, for 2-5 hours at a time, year-round. The field staff works in the wilderness on an every-other week schedule, spending eight days in the field and six days off work. When backpacking, the subjects carry a load of approximately 27 kgs. Many former field staff remain employed by Second Nature after leaving field positions to work in support and managerial positions. Therefore both Second Nature current field staff and former field staff qualified to participate in the study. However, restrictions were placed on former field staff, and to qualify for the study, they were required to have worked as field staff within the past year and to have been currently backpacking at least once per month for 2+ hours at a time, occasionally in cold conditions. All subjects were recruited by posters (Appendix E & F, p. 140-141) in Second Nature's base facility and were offered the incentive of keeping garment prototypes after the study. Subjects participated in two separate procedures of the study: qualitative interviews and wear tests.

Qualitative Interview Subjects Four current male field staff and former field staff who qualified, were recruited for the qualitative interview portion of the study. Each subject signed an informed consent form (Appendix B, p. 130) and current field staff were asked if they wished to be considered for participation in the wear test portion of the study.

Wear Test Subjects Four current male field staff were recruited to participate in the wear test procedure of the study. The subjects signed an informed consent form (Appendix C, p. 134) and took place in a screening process to verify their ability to engage in the wear trials. The recruited subjects completed a written questionnaire, had their body measurements taken by the researcher, and provided a shirt that they liked the fit of to the researcher for measuring. The purpose of this initial screening was to: a) determine subjects' body sizes for garment sizing, b) determine if subjects were available for testing during at least (3) 8-day long work shifts from February to March, c) ensure that subjects backpacked during at least (2) days of every 8-day shift, d) ensure that subjects experienced similar hike difficulty and intensity. As subjects regularly backpacked and were required to have annual physicals as a condition of their employment, it was assumed that they had adequate physical fitness to participate in the backpacking portion of this study. Based on their screening responses, three of the recruited subjects were eligible to participate in the study.

Qualitative Interviews

Qualitative interviews were conducted with the four subjects identified for this portion of the study to gather information about backpacker physiological needs for garment design development. The interviews were conducted one-on-one in the subjects' homes, to maximize their comfort and privacy. The interviews were semi-formal with open-ended questions to get more feedback and response than would be given with closed-ended questions. Each interview was approximately 1 hour and 30 minutes long. Questions addressed backpackers' physiological comfort needs; types of garments and materials typically worn by the subject; dissatisfaction or preferences in garments/materials currently worn, including in thermal and moisture comfort areas; and locations on the body that need greater attention to thermal or moisture comfort. Additionally, subjects were asked to provide an example of a shirt they frequently wore while backpacking, and were asked about the shirt features they liked and disliked. The researcher photographed the example shirts and identified the fiber content and fabric structure. Responses were recorded by hand and by audio recorder. Open coding was used to identify common categories between all subjects based on backpacking conditions, garments commonly worn, dissatisfactions and preferences, and body locations for thermal/moisture comfort. After the interview data was coded, the researcher used member checking to validate that the results reflect subjects' viewpoints. The coded interview data were then compiled into a design criteria matrix, which was used in the design of the prototype backpacking shirt.

Prototype Development

Step One The first step in the prototype development was to select appropriate functional textiles to meet the specific comfort needs. Information from the qualitative interviews, specifically regarding thermal and moisture comfort aspects of the garment, guided the selection of the fabrics. Fabrics used in this study were selected from commercially available textiles commonly used for their major functions in thermal regulation and moisture management. Originally, three fabrics were selected for thermal regulation and six fabrics were selected for moisture management. One final fabric was chosen for each need (thermal and moisture comfort), based on laboratory performance tests. To determine a final fabric to be used to meet thermal comfort, the fabrics selected for thermal properties were tested on a guarded hot plate for thermal resistance (R), according to ASTM C 518-04 Standard Test Method (2004) for Steady-State Thermal Transmission Properties by Mean of the Heat Flow Meter Apparatus (TRMS Thermal Resistance Measurement System, Cohesive Solutions). R-values were converted to Clo value using a conversion factor. After being laundered, the three thermal insulation fabrics were also tested for moisture management ability, using a Moisture Management Tester (Moisture Management Tester, M290, SDL Atlas, Rock Hill, SC) according to AATCC 195 (2011), for the following properties:

- Wetting time
- Absorption rate
- Maximum wetted radius

- Spreading speed
- Accumulative one-way transport capacity,
- Overall moisture management capacity

Additionally, fabric weights and thicknesses were measured according to ASTM D3776/D3776M-09ae2 (2009) and ASTM D1777-96 (2011) (Denver Instrument XS-210 digital scale; Käfer Messuhrenfabrik JD 200 A 12.5mm/0.01 digital thickness gauge). One fabric for use in the prototype garment was selected based on thermal insulation value per fabric thickness. Moisture management ability of the thermal fabric was also taken into consideration when selecting a final fabric.

To select one fabric with the best moisture management ability, the six fabrics chosen for moisture management were tested using the Moisture Management Tester (Moisture Management Tester, M290, SDL Atlas, Rock Hill, SC) according to AATCC 195 (2011), for the moisture properties listed in the above paragraph. The fabrics were tested both before and after laundering. Fabric thicknesses and weights were also determined. One fabric with the most consistent one-way moisture transport ability was selected for use in the garment prototype.

In addition to one fabric for thermal insulation and one fabric for moisture management, a control fabric was selected to represent a typical base layer material worn by backpackers. Information from the qualitative interviews was used to determine an appropriate fabric that is commonly worn by backpackers as a base layer.

Step Two Once fabrics were selected, one style of garment was designed by drafting and flat pattern making. The style included various panels for the researcher to modify with different fabrics in different body areas, based on the criteria developed in the design criteria matrix. Using a single-style for all garments allowed the researcher to control for wearer discomfort due to seam locations, to control for differences in stretch of garments with fabric panels, and to control for differences in durability due to panels. The single style was modified by using different fabrics in the panel areas in two different test garments:

- The experimental prototype used the thermal insulation fabric, the moisture management fabric, and the control fabric in fabric panels in different body areas. Information about the body locations where the different fabrics were used came from the qualitative interviews.
- The control garment used only the control fabric in all garment panels and body areas.

Step Three Finished garment measurements were specified to provide a similar fit and amount fitting ease for each subject. The finished garment measurements allowed for 4 inches of total fitting ease around the circumference of each subject's chest. The 4 inches of ease was kept consistent for each subject to prevent the differences in the air gaps in the garments from affecting the air convention and the thermal insulation. A grade rule was established in accordance with the finished measurements, and patterns were graded to fit each subject. The researcher constructed four duplicates of each of the control and experimental prototype garments. All garments had identical construction.

Garment Testing Protocol

Each of the three subjects chosen for the wear test portion of the study were given one experimental prototype and one control garment. Each subject's body measurements were taken during the screening questionnaire to ensure adequate fit of the garments provided. Testing took place in winter and spring near Bend, Oregon where average temperatures range from 23°F to 57°F and average precipitation ranges from 4.8 cm to 1.65 cm (Western Regional Climate Center, n.d.). Subjects wore the experimental prototype and the control garment for three wear tests. Tests occurred on subjects' regular work days in the field, on days that backpacking is took place. Subjects wore each test garment for a full day, with backpacking making up at least 2 hours of each test day. Due to the range of temperatures and weather conditions subjects encountered while at work in the field, subjects were permitted to wear any other of their own clothing layers necessary, over the garment being tested, to maintain physiological comfort. The order in which subjects wore each garment during the work-week was controlled, with subjects wearing the control garment on the first test day and wearing the experimental garment on the second test day. The tests occurred on the first two hiking days each week. At the end of the week when the subject returned home, the test garments were laundered with detergent and laundry instructions provided by the researcher. The same detergent and laundry instructions were used for both the prototype and the control garment, and were the same for each subject. The trials took place over the course of several separate work weeks for each subject. After each trial day, the subject completed a written questionnaire about their physiological comfort when backpacking with the test garment. Subjects were provided with stamped, addressed envelopes to mail the questionnaires back to the researcher at the end of each work week. Questions addressed physiological comfort during backpacking, physical weather and environmental conditions during the backpacking period, the duration of wear, and whether additional clothing layers were needed at any point during the wear day.

Questionnaire Development

Qualitative Questionnaire The purpose of the qualitative interview used in the initial part of the study was to determine backpacker clothing needs while hiking in cold conditions. Open-ended interview questions were be used to determine:

- The specific conditions occurring while employees backpack that the garments needed to meet. Questions were asked regarding temperature, wind, miles hiked, load carried, and ability to change clothes or add layers.
- Types of garments and materials typically worn by the subject when backpacking, and any comfort dissatisfaction or preferences with these garments.
- Body locations where thermal insulation or moisture management fabric is needed in a garment to improve physiological comfort.

Based on the subjects' responses, questions were revised as needed to provide greater clarity to the participants, resolve discrepancies, or to better elicit the type of response wanted from each question (see Appendix G, p. 142). Prior to beginning interviews, the researcher responded to the interview questions to recognize her own biases and increase the credibility of interview results.

Quantitative Wear Trial Questionnaire The wear trial questionnaire consisted of both closed and open-ended questions (see Appendix I, p. 146). Questions posed in the wear trial questionnaire were developed to meet the following purposes:

- To determine if the experimental prototype had better ability to maintain subjects' overall physiological comfort while backpacking in comparison to the control.
- To determine if the experimental prototype had better ability to meet the thermal and moisture comfort of the wearer, in comparison to the control garment.
- To determine if any areas of the body lacked physiological comfort during backpacking.
- To determine if the overall physiological comfort of the prototype garment changed over the course of 3 wear trials.
- To determine if there were visible changes in the durability of the prototype garment over time in terms of pilling and shrinkage.

Comfort Measurement Similar to the rating system described by Wong et al. (2003), the subjects indicated perceptions of thermal and moisture comfort and overall comfort ratings. Feelings of the garment being "hot" and "cold" were assessed on an 11-point Likert scale of (0) "not at all" to (10) "extremely." Moisture management perceptions were rated based on several descriptive words of comfort sensations (clammy, clingy, sticky, damp, and breathable) on the Likert scale, from (0) “not at all,” to (10) “extremely.” Overall physiological comfort was measured by asking subjects to indicate the overall comfort perceived during the hiking period on the Likert scale from (0) “not at all comfortable,” to (10) “extremely comfortable” (Wong et al., 2003). Additionally, in an open-ended question, subjects were asked to note particular areas of the body that did not feel comfortable.

Durability In open-ended questions, the subjects indicated if any durability issues were observed, and were asked to note specific locations on the garment where the problems were visible. Subjects were given examples of durability issues that could occur: seam tearing, pilling, holes, shrinkage, etc.

Conditions In addition to the questions used to determine the comfort and durability of the garments, closed-ended questions were used to determine the conditions under which the subject was backpacking during the test day. For the purpose of this study, the backpacking conditions were not analyzed for a relationship to garment performance; however, the conditions may have had some influence on garment comfort, and functioned to rationalize unexpected study results. Subjects indicated the backpacking conditions by answering questions about:

- The duration of time spent wearing the garment, the duration of time spent backpacking, and the perceived physical exertion while backpacking.
- The temperature, wind, sun/cloud cover, and precipitation
- Whether additional clothing layers were needed for physiological comfort

Thermal Manikin Testing

For comparison purposes, the experimental prototype and control garments were tested on a sweating thermal manikin, according to ASTM F1291 Standard Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin (2006). The manikin is the 26-zone Newton model manufactured in 2005 by Measurement Technology Northwest and consists of a carbon-epoxy shell equipped with internal heater elements, 26 temperature sensors, and a fluid supply system that enable perspiration simulation. Throughout the duration of all tests, the thermal manikin wore the sweat skin provided by the manikin's manufacturer and remained in a stationary position. For all tests, the manikin's shell temperature was set to 35 degrees Celsius. The ambient temperature averaged 20.13 $\pm$ .216 and the relative humidity averaged 42.28 $\pm$ 4.06. Wind velocity in the test chamber was measured using a Fisher Scientific hot wire anemometer and ranged from 0 to 0.1 meters per second.

Thermal resistance values were collected for three different treatments: thermal manikin with no shirt, thermal manikin with control shirt, and thermal manikin with prototype shirt. Two replications were performed for each of the three treatments. During a replication, thermal resistance data were collected at 60 second intervals for a minimum of two hours. To ensure that results only reflect steady states, Clo value, ambient temperature, and relative humidity were calculated based on the data generated during the final 20 minutes of each replication.

Data from the "thermal manikin with no shirt" treatment was used to establish a baseline from which the control shirt treatment and prototype shirt treatment Clo values could be calculated. The average Clo values, standard deviations, and differences between the control and prototype shirt have been reported. Additionally, the average Clo values, standard deviations, and differences have been reported for the arms, chest, shoulders, stomach, and back regions of the manikin.

Data Analysis

Qualitative Interviews Responses from the qualitative interviews were analyzed using an open-coding process to identify common themes among subject responses in the following categories: backpacking conditions at Second Nature, garments typically worn, dissatisfactions and preferences, and body locations needing better thermal or moisture comfort. These themes were then used to determine priorities in the design of the experimental prototypes.

Quantitative Wear Tests Data from the wear test portion of the study was analyzed by a combination of descriptive statistics and non-parametric statistics tests. To determine the difference between the experimental and control garments in overall physiological comfort, the difference in physiological comfort in thermal and moisture categories, and the change in comfort ratings over time, means and standard deviations were calculated. The mean overall physiological comfort values and the mean comfort values based on the seven moisture and thermal comfort sensations were calculated and reported for each garment (experimental prototype and control) based on the following:

- The mean value across all trials and all participants for each garment.
- The mean value of three trials for each subject, for each garment.
- The mean value for each trial, across all subjects, for each garment.

The researcher interpreted the means to assess if there was a difference in: the comfort of the two garments, the comfort of the garments based on the subject, and the comfort of the garments over time.

Non-parametric statistics were also used to determine the significance of differences in comfort ratings between the prototype and control garments. The comfort ratings were entered in R (version 2.11.1, The R Foundation for Statistical Computing, Vienna, Austria), and Wilcoxon Signed-Rank tests for paired data were used to determine a difference between the prototype and control ratings for all subjects and trials, across trials, and across subjects, based on overall comfort and the 7 comfort sensations. To calculate the test statistics, the sum of the ranks of the positive differences between the prototype and control scores were added. T-tests determined any significant differences between the prototype and control garments for overall comfort, and the 7 comfort descriptors. Significant P-values have been reported.

Additionally, the mean comfort values from combined thermal and moisture scores were calculated by combining the thermal and moisture sensations. "Hot" and "cold" ratings were pooled to provide thermal comfort values, and "sticky," "clammy," and "damp" were pooled to provide moisture comfort values. "Clingy," "breathable," and "overall comfort" were not combined with the thermal or moisture data. "Clingy" was unable to be included in the combined moisture values due to subject discrepancies about the definition of “clingy.” “Breathable” and “overall comfort” were not included in combined comfort values because their rating scales were opposite those of the other comfort sensations. The combined mean thermal and moisture scores have been organized: across all trials and all subjects; according to each subject; and according to each trial number.

Wilcoxon Signed-Rank tests were also used with pairs of the combined thermal and moisture data, to determine a difference between the prototype and control garments for all trials and subjects, across trials, and across subjects. Significant P-values have been reported.

CHAPTER IV

RESULTS & DISCUSSION

The purpose of this study was to design and evaluate a single layer shirt, consisting of different types of textiles, to improve the physiological comfort of male wilderness backpackers in cold conditions. The objectives of this study were:

1. To identify the physiological comfort needs of male wilderness backpackers in cold conditions.
2. To design one prototype single-layer backpacking shirt for improved physiological comfort of male wilderness backpackers.
3. To determine the effectiveness of the design solution by conducting wear tests of the prototype shirt to assess physiological comfort and garment performance over time, in comparison to a control.

The procedures for meeting the study objectives were outlined in Chapter III Methods. This chapter presents and discusses the data collected and the results, according to the study objectives.

Qualitative Interview Results

To identify the physiological comfort needs of male wilderness backpackers in cold conditions, qualitative interviews were conducted with four male subject employees of Second Nature Wilderness Program. Responses from the qualitative interviews were analyzed using an open-coding process to identify common themes among subject responses in the following categories: backpacking conditions, garments typically worn, preferences and dissatisfactions, and body locations needing better thermal or moisture comfort. Tables 2a and 2b summarize the most frequently occurring responses to interview questions.

Table 2a: Summary of Qualitative Interview Responses

Question Topic	Response	Number of Responses
Backpacking Conditions		
Weather conditions in the field	daytime temperatures from 0˚F to 50˚F	4
	snow fall	3
	windy	2
Conditions where subjects do not hike at Second Nature	below 11˚F	3
Hours spent hiking on a cold day	hiking time does not depend on temperature	1*
	1-4 hrs.	1
	1-12 hrs.	1
	varies depending on temperature extremes	1
Difficulty of hikes at Second Nature	hikes take place on rolling terrain	2
	hikes in winter take place on dirt roads	2
	dirt road hikes are easier	4
	"cross country" hikes are harder	3
Estimated pack weight	60-80 lbs.	1
	60-70 lbs.	1
	about 60 lbs.	1
	40-70 lbs.	1
Change of clothing before hiking	do not change clothing	2
Garments Typically Worn		
Layers worn on the upper body	prefers to wear layers	4
	synthetic wicking layer	3
	lightweight fleece insulation layer	3
	down or synthetic fiber fill vest	2
Cold sensations felt when not wearing layers	if layers are removed, only feels cold after hiking has stopped	2
Features of base layer shirt example	polyester or polyester/spandex blend	4
	single knit jersey	4
	long sleeve	3
	short sleeve	2
	crew neck	2
	underarm gusset	2
Cost of shirt example	$30-$40	2
	$70-$80	2
What subject does not like about shirt example when hiking	Discomfort under waist belt or shoulder straps	4
	Fabric/seam chafing under waist belt	2
	Seam/armscye chafing	2
	Not long enough	2

* This table is a summary of responses that occurred more than once. Some responses that occurred once are included, because no two subjects had the same responses to that topic question

Table 2b: Summary of Qualitative Interview Responses

Question Topic	Response	Number of Responses
Preferences		
Material Preferences	prefers to wear synthetic materials	3
	prefers to wear wool	2
	prefers to wear lightweight baselayer	2
	prefers to wear soft materials against the skin	2
Reasons for Material Preferences	wool wicks moisture	1
	wool stays warm when wet	1
	wool doesn't smell bad	1
	synthetic materials dry faster than wool	1
	polyester smells bad	1
	polyester wicks moisture	1
	cotton is not good to wear for hiking	1
Baselayer Shirt Style Preferences	collar	3
	partial length zipper	3
	long sleeve cuffs	2
	sleeve cuffs with thumb holes	2
	long back hem	2
	pockets to keep batteries warm	3
	a hood	2
Baselayer Shirt Functional Preferences	durable	2
	prevention of seams from chafing/being scratchy	4
Ideal baselayer shirt cost	willing to pay up to $50	2
	willing to pay $50-$100	2
Thermal and Moisture Comfort		
Warmth/dryness complaints about hiking clothing	Drafts at the waist due to short length	2
	Sleeves not long enough to cover wrist, hand	2
Body areas needing more thermal insulation	chest/core	4
	arms	2
	back	2
Body areas needing less thermal inslution	underarms	3
Body areas that get the most sweaty	back	4
	underarms	3

Backpacking Conditions Subjects indicated that winter weather conditions in the field areas of Second Nature, where backpacking takes place, are most commonly snowy and windy, but can also be sunny, dry, dusty, raining, or sleeting. All subjects responded that temperatures can range from 0˚F to 50˚F during the day. Three out of four subjects mentioned that a policy existed at their workplace that did not permit them to hike in temperatures below 11˚F.

Depending on the terrain being crossed, subjects all responded that the difficulty of hikes varied, and that snow also increased hike difficulty in the winter. Two subjects noted that winter hikes often occur on the road, where terrain is easier to navigate. One subject mentioned that hiking with Second Nature requires less physical exertion than hiking for his own enjoyment. The estimated weight of subjects' backpacks while hiking varied from 40 to 80 lbs.

Garments Typically Worn All of the subjects preferred to wear layers of clothing while hiking in the cold. The types of layers they reported typically wearing included a synthetic fabric wicking layer (3 occurrences), a lightweight fleece insulation layer (3 occurrences), and a synthetic fiber or down-filled vest insulation layer (2 occurrences). Additionally, some subjects reported wearing an outer shell jacket for wind and rain protection. One subject wore a wool base layer with a wool thermal insulation layer. Another subject felt self-conscious about the appearance of his tight-fitting wicking base layer, and for this reason, he typically wore a cotton t-shirt over his base layer "for fashion," even when the conditions were warm enough to wear the base layer alone. Two subjects noted that if they remove thermal insulation layers while hiking, they feel cold when they stop hiking.

Of the example base layer shirts that subjects showed to the researcher, 4 shirts were composed of wicking polyester fiber and 1 shirt was composed of 100% merino wool fiber. One subject provided two base layer shirt examples of polyester fiber. As for the base layer fabric structures, four shirt examples were made of single-knit jersey fabric. Commonly occurring style features in the example shirts were long sleeves (3 shirts), short sleeves (2 shirts), crew necks (2 shirts), and underarm gussets (2 shirts).

Base Layer Shirt Preferences Material The subjects reported that they prefer to wear synthetic materials (3 responses) or wool fibers (2 responses) when hiking. One subject liked both synthetic and wool fibers, and preferred to wear either material. Subjects' reasons for preferring synthetic materials were that:

- Synthetic materials wick moisture
- Synthetic materials dry faster than other materials.

The reasons that subjects preferred wool were that:

- Wool wicks moisture
- Wool stays warm when wet
- Wool doesn't smell bad

One subject preferred shirts that incorporated different thicknesses of material, and had greater thermal insulation in the core of the body than other areas.

Style The most frequently occurring style feature preferences for base layer shirts were: a collar (3 responses), a partial-length zipper (3 responses), small pockets (3 responses), long cuffs (2 responses), cuffs with thumb holes (2 responses), a long hem (2 responses). Some subjects had more specific preferences, such as: a pocket located on the sleeve and a stripped seam at the collar to prevent distortion.

Function Additional functional preferences for base layer shirts included durability (2 responses), and the prevention chafing or scratching (4 responses). Subjects cited some features that may contribute to chafing or scratching, such as seams at the hip belt, underarm, or top of shoulder; scratchy stitches; and tags.

For an ideal base layer shirt incorporating their major preferences, subjects responded that they would be willing to pay from $45 to $100. Some subjects acknowledged that they would be willing to pay more for certain clothing fibers, like wool, than others.

Base Layer Shirt Dissatisfactions Regarding the typical base layer shirts the subjects provided as examples to the researcher, the subjects were dissatisfied with the short hem lengths (2 responses), the short sleeve lengths (2 responses), the discomfort of shirts under the backpack shoulder straps and hip belt (4 responses), seam chafing at the underarm (2 responses), and fabric or seam chafing at the waist belt (2 responses). Subjects responded that they had paid anywhere from $25 to $80 for their base layer shirts, with a price ranging form $30 to $40 being the most popular choice.

Body Locations Needing Better Thermal or Moisture Comfort The most commonly cited complaints about shirts that the subjects' typically wore were short hem lengths and short sleeve lengths. This is mainly because their short length allowed cold air to reach the skin. As for specific areas of the body needing thermal comfort, the subjects indicated that the chest/body core (4 responses) and arms (2 responses) need more thermal insulation than other areas of the body. The subjects responded that the areas of the body that needed less thermal insulation were the back (2 responses) and the underarms (3 responses). However, the subjects were not specific as to whether the upper or lower back needed less insulation. As for moisture comfort, the majority indicated that the following body areas sweat the most during activity: the back (4 responses), and the underarms (3 responses).

Discussion of Qualitative Interview Themes

Backpacking Conditions From the variety of responses given about the backpacking conditions experienced by the subjects while working for Second Nature, it can be summarized that winter conditions were snowy and windy, and the day time temperatures ranged from 0˚ to 50˚ F. The weather can vary considerably in the high dessert environment in the winter, as shown in the subject responses, which also included sunshine, dust, and sleet. Likewise, the difficulty of hikes varied, and were dependent on the individual, the abilities of others in the hiking group, the weather, and the terrain. As it is a company policy not to hike in certain conditions, it was agreed by most subjects that they did not hike in temperatures below 11˚F.

Garments Typically Worn The subjects were generally aware of the thermal and moisture needs of their bodies while hiking, and had some knowledge of materials and clothing systems. Most subjects tended to wear layers while hiking in the cold. These layers included synthetic fabric wicking layers, long-sleeve base layers, lightweight fleece insulation layers, and synthetic fiber or down-filled vest insulation layers.

Clothing Preferences and Dissatisfactions Subjects' clothing preferences differed slightly from the features of the garments they typically wore while hiking. The most common clothing fibers the subjects preferred were synthetic materials and wool. A variety of reasons were provided for these preferences, but in general, it was stated that both of these materials wick moisture, and that synthetic materials dry quickly. One subject in favor of wool, "Nate," noted:

> *It's not literally warm, but it doesn't hold the cold if that makes sense. Not the way the polyester stuff does. And, it doesn't stink either. The other stuff—the blended stuff stinks. It holds your body odor in it really well. And it gets stinky—really stinky. I've found that wool doesn't do that. And it insulates when it's wet.*

On the other hand, "Matt" responded:

> *"I do definitely tend to have synthetic stuff on when I'm hiking. I'm thinking about my reason behind it, and it seems like that dries more quickly when I've stopped—whereas wool will stay warm, but it will stay wet longer—whereas synthetics will dry."*

While all subjects had specific clothing material preferences, subjects differed in their knowledge of materials. Some knew specific properties of fibers used in their clothing, while others were unable to distinguish between fiber types. "Polypro" was used by more than one subject to describe wicking synthetic fiber garments, and was a term applied to both polypropylene and polyester shirt examples. Some subjects were also concerned with the softness of the base layer material, stating that they did not want a material that felt like plastic against their skin.

The overall concern with style features of base layer shirts was directed towards warmth and comfort. The subjects indicated that they would prefer a collared shirt, to prevent drafts from reaching the neck, along with a partial-length zipper to allow them to ventilate heat when hiking. Length was a concern, particularly the back length of the shirt and the length of the arms. The subjects reported that they did not want gaps in between the shirt and pants, or the shirt cuffs and gloves, where cold drafts could reach the skin. Subjects preferred to have thumb-holes in the sleeves of shirts, to allow them to pull the shirt cuff over the palm of their hand for additional warmth: *"So instead of the cuff cutting off at the wrist or below the wrist, it kind of comes up to the base of the palm.*

Just. . . for me that helps in warmth. . . .your top layer isn't over it scrunching it back." A major preference among all of the subjects was that seams, stitching, and fabrics should not chafe the skin. The subjects specifically identified the locations of the chafing occurring under the backpack shoulder straps, under the waist belt, and in the underarms.

In addition to comfort concerns expressed, the subjects had practical concerns about style features. They preferred their base layer shirt to have a pocket for battery storage. The majority of subjects responded that they removed batteries from cell phones and electronics when not in use, and had to keep them close to the body in pockets to keep them from freezing. The durability of hiking clothing was another concern, with subjects noting their problems with snags in knit garments, and buttons and snaps being lost.

Body Locations Needing Better Thermal or Moisture Comfort When asked about their complaints with hiking clothing that the subjects typically wore, most subjects did not initially have problems with warmth or dryness, aside from those due to the length and style of the garment, as listed above. When asked to consider their comfort while hiking and if any body areas need less or greater thermal insulation, the majority of subjects responded that the arms and core/chest need greater thermal insulation than other body areas. In terms of moisture and body cooling when hiking, they reported that their underarms and backs became more sweaty than other body areas, and that less thermal insulation was needed in these locations. The subjects were not specific as to whether their upper backs or lower backs needed less insulation.

Design Criteria

From the qualitative interview, criteria were developed for designing a prototype backpacking shirt. The most frequently occurring responses to interview questions about garment design features and preferences were listed in Table 3. The matrix summarizes design priorities that were considered in the selection of fabrics to be tested, the application of different fabrics in different body areas, and the design of the prototype shirt. These design criteria are discussed in the subsequent sections.

Table 3: Design Criteria Matrix

Fabric and Material Properties						
Synthetic Materials	XXX					
Wool	XX					
Knit Material	XXXX					
Lightweight Material	XX					
Soft Material	XX					
Fabric Function and Garment Areas						
	Core/Chest	Arms	Neck	Back (Overall)	Underarms	Side Torso
More Thermal Insulation	XXXX	XX	X			
Less Thermal Insulation		X		XX	XXX	X
Moisture Management	X			XXXX	XXX	
Important Design Features						
Collar	XXX					
Zipper	XXX					
A Hood	XX					
Long Sleeve Cuffs	XX					
Thumb Holes	XX					
Long Back Hem	XX					
Small Storage Pockets	XXX					
Non-Chafing Seam/Stitchings	XXXX					
Seam Chafing/Scratching Locations						
Shoulder	X					
Side/waist	X					
Waist (General)	XX					
Underarms	X					
Other Functions						
Durability:	XX					
Fabric should not tear easily	X					
Plastic snaps should not be used--break easily	X					

Key: X indicates (1) subject response

Fabric Materials and Properties

In order to design a single-layer backpacking shirt of various textile materials, the first step of the prototype development was the selection of the textile materials. In the selection of fabrics to be tested, synthetic, lightweight, and soft knit fabrics were the general criteria to be considered, based on the Design Criteria Matrix, as shown in Table 3. Wool fiber fabrics were not considered for testing purposes, due to the unavailability locally of an appropriate wool knit fabric for thermal insulation testing, and due to the fact that previous literature has concluded that wool has inferior results when tested for moisture management, in comparison to wicking synthetic materials.

Thermal Insulation Fabric Testing and Selection The three fabrics selected for thermal insulation testing were polyester fleece pile weft knit fabrics. The results of testing the thermal insulation fabrics are summarized in Table 4. In addition to thermal insulation properties, fabric sample 1 was advertised as having additional moisture management properties, while fabric sample numbers 2 and 3 were advertised as having wind resistance. These fabrics were selected for testing due to their fiber content, soft hand feel, and light weight being consistent with the design criteria. Additionally, the wind-resistant fabrics were tested due to the subjects' interview information that the field area could be windy in the winter. In terms of thermal resistance, fabric sample 3 had the highest intrinsic thermal resistance (I_{cl}), with a Clo value of 6.17 per inch thickness of material. Samples 1 and 2 had Clo values of 4.76 and 4.28, respectively, per inch of fabric thickness.

Table 4: Summary of Thermal Insulation Fabric Testing

Sample Number	**Fabric Name**	**Fabric Structure**	**Fiber Content**	**Fabric Thickness**	**Fabric Weight (oz/yd^2)**	**Intrinsic Thermal Resistance (Clo)**	
						I_{cl} per 1-layer of fabric	**I_{cl} per in. thickness**
* 1	Polartec® Power Dry® Textured	pile weft knit	100% polyester	1.864 mm .073 in.	6.537	0.35	4.76
2	Polartec® Wind Pro® Velour	pile weft knit	49% Polyester/ 36% nylon/ 15% spandex	2.23 mm .088 in.	9.58	0.376	4.28
3	Polartec® Windbloc® Survivor	pile weft knit	100% Polyester with Vapex membrane	2.86 mm .113 in.	8.517	0.697	6.17

* Selected for prototype shirt for the purpose of thermal insulation

Although fabrics with good thermal insulation do not necessarily provide good moisture management properties, to ensure the selection of an optimal thermal insulating fabric for the prototype shirt, moisture management tests were also conducted on these 3 polyester fleece pile knit fabrics. Table 5 displays the moisture management testing results of the 3 laundered fleece pile knit fabrics. Fabric moisture management properties tested included the maximum wetted radius top and bottom, and one-way moisture transport capacity. Liquid is dropped from the moisture management tester onto a fabric and spreads across the top and bottom of the fabric surfaces as it is absorbed. The maximum wetted radii are measurements of the spread of moisture, with a greater wetted radius on the bottom (outside) surface of the fabric than the top (inside) surface indicating a better ability to transport moisture. One-way transport capacity is defined as the transfer of moisture from the inside to the outside of the fabric, and is calculated by subtracting the area of the moisture spread on the top surface from the bottom surface and dividing this number by the total time of the test.

Table 5: Summary of Moisture Management Fabric Testing

	Sample Number	Fabric Name	Fabric Structure	Fiber Content	Fabric Thickness	Fabric Weight (oz/yd^2)	One-Way Moisture Transport Index	Maximum Wetted Radius Top (MWR_T) (mm)	Maximum Wetted Radius Bottom (MWR_B) (mm)
*	1	Polartec® Power Dry® Textured	pile weft knit	100% polyester	1.864 mm .073 in.	6.537	869.52	0.00	25.00
	2	Polartec® Wind Pro® Velour	pile weft knit	49% Polyester/ 36% nylon/ 15% spandex	2.23 mm .088 in.	9.58	-798.49	5.00	0.00
	3	Polartec® Windbloc® Survivor	pile weft knit	100% Polyester with Vapex membrane	2.86 mm .113 in.	8.517	-636.6875	5.00	0.00
**	4	Polartec ® Power Dry® Mesh	Mesh knit/pique knit	100% polyester	.68 mm .027 in.	3.99	93.57	26.00	26.00
	5	Polartec® Power Dry® Silk Weight	Single knit plain jersey	100% polyester	.46 mm .018 in.	3.866	185.15	25.00	25.00
	6	Wicking Polyester Grid	Jacquard jersey	100% polyester	.568 mm .022 in.	5.204	67.51	25.00	25.00
	7	Nike Dri-FIT	Single knit plain jersey	88% polyester / 12% spandex	.613 mm .024 in.	5.189	92.9	21.00	23.00
	8	Nike Dri-FIT	Single knit plain jersey	88% polyester/ 12% spandex	.77 mm .03 in.	9.053	92.55	15.00	20.00
	9	Polartec ® Power Dry® Mesh	Mesh knit/pique knit	100% polyester	.606 mm .024 in.	4.715	50.21	23.00	24.00
***	10	Brushed Wicking Polyester	Double knit	95% polyester/ 5% spandex	.87 mm .034 in	6.91	0.897	17.50	20.00

* Selected for prototype shirt for the purpose of thermal insulation
** Selected for prototype shirt for the purpose of moisture management
*** Selected for prototype shirt as the control fabric

A high one-way transport capacity is associated with a greater quantity of moisture transported over a given period of time, and thus, faster moisture wicking. As can be seen in Table 5, sample 1 had a high capacity for one-way moisture transport, with a value of 869.52. Samples 2 and 3 exhibited negative one-way transport capacities of -798.49 and -636.6475, respectively. These results indicate samples 2 and 3 would have limited ability to transfer moisture from the body to the outside of the fabric, and would allow sweat and moisture vapor to accumulate within the clothing. During the test, the water dripped by the Moisture Management Tester onto samples 2 and 3 produced a bead of water on the surface. One of the reasons for the low moisture transfer abilities of these fabrics may be due to the windproof membrane (sample 3) or finish on the fabric surfaces. On the other hand, sample 1 had a high capacity for one-way transport, indicating the efficiency of the fabric in moving moisture from the inside surface to the outside surface of clothing.

Although fabric sample 3 had the highest Clo value among the 3 samples tested, sample 1 was selected for use as the thermal insulation fabric in the prototype, due to the high value of thermal resistance per material thickness (4.76 Clo), and due to the fact that the material did not inhibit moisture transfer.

Moisture Management Fabric Testing and Selection The six fabrics selected for moisture management testing, based on the characteristics identified in the Design Criteria Matrix (Table 3), were polyester fiber or polyester/spandex blend knit fabrics. Although their knit structures, fabric weights, and fabric thicknesses varied, all of the fabrics tested were advertised as "wicking." Fabric samples were laundered once before testing. Table 5 displays the results of moisture management testing, showing the one-way transport capacities and maximum wetted radii top and bottom for these 6 fabrics (samples # 4-9). Fabric sample number 5 exhibited the highest one-way transport capacity of all of the moisture management fabrics tested, at 185.15. Samples 4, 7, and 8 also demonstrated good one-way transport capacity, with results of 93.57, 92.9, and 92.55, respectively. In addition to one-way transport capacity, the maximum wetted radii should be considered when selecting a fabric for a moisture management application. Fabric samples 4, 5, 6, and 9 had large top (inside) wetted radii, and their top and bottom (outside) radii measurements were similar. Samples 7 and 8 both had smaller top (inside) wetted radii than bottom (outside) wetted radii, which means the moisture traveled through the fabric from the inside to the outside surface, prior to spreading. Fabric thickness may also have had an effect on the moisture management test results, with the thinnest fabric having the highest one-way transport index (sample 5), and the thickest fabric having the smallest wetted radii (sample 8). Overall, there were inconsistencies in the data collected for each sample. The results shown in Table 5 are averages with outlier results removed.

Ideally, a good moisture management fabric should exhibit a high one-way transport index, a low top (inside surface) wetted radius, and a high bottom (outside surface) wetted radius. This means that when the moisture contacts the inside surface of the fabric, it will quickly travel through the fabric and spread on the outside surface in order to evaporate. Fabric sample numbers 4 and 5 were being considered for the shirt prototype, because these fabrics exhibited the highest one-way transport capacities, and had more consistent data in all test results. Although samples 7 and 8 show high one-way transport capacities, low top wetted radii, and high bottom wetted radii, these fabrics had too much inconsistent data throughout the tests. Ultimately, sample 4 was selected for use in the shirt prototype, even though it had the second highest one way moisture transport capacity (next to sample 5). This is because sample 4 was slightly thicker than sample 5, allowing for a better transition between the thick thermal insulation fabric and thin moisture management fabric in the shirt design. Additionally, sample 5 snagged easily when exposed to anything rough, including fingertips, developing runs. This property helped to rule out the use of sample 5 in the prototype, since one of the design criteria included durability.

Control Fabric Testing and Selection Although fabric samples number 7 and 8 were not considered in the selection for the purpose of moisture management, they were considered for use as the control fabric material. The control fabric was intended to be similar to the fabric types in the interview subjects' own backpacking base layer shirts, which were polyester, plain knit jersey fabrics. However, the researcher was not able to obtain sufficient quantities of these materials, and an additional fabric (sample #10) was selected for the control fabric (Table 5). This material was selected primarily to be consistent with the design criteria in fabric thickness and hand. The fabric is made of a polyester and spandex fiber blend, has a double knit fabric structure, and has a brushed inside surface. The brushed surface creates a soft hand feel, consistent with the subjects' request for a material that is soft against the skin. This material was advertised as "wicking;" however, the moisture management data do not indicate that this fabric has good moisture management properties. The lack of moisture management ability was not a concern, since the control fabric was being selected for areas in the prototype shirt that did not require moisture management fabric, and since this fabric was serving as a control to which the prototype was being compared.

Prototype Development

Design Criteria Based on the design criteria identified from the subject interview responses as shown in the Design Criteria Matrix (Table 3), a prototype shirt was developed. The locations of the different textile materials for thermal insulation and moisture management properties, as well as the desired design features and seam locations were considered.

For the location of the different textile materials on the prototype shirt, the chest and the arms were determined by the subjects to be areas needing more thermal insulation than other places on the body while hiking. Contrastingly, it was indicated that the back and the underarms are locations on the body that need less thermal insulation and, instead, moisture management materials.

The most important style features to be considered in the design of the prototype garment were non-chafing seam locations and stitching, a collar, a zipper, small storage pockets, long sleeve cuffs, thumb holes, a long back hem, and a hood. Durability was also considered an important aspect of the overall garment design. The researcher incorporated all of these features in the design of the prototype garment, except for a hood. A hood was excluded from consideration, because only 2 responses for a hood were referenced, and because inconsistencies could have resulted from subjects wearing and removing the hood while completing the wear tests. Seam chafing, in general, was considered to be a priority in the design/construction of the prototype. Although the waist was indicated as the area of greatest concern with chafing, all body areas were examined for chafing possibility in the selection of seam type. The sides of the body, the underarm, and the shoulders were considered when determining seam locations. The sides of the body around the waist presented a difficulty, due to the fact that the garment needed to have had at least one seam at the waist. Further, incorporation of multiple fabrics at the sides of the body made eliminating seams at the waist a challenge.

Prototype Design The researcher applied thermal insulation and moisture management fabrics on the prototype shirt (Figures 5 & 6) in accordance with the Design Criteria Matrix. The selected thermal insulation fabric was located on the arms and the chest of the shirt. The moisture management fabric was placed in a panel at the upper back, in the underarms, and along the sides of the shirt. The researcher chose to use the moisture management fabric on the upper back of the shirt, rather than on the entire back, due to the function of the moisture management fabric and wearing of a backpack. In order for fabric to wick liquid, it must be in contact with the skin and must be wetted (Kissa, 1996). When wearing an internal frame backpack, the pack stands rigid against the wearers' back, and is primarily in contact with the upper back and the waist. A shirt with fitting ease would touch the skin consistently at the upper back and waist only; therefore, the researcher decided that the moisture management fabric needed only to be located on the upper back. Additionally, the moisture management fabric was located at the sides of the garment to allow for heat dissipation. This was because the fabric had an open structure, and according to previous literature the greatest amount of heat is able to dissipate from a garment if breathable fabrics are located at the side seams (Ho et al., 2008). Constructing a garment with small fabric pieces posed a challenge, and to simplify the construction of a garment, the researcher chose to continue the moisture management fabric in a panel from the sides of the body through the underarm, forming a gusset. The control base layer fabric was used on the lower torso (front and back), the sleeve cuffs, the collar, and the pocket on the arm.

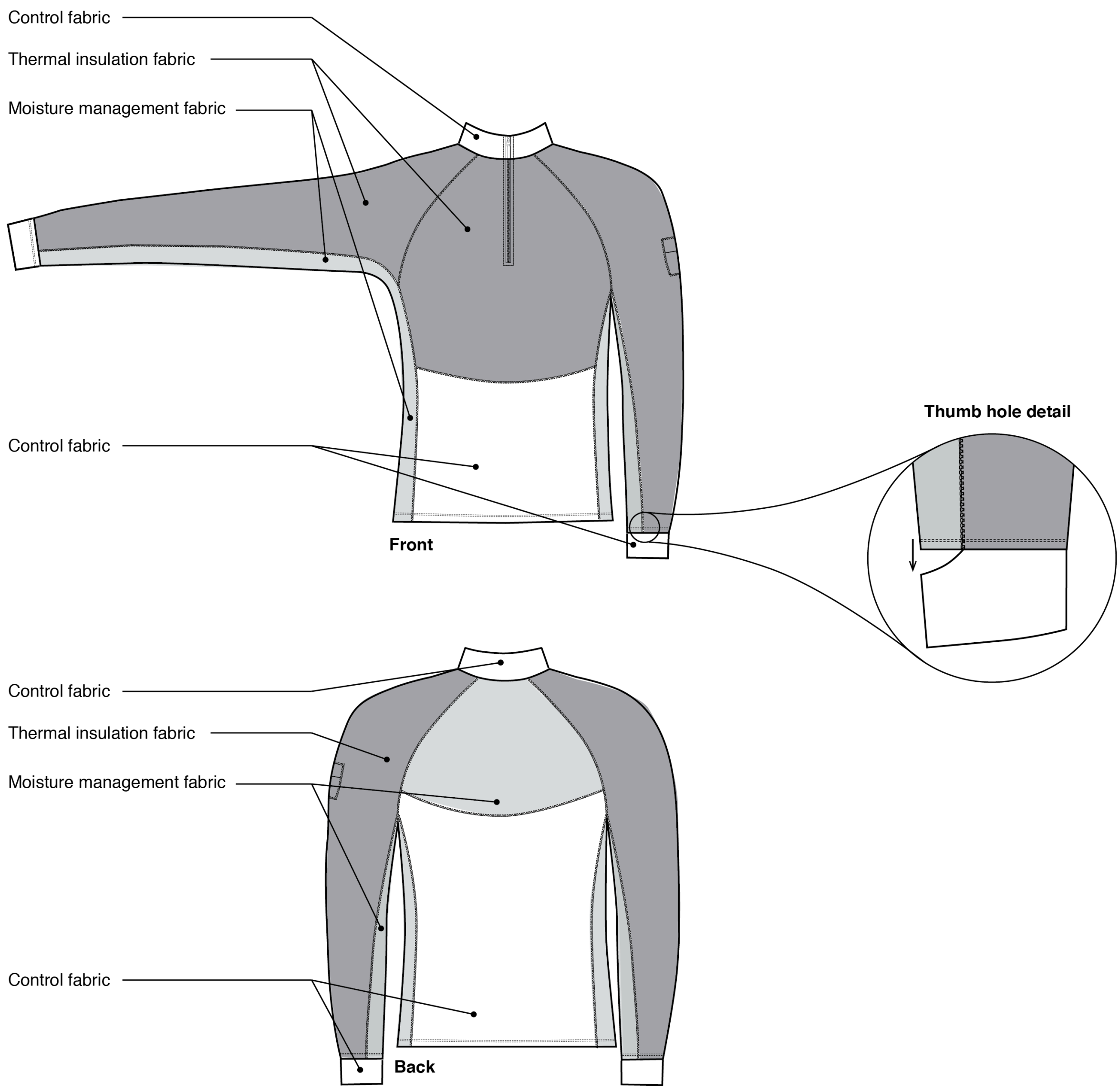


Figure 5: Prototype Shirt Technical Drawings

The control fabric was used in these areas because they were places on the body or style features that the interview subjects did not identify as needing thermal insulation or moisture management fabric. However, it is expected that the control fabric, with a brushed inside surface and double knit structure, will provide a soft hand feel to the skin.

Figure 6: Prototype Shirt Front and Back Views on Model

The prototype shirt was designed with a standing collar, a partial-length zipper, raglan sleeves, underarm gussets, cuffs, and thumb-holes. The standing collar and partial-length zipper were included based on subject preferences for both retention and ventilation of heat. Raglan sleeves were incorporated to prevent a seam from being located on the shoulder of the shirt and to provide for extra range of motion. As the subjects preferred to pull sleeves over their hands for warmth, thumb holes were placed in the sleeves. Cuffs were utilized as part of the thumb-hole design, with the seam between the ends of the sleeves and the cuffs being a convenient place to locate a hole for a thumb. The underarm gusset was included to simplify the design and construction and to allow for the use of the moisture management material in the underarms. The underarm gusset and the moisture management material continue along the length of the sleeves and along the sides of the shirt.

The length of the shirt hem and the sleeves were also noted to be important design criteria. The shirt was designed to be hip-length, to allow it to be tucked into pants and to extend past the hip-belt of a backpack. The sleeves of the shirt were made long enough that the wearer could pull sleeve cuffs over the palm of his hand and tuck his thumbs into the thumb-holes.

Prototype Construction The experimental prototype and the control shirts were constructed identically. The selection of seam and stitch types were somewhat limited by the equipment available to the researcher. The researcher chose to use lapped seams with flatlock serged stitches for all garment assemblies, except for the cuffs, collar, and the zipper. Flatlock stitches were selected for comfort, since they produce a flat, smooth joining of material with minimal thread on the inside of the garment. The drawback of the flatlock stitches was that they did not allow the fabric to consistently lap with the different thicknesses of materials used on the shirts, and in places created a raised seam on the outside of the shirt. Comfort was also considered with the zipper placement, and zipper guards of the control material were used on the inside of the shirts to protect the skin from the zipper teeth.

Quantitative Wear Test: Comfort Sensations

Table 6 shows the individual subjects' responses to the quantitative wear test questions for each comfort sensation. The means and standard deviations of the 7 individual comfort sensations and the overall comfort ratings for the prototype and control garments are displayed in Table 7. P-values for the significant differences between the prototype and the control garments according to the 7 comfort sensations and overall comfort have also been reported, as shown in Table 8. As mentioned in the Chapter III Protocol, each subject expressed his perception of the garment being comfortable or uncomfortable according to seven comfort sensations (sticky, clammy, damp, clingy, cold, hot, and breathable). These perceptions were rated on an 11-point scale of (0) "not at all" to (10) "extremely." Likewise, the overall comfort was measured on a scale of (0) "not at all comfortable," to (10) "extremely comfortable." In the case of the sensations "sticky," "clammy," "damp," "clingy," "cold," and "hot," a lower rating indicates that the subject felt less of that sensation, and thereby felt greater comfort. A higher rating demonstrates a greater feeling of these sensations and the failure of the garment to provide thermal or moisture comfort. In contrast, for the sensations "breathable" and "overall comfort," a higher rating indicates greater comfort.

Table 6: Quantitative Questionnaire Responses

	Subject 1 Trial 1		Subject 1 Trial 2		Subject 1 Trial 3		Subject 2 Trial 1		Subject 2 Trial 2		Subject 2 Trial 3		Subject 3 Trial 1		Subject 3 Trial 2		Subject 3 Trial 3	
Garment	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**
Test Conditions																		
Time spent hiking (hrs.)	6+	2 to 4	6+	less than 2	less than 2	less than 2	less than 2	2 to 4	2 to 4	2 to 4	less than 2	2 to 4	2 to 4	less than 2	less than 2	2 to 4	less than 2	less than 2
Exertion (1-5) 1=low, 5=high	3	3	5	1	3	5	3 to 4	2	2	2	2	2	3	4	3	2	3	2
Temperature range (˚F)	26-36	29-36	17-26	20-50	20-30	35-40	38-46	29-43	40-42	26-40	45-49	36-41	33-37	43-46	40-42	40-42	42-49	48-52
Wind (1-4) 1=no wind, 4=very windy	2	1	3 to 4	2	3	1	1	2	3	2	2	2	2	1	2	3	4	3
Precipitation (1-4) 1=no precip., 4=heavy	1	1	1	2	2	1	1	1	2	1	1	2	1	1	1	3	1	1
Sun (1-4) 1=cloudy, 4=full sun	4	4	3	3	2	2	3	2	2	2	3	2	4	2	3	1	2	3
Length of wearing (hrs.)	13 to 17	17+	17+	17+	17+	less than 8	8 to 12	13 to 17	13 to 17	13 to 17	8 to12	8 to 12	13 to 17	8 to 12	8 to12	17+	17+	17+
Other garment worn with test shirt?	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes/ No	No	Yes	Yes	Yes
How zipper worn	1/4 dn	1/4 dn	1/4 dn	1/4 dn	1/4 dn	dn	dn	up	up	up	up	dn	dn	dn	dn	dn	dn	dn
Comfort Ratings																		
Sticky	0	0	3	0	0	0	0	0	0	0	-	0	0	0	0	0	1	0
Clammy	0	0	9	0	1	0	0	0	2	0	-	0	0	4	0	0	1	0
Damp	0	0	1	0	0	0	3	4	3	0	5	2	3	4	-	1	3	0
Clingy	0	0	1	3	0	2	0	0	1	0	-	0	0	0	1	0	2	0
Cold	2	4	0	2	6	0	0	0	0	0	-	2	2	1	6	2	6	3
Hot	1	0	9	0	0	0	3	2	1	1	-	0	5	7	5	0	3	2
Breathable	7	6	2	5	3	10	7	8	8	9	7	7	8	5	8	7	6	8
Overall Comfort	8	8	4	7	8	9	8	-	8	9	8	8	8	8	9	9	9	10

0 = not at all, 10 = extremely

Table 7: Means and Standard Deviations of Comfort Ratings by Comfort Sensation

	All ratings Mean ± SD		Subject 1 Ratings Mean ± SD		Subject 2 Ratings Mean ± SD		Subject 3 Ratings Mean ± SD		Trial 1 Ratings Mean ± SD		Trial 2 Ratings Mean ± SD		Trial 3 Ratings Mean ± SD	
Garment	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**
Sticky	0.5 ± 1.07	0 ± 0	1 ± 1.73	0 ± 0	0 ± 0	0 ± 0	0.3 ± .58	0 ± 0	0 ± 0	0 ± 0	1 ± 1.73	0 ± 0	0.5 ± .71	0 ± 0
Clammy	1.63 ± 3.07	0.44 ± 1.33	3.33 ± 4.93	0 ± 0	1 ± 1.41	0 ± 0	0.3 ± .58	1.3 ± 2.31	0 ± 0	1.3 ± 2.31	3.67 ± 4.73	0 ± 0	1 ± 0	0 ± 0
Damp	2.25 ± 1.75	1.22 ± 1.72	0.33 ± .58	0 ± 0	3.67 ± 1.15	2 ± 2	3 ± 0	1.67 ± 2.08	2 ± 1.73	2.67 ± 2.31	2 ± 1.41	0.3 ± .58	2.67 ± 2.52	0.67 ± 1.15
Clingy	0.625 ± .74	0.56 ± 1.13	0.33 ± .58	1.67 ± 1.53	0.5 ± .71	0 ± 0	1 ± 1	0 ± 0	0 ± 0	0 ± 0	1 ± 0	1 ± 1.73	1 ± 1.41	0.67 ± 1.15
Cold	2.75 ± 2.82	1.56 ± 1.42	2.67 ± 3.06	2 ± 2	0 ± 0	0.67 ± 1.15	4.67 ± 2.31	2 ± 1	1.3 ± 1.15	1.67 ± 2.08	2 ± 3.46	1.3 ± 1.15	6 ± 0	1.67 ± 1.53
Hot	3.38 ± 2.92	1.3 ± 2.29	3.33 ± 4.93	0 ± 0	2 ± 1.41	1 ± 1	4.3 ± 1.15	3 ± 3.61	3 ± 2	3 ± 3.61	5 ± 4	0.3 ± .58	1.5 ± 2.12	0.67 ± 1.15
Breathable	5.44 ± 2.22	6.89 ± 1.72	4 ± 2.64	7 ± 2.65	7.3 ± .58	8 ± 1	7.3 ± 1.15	6.67 ± 1.53	7.3 ± .57	6.3 ± 1.53	6 ± 3.46	7 ± 2	5.3 ± 2.08	8.3 ± 1.53
Overall Comfort	7.78 ± 1.48	8.5 ± .93	6.67 ± 2.3	8 ± 1	8 ± 0	8.5 ± .71	8.67 ± .58	9 ± 1	8 ± 0	8 ± 0	7 ± 2.65	8.3 ± 1.15	8.3 ± .58	9 ± 1

Ratings: 0 = not at all, 10 = extremely

C: Control Garment   P: Experimental Prototype

Table 8: P-values for Significant Differences Between the Comfort Ratings of Control and Prototype by Comfort Sensation

	All Trials and Subjects		Subject 1		Subject 2		Subject 3		Trial 1		Trial 2		Trial 3	
Comfort Sensation	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**
Overall Comfort	0.04	.01 < P < .05	0.19	P > .1	0.50	P > .1	0.50	P > .1	No differences in C & P data values		0.19	P > .1	0.17	P > .1
Clammy	0.21	P > .1	0.19	P > .1	0.50	P > .1	0.81	P > .1	0.98	P > .1	0.98	P > .1	0.17	P > .1
Clingy	0.61	P > .1	0.97	P > .1	0.50	P > .1	0.19	P > .1	No differences in C & P data values		0.61	P > .1	0.68	P > .1
Sticky	0.19	P > .1	0.50	P > .1	No differences in C & P data values		0.50	P > .1	No differences in C & P data values		0.50	P > .1	0.50	P > .1
Damp	0.10	P = .1	0.50	P > .1	0.50	P > .1	0.21	P > .1	0.97	P > .1	0.19	P > .1	0.17	P > .1
Breathable	0.20	P > .1	0.21	P > .1	0.17	P > .1	0.80	P > .1	0.86	P > .1	0.29	P > .1	0.19	P > .1
Hot	0.10	P = .1	0.19	P > .1	0.50	P > .1	0.39	P > .1	0.61	P > .1	0.19	P > .1	0.50	P > .1
Cold	0.15	P > .1	0.61	P > .1	No differences in C & P data values		0.91	P > .1	0.81	P > .1	0.81	P > .1	0.19	P > .1

Lower values for "breathable" and "overall comfort" indicate a failure of the garment to provide comfort in these areas.

Four subjects completed the qualitative interviews and wear test screening process. One subject that participated in the wear test screening did not meet the study requirements of being a current field staff member. This subject was an employee of Second Nature that occasionally worked as a field staff, and backpacked at least once a month. Since this subject did not meet the requirements, he was not considered for participation in the wear tests, and withdrew from the study. The three other subjects qualified and participated in the wear test phase of the study.

Mean Comfort Values Across All Trials and Subjects The mean comfort values for the prototype and control shirts across all trials and subjects are listed in Table 7. Figure 7 provides visual comparisons of the mean comfort ratings of the prototype and control for each comfort sensation across all subjects and all trials.

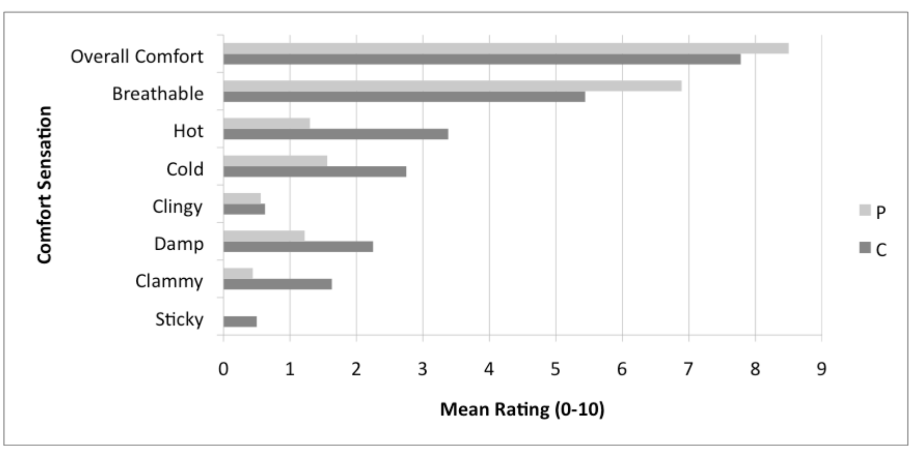


Figure 7: Mean Comfort Values Across All Trials and Subjects

Both the prototype and the control garments had low mean comfort values in the categories of "sticky," "clammy," "damp," and "clingy," indicating good moisture comfort in these categories for both shirts. For both garments, the mean "hot" ratings were low to neutral with scores of 1.3 $\pm$ 2.29 for the prototype and 3.38 $\pm$ 2.92 for the control. Likewise, the mean "cold" ratings were low to neutral, with ratings of 1.56 $\pm$ 1.42 and 2.75 $\pm$ 2.82 for the prototype and control, respectively. These scores suggest subjects perceived to have both shirts to have good thermal comfort. The mean comfort value for "breathable" was 6.89 $\pm$ 1.72 for the prototype and 5.44 $\pm$ 2.22 for the control, indicating that the subjects felt somewhat neutral about the breathability of both shirts. In addition, it is noteworthy that both the control and the prototype received high mean scores for overall comfort: the control received a mean rating of 7.78 $\pm$ 1.48 and the prototype received a mean rating of 8.5 $\pm$ .93.

P-values for Significant Differences Across All Trials and Subjects (Table 8) Wilcoxon Signed-Rank tests based on paired values of the prototype and the control, yielded a significant p-value only in the category of overall comfort. There is moderate evidence that the prototype had higher overall comfort scores than the control ($.01 < p < .05$).

Discussion Overall, both garments were perceived to have good to neutral comfort in all comfort sensation categories. Looking at the moisture ratings in particular, the expectation was that low to medium-low ratings for "sticky," "clammy," "damp," and "clingy," would correspond with high ratings for "breathable," because each of these comfort sensations are related to moisture management; however, the mean ratings for "breathable" were neutral. Subject 1's breathability ratings for both garments were slightly lower than those of the other subjects (Table 6), which affected the mean breathability scores. In trial 2, subject 1 perceived the control to be the least breathable of all trials. These ratings may be explained by the high physical exertion of subject 1 during this trial, which was higher than that of most other trials and subjects.

The only difference that can be concluded between the two garments across all trials and subjects was that the prototype had slightly better overall comfort than the control, as evidenced by the low p-value ($.01 < p < .05$).

Mean Comfort Values Across Subjects (Table 7) Subject 1 The mean comfort values for subject 1 were low for both garments in the categories of "sticky," "damp," and "clingy." The greatest differences between the control and prototype mean garment ratings were in the categories "clammy," "breathable," and "hot," where the prototype had slightly better ratings than the control. The mean "clammy" rating for the prototype was 0 ± 0, while the mean rating for the control was 3.33 ± 4.93. For "breathable," the prototype received a score of 7 ± 2.65 and the control received a score of 4 ± 2.64. For the category "hot," the mean score of the prototype was 0 ± 0 and the mean score of the control was 3.33 ± 4.93.

Subject 2 The mean comfort ratings for the categories "sticky," "clammy," "clingy," and "cold," were low for both garments, indicating that the subject 2 perceived both control and prototype garments to be comfortable in these areas. Both garments received high mean scores for "breathable" and "overall comfort." The prototype had a mean breathability score of 8 ± 1, while the control had a mean score of $7.3 \pm .58$. The overall comfort scores were 8.5 $\pm$ .71 and 8 $\pm$ 0, for the prototype and the control, respectively. There were no great differences between the prototype and the control in any comfort category. As seen in Table 6, subject 2 did not respond to several questions during his 3rd trial of the control, which provided fewer scores for the calculations of means in some comfort categories.

Subject 3 Both garments received low mean comfort ratings in the categories "sticky," "clammy," and "clingy." Similarly, both garments received high mean ratings for "breathable" and "overall comfort." The prototype had lower mean scores than the control in all categories except for "clammy" and "overall comfort." The prototype was perceived to be slightly worse than the control in breathability, with a mean score of 6.67 $\pm$ 1.53, in comparison to 7.3 $\pm$ 1.15. The greatest difference between the prototype and the control garments was in the category "cold," with the control receiving a mean rating of 4.67 $\pm$ 2.31 and the prototype receiving a rating of 2 $\pm$ 1.

P-values for Significant Differences Across Subjects (Table 8) Across subjects there were no significant p-values, thus, no difference was found between the prototype and control shirts.

Discussion In general, the subjects rated both garments to be comfortable in most comfort categories. However, there were large ranges in the ratings, and one garment did not have consistently higher ratings than the other.

Subjects' perceptions of the garments varied, and could have been related to external factors. For example, although subject 1 and 2 rated the prototype to be less "clammy" than the control, subject 3 perceived the prototype to be slightly more "clammy" than the control. Temperatures for subject 3's prototype test days were the same or slightly higher than those on the control test days (Table 6). The slightly higher temperatures may offer some explanation as to why the prototype was perceived to be slightly more "clammy" by subject 3. Additionally, in trial 2, the temperatures were the same for both subject 3's control and prototype test days; however, subject 3 wore additional outer clothing layers while wearing the prototype and did not wear additional clothing while wearing the control. Additional layers could have resulted in greater sweat accumulation, affecting the subject's perception of clamminess.

No conclusive evidence about a difference between garments can be drawn; however, both garments were rated by subjects to have good overall comfort, with mean values ranging from 6.67 $\pm$ 2.3 to 8.67 $\pm$ 0.58 for the control and 8 $\pm$ 1 to 9 $\pm$ 1 for the prototype.

Mean Comfort Values Across Trials (Table 7) Trial 1 Both the control and prototype garments received low mean scores in the categories "sticky," "clammy," and "clingy," and a high mean score in "overall comfort." The mean comfort ratings from all subjects for trial 1 indicate that the prototype had the same comfort performance as the control. The prototype had slightly higher mean ratings than the control for "clammy," "damp," and "cold," and a slightly lower mean rating in "breathable." The prototype and the control had the same mean ratings for all other comfort categories.

Trial 2 Both the prototype and the control had low mean scores in the categories "sticky," "damp," and "clingy" for trial 2. Likewise, both garments had relatively good scores for "overall comfort," with mean ratings of 8.3 $\pm$ 1.15 for the prototype and 7 $\pm$

2.65 for the control. The prototype had lower mean ratings than control for the categories "sticky," "clammy," and "hot." The greatest difference between scores occurred in the category "hot," with mean ratings of 5 ± 4 and $.3 \pm .58$ for the control and prototype, respectively.

Trial 3 In trial 3, there were low mean comfort values for both garments in the categories "sticky," "clammy," "clingy," and "hot." Both the prototype and the control received high ratings for overall comfort, with mean values of 9 ± 1 and $8.3 \pm .58$ for the prototype and the control, respectively. The prototype was given a slightly lower rating than the control in the category "clammy," receiving a score of 0 ± 0, compared to 1 ± 0. The greatest difference between the ratings of the prototype and the control occurred in the category of "cold," with the prototype receiving a score of 1.67 ± 1.53, compared to 6 ± 0.

P-values for Significant Differences Across Trials (Table 8) Wilcoxon Signed-Rank tests for paired values of the prototype and the control for trials 1, 2 and 3 do not yield any significant p-values. The p-values for each comfort category are greater than .1, indicating no statistically significant evidence that the prototype has better comfort performance than control in any of the comfort categories.

Discussion The mean comfort scores from each wear trial do not suggest any definite increase or decrease in the comfort of the garments that could have occurred with the affects of wearing and washing the garments over time. There were some slight increases or decreases in mean values across trials, but for many comfort categories, the mean ratings rose, fell, or stayed the same. For example, the mean "cold" ratings for the prototype are similar for the 3 trials with the man ratings 1.67 $\pm$ 2.08 for trial 1, 1.3 $\pm$ 1.15 for trial 2, and 1.67 $\pm$ 1.53 for trial 3.

Across trials, both garments were given low comfort ratings in the categories "sticky," "clammy," and "clingy," indicating good comfort in these areas. Both garments, likewise, received high "overall comfort" scores across the trials. Among the other comfort sensations, the ratings varied, and may be explained by differences in temperature, garment layers, and physical exertion during certain trials. For example, in trial 1 the prototype had higher ratings for "damp" and "hot" than can be seen in any other trials of the prototype. The higher ratings for "damp" and "hot" occurred with subjects 2 and 3, where temperatures were in the 40's for at least part of each trial (Table 6). Both subjects were also wearing additional clothing layers during these two trials, with subject 3 indicating that he removed his outer clothing layers during the hike. The exertion level of subject 3 was also relatively high (4) during this trial. Higher temperatures, additional clothing layers, and higher physical exertion may have caused greater heat build-up and excess sweating, causing the subjects to give the prototype high ratings for this trial. An additional explanation for the low ratings of the prototype in trial 1 may have been that subjects had less familiarity with the questionnaire at the beginning of the study and had less practice observing their comfort feelings. It should be noted, however, that the prototype trials always occurred after the control trials, so the subjects had answered one questionnaire prior to their first prototype trial.

The prototype received slightly lower scores than the control in several comfort areas, including "cold" and "clammy" in trial 2 and "sticky," "clammy," and "hot" in trial

3. The temperatures varied considerably in these trials, and do not seem to directly impact the prototype having better ratings in these categories. Other garments worn with the test shirts may have impacted the subjects' perceptions of comfort. For example, in trial 2 for subject 3, the temperatures were the same for both the prototype and the control garments (Table 6), but the subject wore no additional clothing layers when testing the control and did wear additional clothing when testing the prototype. Although the physical exertion was greater for the control than for the prototype in this trial, he perceived the control to be more cold than the prototype. In this case, a lack of additional clothing layers may have been a reason that the control shirt was perceived as more cold for trial 2.

Quantitative Wear Test: Combined Thermal and Moisture Sensations

The means and standard deviations of the combined scores for thermal and moisture comfort are displayed in Table 9. These have been calculated and placed in columns for all ratings (all trials and subjects), for each subject, and for each trial. Additionally, p-values for significant differences between the control and prototype based on combined thermal sensations are shown in Table 10.

The combined thermal comfort scores were calculated by pooling the comfort sensations "hot" and "cold," and the combined moisture comfort scores were calculated by pooling "clammy," "sticky," and "damp." Same as the individual comfort sensation ratings, the higher combined thermal and moisture ratings indicate less comfort that the subjects felt. The breathability and overall comfort shown previously are also displayed in Table 9, but were not included in the combined thermal or moisture calculations, and will not be discussed in this section. Breathability could not be included in the moisture comfort calculations, because the scale of values was opposite that of the other moisture comfort descriptors. "Clingy" was also not included in combined thermal and moisture calculations, due to discrepancies among subjects about the meaning of the word. The researcher did not define "clingy" for the subjects, and when later asked for their own definition, responses varied from "clingy" being related to moisture or "clingy" being a dry static sensation.

Table 9: Means and Standard Deviations of Comfort Ratings for Combined Comfort Sensations

	All Trials and Subjects Mean ± SD		**Subject 1 Ratings Mean ± SD**		**Subject 2 Ratings Mean ± SD**		**Subject 3 Ratings Mean ± SD**	
Garment	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**
Thermal Comfort	3.06 ± 2.79	1.44 ± 1.85	3 ± 3.69	1 ± 1.67	.8 ± 1.41	0.83 ± .98	4.5 ± 1.31	2.5 ± 1.73
Moisture Comfort	1.46 ± 2.12	0.46 ± 1.31	1.55 ± 2.96	0 ± 0	1.86 ± 1.95	0.67 ± 1.41	1 ± 1.64	1 ± 2.43
Breathability	5.44 ± 2.22	6.89 ± 1.72	4 ± 2.64	7 ± 2.65	7.3 ± .58	8 ± 1	7.3 ± 1.15	6.67 ± 1.53
Overall Comfort	7.78 ± 1.48	8.5 ± .93	6.67 ± 2.3	8 ± 1	8 ± 0	8.5 ± .71	8.67 ± .58	9 ± 1

	Trial 1: all subjects Mean ± SD		**Trial 2: all subjects Mean ± SD**		**Trial 3: all subjects Mean ± SD**	
Garment	**C**	**P**	**C**	**P**	**C**	**P**
Thermal Comfort	2.17 ± 1.72	2.33 ± 2.73	3.5 ± 3.01	0.83 ± .33	3.75 ± 2.87	1.17 ± 1.33
Moisture Comfort	0.67 ± 1.32	1.3 ± 2	2.25 ± 3.73	0.1 ± .98	1.57 ± 1.81	0.22 ± .67
Breathability	7.3 ± .57	6.3 ± 1.53	6 ± 3.46	5.3 ± 2	5.3 ± 2.08	8.3 ± 1.53
Overall Comfort	8 ± 0	8 ± 0	7 ± 2.65	8.3 ± 1.15	8.3 ± .58	9 ± 1

Thermal Comfort: combined ratings of "cold," "hot"
Moisture Comfort: combined ratings of "sticky," "clammy," "damp"
"Clingy" was not used in these calculations

Higher thermal and moisture ratings indicate less comfortable extremes of the comfort sensation. 0 = "not at all", 10 = "extremely"

Table 10: P-values for Significant Differences Between the Prototype and Control: Combined Comfort Descriptors

	All Trials and Subjects		Subject 1		Subject 2		Subject 3	
Comfort Sensation	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**
Thermal	0.05	P = .05	0.71	P > .1	0.50	P > .1	0.71	P > .1
Moisture	0.03	.01 < P < .05	0.05	P = .05	0.10	P = .1	0.50	P > .1

	Trial 1		Trial 2		Trial 3	
Comfort Sensation	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**	**P-Value**	**Conclusion**
Thermal	0.71	P > .1	0.10	P = .1	0.09	.05 < P < .1
Moisture	0.97	P > .1	0.03	.01 < P < .05	0.03	.01 < P < .05

Mean Comfort Values Across All Trials and Subjects (Table 9, Figure 8) As can be seen in Table 9, both garments had low to medium-low thermal comfort ratings, with the control having a mean rating of 3.06 $\pm$ 2.79, and the prototype having a mean rating of 1.44 $\pm$ 1.85. Similarly, the mean moisture comfort scores of both garments were low: the mean value of the control was 1.46 $\pm$ 2.12 and the mean value of the prototype was .46 $\pm$ 1.31. Figure 8 provides a visual of the low to medium-low combined thermal and moisture comfort scores. Also evident from Figure 8, is a slight difference in the mean ratings between the prototype and the control; however, based on the means and standard deviations, no conclusions can be made about a difference in comfort performance between the two garments.

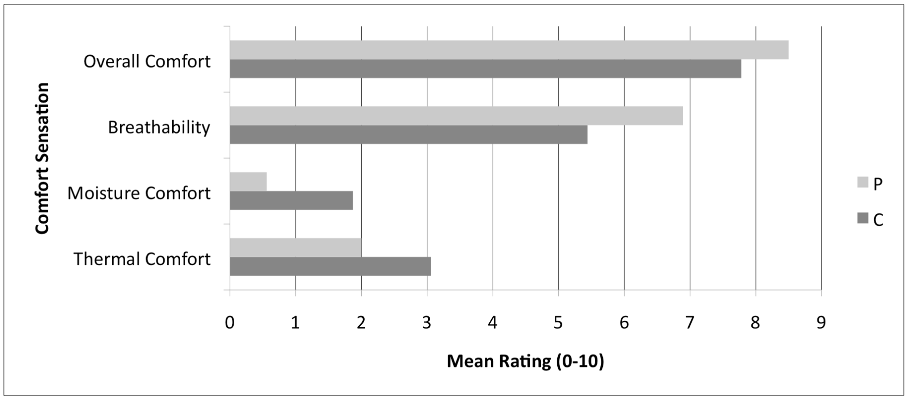


Figure 8: Means of All Comfort Values for Combined Thermal and Moisture Sensations

P-values for Significant Differences Across All Trials and Subjects P-values for significant differences between paired data in thermal and moisture comfort are displayed in Table 10. Among all trials and all subjects, there is suggestive evidence that moisture ratings of the control were significantly higher than those of the prototype ($p = .05$), and there is moderate evidence that thermal ratings of the control were significantly higher than those of the prototype ($.05 < p < .1$).

Discussion It is noteworthy that, over all trials and subjects, both garments scored low to medium-low in thermal and moisture comfort areas, indicating that both garments were moderately comfortable. Interestingly, the p-values indicate that the prototype was somewhat more comfortable than the control in thermal and moisture comfort, despite the fact that the means and standard deviations do not suggest a difference between garments. No simple explanation for these conflicting results can be offered, but it may be concluded that the differences found between the garments are only slight.

Mean Comfort Values Across Subjects (Table 9) Subject 1 The mean combined thermal and moisture comfort values for subject 1 were both low to medium-low. The mean thermal comfort values for the prototype and the control were 1 $\pm$ 1.67 and 3 $\pm$ 3.69, respectively. The mean moisture comfort value for the prototype was 0 $\pm$ 0, while the mean moisture comfort value for the control was 1.55 $\pm$ 2.96. There was no difference in the comfort performance of the two garments.

Subject 2 The combined mean thermal and moisture comfort values for subject 2 were also low. The prototype had a mean thermal comfort score of .83 $\pm$ .98, while the control had a mean thermal comfort score of .8 $\pm$ 1.41. Similarly, the moisture comfort scores of the prototype and control were .67 $\pm$ 1.41 and 1.86 $\pm$ 1.95, respectively. There were no significant differences in the comfort ratings of the two garments.

Subject 3 The mean combined thermal and moisture comfort scores according to subject 3 were, again, low to medium-low. In thermal comfort, the prototype and the control had mean ratings of 2.5 $\pm$ 1.73 and 4.5 $\pm$ 1.31, respectively. The mean moisture comfort score for the prototype was 1 $\pm$ 2.43 and the mean moisture score for the control was 1 $\pm$ 1.64. No difference can be determined between the comfort ratings of each garment.

P-values for Significant Differences Across Subjects Across subjects, a significant difference between garments was found with subject 1, the p-value giving suggestive evidence that the control moisture scores were higher than that of the prototype ($p = 0.05$). With all other p-values greater or equal to .1, no other conclusions about the difference between the garments can be drawn.

Discussion The mean combined thermal and moisture comfort values were low to medium-low for both garments and for each subject, indicating that all of the subjects felt reasonably comfortable when wearing either shirt. There were some variations in the mean ratings, based on each subject, which may be accounted for by differences in the trial conditions or clothing worn. Subject 3, for example, had a higher mean thermal comfort rating than other subjects for the control. Referring to Table 6, subject 3 did not wear additional clothing for his second trial of the control, despite the fact that the temperatures and physical exertion were similar to other trials where additional clothing was worn. His ratings of the control garment in this trial were medium for both “cold” (6) and “hot” (5). The lack of additional clothing may explain why the subject felt colder than other trials of the same shirt in similar conditions. Also, the subject reported partly sunny skies, a lack of precipitation, and a lack of wind on the trial day, so weather conditions could have had an influence on the higher rating for “hot.” The fact that the subject felt both moderately “cold” and “hot” while wearing the control shirt suggests that there could have been a change in conditions, such as change of physical exertion or cloud cover, that could not be detected by the questionnaire.

It can be noted that for all of the subjects, the mean thermal and moisture comfort values were higher for the control than for the prototype. Likewise, among the ratings for all subjects and trials, the p-values indicated that the prototype had slightly better thermal and moisture comfort than the control. However, a statistically significant difference across subjects was only found for subject 1 in moisture comfort. According to this subject, the prototype had slightly better moisture performance than the control. The larger amount of data from combining all subjects and trials allowed for more ability to see differences between garments than the small amount of data for each subject.

Mean Comfort Values Across Trials (Table 9) Trial 1 The mean combined thermal and moisture comfort ratings from trial 1 were low for both garments. The mean ratings for thermal comfort were 2.33 $\pm$ 2.73 and 2.17 $\pm$ 1.72 for the prototype and the control, respectively. The mean moisture comfort value for the prototype was 1.3 $\pm$ 2, and the mean moisture comfort value for the control was .67 $\pm$ 1.32. No difference in the comfort of the garments can be determined.

Trial 2 In trial 2 the mean thermal and moisture comfort ratings were low to medium-low for both garments. The mean thermal comfort rating of the prototype was .83 $\pm$ .33, and the mean thermal comfort rating of the control was 3.5 $\pm$ 3.01. The mean moisture comfort scores for the prototype and the control were .1 $\pm$ .98 and 2.25 $\pm$ 3.73, respectively. Although the mean comfort ratings were higher for the control than the prototype in both categories, there were large ranges in data, so no conclusion can be made about one garment having better ratings than the other.

Trial 3 Similarly, the trial 3 thermal and moisture comfort rating were low to medium-low for both garments. The mean thermal comfort score for the prototype was 1.17 $\pm$ 1.33, and the mean thermal comfort score for the control was 3.75 $\pm$ 2.87. The mean moisture comfort ratings for the prototype and the control were .22 $\pm$ .67 and 1.57 $\pm$ 1.81, respectively. Due to the variation in the data, there are no apparent differences in the comfort ratings of the prototype and the control.

P-values for Significant Differences Across Trials In both trials 2 and 3, there is moderate evidence that the control had significantly higher moisture ratings than the prototype ($.01 < p < .05$ for both trials). Additionally, trial 3 resulted in suggestive evidence that the control had higher thermal comfort ratings than the prototype ($.05 < p < .1$). All other p-values across trials were .1 or higher, showing no statistically significant evidence that the control had higher scores than the prototype.

Discussion In all trials, both garments had mean combined thermal and moisture comfort scores that were low to medium-low, indicating that both shirts were mostly comfortable in these categories.

There were some variations in the mean comfort scores according to trial. In Trial 1, for example, both the mean thermal and moisture comfort scores for the control are slightly lower than those for trials 2 and 3. One possible explanation that the control garment had lower values for the first trial could be the subjects' lack of familiarity with the questionnaire and wear test procedure. The first trial for the control garment was the subjects' first experience with the wear test questionnaire.

Aside from the thermal comfort ratings of the control garment becoming progressively worse in later trials, no specific pattern can be drawn about the comfort performance of either garment over time as subjects wore and laundered the garments. Previous information has suggested that the moisture management performance of some garments decreases with multiple launderings, however, this was not found when examining the mean ratings from the wear tests (B. Hurd, personal communication, May 2, 2011; McQueen, Batcheller, Olsen, & Hooper, 2012).

Statistically significant differences between the control and the prototype garment were found for moisture comfort in trial 2 and trial 3, suggesting that the control garment had slightly worse moisture comfort than the prototype in these instances. Trial 3 had significant p-values in thermal comfort, suggesting that there was at least some evidence that the prototype was more comfortable than the control in terms of thermal comfort. In comparison to the p-values across trial reported previously by each comfort sensation, the pooled ratings for thermal and moisture comfort provided more data for the estimation of a p-value, allowing for a greater ability to see differences between the ratings of the garments. The significant p-values from trials 2 and 3 confirm the slight differences between the prototype and the control garment that were seen in the means of the combined thermal and moisture comfort values (Table 10).

Wear Test: Open-Ended Questions (Table 11)

Comfort in Different Body Areas The subjects made only a few comments about body areas that felt uncomfortable while they were hiking in the test shirts. The only commonly occurring response was noted 2 times for both the prototype and control shirts. Subjects responded that their chins were uncomfortable due to the collar/zipper rubbing. This problem was noted by 2 different subjects, and was related to the fit of the collar and the placement of the zipper. They described the collar as being awkward when zipped, and one subject explained that the top of the zipper and the collar were too high, hitting his chin. Since the construction of the prototype and control garments were identical, the collar and zipper were a problem for both test shirts.

Table 11: Responses to Open-Ended Wear Test Questions

Question Topic	Response	Number of Responses: Prototype	Number of Responses: Control
Uncomfortable body areas	Chin, due to zipper	2	2
	Forearms, due to tightness/fit	1	0
	Back felt damp	1	1
	Neck, due to loose fit of collar	0	1
Would recommend shirt to other hikers	Yes	9	9
Other clothing worn over test shirt	Thermal insulation when not moving	2	2
	Light/thin shirt when moving	4	2
	Hard shell when moving	1	2
	Thermal insulation when moving	4	3
	Nothing worn over test shirt	2	2
How shirt zipper was worn	Unzipped 1/4 of the way for most of hike	2	3
	Unzipped for most of hike	5	4
	Zipped for most of hike	2	2
Durability	Loose threads	2	2
	Seam ruptures	3	2
Other/overall comments	*Positive*		
	Likes thumb-holes	1	1
	Likes size of pocket	1	1
	Comfortable	2	1
	Light	1	0
	Breathable	1	1
	Good fit	2	1
	Dried quickly	3	1
	Back does not feel as sweaty	1	0
	Underarms do not feel as sweaty	1	0
	Negative		
	Zipper awkward when zipped	1	1
	Lower half of shirt too loose	1	0
	Not breathable	0	2

There was one issue related to thermal and moisture comfort for the prototype shirt and one issue related to thermal and moisture comfort for the control shirt. Both of these comments were made by the same subject (subject 2), and occurred during the same trial week (trial 3). The subject stated that his back felt sweaty while wearing both shirts; however, it is possible that these comments could be explained by the conditions the subject experienced each day. During the control trial, subject 2 hiked during the highest temperatures of any trial he completed. The temperatures during the prototype test were not high, but it can be noted that the subject was wearing 3 other garment layers on top of the shirt during this wear trial. The subject may have produced more sweat during these trials due to the temperatures and/or his clothing layers, resulting in more moisture on his back.

Recommendation of Test Shirt to Other Hikers All of the subjects answered that they would recommend both the prototype and the control shirt to other hikers (Table 11). This response is consistent with and may be related to the mean scores for overall comfort (Table 7), which were greater than 6 for both shirts for all subjects and all trials.

Clothing Worn Over Test Shirt For the majority of the wear trials, the subjects had to wear additional clothing over the test shirt (Table 11). The additional clothing included thermal insulation layers worn during hiking breaks; and light/thin layers, hard shells, or thermal insulation worn while hiking. For a total of 4 out of 18 trials for the wear test, the subjects did not wear additional clothing over the test shirts. This occurred twice for the prototype and twice for the control. Reviewing Table 6, comparisons can be made between the trials that subjects did not wear additional clothing and the conditions of the trial. During subject 1's third trial of the prototype, the temperatures ranged from 35-40 ˚F, there was no reported wind or precipitation, and the subject's exertion level was 5 (high.) Although the temperatures were not high for this trial, the subject's high level of exertion may explain why no additional clothing was needed. The subject did not note any thermal or moisture problems with the shirt for this trial. During his first trial of the prototype, subject 3 began the hike wearing an additional clothing layer (a lightweight hooded shirt), which he removed partway through the hike due to overheating. The temperatures during this trial were slightly warm (43-46˚F), and the subject's exertion level was somewhat high (4). Both the temperatures and the exertion level may explain the need to remove the extra clothing worn during the hike. The subject noted that the shirt was clammy, damp, hot, and breathable for this trial. It is unclear whether these ratings were for the period of time the subject was wearing the additional layer or for the remainder of the hike, after the layer had been removed. Subject 2 did not require additional clothing during his third trial of the control shirt. During this trial, the temperature during hiking was warmer (45-49 ˚F), and his exertion level was lower (2). He notes the shirt as being somewhat damp (5), but breathable (7). He did not note any thermal problems, despite the fact that he felt "damp," presumably due to sweat build-up. The temperature range during this trial may help explain why the subject did not feel hot or cold, and why additional clothing wasn't worn. Subject 3's second trial of the control shirt occurred in temperatures ranging from 40-42˚F, warmer than some of the trials, and the subject's exertion level was medium (3). The subject perceived the shirt to be cold (6), hot (5), and breathable (8) during the trial. From the data, temperature may help to explain why no additional clothing was worn by the subject, but cannot explain why the subject felt both hot and cold while wearing the shirt. Overall, the temperatures and exertion levels were generally lower on days that subjects had to wear additional clothing on top of either test shirt. There was also little precipitation or wind reported on the days where no additional clothing was worn.

Despite the fact that the prototype shirt was designed to be worn without additional upper-body clothing layers, the subjects had to wear additional clothing during most of the trials due to the need of greater thermal, precipitation, or wind protection. From the reports of temperatures during which the subjects did not wear additional clothing, it can be concluded that the prototype shirt can be comfortably worn alone in temperatures greater than 35˚F, and that the control shirt can be worn alone in temperatures greater than 40˚F. The comfort when wearing the prototype shirt alone in various temperatures will depend on the subject's physical exertion, the precipitation, and the wind.

How Shirt Zipper Was Worn During the majority of the wear trials (14), the subjects wore the shirts unzipped in some way (Table 11). One subject (subject 1) specifically noted wearing the zipper ¼ of the way down or all of the way down. This subject also made comments about the zipper being uncomfortable at his chin, stating that he always had to wear the zipper at least ¼ down to be comfortable. Referring again to Table 7, he wore the zipper all of the way down during his last trial of the prototype, where temperatures were slightly higher than the other trials, and where his amount of physical exertion was the highest (5). His ratings for the breathability (10) and overall comfort (9) of the prototype indicate good garment performance with this temperature range and amount of exertion. The ability to open the zipper may have had an influence on the comfort during this trial.

Looking at all trials, there can be no overall conclusions drawn about the wearing of the zipper in relation to temperature or physical exertion. All of the instances of the zipper worn completely up were reported by subject 2, during trials where the temperatures and wind conditions slightly varied, and the physical exertion levels were low. Likewise, the conditions where the zipper was worn down by subjects vary, allowing no definite statements to be made about the temperature or physical exertion being related to how the zipper was worn. As subject 1 stated, however, the need for the zipper to be worn down may have been due to the discomfort of the collar and zipper placement at the chin. It can be concluded that providing a means to open the neck of the garment was useful, because it allowed for flexibility, whether the need to wear the zipper open depended on the garment construction or on physical conditions.

Durability The problems noted with the durability of the garments relate to construction only, and were loose threads (4 total occurrences) and seam ruptures (5 total occurrences) (Table 11). For seam ruptures, subjects did not indicate specific areas they occurred on a garment, and in some cases, referred to the same garment over different trials. (The garments were not repaired in between trials.) The subjects that reported loose threads did not report seam ruptures, and vice versa, although it can be assumed that when the seams ruptured, loose threads resulted. The prototype and control garments had identical construction, so the durability issues were divided equally among the two garments, with neither out-performing the other. However, there was an increase in durability problems as the garments were subjected to wearing and laundering, with more reports of loose threads and seam ruptures occurring in trials 2 and 3.

It is noteworthy that all instances of the seams rupturing occurred with subject 3, who wore the test shirts more frequently than just the wear test days. Subject 3 indicated that the seams did not stretch well when he put the garments on, causing the stitches to break. The durability issues with the seams and stitches are likely related to the flatlock stitches selected, which can unravel at seam intersections if not well tied-off, and which form looping stitches on the outside of the garment that can snag. The lack of seam elongation is related to the machine tension used with the flatlock stitches.

Other/Overall Comments There were positive comments made about both the prototype and the control garments, but the commonly occurring ones related to: breathability, comfort, fit, and drying time (Table 11). Two comments were made about the control garment not being breathable, one specifically was that: *"It is pretty thick and does not breathe well. Is good for a base camp base layer, as I didn't take it off all week, and is not good for hiking involving a high level of physical exertion."* Subjects made two comments about the prototype shirt being comfortable and one comment about the control shirt being comfortable. Comments about the fit or drying time of the shirts were made along with statements about the comfort. The prototype received remarks like: "*I really like the fit of this shirt. It moves well as a stand alone piece and doesn't bunch up under other layers. It seems like it is dry as soon as I stop sweating."* and *"My back feels less sweaty in this shirt than the other one. After I take my pack off. Likewise with my arm pits. It seems like it dries very quickly after I stop hiking."* The control shirt received a similar comment: *"Felt Great. I love the fit. It moves well and the seams off of the top of the shoulder were nice on the hike."* All together, there were 2 comments made about the good fit of the prototype, and 1 comment made about the good fit of the control. There were 3 responses that the prototype dried quickly and 1 response that the control dried quickly.

The number of positive and negative comments made varied with the subjects. Subject 1 had positive comments about the comfort of the prototype and negative comments about the control, while subjects 2 and 3 had positive comments about the comfort of both the prototype and the control. Subjects were asked if they had "any other overall comments or concerns" for this question, which resulted in the question not being answered for all wear trials. Some subjects repeated the same comment over multiple wear trials of the same garment. Additionally, if a subject replied about the design, construction, or fit of a garment, he often made the same comment for the other test garment.

Overall, in the "other/overall comments" section of the questionnaire, the prototype garment received 13 positive comments and the control received 6 positive comments (Table 11). There were 2 negative statements made about the prototype and 4 negative statements made about the control. The negative statements made about the prototype related to the fit of the bottom half of the shirt and the zipper hitting the subject's chin, while the negative statements made about the control also included breathability. Two subjects responded that the shirts in some way exceeded what they were currently wearing to hike in the field, one subject stating in regards to the prototype, "*This will be my shirt-of-choice for future rotations,"* and another stating that the control was *"Nicer than what I have been wearing."*

Thermal Manikin Testing

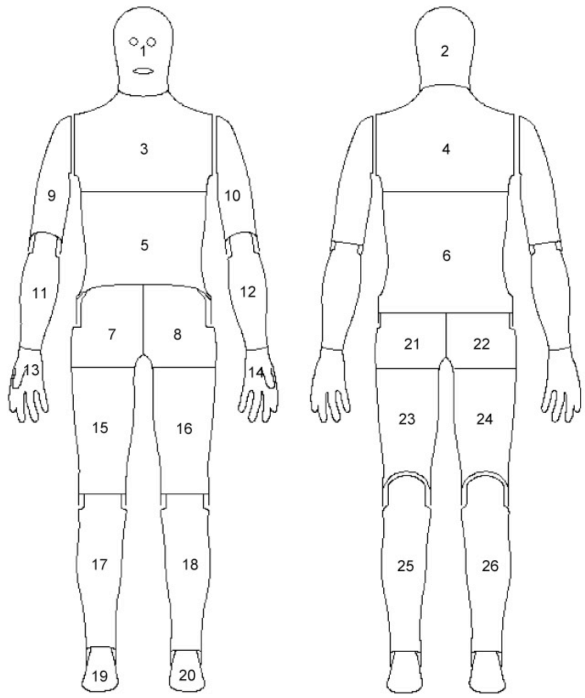
Table 12 displays the average Clo values, standard deviations, and differences between the control and prototype shirt based on the entire shirt region, and the arms, chest, shoulders, stomach, and back regions of the manikin. Figure 9 provides a visual explanation of the body regions used.

Entire Shirt Region In the dry tests of the prototype and control for the overall shirt region, there was no difference in Clo value between the two shirts, the Clo averages being 1.45 ± .054 and 1.45 ± .045 for the prototype and control, respectively.

Arm Region Some difference between the prototype and the control can be seen in the thermal insulation provided by the arm areas of the shirts. The average Clo values were determined for the arms by combining the upper arm and forearm regions of the right and left arms (Figure 9). The average Clo value for the arm regions of the prototype and the control shirt, respectively, were 1.32 ± .039 and 1.233 ± .036, resulting in a difference of 0.083 Clo. Thus, the prototype provides slightly greater thermal insulation to the arms than the control.

Table 12: Average Clo-Values of the Prototype and Control Shirts by Body Region

Region	Prototype			Control			Clo Value Difference
	Temperature °C	% Relative Humidity	Clo Value (Avg. ± SD)	Temperature °C	% Relative Humidity	Clo Value (Avg. ± SD)	
Entire Shirt	20.12 ± .07	38.95 ± 1.91	1.45 ± .054	20.13 ± .37	45.6 ± 1.27	1.45 ± .045	None
Arms			1.32 ± .039			1.233 ± .036	0.087
Chest			1.425 ± .08			1.403 ± .083	0.022
Shoulders			1.317 ± .092			1.501 ± .079	-0.184
Stomach			1.95 ± .138			2.016 ± .112	-0.067
Back			1.703 ± .021			1.926 ± .011	-0.223



Key to Body Regions

Arms: 9, 10, 11, 12
Chest: 3
Shoulders: 4
Stomach: 5
Back: 6

Figure 9: Thermal Manikin Body Regions (Measurement Technology Northwest, 2010)

Chest Region The average Clo value for the chest region of the prototype was 1.425 ± .08, compared to the chest region of the control, which was 1.403 ± .083. The difference between the shirts was .022, but due to the range in data, no significant difference in the thermal insulation of the chest regions can be determined.

Shoulder Region The shoulder region of the manikin refers to the upper back and scapular areas (Figure 9). The control shirt had slightly higher Clo values than the prototype, as seen in the averages of 1.317 ± .092 for the prototype and 1.501 ± .079 for the control. The difference in average values between the two shirts was -0.184 Clo, with the control providing slightly more thermal insulation than the prototype in the shoulder region.

Stomach There was no significant difference in the average Clo values of the prototype and the control. The average values of the stomach regions were 1.95 ± .138 for the prototype and 2.016 ± .112 for the control, resulting in an insignificant difference of -0.067 Clo.

Back The Clo values of the control shirt were slightly higher than the prototype shirt, with a value of 1.926 ± .011, in comparison to 1.703 ± .021. The difference between the two shirts was -0.223 Clo, indicating that more thermal insulation is provided by the back area of the control shirt than the back area of the prototype.

Discussion Although tests of the entire shirt area resulted in the same Clo value for both shirts, differences can be seen in thermal insulation provided by the different body regions. The prototype had higher Clo values than the control in the arms, while the control had higher Clo values than the prototype in the shoulders and back. These differences may be explained by comparing the use of thermal insulation and moisture management fabric in the body regions.

The arms of the prototype primarily used fleece pile knit thermal fabric, which provided greater thermal insulation to the manikin's arms than the thinner, double knit fabric used in the arms of the control. A strip of mesh knit moisture management fabric runs the length of the underarm in the prototype, and it can be argued that without this fabric, the difference in Clo values between the two garments would have been greater. Although moisture wicking did not take place to cool the arms of the thermal manikin, the moisture management fabric was thinner and had a more open structure than the both thermal insulation and the control fabrics, allowing greater dissipation of heat. It is likely that the lack of warmth provided by the moisture management fabric offset the thermal insulation in the arms of the prototype, to some extent. However, by providing greater thermal insulation to the arms than the control, the prototype better meets the subjects' preference for more thermal insulation in the arms, as mentioned in the qualitative interviews.

The lower average Clo value in the shoulder region of the prototype is due to the moisture management fabric placed in this area, which, again, is thinner and has a more open fabric structure than the control fabric. The use of the moisture management fabric in the upper back/shoulder region allows for greater dissipation of heat, which is consistent with the subjects' interview preferences for less thermal insulation in the back of the shirt where a backpack would be touching.

Despite the use of the control fabric for the lower backs of both shirts, the prototype had a lower Clo value than the control shirt. This could be due to the fact that the strip placed along the side seams of the prototype may have affected the Clo value of the back, chest, and stomach areas.

Despite the fact that the pile knit thermal insulation fabric is used on the chest of the prototype, the Clo values were the same for the prototype and control, which may be due to the moisture management fabric at the side seams of the prototype offsetting the additional warmth that would have been provided by the pile knit fabric on the chest. It is expected that the thermal insulation value of the chest of the prototype would have been greater without the use of moisture management fabric at the side seams.

The control fabric was used in the stomach regions of both shirts, and the Clo values for these areas were the same. Both the moisture management fabric used at the side seams and the thermal insulation on the chest of the prototype may have affected the Clo value, the moisture management fabric reducing the value, and the thermal insulation increasing it, to result in an equal value to that of the control.

Since the goal was to provide greater and less thermal insulation in different body areas to allow for both heat retention and dissipation while exercising in the cold, differences in Clo value between the prototype and the control were expected and desired. Less thermal insulation in areas like the upper back and greater thermal insulation in areas like the arms better meet subjects' preferences for a base layer shirt to wear in the cold.

CHAPTER V

CONCLUSION

In cold conditions, backpackers are at risk of developing cold-related injuries and illnesses, such as hypothermia, due to the inability of the body to maintain internal temperature and the backpackers' remoteness from shelter or emergency aid. Clothing is the primary means that backpackers have to protect themselves from the environment; however, the current method of layering clothing may not meet backpacker's thermal and moisture protection needs, particularly in areas of the body that produce greater sweat, and during times of high physical exertion. Despite this unmet need, no previous studies have specifically focused on the design of a single layer garment for backpacking to meet the thermal and moisture comfort needs of various areas of the body. The purpose of this study was to design and evaluate a single-layer garment of different textiles, to improve the physiological comfort of male backpackers hiking in cold conditions.

Qualitative data about backpacker's physiological comfort needs while hiking in the cold were collected via interviews, and were used to guide the researcher in the design of a prototype backpacking shirt. Major findings that informed the design were that subjects preferred:

1. Base layer shirts made of synthetic knit fabrics
2. Base layer shirt styles with a collar, zipper, non-chafing seams, pockets, long back and sleeve hems, and thumb holes in cuffs
3. Greater thermal insulation in the arms and body core

4. Less thermal insulation in the underarms and back due to greater sweat production in these areas
5. Durability

The subjects' needs for less thermal insulation in the back was consistent with previous studies that observed that the back was the area of greatest sweat production on the body, aside from the head (Machado-Moreira et al., 2008; Nielsen and Endrusick, 1992; Smith and Havenith, 2011). Likewise, the subjects' desire for greater thermal insulation in the arms while hiking in the cold may be attributed to vasoconstriction, which prevents body heat loss by reducing blood flow to the arms, causing them to feel colder than the body core (Doubt, 1991).

According to the design criteria, one thermal insulation and one moisture management fabric were selected for use in the prototype shirt based on data provided by guarded hot plate and moisture management testing. Likewise, a control fabric was selected based on design criteria. The thermal insulation material selected was a polyester fleece pile-knit fabric, and was located on the chest and arms of the prototype. The moisture management fabric was a polyester mesh knit fabric, and was used at the upper back, underarms, and at the sides of the prototype garment. The control fabric selected was a brushed polyester double knit fabric, and was used for all other areas of the prototype shirt, as well as for all areas of the control shirt.

Quantitative data about the comfort of the prototype and control shirts were collected by questionnaire, from wear tests that the subjects completed while backpacking. Comfort ratings were grouped and analyzed by 7 individual comfort sensations, overall comfort, and by combined thermal and moisture comfort.

The comfort rating data based on the 7 comfort sensations and overall comfort resulted in good mean comfort ratings for both the prototype and control garments for all sensations. The only significant difference found between garments was in overall comfort across all trials and subjects, with the prototype being perceived as slightly more comfortable than the control. The wearing and laundering of the garments over time had no clear effect on the comfort performance, as indicated by ratings across trials. Previous study has suggested that the comfort performance of some moisture management fabrics decreases within the first five launderings, however, that was not observed in this study (B. Hurd, personal communication, May 2, 2011; McQueen et al., 2012).

The quantitative data from the combined thermal and moisture scores resulted in good comfort ratings for both garments and some evidence of better comfort performance by the prototype than the control. Significant p-values for the difference between the prototype and control in moisture comfort were found across all trials and subjects, in trials 2 and 3, and from subject 1 and 2, suggesting that the prototype had significantly better moisture comfort ratings in trials 2 and 3, and was perceived more comfortable by subjects 1 and 2. The thermal comfort ratings of the prototype, likewise, were found to be significantly better than the control across all trials and subjects, and for trial 3. However, throughout the entire wear test procedure, the prototype did not consistently receive better comfort ratings than the control. This may be due to trial conditions, such as temperature and additional clothing worn by the subject. No decrease in the combined thermal or moisture comfort of the shirts with wearing and laundering over time was found.

Qualitative data from open-ended questions on the wear test questionnaire provided additional information about the comfort performance of the shirts. The only areas of the shirts that subjects consistently thought were uncomfortable were the collar and the zipper at the chin. This was due to the construction of the shirts, and there was no difference between the prototype and the control. The durability of the shirts was also an issue for several of the trials, with seam ruptures and loose threads being reported, particularly in later trials, after garments were subjected to more wearing and laundering. The durability issues were also due to garment construction, and were a problem for both test shirts. It is noteworthy that all subjects responded that they would recommend both shirts to other hikers, and that there were many positive comments made about the comfort of the both shirts. Two subjects stated that the test shirts were superior to base layers that they already owned, and wore the test shirts more often than just the wear tests.

It was the intent of the study for the prototype to have better thermal and moisture comfort than the control by incorporating different fabrics in different body areas; however, both garments were found to be comfortable. It can also be noted that, at times, both shirts had ideal comfort performance in some comfort categories, earning multiple ratings of “0.” Since the control fabric was selected according to the design and comfort criteria, the control also resulted in good comfort performance, and only minimal perceived differences could be seen between the comfort of the shirts.

It was proposed that by including different fabrics in different body areas, a single-layer shirt would sufficiently meet the comfort needs of hikers. However, the subjects wore the test shirts with additional clothing layers for the majority of the trials. Subjects most comfortably wore the prototype shirt alone in temperatures of 35˚F or higher and the control shirt in temperatures of 40˚F or higher. Additionally, when the prototype was worn under the highest temperatures and during subjects' highest physical exertion possible, it had the best comfort performance of all trials.

Quantitative data was also collected by thermal manikin testing to compare the thermal insulation properties of the prototype and control shirts overall and in different body regions. The overall thermal insulation of the entire shirt region of the test shirts were the same, but there were differences based on body area. The arms of the prototype were warmer than the control, and can be explained by the use of the thermal insulation fabric in the arms. The shoulders region of the prototype was cooler than the control, due to the thin moisture management fabric used in this area. In body regions where the prototype and control shirts were equally warm, the lack of difference can be explained by the use of the moisture management fabric on the prototype. The differences in the warmth of the shirt in different body areas are consistent with both the subjects' preferences for greater thermal insulation in the arms and less thermal insulation in the back, and with previous literature.

In summary, the prototype shirt designed in this study has accomplished the goal of providing backpackers' physiological comfort needs identified in the qualitative interviews. Although both the prototype and the control shirts were found to have good thermal, moisture, and overall comfort, the prototype had slightly higher overall comfort ratings than the control. In addition, both the prototype and the control were perceived to be better than the subjects' own base layer shirts, and all subjects were willing to recommend the shirts to other hikers.

Significance

The information presented in this study summarizes the physical comfort needs of base layer shirts for male backpackers, and provides a design solution to meet these needs. The design prototype, when worn alone, is able to keep backpackers comfortable when hiking in cold conditions, particularly in temperatures above 35˚F, or when the backpacker is physically exerting himself. Although not intended to be worn as part of a layer system, the prototype also keeps backpackers comfortable when they are wearing multiple clothing layers. The use of different fabrics in different body areas satisfies the backpackers' needs of both retaining and dissipating body heat with changes in physical activity. Additionally, the ability of the prototype to wick moisture in the areas of greatest sweat accumulation helps to prevent post-physical activity chill that can occur when the skin or the inside of clothing remains wet after hiking. Overall, the prototype keeps backpackers comfortable in cold conditions, contributing to their enjoyment of the outdoors and preventing cold-related illnesses and injuries that can occur while hiking.

Limitations of the Study

There were several limitations in conducting this study, as described in this section.

1. The results of this study are applicable to male backpackers at Second Nature Wilderness Program only, and do not represent the needs of female backpackers, or of backpackers hiking in different conditions.
2. The use of only three subjects in the wear tests limits the ability to detect a difference between the prototype and the control garments and further prevents the application of the study results to a larger population.
3. Due to the nature of completing wear tests in the field, the test conditions were unable to be controlled the researcher, and the differences in weather, physical exertion, and the additional clothing worn by the subjects affected study results.
4. Wear test subjects were able to determine which test garments were the control and the prototype, because of the use of different fabrics. This may have impacted subjects' perceptions of the test garments.
5. The data from testing the moisture management fabrics was inconsistent, limiting the options of possible fabrics to be used in the prototype.
6. The construction of the test shirts was limited by the skills of the researcher and the resources available.

7. The selection of the fabric fiber content for the thermal insulation fabrics (wool) and the selection of fabric structures for both thermal and moisture management applications was limited by what was available locally.

Recommendations for Future Research

This study involved only four total male subjects, and to apply the study results to larger populations, future studies would benefit from having a greater number of subjects in both the assessment of needs and the wear testing of a prototype. Additionally, since this study addressed only the needs of male backpackers, and it is likely that female backpackers would have different preferences, it is recommended that future studies investigate the needs and design criteria of a garment for females. Both the larger sample size and the inclusion of females would further understanding of the backpacker population.

The qualitative results of this study implied that the comfort performance of the design prototype may have been better than the shirts currently worn by the subjects. To have a better assessment of the difference between the design prototype and shirts currently worn, however, the control shirts could be made in an identical fabric to the typical base layer shirts worn by the subjects.

Additionally, the variety of weather and wear trial conditions in this study presented a challenge in interpreting the quantitative test data. Although the varying weather conditions allowed the researcher to determine relationships between different temperatures and comfort ratings, future studies may benefit from conducting wear tests in a controlled laboratory settings, which would lessen the number of extraneous factors that influence subject ratings.

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APPENDICES

APPENDIX A HUMAN SUBJECT APPROVAL LETTER

Institutional Review Board ● Office of Research Integrity
B308 Kerr Administration Building, Corvallis, Oregon 97331-2140
Tel 541-737-8008 | Fax 541-737-3093 | IRB@oregonstate.edu
http://oregonstate.edu/research/ori/humansubjects.htm

NOTIFICATION OF APPROVAL
November 7, 2011

Principal Investigator:	Hsiou-Lien Chen	Department:	Design and Human Environment
Study Team Members:			
Student Researcher:	Lynn Rau		
Study Number:	5102		
Study Title:	The Effect of Textiles on Perceived Physiological Comfort While Backpacking in the Cold		
Funding Source:	None		
Funding Proposal #:			
PI on Grant/Contract:			
Submission Type:	Initial Application received 10/07/2011		
Review Category:	Expedited	Category Number:	6, 7
Waiver(s):	None	Number of Participants:	20
Risk level for children[1]:	N/A		

The above referenced study was reviewed and approved by the OSU Institutional Review Board (IRB).

Approval Date: 11/07/2011
Expiration Date: 11/06/2012

Annual continuing review applications are due at least 30 days prior to expiration date

Documents included in this review:

- ☒ Protocol
- ☒ Consent forms
- ☐ Assent forms
- ☐ Grant/contract
- ☐ Other:
- ☒ Recruiting tools
- ☒ Test instruments
- ☐ Attachment A: Radiation
- ☒ Letters of support
- ☐ External IRB approvals
- ☐ Translated documents
- ☐ Attachment B: Human materials
- ☐ Project revision(s)

Comments:

Principal Investigator responsibilities for fulfilling the requirements of approval:

- All study team members should be kept informed of the status of the research.
- Any changes to the research must be submitted to the IRB for review and approval prior to the activation of the changes.
- Reports of unanticipated problems involving risks to participants or others must be submitted to the IRB within three calendar days.
- Only consent forms with a valid approval stamp may be presented to participants.
- Submit a continuing review application or final report to the IRB for review at least four weeks prior to the expiration date. Failure to submit a continuing review application prior to the expiration date will result in termination of the research, discontinuation of enrolled participants, and the submission of a new application to the IRB.

[1] Where parental permission is to be obtained, the IRB may find that the permission of one parent is sufficient for research to be conducted under §46.404 or §46.405. Where research is covered by §§46.406 and 46.407 and permission is to be obtained from parents, both parents must give their permission unless one parent is deceased, unknown, incompetent, or not reasonably available, or when only one parent has legal responsibility for the care and custody of the child.

APPENDIX B INFORMED CONSENT: INTERVIEWS

OSU Oregon State UNIVERSITY

Department of Design and Human Environment
Oregon State University, 224 Milam Hall, Corvallis, Oregon 97331-5101
T 541-737-3796 | **F** 541-737-0993 | http://www.hhs.oregonstate.edu/dhe

CONSENT FORM

Project Title:
The Effect of Textiles on Perceived Physiological Comfort While Backpacking in the Cold
Principal Investigator: Hsiou-Lien Chen, Ph.D.
Student Researcher: Lynn Rau
Version Date: 10/27/11
Phase of Study: Qualitative Interviews

---

1. WHAT IS THE PURPOSE OF THIS FORM?

This form contains information you will need to help you decide whether to be in this study or not. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS STUDY BEING DONE?

The purpose of this study is to design a shirt for backpacking that is comfortable in cold weather. Our goals are to learn what backpackers need to be comfortable, and how we can incorporate backpacker's needs into clothing designs by using different textile materials.

We are doing this study to fulfill a requirement for the student researcher's masters' thesis.

Up to 5 participants may be invited to take part in interviews. For all phases of the study, up to 20 participants total may be invited to take part.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a male field staff or male former field staff of Second Nature. Due to your position, you either backpack regularly or have recently backpacked regularly as part of your work duties. Therefore, what you think about backpacking clothing will be helpful to us.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

Study activities
If you agree to participate in this phase of the study, I will interview you for about one hour and thirty minutes. During the interview, I will ask you to tell me about your clothing preferences when you backpack in the cold. I will also ask you to show me an item of clothing that you like to wear while backpacking, and I will take photos of it. During the interview, you are free to

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skip any questions that you would prefer not to answer. Your interview will be audio recorded, and I will take notes during the interview. This will help us to arrive at more accurate conclusions about our research topic. Only Dr. Chen and I will have access to the clothing photos, audio recordings, and the transcriptions.

Study duration:
If you agree to participate in this phase of the study, I will interview you for approximately 1 hour and 30 minutes.

Audio recordings and photographs: As I said earlier, if you agree to participate in interviews, your interview will be audio recorded. Therefore, if you do not wish for your responses to be recorded, you should not plan on enrolling in this study. During the interview, I will take photographs of your backpacking clothing. If you do not want photographs to be taken of your clothing, I will take notes on the appearance of your clothing.

Storage and Future use of data or samples: All audio recordings will be stored in a locked file cabinet in the Principal Investigator's (Dr. Chen's) office. Any notes and transcriptions will be stored on Dr. Chen's private computer. Data from your interview may also be stored by the student researcher (Lynn Rau), but no information will be stored by the student researcher that will link the data to your personal identity. Three years after the completion of this study, we will destroy all audio tapes, interview transcriptions, and notes.

Study Results: We can give you a copy of the final results from this study. If you want a copy of the results, check the box below or contact Lynn Rau at raul@onid.orst.edu.

☐ Please provide me with a copy of the final results of the study (check box).

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

Email: The security and confidentiality of information sent by email cannot be guaranteed. Information sent by email can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

6. WHAT ARE THE BENEFITS OF THIS STUDY?

There are no foreseeable benefits associated with participating in the study. This study is not designed to benefit you directly.

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7. WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid for being in this research study. Interviews will take place at a time when you are not scheduled to work.

8. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

If the results of this project are published your identity will not be made public.

To help ensure confidentiality, access to all audio recordings and notes will be limited to Dr. Chen and me. Audio recordings will be stored in a locked cabinet in Dr. Chen's office. Typed notes will be stored on Dr. Chen's private computer.

9. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. Your decision of whether or not to participate in this study will not impact the relationship you have with Second Nature. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

10. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact: Dr. Hsiou-Lien Chen at Hsiou_Lien.Chen@oregonstate.edu or at 541-737-0996.

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

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11. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date: 11/06/2012

Participant's Name (printed): ____

____ _________________________________
(Signature of Participant) (Date)

____ _________________________________
(Signature of Person Obtaining Consent) (Date)

APPENDIX C INFORMED CONSENT: WEAR TESTS

Department of Design and Human Environment
Oregon State University, 224 Milam Hall, Corvallis, Oregon 97331-5101
T 541-737-3796 | **F** 541-737-0993 | http://www.hhs.oregonstate.edu/dhe

CONSENT FORM

Project Title:
The Effect of Textiles on Perceived Physiological Comfort While Backpacking in the Cold
Principal Investigator: Hsiou-Lien Chen, Ph.D.
Student Researcher: Lynn Rau
Version Date: 10/27/11
Phase of Study: Wear Test Questionnaire

1. WHAT IS THE PURPOSE OF THIS FORM?

This form contains information you will need to help you decide whether to be in this study or not. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS STUDY BEING DONE?

The purpose of this study is to design a shirt for backpacking that is comfortable in cold weather. Our goals are to learn what backpackers need to be comfortable, and how we can incorporate backpacker's needs into clothing designs by using different textile materials.

We are doing this study to fulfill a requirement for the student researcher's masters' thesis.

Up to 20 participants total may be invited to participate in this study.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a male field staff of Second Nature. Due to your position, you backpack regularly as part of your work duties. Therefore, what you think about backpacking clothing will be helpful to us.

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4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

Study activities:

1. Screening

We are only able to have 5 subjects take part in the wear test portion the study; therefore, we will not be able to have everyone interested participate. We will ask you to participate in screening to determine if you qualify for the study. During the screening, you will be asked to complete a questionnaire about your work schedule and backpacking. You are free to skip any questions that you would prefer not to answer. I will take (2) measurements of your body over top of your clothing: your chest diameter and the length of your back from your neck to your waist. I will also ask to see a garment that you wear for backpacking, and I will take measurements of it. Based on this screening, if you qualify to take part in the study, I will notify you by email.

2. Wear Tests

If you progress past screening, I will ask you to wear 2 prototype backpacking shirts during your regular work days hiking and working in the field. You will wear each shirt for one full day during your 8-day work shift, and you will repeat this for 3 work shifts. In the end, you will have worn each shirt 3 times and have spent 6 days total wearing the prototype shirts. Before and after hiking each day, you'll be asked to take the air temperature using a provided thermometer. At the end of each day, you will complete a questionnaire about how the prototype shirt made you feel. You are free to skip any questions that you would prefer not to answer. Since you will wear each prototype shirt 3 times, I will give you laundry instructions and detergent, and I will ask you to launder each shirt at the end of each work-week.

Study duration

If you agree to participate in this study, you will be asked to spend approximately 30 minutes in screening.

If you qualify to participate in the wear tests, you will be asked to spend 6 work-days total wearing prototype shirts. We will ask you to complete a questionnaire each day that will take approximately 20 minutes to complete. We will also ask you to launder the shirts after wearing them. The shirts will need to be laundered 2 times, for approximately 1 hr. and 30 minutes each time. The testing and questionnaires will take place over the course of (3) 8-day work shifts.

Storage and Future use of data or samples: Your completed screening materials and wear test questionnaires will be stored in a locked file cabinet in the Principal Investigator's (Dr. Chen's) office. Data from your wear test questionnaire may also be stored by the student researcher (Lynn Rau), but no information will be stored by the student researcher that links the data to your personal identity. Three years after the completion of this study, we will destroy all questionnaires.

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Study Results: We can give you a copy of the final results from this study. If you want a copy of the results, check the box below or contact Lynn Rau at raul@onid.orst.edu.

☐ Please provide me with a copy of the final results of the study (check box).

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?
Wear Test Questionnaire: This study poses minimal risks beyond those you already experience during your work in the field. You may experience discomfort when wearing the test garments, including skin irritation and sweatiness. Additionally, you could potentially have an allergic reaction to the test garments or the provided laundry detergent. In the case of an allergic reaction, please stop wearing the test garment and avoid contact with the laundry detergent. Please immediately contact Dr. Chen at 541-737-0996 or at Hsiou_Lien.Chen@oregonstate.edu.

Email: The security and confidentiality of information sent by email cannot be guaranteed. Information sent by email can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

6. WHAT ARE THE BENEFITS OF THIS STUDY?

There are no foreseeable benefits associated with participating in the study. This study is not designed to benefit you directly.

7. WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid for being in this research study. Screening will take place during hours you are not scheduled to work. If you qualify for the wear tests, you will wear the prototype shirts and complete the questionnaires during your scheduled work hours. You may keep your test shirts.

8. WILL IT COST ANYTHING TO BE IN THIS STUDY?

Yes. It will cost you to launder each test shirt after wearing it. We will give you laundry detergent, but you will need to provide your own washing machine or laundry facilities.

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9. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

If the results of this project are published your identity will not be made public.

To help ensure confidentiality, access to the information you provide us on the questionnaires will be limited to Dr. Chen and me. Completed questionnaires will be stored in a locked cabinet in Dr. Chen's office.

10. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. Your decision of whether or not to participate in this study will not impact the relationship you have with Second Nature. If you decide to participate, you are free to withdraw at any time without penalty, and you may keep the prototype shirts. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

11. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact: Dr. Hsiou-Lien Chen at Hsiou_Lien.Chen@oregonstate.edu or at 541-737-0996.

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

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12. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date: 11/06/2012

Participant's Name (printed): ____

____ _______________________________
(Signature of Participant) (Date)

____ _______________________________
(Signature of Person Obtaining Consent) (Date)

APPENDIX D LETTER OF PERMISSION

OSU
Oregon State
UNIVERSITY

Department of Design and Human Environment
Oregon State University, 224 Milam Hall, Corvallis, Oregon 97331-5101
T 541-737-3796 | F 541-737-0993 | http://www.hhs.oregonstate.edu/dhe

Letter of Permission

Study Title:
The Effect of Textiles on Perceived Physiological Comfort While Backpacking in the Cold

Permission is hereby given to Lynn Rau (student researcher) under the guidance of Dr. Hsiou-Lien Chen (principal investigator) to recruit subjects and conduct research at Second Nature Wilderness Program in Bend, OR. Recruitment will include posted flyers at Second Nature. Research processes involving interested employees will consist of an interview in the employee's home, a screening questionnaire, clothing testing, and a wear test questionnaire. During work hours, subjects will complete clothing testing and the wear test questionnaire.

Purpose of the study:

The purpose of this research is to improve the clothing comfort of backpackers hiking in cold conditions. The specific objectives are to identify the clothing comfort needs of backpackers, to design a prototype garment to improve comfort, and to determine the effectiveness of the design solution by conducting wear tests.

Lynn Rau 9/8/11
Permission requested by: Date:

– PhD 9.8.11
Permission given by: Date:

Willow Huggins PhD 9.8.11
Permission given by: Date:

APPENDIX E INTERVIEW RECRUITMENT POSTER

Male volunteers needed to take part in a research study about backpacking clothing

Study title:
The Effect of Textiles on Perceived Physiological Comfort While Backpacking in the Cold

What is the purpose of this study?

- The purpose of this research is to gain information about the design of clothing for backpacking, and to design a backpacking garment to meet the body's needs when hiking in the cold.

What does the study entail?

- If you agree to participate in this study, you will be interviewed by the researcher about your clothing preferences and comfort when hiking in the cold. Interviews will take place in your own home, and will last approximately 1 hr. and 30 minutes.

Who can participate?

- Male employees of Second Nature who are current field staff members
  OR
- Male employees that are former field staff members but have worked as a field staff within the past year
- Your participation is strictly voluntary and will have no effect on your relationship with Second Nature.

Who is conducting this study?

- This study is being conducted by Dr. Hsiou-Lien Chen, Textiles professor, and Lynn Rau, graduate student, at Oregon State University.

How can I participate?

If you are interested in participating or have questions, please contact Lynn Rau at raul@onid.orst.edu. Thank you for your interest!

APPENDIX F WEAR TEST RECRUITMENT POSTER

Male volunteers needed to take part in a research study about backpacking clothing

Study title:
The Effect of Textiles on Perceived Physiological Comfort While Backpacking in the Cold

What is the purpose of this study?

- The purpose of this research is to gain information about the design of clothing for backpacking, and to design a backpacking garment to meet the body's needs when hiking in the cold.

What does the study entail?

- If you agree to participate in this study, we will ask you to complete a short screening questionnaire, and we will take your chest and back measurements. We will also ask you to show us a shirt that you like the fit of, and we will take measurements of it. The researchers will choose individuals to participate in the study based on the screening. If you are selected to participate, you will be asked to wear prototype backpacking shirts while hiking and working in the field. At the end of each day wearing the prototype, you will need to complete a short questionnaire. This will take place over 6 separate work days for each participant.

Is there compensation?

- If you are chosen to participate, as compensation, you will be allowed to keep the (2) prototype shirts you test in the study.

Who can participate?

- Male employees of Second Nature who are current field staff members

Who is conducting this study?

- This study is being conducted by Dr. Hsiou-Lien Chen, Textiles professor, and Lynn Rau, graduate student, at Oregon State University.

How can I participate?

If you are interested in participating or have questions, please contact Lynn Rau at raul@onid.orst.edu. Thank you for your interest!

APPENDIX G INTERVIEW QUESTIONS

1. First, I'm going to ask some general questions about backpacking at Second Nature.
   a. In the winter, what are the weather conditions like in the field?
   b. Are there weather conditions that you do not backpack in?
   c. For how many hours might you backpack on a cold day?
   d. Is there a difference in difficulty between different hikes?
   e. Can you estimate weight of the backpack you typically carry?
   f. Do you have time to change clothing before, during, or after backpacking?

2. The next questions relate to the clothing you wear while backpacking. For these questions, we'll define "cold" as moderate cold temperatures between 30-45 degrees.

   a. Do you wear layers of clothing on your upper body when you are backpacking in the cold?

      If yes:

      - What types of clothing layers do you wear?
      - Do you generally keep all layers on for the entire duration of the hike?
        - If so, do you ever feel too warm or too cold while backpacking? Do you ever feel like your skin is sweaty while backpacking?
        - If not, when do you remove layers? Do you ever feel too cold when you are not wearing all layers? For how long do you typically keep layers off?

      If no:

      - If you do not wear layers, what type of clothing do you wear?
      - Do you ever feel too warm or too cold while backpacking?
      - Do you ever feel like your skin is sweaty while backpacking?

   b. Do you have preferences for clothing materials that you wear on your upper body while backpacking in the cold? If so, what kinds of materials?
   c. What weight of materials do you prefer to wear while backpacking in the cold?

- If you wear layers, please describe the weight of each layer.

d. Do you prefer to wear certain styles of backpacking clothing? What style features are important to you?

e. Could you show me an example of clothing that you like to wear while backpacking?
    - Why do you like to wear this item?
    - Do you remember how much this item cost you?
    - Is there anything you don't like about this item?

f. Do you have any complaints about the comfort of the clothing you wear when backpacking?
    - Are there any areas of your upper body that feel uncomfortable when backpacking?
    - If so, what areas? How would you describe the uncomfortable sensation you feel?

g. Do you have any complaints about the ability of the clothing you wear when backpacking in the cold to keep you warm or dry?
    - Is there anywhere on your upper body that you think needs more thermal insulation while hiking in the cold?
    - Is there anywhere that needs less thermal insulation?
    - Is there anywhere on your upper body that you think gets more sweaty than other areas while hiking in the cold?

h. What would you like your ideal clothing for backpacking in the cold to be like?
    - What do features and materials do you like and not like in backpacking clothing?
    - What would the cost of your ideal backpacking clothing be?

APPENDIX H WEAR TEST SCREENING QUESTIONNAIRE

1. Subject Number (to be entered by researcher)_______
2. How many total shifts in the field will you be working during the test months (Feb. and March)?________
3. Is there anything that would keep you from wearing a test garment during your shifts in the field? If so, please explain. (The test garment will be worn for an entire day in the field, and additional clothing can be worn over it.)

   ____

   ____

4. Do you have any allergies to specific chemicals, clothing materials, and/or dyes?

   _____No _____Don't Know ______Yes

   If yes, you could potentially experience an allergic reaction when wearing the test garments. We recommend that you do not continue with this study.

5. How many days, on average, do you backpack during an 8-day shift in the winter?______
6. How easy do the hikes at Second Nature in the winter typically feel to you? (Please circle a response from 1 to 5)

1	2	3	4	5
Very Easy		Neutral		Very Difficult

7. What size shirts do you typically wear in outdoor clothing? _______

AREA BELOW TO BE COMPLETED BY RESEARCHER

8. I will now take your chest and center back measurements. The reason we need your measurements is so that we can verify what size test garment you are able to wear.

   a. Chest circumference:_______________in.
   b. Center back length: _______________in.
      (On the back of the torso from base of neck to natural waist)

9. Is there a shirt that you wear for backpacking that you like the fit of? If so, could you show me the shirt and allow me to take measurements of it? This is to ensure that the garment size I select for you will be comfortable.

If you do not have a backpacking shirt that you like the fit of, the sizing of your test garment will be based on a standard size for your chest and center back measurements.

Researcher to take the following measurements from shirt:

a. Across waist:
Front: ________________in.
Back: ________________in.
b. Neck: ________________in.
c. Full length:
(The side of neck to natural waist)
Front: ________________in.
Back: ________________in.
d. Across shoulder:
(From center of neck to tip of shoulder)
Front: ________________in.
Back: ________________in.
e. Center length:
(From base of neck to natural waist)
Front: ________________in.
f. Across back: ________________in.
(From center of shirt armhole across shoulder blades to the center of back)
g. Back neck: ________________in.
h. Across chest: ________________in.
(From armpit to the center of chest)
i. Shoulder length: ________________in.
j. Shoulder slope:
(From tip of shoulder to center of natural waist)
Front: ________________in.
Back: ________________in.
k. Sleeve length: ________________in.
l. Across Bicep:
Front: ________________in.
Back: ________________in.

APPENDIX I WEAR TEST QUESTIONNAIRE

Date:______________Garment (E or C):________Trial # (1, 2, or 3):________Subject Number:

Temperature at start of hike:__________Temperature at end of hike:__________

1. How long was your hike today, from the time you left camp to the time you reached your destination?

less than 2 hrs.	2-4 hrs.	over 4 hrs.-6 hrs.	over 6 hrs.

2. Approximately how much time did you spend hiking during the hike today?
(Not including time spent taking breaks.)

less than 2 hrs.	2-4 hrs.	over 4 hrs.-6 hrs.	over 6 hrs.

3. For how long did you wear the test shirt today? Portions of an hour should be rounded. (e.g. between 12.5 and 12.9 hrs. would be considered 13 hours, between12.1 to 12.4 hrs. would count as 12 hrs.)

less than 8 hours	8-12 hrs.	13 hrs.-17 hrs.	over 17 hrs.

If less than 8 hrs., why?____

4. What do you think your average level of physical exertion was while backpacking today? (To what extent did you sweat or feel out-of-breath?)

1	2	3	4	5
Low	Medium-Low	Medium	Medium-high	High

5. Overall, what did the weather conditions feel like while backpacking today?

-5	-4	-3	-2	-1	0	1	2	3	4	5
Too Cold					Neutral Too Hot					

6. What was the wind like during the hike today?

1	2	3	4
Not windy	Slight breeze	Moderate Wind	Very windy

7. What was the precipitation (rain, sleet, snow, or hail) like during the hike today?

1	2	3	4
No precipitation	Light precipitation	Steady precipitation	Heavy precipitation

8. What was the sun or cloud cover during the hike today?

1	2	3	4
Completely cloudy	Mostly cloudy with a few sun breaks	Mostly sunny with a few clouds	Completely sunny

9. How would you describe how the test garment felt while you were backpacking today?

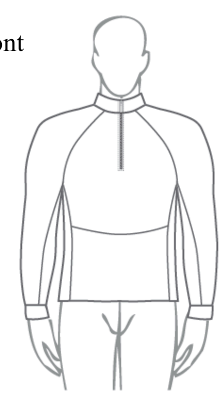
	Not at all										Extremely
a. sticky	0	1	2	3	4	5	6	7	8	9	10
b. clammy	0	1	2	3	4	5	6	7	8	9	10
c. damp	0	1	2	3	4	5	6	7	8	9	10
d. clingy	0	1	2	3	4	5	6	7	8	9	10
e. cold	0	1	2	3	4	5	6	7	8	9	10
f. hot	0	1	2	3	4	5	6	7	8	9	10
e. breathable	0	1	2	3	4	5	6	7	8	9	10

10. How would you rate the overall comfort of the test shirt while you were hiking today?

0	1	2	3	4	5	6	7	8	9	10
Not at all comfortable										Extremely comfortable

11. Did any of your upper body areas feel uncomfortable while backpacking today?
Please circle and number the areas that felt uncomfortable. Write an explanation of the uncomfortable feeling on the numbered lines to the right to correspond with the circles drawn on the picture.

Front



1. ______________________________

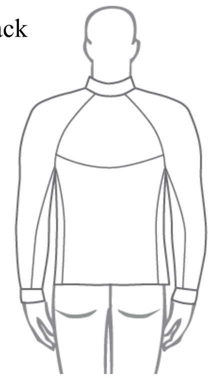
2. ______________________________

3. ______________________________

4. ______________________________

5. ______________________________

Back



6. ______________________________

7. ______________________________

8. ______________________________

9. ______________________________

10. ______________________________

12. Would you recommend this shirt to other hikers?

Yes No

13. Did you wear any clothing layers on top of the test shirt today? If so, please describe what additional clothing you wore and why:

14. While you were hiking today, how did you wear the zipper on the shirt?

- ☐ zipped up for the entire hike
- ☐ unzipped for part of the hike
- ☐ unzipped for all of the hike

15. Have you noticed any durability issues with test shirt during wearing or laundering? If so, please describe the problem and the location on the shirt. Examples may be pilling, seam tearing, holes in the body of the garment, shrinking, distorting out of shape, etc.

16. Do you have any other overall comments or concerns regarding this shirt?