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

Abstract

The purpose of this study is to design and evaluate a single-layer garment that incorporates different textiles to improve the physiological comfort of backpackers hiking in cold weather conditions. The objectives are to identify comfort needs, to design a prototype shirt, and to evaluate comfort and performance of the prototype over time, in comparison to a control. Qualitative data were collected by interviewing wilderness backpackers regarding their physiological comfort needs and hiking clothing preferences. Findings were used to develop a prototype garment and a control garment. Both garments were wearing tested by subjects while backpacking. Additionally, thermal properties of both garments were measured using a thermal manikin and compared.

Major findings from the qualitative interviews revealed that subjects preferred hiking shirts made with synthetic fibers and style features that helped regulate body heat. Overall, subjects preferred greater thermal insulation in the chest and the arms, and less in the underarms and upper back area where the backpack sits. Additionally, subjects were concerned about durability. A prototype garment was constructed using a combination of three fabrics, specifically a thermal fabric, a moisture wicking fabric, and a control fabric, strategically placed in different areas of the body. A control garment was constructed using only the control fabric. Wear test data indicated that both the control and prototype garments were perceived as comfortable overall when worn in cold conditions. Thermal manikin testing results confirmed that although the overall thermal insulation of both test shirts was equal, the prototype had greater or less thermal insulation than the control in specific body areas; this suggests that use of specialized fabrics in targeted body areas can potentially satisfy backpackers' needs of both retaining and dissipating body heat with changes in physical activity.

Keywords: Textiles; Clothing comfort; Backpacking; Thermal insulation; Moisture management; Wicking

Research Article

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Introduction

Wilderness hiking and backpacking are enjoyed by many people as a fitness activity, an escape from daily routine, and as an educational experience. Due to the fact that this activity often occurs in a location far from shelter 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 that occur are of great concern. Among the illnesses or injuries confronting wilderness hikers, those related to the body's ability to respond to heat or cold exposure are particularly important, as the human body must maintain core temperatures within a narrow range for the body to function properly. Cold exposure can cause discomfort and distraction, which can lead to an increased risk of accidents [1], and more severe consequence, like hypothermia.

The primary means of protection that backpackers have against cold-related injuries and illnesses is clothing. When hiking in the cold, the clothing layers commonly recommended for backpackers [2] may not meet the needs for both thermal insulation and heat dissipation particularly in areas of the body that produce greater sweat during times of high physical exertion. This is due to the fact that 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 among backpackers, where the backpack can cause greater sweat accumulation and a higher temperature on the hiker's back when hiking in the cold [3]. Combining clothing layers can reduce the breathability and moisture-wicking capabilities of the fabrics while the hiker is moving, leaving sweat moisture on the inside base layer, and causing discomfort and a chilling effect when the hiker stops and/or removes the outer layers [4].

The body loses heat by conduction, convection, radiation, sweat evaporation, and respiration [5]. During exercise, different parts of the body have been found produce different amounts of sweat. In their study of regional sweat rates, Smith and Havenith [6] mapped the sweating locations on the bodies of nine male runners. 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 and on the body extremities. Clothing helps provide moisture wicking and thermal balance and the protection from the environment that the physiological responses of the human body cannot sustain alone. For moisture wicking to occur, it requires 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, yarn, fabric [7] and the combination of clothing layers. To provide thermal insulation, textiles rely on trapped air between the fabric and the wearer's skin and/or in the interstices of the textiles.

In addition to the textile factors, 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. For example, research shows that when mesh panels and uncovered openings are placed at the side seams of a t-shirt, thermal and vapor retention are reduced, and consequently, greater thermal comfort can result [8]. This is due to the fact that at the side seams there is more space between the wearer and the garment, allowing more air and moisture flow through the openings. To address backpackers' needs for both thermal insulation and moisture control in different body areas, this study attempted to design and evaluate a single-layer garment consisting of different textiles with varying thermal, moisture-wicking and breathability properties. The textiles incorporated in the garment were strategically placed in different areas of the garment to meet the complex thermal and moisture requirements for various regions on the body, and ultimately to improve the physiological comfort of those engaging in physical activity under cold weather conditions.

Materials and Methods

Subjects

Eight male subjects were recruited from a wilderness program. All subjects were employees of the wilderness program; duties included regularly backpacking in the cold. Subjects participated in two separate procedures of the study: qualitative interviews and wear tests.

Qualitative interviews

Qualitative interviews were conducted with four subjects to gather information about backpacker physiological needs for garment design development. Open-ended interview questions were used to determine:

a. The specific conditions subjects and their hiking apparel were subjected to, such as temperature, wind, miles hiked, load carried.

b. Types of garments and materials typically worn by the subject when backpacking, and any comfort dissatisfaction or preferences with these garments.

c. Regions of the body where thermal insulation or moisture management fabric is needed in a garment to improve physiological 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. Interview data were then compiled into a design criteria matrix, which in turn was used in the design of the prototype backpacking shirt.

Prototype development

Fabric Selection Based on information obtained from the qualitative interviews, three fabrics were ultimately selected for use in the design of the prototype garment: one moisture wicking fabric, one thermal fabric, and one control fabric. Thermal insulation and moisture wicking testing of several fabrics was first conducted to identify the fabrics most in-line with the comfort needs identified during the qualitative phase of the study. Initially, three thermal fabrics and six moisture wicking fabrics were chosen and subjected to the laboratory performance tests to determine the final candidates for the prototype. In addition to thermal insulation and moisture wicking fabrics, 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.

To determine fabric to meet thermal comfort, the guarded hot plate [9] and liquid moisture management properties according to AATCC 195 [10] test methods were used. The fabric chosen to incorporate in regions of the prototype requiring thermal insulation was selected because it provided an optimal combination of both thermal insulation and moisture transport. To identify a fabric most suitable for incorporation in regions of the prototype requiring moisture wicking, liquid moisture management properties AATCC 195 test method [10] was used; of the six potential fabrics tested, the one with the most consistent one-way moisture transport ability was selected for use in the garment prototype.

Prototype Garment Construction Once fabrics were selected, the garment was designed and constructed. The style included various panels for the researcher to modify with different fabrics in different body areas, based on the criteria identified in the qualitative interviews. The single style garment was modified by using different fabrics in the panel areas in two different test garments:

i. The experimental prototype used the thermal insulation fabric, the moisture wicking fabric, and the control fabric

ii. The control garment used only the control fabric.

Prototype Garment Testing Finished garment measurements were specified to provide a similar fit and amount of 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 researcher constructed four duplicates of each of the control and experimental prototype garments. All prototype and control garments had identical design and construction, with exception to the types of fabrics incorporated into different regions of the garments.

Garment wear testing

Four male subjects were recruited to participate in the wear test of the study. Each subject was given one experimental prototype and one control garment. Testing took place in winter where average temperatures range from 23˚F to 57˚F and average precipitation ranges from 1.65 cm to 4.8 cm. Subjects wore the experimental prototype and the control garment for three wear trials (within a three week time span). For each wear trial, subjects wore a test garment for a work day of backpacking. All subjects were required to wear the control garment on the first day of each trial test and the experimental garment on the second day. After each wear trial, garments were laundered using the detergent and procedures provided by the researcher. Due to the range of temperatures and weather conditions subjects might encounter while working in the field, they were permitted to wear any other of their own clothing, over the garment being tested, to maintain physiological comfort. After each trial day, the subject completed a written questionnaire about their physiological comfort when backpacking with the garment.

The wear trial questionnaire consisted of both closed and open-ended questions. Questions posed in the wear trial questionnaire were developed to obtain information regarding the comfort and durability aspects of the garments tested. Using the rating system described by Wong et al. [11] and an 11-point Likert scale of (0) "not at all" to (10) "extremely", the subjects ranked the garments on the following comfort aspects:

a. Thermal insulation as being "hot" or "cold".

b. Moisture wicking perception such as clammy, sticky, clingy, damp, and breathable.

c. Overall physiological comfort during the hiking period.

Additionally, in an open-ended question, subjects were asked to note particular areas of the body that did not feel comfortable and to indicate any durability issues observed in any locations on the garment. Closed-ended questions were also used to determine the conditions under which the subject was backpacking during the test day. Subjects also indicated the perceived physical exertion while backpacking, the weather conditions and whether additional clothing layers were used.

Thermal manikin testing

In addition to the subjective assessments from the wear tests, objective garment thermal insulation and moisture management date were also obtained on the experimental prototype and control garments using a sweating thermal manikin according to ASTM F1291 test method [12]. 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. Thermal resistance values were collected for three different treatments: thermal manikin with no shirt, with control shirt, and with prototype shirt. Two replications were performed for each of the three treatments. 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 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 weather conditions at the wilderness, estimated pack weight, 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 prototype.

Garment Wear Testing Data from the wear test were analyzed by descriptive statistics to determine the difference between the experimental and control garments in overall physiological comfort and the physiological comfort in thermal and moisture categories. The means were used to determine if there was a difference of the three garments in

A. The comfort sensation of each category.

B. The combined thermal and moisture comfort.

C. The comfort of the garments based on the trials to reveal the change of garment comfort over time.

The combined mean comfort scores were determined by combining the thermal and moisture sensations. The ratings of "hot" and "cold" were pooled to provide overall thermal comfort values, and "sticky," "clammy," and "damp" were pooled to provide overall moisture comfort values.

Thermal Manikin Testing 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 and standard deviations are reported. Additionally, the average Clo values and standard deviations are reported for the arms, chest, shoulders, stomach, and back regions of the manikin.

Results and Discussion

Qualitative interview results

For backpacking weather conditions, subjects indicated that weather conditions in the field areas were most commonly snowy and windy, but could also be sunny, dry, dusty, raining, or sleeting. All subjects responded that temperatures ranged from 0°F to 50°F during the day. 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. The estimated weight of subjects' backpacks while hiking varied from 40 to 80 lbs.

The types of layers they reported typically wearing included a synthetic fabric wicking layer, a lightweight fleece insulation layer, or a synthetic fiber or down-filled vest insulation layer. Additionally, some subjects reported wearing an outer shell jacket for wind and rain protection. Based on the interviews, the following is a summary of base layer shirt preferences for hiking in the cold weather condition.

Material the subjects reported that they prefer to wear synthetic materials or wool fibers when hiking. Subjects' reasons for preferring synthetic materials were that due to moisture wicking and fast drying. The reasons that subjects preferred wool were due to moisture wicking, thermal insulation, and no odor.

Style all of the subjects preferred to wear layers of clothing while hiking in the cold. The most frequently occurring style feature preferences for base layer shirts were: a collar, a partial-length zipper, small pockets (for batteries), long cuffs, cuffs with thumb holes, and long hem.

Function additional functional preferences for base layer shirts included durability, and the prevention of chafing or scratching. 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.

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 was 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. However, the overall concern with style features of base layer shirts was directed towards warmth and comfort. Clothing features that provide additional skin coverage or the ability to ventilate were preferred. A major preference among all of the subjects was that seams, stitching, and fabrics should not chafe the skin.

Body Locations Needing Better Thermal or Moisture Comfort when asked to consider their comfort while hiking and if anybody 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 sweatier than other body areas, and that less thermal insulation was needed in these locations.

A design criteria matrix was developed based on the information obtained from the interviews. These criteria were used for the selection of fabrics to be tested, the application of different fabrics in different body areas, and the design and development of the prototype garments.

Fabric selections for prototype

Thermal Insulation Fabric Selection the three fabrics selected for thermal insulation testing were polyester fleece pile filling knit fabrics. These fabrics were selected for testing due to their fiber content, soft hand, and light weight being consistent with the design criteria. The final fabric selected for thermal insulation had the highest intrinsic thermal resistance (I_{cl}), with a Clo value of 4.76 per inch thickness of material and a high one-way moisture transport capacity. 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.

Moisture Management Fabric Selection Six fabrics were selected for moisture management testing based on the characteristics identified in the qualitative interviews. Although the fabric structures, weights, and thicknesses varied, all of the fabrics tested were advertised as "wicking." Fabric selected for the prototype exhibited the highest one-way transport capacity of all of the moisture management fabrics tested, at 93.57. Also the thickness of the fabric selected was not too different from that of the thermal insulation fabric, allowing for a better transition between the thermal insulation fabric panels and moisture management fabric panels in the garment design.

Control Fabric Selection Based on the design criteria, an additional fabric was also selected for the control fabric. The fabric is a polyester/spandex blend, has a double knit fabric structure, and has a brushed inside surface. The brushed surface creates a soft hand, consistent with the subjects' request for a material that is soft against the skin. Although this material was advertised as "wicking;" the moisture management data do not indicate that this fabric has great moisture management properties. However, this was not a concern because the control fabric was being used for areas in the prototype shirt that did not require moisture management fabric, and because this fabric was serving as a control to which the prototype was being compared.

Prototype development

Prototype Design the thermal insulation and moisture management fabrics were applied to the prototype shirt according to the design criteria identified in the qualitative interviews. 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. 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 [8]. 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 as shown in Figures 1 & 2.

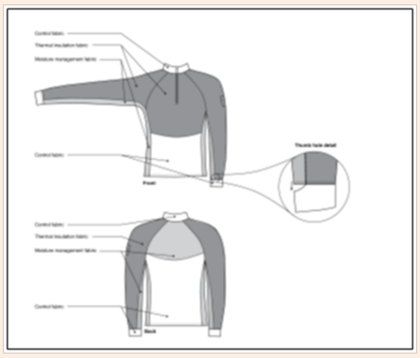

Figure 1: Prototype Garment Technical Drawings.

Figure 2: Prototype garment front and back views on model.

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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. 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 his hands.

Prototype Construction The researcher chose to use lapped seams with flat lock serged stitches for all garment assemblies, except for the cuffs, collar, and the zipper. Flat lock 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 flat lock 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. The experimental prototype and the control shirt were constructed identically.

Quantitative wear test: thermal and moisture comfort sensations

Mean Comfort Values across All Trials the mean comfort values for the prototype and control shirts across all trials are shown in Table 1 and in Figure 3.

Table 1: Mean Comfort Sensation Ratings.

Garment	All Ratings		Trial 1 Ratings		Trial 2 Ratings		Trial 2 Ratings	
	P	C	P	C	P	C	P	C
Sticky	0.0±0.0	0.5±1.07	0.0±0.0	0.0±0.0	0.0±0.0	1.0±1.73	0.0±0.0	0.5±0.71
Clammy	0.44±0.33	1.63±2.07	1.30±1.31	0.0±0.0	0.0±0.0	3.69±2.7	0.0±0.0	1.0±0.0
Damp	1.22±1.52	2.25±1.75	2.67±1.31	2.0±1.73	0.3±0.58	2.0±1.41	0.67±1.2	2.67±2.52
Clingy	0.56±0.13	0.63±0.74	0.0±0.0	0.0±0.0	1.0±0.73	1.0±0.0	0.67±1.2	1.0±1.41
Cold	1.56±1.22	2.75±1.82	1.67±1.08	1.3±1.1	1.0±1.15	2.0±2.46	1.67±1.5	6.0±0.0
Hot	1.30±1.29	3.38±2.92	3.0±2.61	3.0±2.0	0.3±0.58	5.0±3.0	1.67±1.5	1.5±1.12
Breathable	6.89±1.72	5.44±2.22	6.30±1.53	7.3±0.57	7.0±2.0	6.0±3.46	8.3±1.53	5.0±2.08
Overall Comfort	8.5±0.93	7.78±1.48	8.0±0.0	8.0±0.0	8.3±1.15	7.26±2.65	9.0±1.0	8.3±0.58

C: Control Garment, P: Experimental Prototype

Ratings: 0=Not at all, 10=Extremely

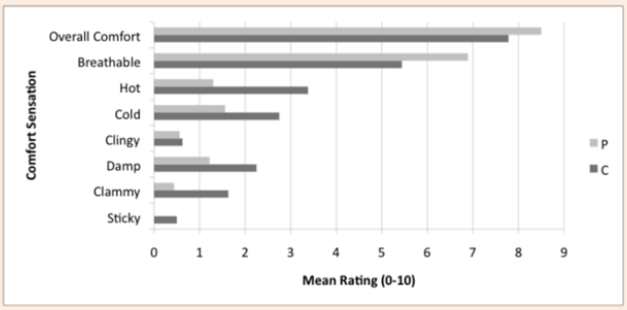

Figure 3: Graph showing overall mean comfort sensation ratings.

Both the prototype and the control garments had low mean 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 1.30±1.29 for the prototype and 3.38±2.92 for the control. Likewise, the mean "cold" ratings were low to neutral, with ratings of 1.56±1.22 and 2.75±1.82 for the prototype and control, respectively. These scores suggest that subjects perceived both shirts to have good thermal comfort. Although the means for the prototype are in general lower than that of the control garment, due to the high standard deviation values (due to low number of subjects), no significant differences between the prototype and control garments can be drawn. The mean comfort value for "breathable" was 6.89±1.72 for the prototype and 5.44±2.22 for the control, indicating that the subjects felt somewhat neutral about the breathability of both shirts, with prototype means slightly higher than that of the control. However, same situation as those for other category ratings, no significant differences can be drawn either. In addition, it is noteworthy that both the control and the prototype received high mean combined scores for overall comfort: the prototype received a mean rating of 8.5±0.93 and the control received a mean rating of 7.78±1.48.

When looking at the mean comfort scores from each wear trial, it does not suggest any consistent pattern of increase or decrease in the comfort of the garments that could have occurred with the affects of wearing and washing the garments over time. Across trials, both garments were given low 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.

Quantitative wear test: combined overall thermal and moisture comfort sensations

Table 2 displays the combined thermal and moisture comfort sensation values provide the overall garment comfort information as perceived by the hikers.

As can be seen in Table 2, both garments had low to medium-low thermal comfort ratings, with the prototype having a mean rating of 1.44±1.8 and the control having a mean rating of 3.06±2.79. Similarly, the mean moisture comfort scores of both garments were low: the mean value of the prototype was 0.46±1.3 and the mean value of the control was 1.46±2.12. Evident from Figure 4 shows a slight difference in the mean ratings between the prototype and the control; however, based on the standard deviations, no conclusions can be made about a significant difference in comfort performance between the two garments. For overall garment comfort, both garments scored low to medium-low in overall comfort areas, indicating that both garments were perceived by the hikers as relatively comfortable.

Table 2: Mean Combined Comfort Sensation Ratings.

Garment	All Ratings		Trial 1 Ratings		Trial 2 Ratings		Trial 2 Ratings	
	P	C	P	C	P	C	P	C
Thermal Comfort	1.44±1.8	3.06±2.79	2.3±2.7	2.17±1.7	0.83±0.3	3.5±3.01	1.17±1.3	3.75±2.87
Moisture Comfort	0.46±1.3	1.46±2.12	1.30±2.0	0.67±1.3	0.1±0.98	2.25±3.7	0.22±0.6	1.57±1.81
Breathability	6.80±1.72	5.44±2.22	6.3±3.46	7.3±0.57	5.3±2.0	6.0±3.46	8.3±1.53	5.3±2.08
Overall Comfort	8.5±0.93	7.78±1.48	8.0±0.0	8.0±0.0	8.3±1.15	7.26±2.65	9.0±1.0	8.3±0.58

P: Experimental Prototype, C: Control Garment

Ratings: 0=Not at all, 10=Extremely

Thermal Comfort: Combined ratings of "cold" & "hot"

Moisture Comfort: Combined ratings of "sticky" "clammy" & "damp"

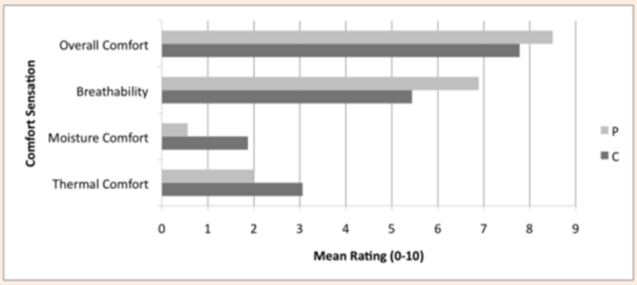

Figure 4: Graph showing overall combined mean thermal and moisture sensation rating.

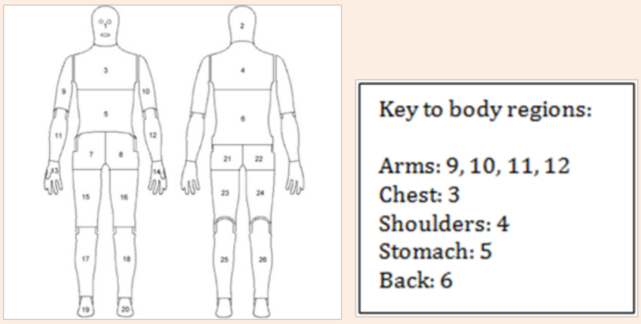

Figure 5: Thermal manikin body regions.

Thermal manikin testing

Table 3 displays the mean Clo values of the prototype and control garments based on 1) the entire shirt region and 2) the arms, chest, shoulders, stomach, and back regions of the manikin. Figure 5 provides a visual explanation of the body regions used.

Table 3: Mean Clo-Values of the Prototype and Control Garments by Body Region.

Region	Prototype	Control
Entire Garment	1.45±0.054	1.45±0.045
Arms	1.32±0.031	1.233±0.036
Chest	1.425±0.08	1.403±0.083
Shoulders	1.317±0.092	1.501±0.079
Stomach	1.95±0.138	2.016±0.112
Back	1.703±0.021	1.926±0.011

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±0.054 and 1.45±0.045 for the prototype and control, respectively. 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 different body regions.

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 value for the arm regions of the prototype and the control shirt, respectively, were 1.32±0.031 and 1.233±0.036. Thus, the prototype provides slightly greater thermal insulation to the arms than the control. The arms of the

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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. 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.

Chest Region The mean Clo value for the chest region of the prototype was 1.425±0.08, compared to the chest region of the control, which was 1.403±0.083. No significant difference in the thermal insulation of the chest regions can be determined.

Shoulder Region The control shirt had slightly higher Clo values than the prototype, as seen in the averages of 1.317±0.092 for the prototype and 1.501±0.079 for the control. The lower average Clo value in the shoulder region of the prototype is due to the moisture management fabric placed in this area, which is thinner and has a more open fabric structure than the control fabric. The use of the moisture wicking fabric in the shoulder region allows for greater dissipation of heat, which is consistent with the subjects' interview preferences for less thermal insulation in these areas.

Stomach there was no significant different in the mean Clo values for the stomach region for both prototype and control shirts which were 1.95±0.138 and 2.016±0.112.

Back The Clo values of the control shirt were slightly higher than the prototype shirt, with a value of 1.926 ± 0.011 in the control shirt compared to1.703±0.021 in the prototype. This suggests more thermal insulation is provided by the back area of the control shirt than the back area of the prototype. The use of the moisture wicking fabric in the upper back 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.

Since the goal was to provide different 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 such as the upper back and greater thermal insulation in areas such as the arms better meet subjects' preferences for a base layer shirt to wear in the cold.

Conclusion

The purpose of this study is to design and evaluate a single-layer garment that incorporates different textiles to provide different thermal insulation and moisture wicking properties in targeted areas of the garment in order 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 development of a prototype backpacking shirt. According to the design criteria, one fabric for thermal insulation and one for moisture wicking were selected for use in the prototype shirt. Likewise, a control fabric was selected based on design criteria. Via questionnaire, quantitative data about the comfort of the prototype and control shirts were collected from subjects that participated in the wear test phase of the study. The comfort rating data based on the seven comfort sensations and the combined thermal and moisture scores resulted in good mean comfort ratings for both the prototype and control garments for all sensations. Objective thermal insulation 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. Although the overall thermal insulation of the entire shirt was the same for both shirts, thermal insulation provided by the prototype versus the control did vary when Clo values of different body regions were compared. The differences in the warmth of the shirt in different body areas are consistent with both the subjects' preferences for thermal insulation in certain body areas 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. Both the prototype and the control shirts were found to provide good thermal, moisture, and overall comfort when worn in cold conditions. Although the mean values of all comfort categories for the prototype shirt were somewhat lower than those of the control, based on the large number of standard deviations (due to the small number of subjects participated in this study), no statistical significant differences between both shirts could be drawn from the results. However, thermal manikin data suggested that the prototype garment provided better thermal insulation and moisture dissipating properties in the specific areas of the body that subjects from the qualitative interviews indicated had a greater need for thermal insulation and a greater need for moisture wicking. The information presented in this study summarizes the physiological 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^{0}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.

Recommendations for Future Research Future studies would benefit from having a greater number of participants as well as including female subjects. Additionally, future studies may benefit from conducting wear tests in a controlled laboratory setting, which would lessen the number of extraneous factors that influence subject rating.

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