〔보 문〕

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Detachable Liner and Insulation of Outdoor Clothing
착탈식 라인어와 아웃도어 의복의 보온성

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Abstract

본 연구의 목적은 의복시스템 내에서 착탈이 가능한 라이너가 있을 때 얼마만큼의 보온성이 증가되는가를 알고자 하는 것이다. 서로 다른 섬유조성과 두께를 가지는 3개의 의복앙상블을 선정하여 움직일 수 있는 마네킨을 사용하여 14℃로 조절되어 있는 인공기후실에서 보온성을 측정하였다. 그 결과 라이너 사용 후 보온성이 증가되었는데 그 정도는 라이너의 두께와 섬유조성에 따라서 다르며 약 0.5 clo 증가하였다. 이 결과로부터 착탈 가능한 라이너의 사용으로 추운기후에 어느정도 적응 할 수 있는가를 확인할 수 있었다.

Key words: insulation, detachable liner, outdoor clothing, thermal manikin, cold weather; 보온성, 착탈식 라인어, 아웃도어 의복, 써멀마네킹, 추운 기후

I. Introduction

People are spending lots of time in cold environments where they enjoy outdoor recreational activities such as hiking, camping, skiing, hunting, and going on expeditions. They are also exposed to cold environments in working places such as food processing plants, military fields, and cold rooms. In cold weather, heat is going to flow from the warm body to a cold environment via conduction, convection, and radiation. Also heat is transferred via evaporation when sweat evaporates from the surface of the skin because the latent heat is extracted from the body. Even if heat is continuously produced in the body by metabolism, it is not able to maintain the proper heat balance due to the limited capacity of the human thermoregulary system. If too much heat is lost, a person might suffer from cold stress, hypothermia, and other types of cold ailments. Thus people use cold weather clothing for thermal protection by minimizing a person's body heat loss in daily activities (i.e., travel to work, school, shopping), in sports activities, and in cold work environments. We are concerned about the use of detachable liner in outdoor clothing for adjusting to cold weather. The ideal clothing system should have a high thermal resistance value during periods of low body heat production (i.e., rest and low activity).

Numerous studies have shown that dynamic insulation is lower than static insulation because the air movement through garment openings, between garment layers and fabric pores increases convective heat loss. Some researchers have investigated the effect of body motion on insulation using a movable thermal manikin (Fan & Keighley, 1991; Holmér, Gavhed, Grahn & Nilsson, 1992; McCullough & Hong, 1994; Nilsson, Gavhed & Holmér, 1992; Olesen & Madsen, 1983; Olesen, Sliwinska, Madsen & Fanger, 1982). If people are active, there are heat production and reduced insulation of clothing due to the pumping effect. Since the thermoregulatory system is limited within a certain environment, the role of clothing is more important to get thermal comfort of people. Layering clothes is the best way to keep in body heat and keep out draft. Layering or building up of several thin layers may be more effective than wearing a single thick layer because of protected air spaces between the fabric layers (Watkins, 1984). One problem of the multi-layer clothing system is the bulk of material in the armpit and crotch, and the stack of collars and junctions at the wrist and ankle (Nielsen, 1991). Thus we must consider limits on mobility, because the bulk of clothing causes a hobbling effect. Outdoor clothing might consist of layering systems including an absorbent underwear and several thin layers of high loft fabric.

This study is concerned with clothing systems that can be adjustable to cold environments during outdoor activities. If one garment has detachable liner, which is insulated, it will be easier to adjust to changeable or transient environments. Therefore, the purpose of this study was to determine how much insulation will be increased when detachable liner is put inside outdoor clothing such as ski clothing, hunting gear and trench coat, in standing and walking conditions, using a moveable thermal manikin.

II. Method

1. Selection of clothing

Three ensembles for the detachable liner effect were selected based on outdoor activities. Detachable liner was selected based on representative material in the current market.

2. Measurements of Clothing Characteristics

1) Clothing ensemble weight: it was determined by adding the weight of each component garment for an ensemble. The weights of shoes and belts were excluded because they were made of materials other than textiles and covered only a small amount of body surface area. They would provide more weight relative to insulation than other types of garments (McCullough, Jones, & Huck, 1985).

2) Opening area: it was determined by measuring the area between the outermost clothing layer and the skin or between the outermost clothing and a tightly closed inner layer at the sleeve hemline, the jacket or coat hemline, and pants bottom hemline. If a jacket or vest covered pants at the hip and waist area, there was an opening area between jacket and pants underneath. In this case, circumference of a jacket or vest hemline and circumference of pants underneath a jacket or vest were measured for determining the opening area. The following equation was used for the calculation.

$$A_o=\pi[(\frac{C_c}{2\pi}-t_{oc})^2-(\frac{C_{pants,\ hip}}{2\pi})^2] \quad 1)$$

where,

A_o = area of opening, cm^2

C_c = circumference of the outermost layer of clothing at the jacket or vest hemline, cm

t_{oc} = thickness of the outermost layer of clothing, cm

$C_{pants, hip}$ = circumference of pants underneath the jacket or vest hemline at the hip area, cm

The following equation was used for the opening area of the coat hemline or jacket hemline over pants at the thigh area.

$$A_o=\pi[(\frac{C_c}{2\pi}-t_{oc})^2-2(\frac{C_{pants,\ leg}}{2\pi})^2] \qquad 2)$$

where,

A_o = area of opening, cm^2

C_c = circumference of the outermost layer of clothing at the coat or jacket hemline, cm

t_{oc} = thickness of the outermost layer of clothing, cm

$C_{pant, leg}$ = circumference of one outer pant leg underneath the coat or jacket hemline, cm

The following equation was also used for the opening area between the coat hemline over the skirt and nude legs.

$$A_o=\pi[(\frac{C_c}{2\pi}-t_{oc})^2-2\pi(\frac{C_{leg}}{2\pi})^2] \qquad 3)$$

where,

A_o = area of opening, cm^2

C_c = circumference of the outermost layer in the coat hemline, cm

t_{oc} = thickness of coat and skirt at the hemline area, cm

C_{leg} = circumference of one nude leg underneath the coat hemline, cm

The sum of the opening areas was determined by adding those three areas together.

3) the number of garment layers on the torso, arms, thighs, and calves: each garment was counted as one layer only if it covered more than 80% of the body part. A detachable liner in a garment was counted as one separate layer.

4) Total thickness of garment layers: it was determined by adding the thickness of each garment layer for an ensemble. The thickness of the component conventional fabrics as they are sewn in the garments was measured according to ASTM D 1777 with a C & R tester. The thickness of fiberfil or down filled fabrics was measured with a pendulum method. First the length of the thread/needle of pendulum was recorded as a baseline when the needle just touched the surface of a flat table. Specimens were placed under the pendulum on the same flat surface. Then the length of the thread/needle of pendulum was recorded in five different places when the needle just touched the fabric surface without any pressure. The fabric thickness value was obtained by subtracting the initial baseline reading from the average fabric reading.

5) Measurement of Clothing Insulation Values: The Movable Thermal Manikin

The insulation value of the clothing ensembles was determined by the manikin test in an environmental chamber according to ASTM F 1291-90, Standard Test Method for Measuring the Thermal Insulation of Clothing using a Heated Manikin (ASTM, 1991). Fred is a computerized, movable, thermal manikin with 18 electrically separated segments. Each segment has independent temperature measurement and control. His height is 179.1 cm (70.5 in) and his surface area is 1.82 m^2.

The selected air temperature was 14 ℃ (57 °F); it did not fluctuate more than 1 ℃ from test to test throughout the project. Air velocity was maintained at 0.15 m/s with fans. The mean skin temperature of the manikin was maintained at 33.2 ℃ (92 °F).

Fred was dressed in the ensemble and his wrist and ankles were connected to locomotion device. After the manikin system was stable, manikin test was conducted for 30 min to get standing insulation while the manikin was standing on the floor with his arms at his sides. Then the manikin's locomotion device was turned on. After a 8-10 minute warm-up walking period, a test was conducted for 8 minutes to get dynamic insulation while the manikin was walking at 90 steps/min. Two replications of these tests were conducted. The deviation from the mean was not more than 3% for standing and 5% for walking. This procedure was repeated with other ensembles.

a) Total insulation:

Total insulation (I_T) is the resistance from the body surface to the environment and includes the air layer around the clothed body. This value for each ensemble was reported as an average of two replications. Total insulation was calculated as follows:

$$I_T=\frac{K \cdot A_S \cdot (T_s - T_a)}{Q} \quad 4)$$

where,

I_T = total thermal insulation of the clothing plus air layer, clo

K = constant = 6.45 cloW/m²℃

T_s = mean skin temperature, ℃

T_a = ambient air temperature, ℃

A_s = manikin surface area, m^2

Q = power input, W

b) Intrinsic clothing insulation (I_{cl})

This value is the insulation from the skin to the clothing surface, and it was determined as follows:

$$I_{cl}=I_T-\frac{I_a}{f_{cl}} \quad 5)$$

where,

I_{cl} = intrinsic thermal insulation of clothing, clo

I_a = thermal insulation of air layer around the nude manikin, clo

f_{cl} = clothing area factor

In the above equation, the value for I_a was obtained by operating the manikin without clothing while standing (0.68 clo) and walking (0.49 clo).

c) Percent change in insulation: it was obtained by dividing the absolute change in insulation by the static insulation value and multiplying by 100.

III. Results and Discussion

In this study, the use of a detachable liner increased the insulation of the ensembles. This finding is shown by comparing ensembles of ski clothing, hunting gear and business suit, where the only difference between them was the presence of a detachable liner in the jacket or coat. Characteristics of the fabric of each garment in the ski ensemble are provided in table 2. The filing material for the liner was 77% polyester/23% polyolefin, which is called Thinsulate Lite Loft, and its lining material was 100% nylon.

When the liner was attached to ski clothing (ensemble SKIL), standing insulation was 2.30 clo (See table 1). Insulation measured while walking, which is called dynamic insulation, was 1.75 clo. But when the liner was detached (SKINL), the amount of standing insulation was 1.77 clo and dynamic insulation was 1.30 clo, thereby 29.9 % of standing insulation and 34.6 % dynamic insulation increased. From this result, the use of detachable liner helped to increase 0.53 clo in standing insulation and 0.45 clo in walking insulation. Table 1 shows that the change in insulation due to movement is smaller in ski clothing with liner (23.8%) than in ski clothing without liner (26.4%). The reason is that ensemble SKIL had less air

Table 1. Insulation Values of Ski Ensemble with/wihout Detachable Liner into Jacket

Code No.	List of Garments	Description of Clothing Characteristics			Insulation	
		Opening area(cm²)	Ensemble wt.(g)	No. of Layers on the Top & Bottom [Thickness, mm]	I_{cl} Standing /walking (clo)	Change in I_{cl} (%)
SKINL (No Liner)	The same as ensemble SKIL, except ski jacket without liner	96.2	2,683	2(1.73), 2(5.97)	1.77/1.30	26.4
SKIL (With liner)	Turtleneck sweater, Thermal long underwear bottom only, Insulated ski pants, Knee length ski socks, Hip length ski jacket with liner, Knit hat, Goggles, Mitten shell with inner fleece golves, Insulated midcalf waterproof boots	96.2	2,943	3(15.39), 2(5.97)	2.30/1.75	23.8
Change(%) with liner, compared to no liner					▲29.9/34.6	

Table 2. Characteristics of Fabric of Each Garment in Ski Ensemble

Code No.	Garments Description	Fiber Content and Fabric Description	Thickness (mm)	Air Permeability ($cm^3/cm^2 \cdot s$)
SKINL	Ski jacket without liner (Other garments are described in SKIL)	Outer Jacket Shell: 100% nylon, plain weave, Lining: 100% nylon	0.46	0
SKIL	Turtleneck sweater,	100% polypropylene knit	1.27	527.0
	underwear bottom	100% capilene single interlock knitted polyester	0.94	641.0
	Insulated ski pants	Shell: 53%, polyster/47% nylon, plain weave, Filing material: 65 olefin/35% polyester Thinsulate, Lining: 100% nylon, plain weave	5.03	0
	Knee length ski socks	100% acrylic, knit	4.01	79.10
	Hip length ski jacket with fiber filled liner	**1) Outer jacker** Shell: 100% nylon plain weave, Lining: 100% nylon, **2) Liner** Filling material: 77% polyester/23% polylefin, Thinsulate Lite Loft, Lining: 100% nylon	14.12 (0.46)	0 (0)
	Mitten shell with inner fleece gloves	**1) Outer Mitten** Shell: 100% nylon with polyurethane letherrete palm, Filling material: hollofil II polyester, Lining: 100% nylon tricot, **2) Inner mitten liner**: 100% polyester Polartec Recycled Series	25.09	0
	Insulated midcalf waterproof boots	Shell: water resistant nylon molded plastic, Filling material: 100% polyester Thermolite	20.32	0
	Knit hat	100% acrylic knic	8.0	132
	Goggles			

space between the clothings outer layer and inner layer than ensemble SKINL, thus the pumping effect is smaller.

We could determine the effect of liner on the insulation of the business ensemble as well (See table 3). In this ensemble, we were concerned with the zip out trench coat liner, which has filling material which is 63% acrylic/37% olefin warp pile

Table 3. Insulation of Men's Business Suit and Trench Coat Ensemble with/wihout Detachable Liner

Code No.	List of Garments	Clothing Characteristics			Insulation	
		Opening area(cm^2)	Ensemble wt.(g)	No. of Layers on the Torso, Arms, Thighs & Calves (Thickness, mm)	I_{cl} Standing /walking	Change in I_{cl}
BNL (No Liner)	The same as BL, except trench coat without liner	1,148.6	2,907	4(2.79) 3(1.88), 2(1.22), 1(0.58)	1.57/0.77	50.9
BL (With liner)	T shirt, Underwear briefs, Dress socks, Long sleeve dress shirt, Tie, Double breast trench coat with detachable liner, Men's business suit, Hard soled street shoes	1,114.4	2,954	5(5.36), 4(2.85) 3(3.78) 1(0.58)	1.63/0.87	46.5
Change(%) with liner, compared to no liner					▲3.8/13.0	

Table 4. Characteristics of Fabric of Each Garment in Men's Business Ensemble with Detachable Liner

Code No.	Garments Description	Fiber Content and Fabric Description	Thickness (mm)	Air Permeability ($cm^3/cm^2 \cdot s$)
BNL (No Liner)	Trench coat without liner(Other garments are described in BL)	**Outer Jacket** Shell: 65% polyester/35% cotton, plain weave Lining: 100% nylon, taffeta	0.64	5.39
BL (With Liner)	T shirt	100% cotton knit	0.91	591
	Underwear briefs	100% cotton knit	1.27	602
	Dress socks	75% HB-acrylic/25% nylon knit	2.74	226
	Long sleeve shirt	100% cotton, plain weave	0.46	420
	Double breasted trench coat with detachable liner	**1) Outer jacker** Shell: 65% polyester/35% cotton, plain weave Lining: 100% nylon,taffeta **2) Liner(Zip out)** Trunk: 63% acrylic/37% olefin, warp pile knit Sleeves: 59% cotton/41% rayon, double cloth satin	Trunk: 3.20, Sleeves: 0.063	5.54
	Men's business suit	**Top** Shell: 65% polyester /35% worsted wool, plain weave, Lining: 100% acetate, taffeta	0.79	24.80
		Bottom: 65% polyester/35% worsted wool, plain weave	0.58	79.40

knit for the trunk, and 59% cotton/41% rayon double cloth satin for the sleeves. Table 4 shows the characteristics of the materials for each of the garment parts.

The trench coat ensemble insulation with liner(BL) while standing/walking was 1.63 clo/0.87 clo. The amount of decreased dynamic insulation was 46.5% in ensemble BL, and 50.9% in ensemble

Table 5. Lining Effect on Insulation Values of Heavy Hunting Jacket and Pants

Code No.	List of Garments	Description of Clothing Characteristics			Insulation	
		Opening area(cm^2)	Ensemble wt.(g)	No. of Layers on the Top & Bottom (Thickness, mm)	I_d Standing /walking	Change in I_d
HNL(No Liner)	The same as HL, except hunting jacket without liner	533.6	2643	2(1.70), 2(20.03)	2.13/1.56	26.8
HL (With liner)	Briefs, Cotton knit turtleneck sweater, Long thick socks, Jean, Thick hunting bib overalls, Jacket, Hat with fleece liner and ear flaps, Insulated gloves, Insulated midcalf water proof boots	420.3	2943	3(35.33), 2(20.07)	2.98/2.32	22.0
Change(%) with liner, compared to no liner					▲39.9/48.7	

Table 6. Descriptions of Heavy Hunting Gear Garments

Code No.	Garments Description	Fiber Content and Fabric Description	Thickness (mm)	Air Permeability ($cm^3/cm^2 \cdot s$)
HNL	Hunting jacket (Other garments are described in HL)	**Outer Jacket** Shell: 100% nylon: Omnitech water proof Brethable StealthII Cloth™, plain weave Linging: 100% nylon, plain weave	0.66	0
HL	Hunthing jacket	1) **Outer jacker** Shell: 100% nylon: Omnitech water proof Brethable StealthII Cloth™, plain weave Lining: 100% nylon, plain weave 2) **Liner** Shell: 100% polyester, plain weave, Filling Material: 100% polyester; Thermoloft^R, Lining: 100% nylon, plain weave	34.29	0
	Briefs	100% cotton knit	1.27	602.0
	Cotton knit sweater	65% polyeter/35% cotton knit	1.04	522.0
	Socks	40% wol/40% acrylic/20% nylon knit	5.06	154.00
	Jeans	100% cotton denim	1.73	11.20
	Water proof boots	Shell: 100% nylon, Omnitech™ waterproof, Breathable Stealth II Cloth™, plain weave	20.32	*
	Insulated gloves	Shell: 100% nylon, Filling material: 100% polyester microfiber Lining: 100% nylon taffeta	26.04	0.94
	Hat	Shell: 100% nylon woven, Liner: 100% polyester, knitted fleece	7.92	24.0

BNL. We realized both BNL and BL had a higher decreased amount of dynamic insulation than SKIL and SKINL, because of more opened area (1,148.6/1,114.4 cm^2). Comparing the insulation of ensemble BL to that of ensemble BNL, the amount of change in standing insulation was 3.8%, and the amount of change in dynamic insulation was 13.0%. Even if the sum of three opening areas such as jacket hemline, sleeve hemline, and pantleg in both ensemble is the same, air volume inside the jacket in ensemble BL is smaller when the 2.56mm liner is attached. Thus dynamic insulation in BL was higher than in BNL because BL had less heat loss from less pumping effect through the neck area or pores of fabrics, due to movement.

Table 5 shows the results of the measurements made for hunting gear. We use warmer material for the liner of hunting jackets, because people are exposed to cold environments for long periods while hunting. Thus we selected thicker liner, which had filled with Thermoloft with nylon lining, and its thickness was 33.63mm (See table 6). If we attached liner to hunting jackets (HL), standing insulation was 2.98 clo and dynamic insulation was 2.32 clo, which means the use of liner increased heat retention 39.9% with standing insulation and 48.7% of dynamic insulation (See table 5). Without liner, standing insulation was 2.13 clo and dynamic insulation was 1.56 clo. The difference of insulation between the insulation with liner and without liner was 0.53clo in standing and 0.45 clo in walking.

The use of detachable liner in clothing could help people adapt to differences in thermal environments because it increases the insulation value of outdoor clothing, depending on the thickness and material used in the liner of the clothing.

Ⅳ. Conclusions

This study shows that the use of detachable liners could help increase the insulation of clothing systems. The amount of increased insulation depends on the types of liner material, and its thickness. The zip out trench coat liner, which has a filling material that is 63% acrylic/37% olefin warp pile knit for the trunk, and 59% cotton/41% rayon double cloth satin for the sleeves, had little influence on the insulation. However, the liner used for hunting jacket, which was made of Thermoloft with nylon lining and a thickness of 33.63mm, was found to be a good insulator. People can adjust to cold weather better using the right detachable liner.

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