DIFFERENT EFFECTS OF COTTON AND POLYPROPYLENE UNDERWEAR ON METABOLIC HEAT PRODUCTION IN EXERCISING AND RESTING WOMEN AT 2°C

Minja Ha, Hiromi Tokura, Jun Gotoh[1] and Ingvar Holmér[2]

Department of Environmental Health, Nara Women's University, Nara 630, Japan, [1]Kyoto R&D Institute, Gunze LTD., Ayabe 623, Japan and [2]Division of Work and Environmental Physiology, National Institute of Occupational Health, S-171 84 Solna, Sweden

INTRODUCTION

Although several papers are available concerned with the effects of clothing on thermophvsiological responses and subjective sensations in the cold (Vokac et al. 1976, Holmér 1985, Nielsen et al. 1988, Nielsen and Endrusick 1990, Bakkevig and Nielsen 1994), the physiological significance of clothing material for metabolic heat production has not been understood systematically so far.

MATERIALS and METHODS

Experimental garments: Two layers of cotton underwear with a two-piece long-sleeved shirt and long-legged trousers (C) and two layers of polypropylene underwear with a two-piece long-sleeved shirt and long-legged trousers (P) were used. Two different sizes of underwear fitting the body shape of the subjects were provided. Furthermore, the subjects put on a two-piece ski wear as outer clothing, two pairs of socks, cap and gloves, respectively. Two different sizes of ski suit were also put on.

The physical properties of fabrics are given in Table 1. The total clo values of our experimental clothing ensembles, measured by a thermal manikin, were 2.42 in C and 2.47 in P. The clothing was stabilized in the environmental conditions (T_a=24±1°C, 30±5% R.H.) before each experiment.

Table 1. Physical properties of underwear fabrics.

Fabrics	Weight ($g \cdot m^{-2}$)	Thickness (mm)	Density wale, course (no·inch^{-1})	Moisture regain (%)
Cotton	242.2	1.83	29.24	6.8
Polypropylene	138.3	1.81	30, 23	0.5

Subjects: Eight adult females participated in this study. The subjects were 22.1±0.9 years in age (means±SE), 163.3A1.6 cm in height, 57.2±3.1 kg in weight and 1.56±0.04 m^2 in body surface area (as calculated by the equation of Fujimoto et al. 1968). The experimental procedure was explained to the subjects, and each subject carried out pretest. All subjects provided their voluntary informed consent before participating in the experiment.

Measurements: The rectal temperature (T_{re}) was recorded by a thermistor probe (TAKARA Thermistor, accuracy; ±0.01°C) inserted 12 cm beyond the anal sphincter. Skin temperatures (T_{sk}) were measured with thermistors (TAKARA

Thermistor, accuracy; ±0.1°C) taped at eight sites: forehead, forearm, hand, chest, back, thigh, leg and foot. Clothing microclimates (temperature and humidity) of the innermost layer, middle layer and the outermost layer at the back levels were measured by thermistors and humidity sensors (Vaisala, HMP-35A, accuracy; ±3% R.H.). Clothing surface temperature at the back level was taken by a thermal video system (TVS-8100, AVIO, Japan, accuracy; ±0.4%) in one subject. The pulse rate was measured every 30 s.

Before the experimental sessions, the maximal oxygen uptake ($\dot{V}o_{2max}$) was measured on a cycle ergometer (Ergociser, model EC-1500 Cateye Co. Japan). The intensity of exercise used in this study was *65%* of $\dot{V}o_{2max}$. The weight of garments was measured at the beginning and at the end of the experimental protocol. Body mass loss was measured continuously by a balance (Sartorius, accuracy; ± 1 g, Germany). Metabolic heat production by the open circuit method was measured by an Aeromonitor (*AE-280*, Minato Med. Sci. Japan) during the last 30 min.

Thermal sensation, clothing sensation, skin sensation and shivering/sweating sensation for whole body were answered every 5 min.

Experimental protocol: The test was carried out in a climatic chamber at a T_a of 2°C and an air velocity of 0.26 m·s^{-1}. The experimental garments were kept in the antechamber at a T_a of 24±1°C, 30±5 % R.H. at least for 2 h before the experiment began. The subjects wore the experimental garments in the antechamber. Thermistor sensor for rectum was inserted by the subjects and thermistors for skin temperature were taped. Each piece of experimental clothing was weighed and then put on the subjects. The temperature and humidity sensors for clothing microclimate of each layer were taped at the chest and back level. After dressing, the subject was asked to rest in a chair.

After the rectal temperature had been stabilized, the subject entered a climatic chamber for the experiment. The subject sat on the chair mounted on a balance. Then, the measurements were recorded. After 10 min, the subject exercised on a cycle ergometer at an intensity of 65% maximal oxygen uptake for 30 min and followed by 60 min recovery. After 30 min from the recovery start, the mask for the measurements of the oxygen uptake ($\dot{V}o_2$) and carbon dioxide ($\dot{V}co_2$) output was put on. After the whole experiment of 100 min, the subject exited the climatic chamber, took off her clothes and their weight was measured again in the antechamber.

Calculations and statistical analysis: Mean skin temperature ($\bar{T}_{sk}$) was calculated by the following modification of the Hardy-DuBois equation: $\bar{T}_{sk} = 0.07\ T_{head} + 0.14\ T_{arm} + 0.05\ T_{hand} + 0.18\ T_{chest} + 0.17\ T_{back} + 0.19\ T_{thigh} + 0.13\ T_{leg} + 0.07\ T_{foot}$. Mean body temperature ($\bar{T}_b$) was calculated by the equation: $\bar{T}_b = 0.6\ T_{re} + 0.4\ \bar{T}_{sk}$.

Metabolic heat production (M) was calculated according to the following equation: $M=21.13(0.23R+0.77)\dot{V}o_2(60/BSA)$, where, M: metabolic heat production (W), $\dot{V}o_2$: total volume of oxygen consumed, where the volume was adjusted to STPD. $\dot{V}co_2$: total volume of carbon dioxide production, where the volume was adjusted to STPD, R: respiratory quotient.

The statistical significance between the means was assessed using repeated-measures analysis of variances (ANOVA) and separately for the two periods of the exercise and recovery. Data obtained every 5 min during exercise and 10 min during the recovery for T_{re}, $\bar{T}_{sk}$, $\bar{T}_b$, clothing microclimate temperatures and humidities were used in the statistical analysis, and every 5 min €or metabolic heat production (the last 30 min). A Student's t-test €or paired comparison was used €or the weight changes in garments, total body mass loss and evaporative body mass loss. A p-value less than 0.05 was regarded as statistically significant, and that with $0.05<p<0.1$ differences was referred to as a tendency in the data.

RESULTS

T_{re}, $\bar{T}_{sk}$ and $\bar{T}_b$ were not significantly different between the two types of underwear during exercise and recovery. However, the fall of T_{re} tended to be greater in P underwear condition during recovery; 0.83±0.08 for C and 0.97±0.05 for P.

Skin temperatures on the back and chest did not differ between C underwear and P underwear. Clothing microclimate temperatures of innermost at the back level were significantly higher in C underwear than in P underwear during the exercise ($F=45.69$, $p<0.01$) and recovery ($F=17.05$, $p<0.01$). Clothing microclimate temperature of innermost at the chest level was significantly higher ($F=10.74$, $p<0.01$) in C underwear than in P underwear during the exercise, but it was not significantly different during the recovery. Clothing microclimate temperature of outermost at back level was not significantly different between the two types of underwear during the exercise and recovery.

Clothing surface temperatures were higher in P during exercise and recovery. These mean values were 16.0°C and 15.0°C in C, and 17.2°C and 15.8°C in P at 25 min after the exercise and at 55 min after the recovery, respectively.

The humidity of each layer quickly increased with the onset of sweating (about 10 min of exercise), the increase continued till the stop of exercise, and it gradually decreased during the recovery. The absolute humidity of innermost layer between skin and underwear was not significantly different during exercise, but it was significantly higher ($F=9.05$, $p<0.01$) in C underwear during recovery. The absolute humidity of middle layer between underwear and outer wear was significantly higher ($F=19.61$, $p<0.01$) in P underwear during the exercise, but it was significantly higher ($F=4.19$, $p<0.05$) in C underwear during the recovery. The absolute humidity of outermost layer inside ski wear was significantly higher ($F=20.52$, $p<0.01$) in P underwear during the exercise, but it was not significantly different during the recovery.

The whole body mass losses by evaporation during exercise and recovery tended to be greater in P underwear than in C underwear.

The changes in underwear weight between the beginning and the end of experiment tended to be greater in C underwear than in P underwear. However, the weight change of ski wear was not significantly different. Total body mass loss during the experimental periods was not significantly different.

Metabolic heat production for last 30 min during recovery was compared between C underwear and P underwear in a subject (Fig.1). As seen in the figure, metabolic heat production was higher in P underwear than in C underwear during the last 30 min recovery.

There was no significant difference in thermal sensation of whole body between the two kinds of underwear condition throughout the exercise and recovery. Sweating sensation of whole body was significantly higher ($F=11.33$, $p<0.01$) in P underwear than in C underwear during exercise, but shivering sensation of whole body was not significantly different during the recovery. The degree of skin wettedness sensation was significantly higher ($F=4.50$, $p<0.05$) in P during the exercise, but it was not significantly different between C and P underwear during the recovery. The degree of clothing wettedness sensation was not significantly different between underwear conditions throughout the exercise and recovery.

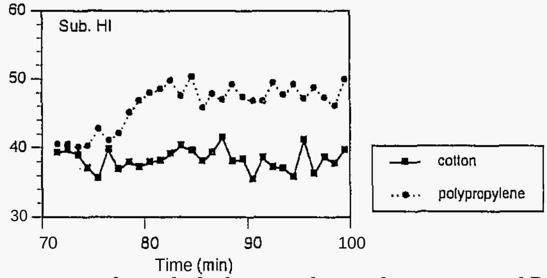

Fig. 1. A comparison of metabolic heat production between C and P underwear during the last 30 min recovery. Solid line: C. Dashed line: P.

CONCLUSIONS

It was concluded that two kinds of underwear with different properties to moisture could influence differently not only clothing microclimate, but also physiological parameters like metabolic heat production under the severe exercise and its recovery in the cold, and the underwear with high absorbancy is better in reducing heat loss from human body into surrounding air.

REFERENCES

Bakkevig, M.K. and Nielsen, R. **(1994)** Impact of wet underwear **on** thermoregulatory responses and thermal comfort in the cold. ***Ergonomics*** **37: 1375-1389**

Fujimoto, S., Watanabe, T., Sakamoto, A., Yukawa, **K.** and Morimoto, **K. (1968)** Studies **on** the Physical Surface Area **of** Japanese. Part **18** Calculation Formulas in Three Stages over All Age. ***Japanese Journal of Hygiene*** **23: 443-450** (in Japanese)

Holmér, I. **(1985)** Heat exchange and thermal insulation compared in woolen and nylon garments during wear trails. ***Textile Research Journal*** 55:511-518

Nielsen, R. and Endrusick, T.L. **(1988)** The role **of** textile material in clothing **on** thermoregulatory responses to intermittent exercise, in F. Aghazadeh (ed.), ***Trends*** *in Ergonomics/Human Factor V* (Elsevier Science Publishers B.V., North-Holland **449-456**

Nielsen, R. and Endrusick, T.L. **(1990)** Sensations **of** temperature and humidity during alternative work/rest and **the** influence **of** underwear knit structure, ***Ergonomics*** 33: **221-234**

Vokac Z., **Køpke,** V., and Keül, **P. (1976)** Physiological Responses and Thermal, Humidity, **and Comfort** Sensations in Wear Trials **with Cotton** and Polypropylene Vests, ***Textile Research Journal*** 46:30-38