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Effects of Wettability of Cotton Shirts on Skin Wettedness and Microclimate between Cloth and Skin under Exercise

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ABSTRACT

The effects of wettability of cotton shirts on microclimate between clothes and skin under exercise were studied using knitted cotton undershirts treated by two surfactants and a finishing agent.

All the shirts used are highly moisture absorbant. However, the shirts treated by an anionic surfactant are highly wettable, those treated by a cationic surfactant are modestly wettable, and those treated by a fluorine-containing finishing agent are not wettable.

Experiments were conducted in a climatic chamber under a temperature of 23°C, a relative humidity of 49% and an air movement of 10 cm/sec. A subject took a 30 minute rest before the 21 minute exercise using a treadmill and a 42 minute rest after exercise.

Local temperatures and vapor pressures were measured at one minute intervals inside and outside the cotton shirts at both right and left sides of the back and in the environment. A heart pulse rate, skin temperature and the body weight loss of the subjects were measured during the experiment. The change of the skin and fabric wettedness was examined. Physical properties of the fabrics were also measured.

The results obtained are summarized as follows : Physical properties except wettability and water repellency of all the treated cotton shirts were similar. Temperature and mean skin temperatures of the subjects in different treated shirts were similar, but vapor pressure and wettedness on skin and fabric of the subjects wearing non-wettable cotton shirts showed higher values than those of wettable cotton shirts. Body weight loss of the subjects wearing non-wettable shirts was greater than that of wettable shirts.

1 Introduction

Clothing comfort is affected by various factors including psychological, physiological, environmental and physical condition. Physical properties and structures of fabrics are important factors affecting clothing comfort. Under the same exercise, temperature and vapor pressure inside the fabric depend on the properties of the fabric. To investigate the effects of microclimate on clothing comfort, it is necessary to equal the condition of the wearing test and the subjects except the factor of fabric. Clothing comfort is influenced by heat and water vapor transmission through fabrics in a human-clothing-environment system. Therefore the wearing test was conducted in a climatic chamber.

The effects of fiber materials in knitted fabrics on wear comfort and microclimate under exercise were studied using wool, descaled wool, cotton, acrylic and blended fabrics[1,2,3,4]. The wettedness of subjects wearing water-repellent cotton fabrics was comparatively higher, whereas the discomfort sensation experienced by subjects wearing water-repellent cotton fabrics was lower than wool.

Thus, the effects of wettability of cotton shirts on wear comfort and micro-climate between clothes and skin were studied using knitted cotton undershirts treated by two surfactants and a finishing agent.

2 Experimental

2-1 Shirts

All the long-sleeved knitted undershirts used are 100% cotton. They are highly moisture absorbant and wettable. The shirts treated by an anionic surfactant are highly wettable, those treated by a cationic surfactant are modestly wettable, and those treated by a fluorine-containing finishing agent are not wettable. For the wearing test, there were three shirts in each experiment, each treated with one of three treatments. These three treatments consisted of : 1) a highly-wettable treatment, 2) a modestly-wettable treatment, and 3) a non-wettable treatment. Subjects wore new shirts in each test because repeatedly-worn clothing absorbs oily components from the body[5].

The thickness was obtained under the pressure of 240 gf/㎠ according to JIS L 1018. The physical parameters of fabrics measured at 20°C for thermal insulation value, air and moisture transmission. Air permeability was given using a Frazier air permeability instrument. Thermal insulation of fabrics was evaluated using the guarded hot plate technique by the method of ASTM D 1518-57T. Moisture transmission was obtained according to JIS L 1099, using an aluminum cup containing distilled water. Water absorption was measured by the following method : A strip of the test fabric (20×2.5㎠) was suspended vertically immersing 1 cm of its lower end in a reservoir of distilled water. Water repellency was then measured using a spray tester.

2-2 Wearing test

Wearing tests were carried out in a climatic chamber which was constructed with a double wall. The temperature of the inside wall of the chamber was adjusted to keep the same temperature as the environment one. In the climatic chamber, an ambient temperature of 23.0±0.5°C, a relative humidity of 49.0±2.0% and an air velocity of 0.1m/sec from the floor toward the ceiling were maintained.

Two healthy females of 21 years were served as subjects for physiological and psychological measurements. Their physical characteristics are shown in Table 1 together with exercise load. Their physiques are similar. Body surface area was calculated by the formula of Takahira[6].

After the subjects were acclimatized over 30 minutes by sitting on a chair before starting the experiments, their nude weights and clothing weights were measured prior to dressing. The clothing ensemble consisted of shorts, training pants, socks and the treated shirt. The treated shirt was worn as inner clothing and was fastened by a rubber belt at the waist. The clothing was kept overnight under the ambient condition in the chamber. Each subject took a 21 minute rest on a chair positioned on a platform scale before the 21 minute exercise using a treadmill, which was followed by another 42 minute rest. The chair was made of plastic with numerous holes punched through it to facilitate ventilation of the body surface. Thus, the experiment was carried out for a total of 84 minutes.

Exercises were conducted by an intensity of about 40% each subject's maximum aerobic capacity determined from a previous maximum exercise tolerance test. The velocity of the treadmill was 63.5 and 58.5 m/min with an 8.6% slope for subject S and I respectively.

2-3 Parameters measured in the wearing test

The temperature and humidity of microclimates inside and on the shirt were measured with Shin-ei Type THP-13 temperature-hygrometers. They were calibrated with a standard humidity generator. The external form of the sensor was compact with 2.7×1.4×0.6 in cm. The four sensors were covered with Gore-Tex fabric to avoid contact with sweat[7], and fixed with moisture permeable surgical tape on the skin and on the shirt surfaces at the right and left

Table 1 Physical caracteristics of the subjects and exercise load.

Subject	Age (yrs)	Height (cm)	Weight (kg)	BSA* (m^2)	Exercise load** (m/min)	Wearing test Sample number
S	21	165	57.9	1.623	63.5	1, 2, 4, 5, 7, 8
I	21	163	54.0	1.567	58.5	3, 6, 9

* Body surface area.

** Velocity of the treadmill with 8.6% slope.

sides of the back. Their signals were collected at one minute intervals.

Local skin temperatures were measured at six sites (upper chest, back (scapura), lower back, hand, shin and calf) with copper-constantan thermocouples. Mean skin temperatures (Ts) were determined by the following equation by applying area weight factors to temperatures measured at each site[8].

$Ts = 0.218\ T\ u.chest + 0.181\ T\ back + 0.150\ T\ l.back + 0.143\ T\ hand + 0.167\ T\ shin + 0.142\ T\ calf$

Internal body temperature was measured at 3 minute intervals with a digital thermometer in the oral cavity. The evaporative weight loss was measured by an electrical output signal from a platform balance with a sensitivity of 1 gf.

Local wettedness on the fabric was calculated by the following equation[9].

$Wf = (Pf - Pa) / (Psf - Pa)$

Wf : Local wettedness on the fabric

Pf : Vapor pressure at the surface of the fabric

Psf : Saturated vapor pressure on the surface temperature of the fabric

Pa : Environmental vapor pressure

And, local wettedness on the skin proposed by Berglund and Cunningham was calculated by the following equation[10].

$Ws = (Ps - Pa) / (Pss - Pa)$

Ws : Local wettedness on the skin

Ps : Vapor pressure on the skin

Pss : Saturated vapor pressure on surface temperature on the skin

Pa : Environmental vapor pressure

3 Results and discussion

Table 2 shows the physical properties of the shirts. The physical properties of all the treated cotton shirts were similar except for water absorption and water repellency.

Fig.1 shows changes in temperature and vapor pressure inside and outside the highly wettable shirt worn by subject S (Sample 1). The difference in temperatures on the right and left sides of the back is very small. The microclimate temperature inside the shirt showed about 29°C. After starting exercise, the temperature increased a little because of heat production caused by muscular activity. The temperature decreased gradually through evaporative heat loss caused by perspiration. The temperature of the outside of the shirt fluctuated more than that of the inside of the shirt.

Immediately after starting exercise, the mean skin temperature decreased a little due to convective heat loss on the skin, and contraction of blood vessels in the skin due to an increase in bloodstream from muscular activity. The mean skin temperature increased gradually with exercise. From the point of about 15 minutes after stopping the exercise, the mean skin temperature decreased again.

Table 2 Physical properties of shirts.

		Highly wettable treatment Sample 1, 2, 3	Modestly wettable treatment Sample 4, 5, 6	Non-wettable treatment Sample 7, 8, 9
Thickness	(mm)	0.608	0.617	0.602
Weight	(g/m²)	165.0	174.1	170.0
Density	(g/cm³)	0.272	0.282	0.282
Porosity	(%)	84.3	83.7	83.6
Air permeability	(cc/cm²/sec)	129	115	123
Thermal insulation	(%)	18.0	16.8	16.7
Moisture transmission	[g/(m²·h)]	89.7	87.1	93.6
Water absorption	(mm)	97.5	68.7	0
Water repellency	(%)	0	0	72.0

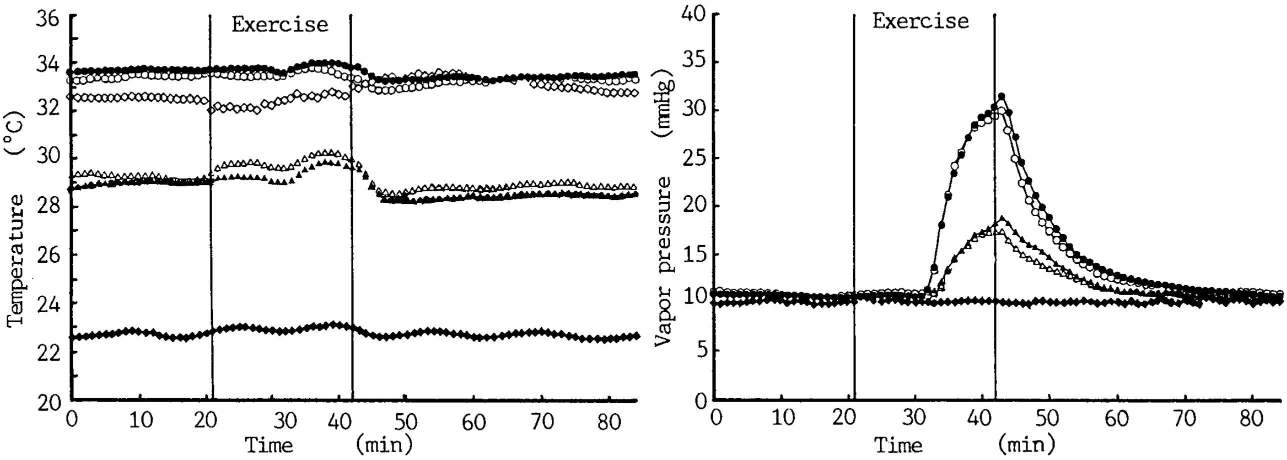

Fig. 1 Temperature and vapor pressure in the microclimate of the highly wettable shirt worn by subject S. (Sample 1)

● Inside the shirt at the right side of the back
○ Inside the shirt at the left side of the back
▲ Outside the shirt at the right side of the back
△ Outside the shirt at the left side of the back
◆ Environment
◇ Mean skin temperature

The vapor pressure increased 10 minutes later from the start of the exercise and reached the maximum value a few minutes later at the end of the exercise. Then, it decreased rapidly. The vapor pressure difference at right and left sides of the back was very little inside and outside the shirt.

This change of the vapor pressure depended on the change of sweat amount due to exercise and the diffusion movement of the moisture.

Fig. 2 shows changes in temperature and vapor pressure inside and outside the non-wettable shirt worn by subject S (Sample 8). The temperature inside the non-wettable shirts was similar to that of the highly wettable shirt.

The mean skin temperature of the subject clothed in the non-wettable shirt was a little higher than that of the one clothed in the highly wettable shirt. The vapor pressure of non-wettable shirt was similar to that of the highly wettable shirt as shown in Fig. 1. But, the raise of the vapor pressure was early in non-wettable shirt because of prompt sweating. The fall of vapor pressure inside the non-wettable shirt after exercise is rapid because of high moisture transmission. The vapor pressure outside was higher than that of the highly wettable shirt.

The changes in temperature and vapor pressure inside and outside the modestly wettable shirts worn by subject S (sample 4, sample 5) were similar to those results.

The mean skin temperature decrease of the six sites on the body was related to the temperature decrease on the back of the hand which was nude and hardly moved with exercise.

Fig. 3 shows decrease of body weight during the experiment. The value of subject S is the mean value of two runs. Since the sweat condition was medium level, sweat was not dripping to the platform balance. So, the body weight loss was the total evaporation amount from body surface or the surface of the fabric. After exercise, the body weight loss increased by sweating. The body weight loss of subject S was more than that of subject I. When non-wettable shirts were worn, the body weight loss was greater than highly and modestly wettable shirts. When the subject wore polyester on the skin,the perspiration amount was more than that of cotton[11]. Sweating was more evi-

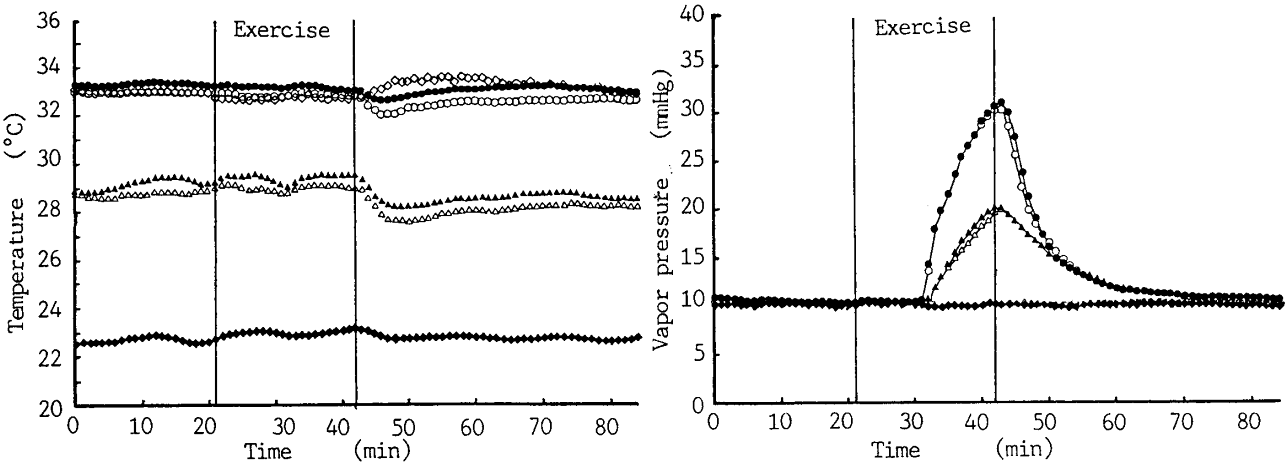

Fig. 2 Temperature and vapor pressure in the microclimate of the non-wettable shirt worn by subject S. (Sample 8)
● Inside the shirt at the right side of the back
○ Inside the shirt at the left side of the back
▲ Outside the shirt at the right side of the back
△ Outside the shirt at the left side of the back
◆ Environment
◇ Mean skin temperature

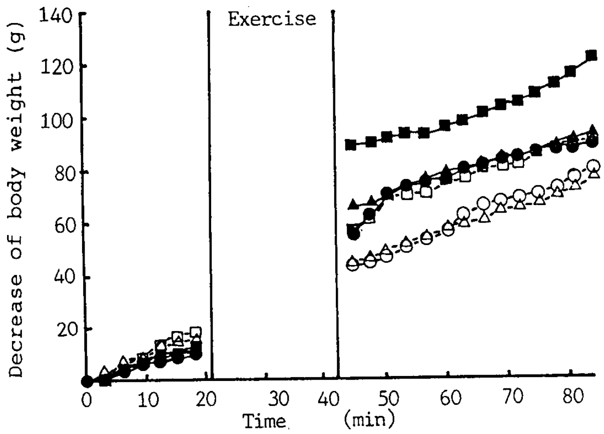

Fig. 3 Decrease of body weight during experiment.
Subject S ● Sample 1,2 ▲ Sample 4,5
■ Sample 7,8 (Mean value)
Subject I ○ Sample 3 △ Sample 6
□ Sample 9

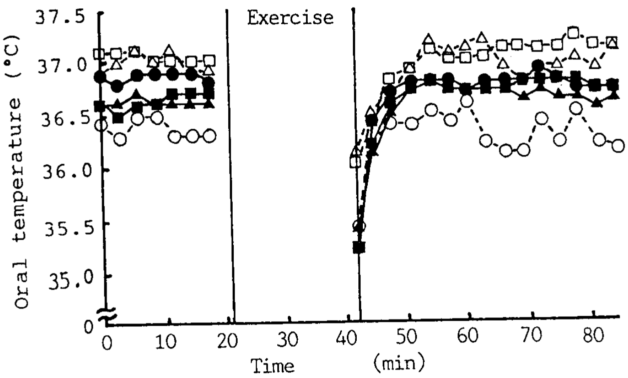

Fig. 4 The oral temperature during exeriment.
Subject S ● Sample 1,2 ▲ Sample 4,5
■ Sample 7,8 (Mean value)
Subject I ○ Sample 3 △ Sample 6
□ Sample 9

dent with untreated polyester than with treated polyester by humidity absorption[12].

The heart pulse rate during the experiment increased rapidly with starting exercise and decreased immediately by stopping it.

Fig. 4 shows the change of the oral temperature during the experiment. Upon stopping the exercise, the oral temperature was considerably low and gradually increased to normal. This low temperature was caused by blood flow from tongue to muscle and ventilation from the nose. The oral temperature of subject S was similar throughout the experiments.

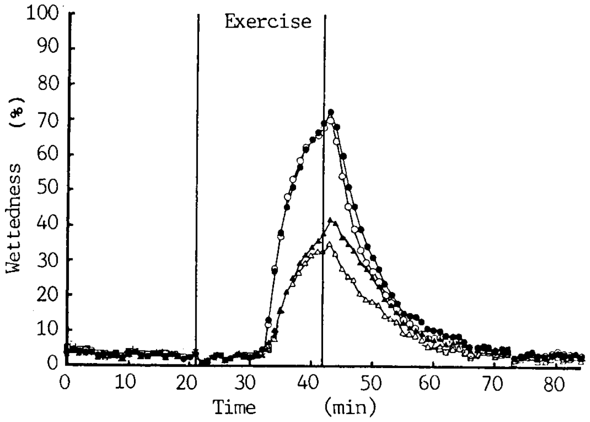

Fig. 5 Skin wettedness and fabric wettedness of the highly wettable shirt worn by subject S. (Sample 1)
● Skin wettedness at the right side of the back
○ Skin wettedness at the left side of the back
▲ Fabric wettedness at the right side of the back
△ Fabric wettedness at the left side of the back

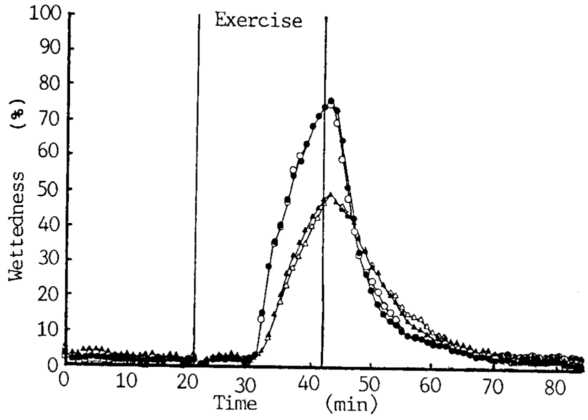

Fig. 7 Skin wettedness and fabric wettedness of the non-wettable shirt worn by subject S. (Sample 8)
● Skin wettedness at the right side of the back
○ Skin wettedness at the left side of the back
▲ Fabric wettedness at the right side of the back
△ Fabric wettedness at the left side of the back

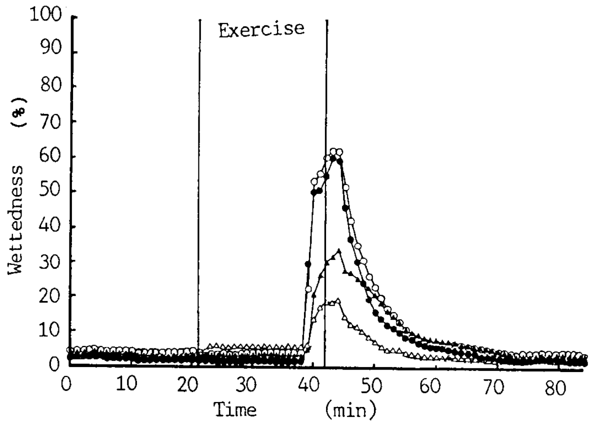

Fig. 6 Skin wettedness and fabric wettedness of the highly wettable shirt worn by subject I. (Sample 3)
● Skin wettedness at the right side of the back
○ Skin wettedness at the left side of the back
▲ Fabric wettedness at the right side of the back
△ Fabric wettedness at the left side of the back

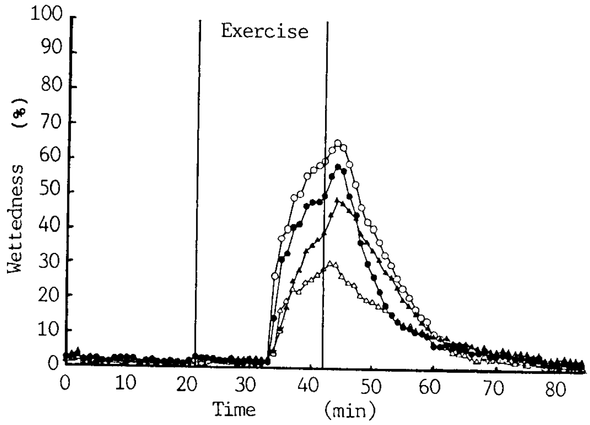

Fig. 8 Skin wettedness and fabric wettedness of the non-wettable shirt worn by subject I. (Sample 9)
● Skin wettedness at the right side of the back
○ Skin wettedness at the left side of the back
▲ Fabric wettedness at the right side of the back
△ Fabric wettedness at the left side of the back

When subject I wore highly wettable shirts (sample 3), the oral temperature was lower considerably.

The local wettedness on the skin and on the surface of a fabric was measured by temperature and vapor pressure inside and outside the shirts. Fig. 5 shows the local wettedness on the skin and on the surface of the highly wettable shirt (sample 1) worn by subject S. About 11 minutes after starting the exercise, the skin wettedness increased and reached a peak one minute later after the end of exercise. After that, it decreased rapidly. The skin wettedness of both right and left sides was much the same. The local wettedness on the fabric was similar except for a little difference in the right and left sides.

Fig. 6 shows the local wettedness on the skin and on the surface of the highly wettable shirts (sample 3) which subject I wore. About 17 minutes later from the start of the exercise, skin wettedness increased rapidly by immediate sweating, reached a peak and then fell down rapidly. The wettedness on the skin and on the surface of the fabric were lower on a whole than sample 1. This related to that the oral temperature and the mean skin temperature were lower. As a result, there were differences in sweating and wettedness among subjects.

Fig. 7 shows the local wettedness on the skin and on the surface of the non-wettable shirt (sample 8) which subject S wore. It was similar to the experiment using highly wettable shirts. Because sweating occurred earlier, skin and fabric wettedness were great along with body weight loss. The rapid decrease of wettedness after exercise was due to high moisture transmission in spite of non-wettable shirt.

Fig . 8 shows the local wettedness on the skin and on the surface of the non-wettable shirt (sample 9) worn by subject I. In the case of subject I clothed in non-wettable shirt, both wettedness and body weight loss were greater than those of wettable shirt. There are some differences between right and left values.

These results show that there are differences of sweat condition among subjects in spite of the same exercise. The values between right and left sides of the back on subject S were much the same, but those of subject I were different. These were due to the differences in the gap between cloth and skin and movement of the upper part of the body.

4 Conculusion

The effects of wettability of cotton shirts in microclimate between clothes and skin under exercise were studied using knitted cotton undershirts treated by two surfactants and a finishing agent. The change of the skin and fabric wettedness was examined. The results are as follows :

1) Physical properties of all the treated cotton shirts were similar except wettability and water repellency.
2) After the temperature inside the shirts increased gradually with exercise, it decreased slowly by evaporative heat regulation with sweating. The change of temperature during the experiment among the samples was similar.
3) Vapor pressure increased rapidly about 10 minutes after starting exercise until it reached a peak. After that, it decreased rapidly because of high water vapor transmission. Vapor pressure inside and outside non-wettable shirts showed higher values than those of wettable shirts.
4) The difference of mean skin temperature of the subjects wearing different treated shirts was little.
5) Body weight loss of the subject wearing non-wettable shirts was greater than those of wettable shirts.
6) Skin and fabric wettedness of the subject wearing non-wettable shirts were greater than those of wettable shirts.

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衣服下気候とぬれ面積率に及ぼす綿シャツ地の吸水性能の影響

三ツ井紀子

運動負荷による，衣服下気候に及ぼす，綿シャツ地の吸水性能の影響について検討した。吸水性，透湿性のある綿肌シャツ地に，２種類の界面活性剤およびフツ素系加工剤を用いて処理し，吸水性の大きな試料，中間的吸水性試料，撥水性試料を作成した。人工気候室にて着用実験を行い，運動時およびその前後における，衣服下，衣服上の温度・湿度の変化，心拍数，皮膚温，体重減少量について検討した。さらに，皮膚上，衣服上の濡れ面積率の変化について検討した。

その結果，吸水性能は異なるが，他の物理的性能は類似していた。衣服下温度および平均皮膚温は，いずれの試料着用時も，大きな差はみられなかった。しかし，撥水性試料着用時の方が，吸水性試料着用時より，衣服下水蒸気圧，および皮膚上，衣服上の濡れ面積率はやや大きな傾向がみられた。被験者の体重減少量も，撥水性試料着用時の方が大きかった。