

# Effects of Clothing Material Dyed with Astringent Persimmon Extract upon Exercise-Induced Thermal Strain and Sensory Responses in a Warm Environment

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## Abstract

This study investigated the effects of persimmon-dyed clothing materials upon thermophysiological responses and subjective comfort sensations during exercise and rest in a warm environment. Six healthy, untrained women participated in two separate testing sessions, with cotton materials dyed with astringent persimmon extract (DC) and undyed cotton materials (UDC). The physical characteristics associated with heat and moisture transfer were improved in DC; also, stiffness, anti-drapery stiffness and crispness in the primary hand values were higher in DC. The experimental protocol consisted of a 10-min rest, 15-min exercise on a treadmill (at 7 km·h<sup>-1</sup>) and 25-min recovery at 28±0.2°C and 50±3% RH. The results were as follows: When wearing DC rather than UDC, mean body temperature, heart rate, heat storage and body mass loss were significantly lower during the whole experimental period. Clothing microclimate temperature showed different profiles between the two clothing materials, being lower with DC than UDC during the first half of exercise and the second half of recovery. Clothing microclimate humidity was significantly lower with DC than UDC during the whole experimental period. When wearing UDC, subjects felt significantly warmer and less comfortable during exercise, and sensed greater humidity during exercise and recovery. These results suggest that eco-friendly clothing materials dyed with astringent persimmon extract can reduce exercise-induced heat load and improve subjective sensations when exercising and resting in a warm environment, due to greater heat dissipation from the body to the outside environment compared with undyed clothing materials.

## Keywords

Clothing materials, Natural dyeing, Astringent persimmon extract, Exercise-induced heat strain, Thermal and sensory responses

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## Introduction

Trying to live in an “eco-friendly” way is becoming a world-wide concern, and the textile-processing industry is known to be an environmental polluter. Recently, the use of natural dyes has become of interest to textile producers as well as consumers. Products dyed with natural dyes are less damaging to the environment, as they are biodegradable, and are preferred by the consumer as they are less allergenic and toxic than synthetic dyes (Samanta & Agarwal, 2009). Moreover, natural

dyes can produce familiar and pleasing natural colors, and a wide range of tints and shades using the same dye, and also have special properties, like antimicrobial activity (Singh et al., 2005). Consequently, fabrics using natural dyes are used for various garments such as underwear, outer wear, work wear and even clothing items with curative effects.

In addition, in the Jeju area of Korea, cellulose fabrics dyed with persimmon extract have traditionally been used as materials for working clothes in the summer, due to the greater thermal comfort and durability they offer (Son, 1988). Furthermore, the traditional persimmon-dyeing technique is perfectly eco-friendly since it uses only pure extracts of persimmon without any metallic mordants which, even though they are used to improve colour fastness and dyeability of the fiber, are not always safe because of the toxic nature of some chemical mordants (Gulrajani, 1992).

Many studies have investigated the physical and hand properties of persimmon-dyed fabrics. Ko and Lee (2003) found that stiffness, as assessed by the Kawabata system (Kawabata, 1980), increased in dyed cotton, silk and linen fabrics. In addition, cotton fabrics dyed with persimmon extract almost completely blocked transmission of UV radiation (Lee, 1996) and enhanced antibacterial activity and deodorization (Huh, 2011). Moreover some investigations (Park, 1995; Yi et al., 2007) have demonstrated that dyeing with persimmon increased air permeability and moisture regain of fabrics made of cellulose fibers. These authors suggested that dyeing with persimmon increased porosity of the fabric and that the pigments had hydrophilic properties. These properties of persimmon-dyed fabrics would seem to have several merits for working clothes, protecting the wearer and alleviating heat-load during exercise and when working outdoors in a warm environment. However, little attention has been paid to physiological responses when wearing clothing made with persimmon-dyed materials. Yi et al. (2007) showed that the dyed T-shirts could lead to a decreased local sweat rate, but not improve subjective comfort, in subjects exercising vigorously in moderate environmental temperatures. However, they did not determine other thermoregulatory responses. Thus, there is a need to study in more detail the role of the persimmon-dyed fabrics as materials for work garments worn in various environmental conditions.

Therefore, to verify objectively the value of persimmon-dyed

materials for outdoor work garments in the summer, the current study investigated the influence of cotton muslin dyed with astringent persimmon extract upon thermophysiological responses, clothing microclimates and subjective comfort sensations in subjects at rest and undertaking mild exercise in a warm environment.

## Materials and Methods

### Experimental Garments

The clothing material used was 100% cotton muslin. The fabric was dyed with astringent persimmon extract using the traditional techniques of the Jeju islands (Son, 1988). The fabric was scoured without a detergent at 95-100°C for 1 h for pre-contraction, to reduce possible shrinkage by the dyeing treatment. Dyeing was done manually, using the juice extracted from unripe (astringent) persimmons, at a room temperature of 25-28°C. The dyed materials were then sun-dried with addition of moisture for 8 days, to obtain dark colouring. The dyed cotton (DC) and scoured but undyed cotton (UDC) materials were used to make two clothing ensembles. To evaluate the primary hand values of the two materials, the mechanical properties (tensile, bending, shearing, compression and

Table 1. Physical and hand properties of experimental clothing materials

	UDC	DC
Fiber contents	cotton 100%	
Construction	plain	
Density (ends×picks·inch <sup>-1</sup> )	59×57	
Thickness (mm)	0.3268	0.4240
Weight (g·m <sup>-2</sup> )	144.1	177.1
Moisture Regain (%) at 20°C, 65%	8.2	8.8
Water vapor transmission (g·m <sup>-2</sup> ·h <sup>-1</sup> )	41.6	42.4
Air Permeability (cm <sup>3</sup> ·cm <sup>-2</sup> ·min <sup>-1</sup> )	1843	4008
Thermal resistance (m <sup>2</sup> ·K·W <sup>-1</sup> )	0.032	0.030
Hand values		
Stiffness (Koshi)	8.479	9.240
Anti-drape stiffness (Hari)	12.711	14.060
Flexibility with soft feeling (Shinayakasa)	-2.972	-4.258
Fullness and softness (Fukurami)	4.544	2.662
Crispness (Shari)	3.266	4.498
Scrooping feeling (Kishimi)	1.981	1.744

surface properties) as well as thickness and weight were measured with the KES-FB system under standard conditions (Kawabata, 1980). The primary hand values were estimated from equations translating the mechanical data into hand values. In the present experiment, KN-201-LDY equations for ladies' summer suits were used, and stiffness (Koshi), anti-drape stiffness (Hari), fullness and softness (Fukurami), crispness (Shari), scooping feeling (Kishimi) and flexibility with soft feeling (Shinayakasa) were evaluated. Additionally, the heat- and moisture-transfer properties associated with comfort when wearing the garment were measured. The detailed characteristics of the DC and UDC materials are listed in Table 1.

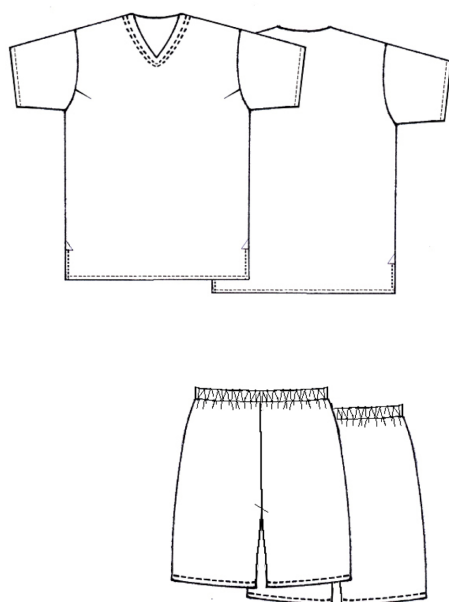


Figure 1. Design of experimental clothing

As shown in Figure 1, the experimental clothing consisted of short-sleeve, collarless shirts and knee-length pants, and was constructed using both materials. A pattern was adjusted for each individual, based upon her body dimensions, to ensure identical ease of clothing at critical body sites. Additionally, subjects wore a basic clothing set (a brassiere, pair of socks and underpants made of 100% cotton) and running shoes. Before being worn, the clothing was laundered without a detergent and dried naturally and stabilized in the experimental chamber for at least 24 h.

### Subjects

Six healthy females participated as subjects in this study. Their physical characteristics were: age, 25.2 (SEM 2.0) years; height, 159.4 (SEM 1.9) cm; body mass, 53.2 (SEM 2.31) kg; and body surface area (BSA) [calculated with weight in kg and height in cm as  $Weight^{0.425} \times Height^{0.725} \times 0.007184$ ], 1.54 (SEM 0.03) m<sup>2</sup>. The subjects were university students with regular sleep-rest daily rhythms, and not involved in regular exercise training programs. Subjects were asked to abstain from alcohol and heavy exercise for a week before the experiment. The general purpose, procedure and possible risks involved in testing were fully explained to each subject and informed consent was given. Each subject was tested on both occasions at the same time of day and same phase of the menstrual cycle.

### Experimental protocol

The experiments were conducted in a climatic chamber controlled at 28±0.2°C and 50±3% RH, with an air velocity of 0.14 m·sec<sup>-1</sup>. Each subject completed two exercise trials with the

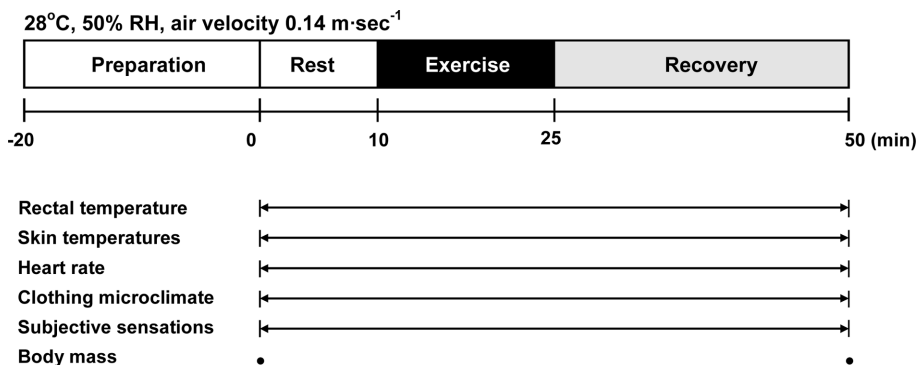


Figure 2. Experimental protocol

two kinds of clothing ensemble, the experimental sessions being arranged in random order at least two days apart. The experimental schedule is shown in Figure 2. Subjects were required to report to the laboratory about 60 minutes before the start of measurements. After taking a rest for 30 min in the anteroom, the subject entered the experimental chamber and measured her nude body mass. The subject then put on the shoes and dressed in the DC or UDC experimental garments worn over the top of the basic clothing set. The subject was fitted with a rectal thermistor probe, skin temperature sensors and an electrode for measuring heart rate. The temperature and humidity sensors for measuring the microclimates between the skin and the shirts were attached at chest level.

After resting calmly for 10 min, the subject exercised on a treadmill at a speed of 7 km·h<sup>-1</sup> (a brisk walking pace) for 15 minutes, followed by 25 minutes for recovery. At the end of the experiment (50 minutes), nude body mass was measured again.

### Measurements

Rectal temperature was measured every minutes by a thermistor probe (YSI, Precision 4000A, USA; accuracy, 0.02°C); skin temperatures were measured at seven sites (forehead, upper abdomen, arm, hand, thigh, leg and foot) using epoxy-coated copper thermistors (EU type, Grant Instruments Ltd., UK; accuracy, 0.05°C). Heart rate was measured every minute with a pulse watch (PE-3000, Sports Tester, Finland). Clothing microclimate temperature and humidity were measured every minute with a hygrothermometer (TRH-CZ, Shinyei, Japan; accuracy, 0.1°C and 0.1% for temperature and humidity, respectively). Body mass was measured before and after the experiment by a platform balance (Braun AG Frankfurt/M, Type 4243, Germany; accuracy, 1 g). Subjective ratings of thermal sensation (using a 9-point scale, where increasing values indicate hotter), comfort sensation (a 6-point scale, where increasing values indicate more uncomfortable) and clothing wetness (a 5-point scale, where increasing values indicate wetter) were recorded every 2 minutes. The scales for each sensation are summarized in Table 2.

### Statistical Analysis

Mean skin temperature ( $T_{sk}$ ) was calculated from the equation of Hardy and DuBois (1938):  $T_{sk} = 0.07 T_{forehead} + 0.35 T_{upper abdomen}$

Table 2. Scales of subjective sensation

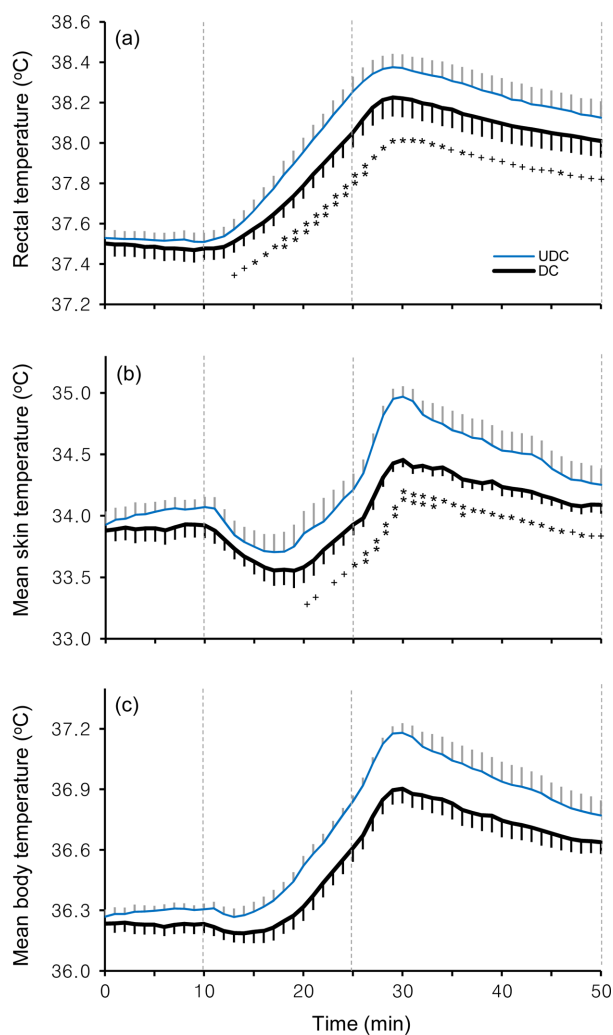
Thermal sensation	Comfort sensation	Clothing wetness
1 very cold	1 very comfortable	1 dry
2 cold	2 comfortable	2 slightly damp
3 cool	3 slightly uncomfortable	3 damp
4 slightly cool	4 uncomfortable	4 wet
5 neutral	5 very uncomfortable	5 soaking wet
6 slightly warm	6 unbearable	
7 warm		
8 hot		
9 very hot		

+ 0.14  $T_{arm}$  + 0.05  $T_{hand}$  + 0.19  $T_{thigh}$  + 0.13  $T_{leg}$  + 0.07  $T_{foot}$ . Mean body temperature ( $T_b$ ) was calculated as follows, based upon equations of Stolwijk and Hardy (1966):  $T_b = 0.65T_{re} + 0.35T_{sk}$ . Heat storage (S) during the experimental period was calculated using the following equation (Burton, 1935):  $S = (0.83 Wt \cdot BSA^{-1}) \times (T_b)$  [kcal·m<sup>-2</sup>], where the constant [equal to 0.83 kcal·kg<sup>-1</sup>·°C<sup>-1</sup>] is the specific heat of the body, Wt (kg) is the body mass (mean of pre- and post-experiment weights), BSA (m<sup>2</sup>) is body surface area, and  $\Delta T_b$  is the change in mean body temperature.

The data were analyzed by a two-way ANOVA with repeated measures, to investigate time course and effect of clothing material. When the interaction between clothing and time was found to be significant, pair-wise differences were identified using paired t-tests. The subjective ratings were the average scores for each period of rest, exercise and recovery, and were analyzed by Wilcoxon's signed-rank tests. The heat storage and loss of body mass were analyzed by Student's paired t-tests. A  $p < 0.05$  was considered significant, and a value  $0.05 < p < 0.10$  was referred to as a tendency. Data were expressed as mean and SEM.

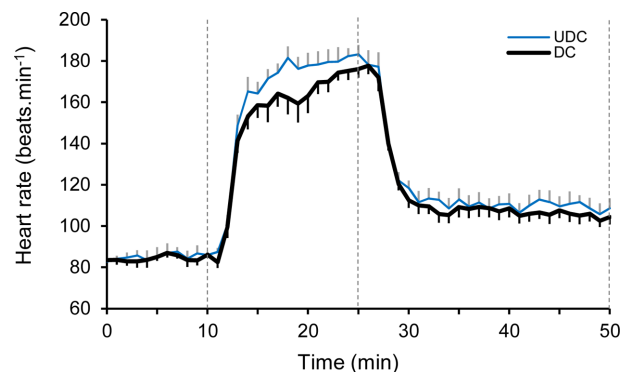
## Results

Figure 3 shows temporal changes of rectal temperature (a) and mean skin temperature (b) and mean body temperature (c) when wearing DC and UDC clothing. Rectal temperature showed a clear rise during exercise and a smaller fall during recovery ( $F_{50, 250} = 64.306, p < 0.01$ ). The effect of clothing on rectal temperature was marginally significant ( $F_{1, 5} = 5.530, p = 0.065$ ),



**Figure 3.** Temporal changes of rectal temperature (a), mean skin temperature (b) and mean body temperature (c) when wearing the two kinds of clothing. Thin line, UDC; Thick line, DC. \*\*, \* and + indicate that the corresponding values differed significantly ( $p < 0.01$ ,  $p < 0.05$ ,  $0.05 < p < 0.10$ , respectively) when the interaction between clothing and time was significant. Values are mean and SEM

and the interaction between clothing and time was significant ( $F_{50, 250} = 3.874$ ,  $p < 0.01$ ), showing lower values with DC clothing especially during exercise and the early part of the recovery period. Mean skin temperature decreased at the start of exercise and rose gradually during the later stage of it and the first 5 min of recovery; it then decreased during the rest of the recovery period ( $F_{50, 250} = 18.974$ ,  $p < 0.01$ ). The effect of clothing material on mean skin temperature tended towards significance ( $F_{1, 5} = 5.881$ ,  $p = 0.060$ ), and there was a significant interaction between clothing

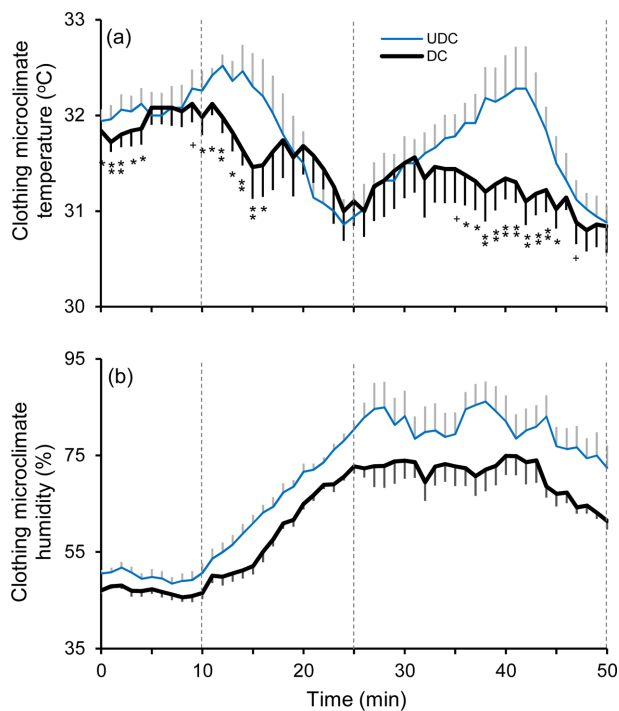


**Figure 4.** Temporal changes of heart rate when wearing UDC (thin line) and DC (thick line)

and time ( $F_{50, 250} = 55.598$ ,  $p < 0.01$ ), values being significantly lower particularly during the recovery period when wearing DC clothing. Mean body temperature showed a significant effect of time ( $F_{50, 250} = 55.598$ ,  $p < 0.01$ ) and was lower with DC clothing during the whole experimental period ( $F_{1, 5} = 8.786$ ,  $p < 0.05$ ). Also, the interaction between clothing and time was significant ( $F_{50, 250} = 6.340$ ,  $p < 0.01$ ), profiles with the two kinds of clothing being similar to those found for rectal temperature.

As seen in Figure 4, heart rate increased quickly with the start of exercise and decreased during the recovery period ( $F_{50, 250} = 141.243$ ,  $p < 0.01$ ). It was significantly lower with DC than with UDC ( $F_{1, 5} = 12.731$ ,  $p < 0.05$ ); there was also a significant interaction between clothing and time ( $F_{50, 250} = 2.167$ ,  $p < 0.01$ ), indicating that the differences in heart rate when wearing DC or UDC clothing were greater, particularly during exercise.

Figure 5 demonstrates the time courses of clothing microclimate temperature (a) and humidity (b). The average temperature of clothing microclimate decreased during exercise, rose with the cessation of exercise, and fell after about 5-15 min of recovery ( $F_{50, 250} = 10.467$ ,  $p < 0.01$ ). The effect of clothing material on clothing microclimate temperature was marginally significant ( $F_{1, 5} = 4.407$ ,  $p = 0.09$ ). Also, the interaction between clothing and time was statistically significant ( $F_{50, 250} = 18.974$ ,  $p < 0.01$ ), the temperature being lower during the first few minutes of rest, the first half of exercise and the second half of recovery when wearing DC clothing. Clothing microclimate humidity increased rapidly during exercise, plateaued during the first part of recovery and then fell slightly during the last 10 min of recovery ( $F_{50, 250} = 28.387$ ,

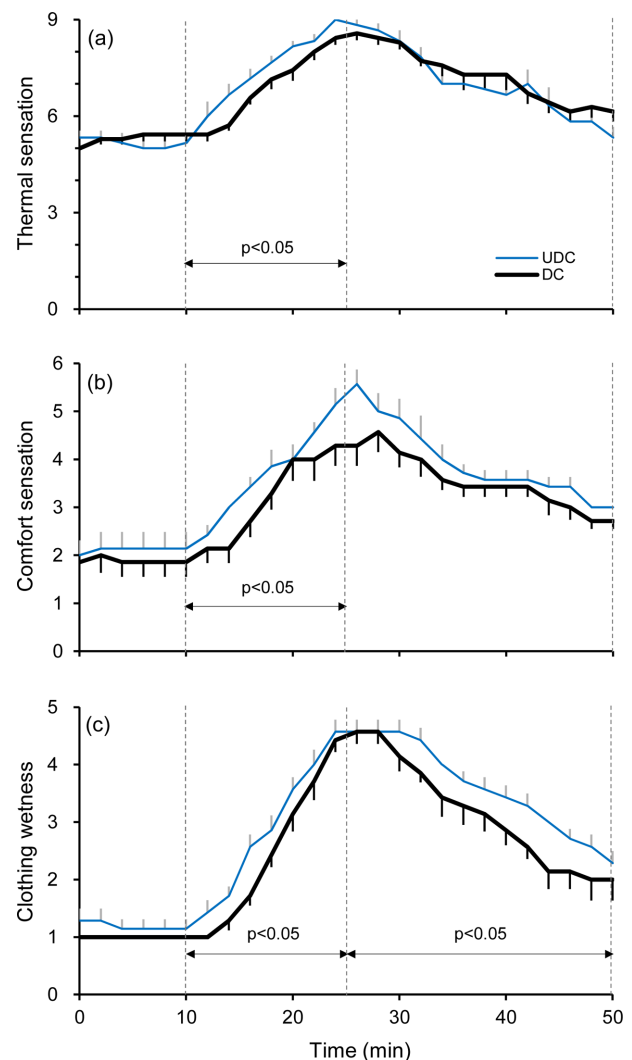


**Figure 5.** Temporal changes of clothing microclimate temperature (a) and clothing microclimate humidity (b) when wearing the two kinds of clothing. Thin line, UDC; Thick line, DC. Statistical significance indicated as in Figure 3

$p < 0.01$ ). The humidity was significantly higher with UDC than DC throughout the experimental period ( $F_{1,5} = 8.786$ ,  $p < 0.05$ ). The size of the effect of clothing on the humidity depended upon the stage of the experiment ( $F_{50,250} = 1.737$ ,  $p < 0.01$ ).

Figure 6 compares temporal changes of subjective ratings for thermal sensation of the whole body (a), comfort sensation (b), and clothing wetness (c) between the two kinds of clothing material. When wearing DC rather than UDC clothing, the subjects felt significantly less warm during exercise (Wilcoxon's signed rank test,  $p < 0.05$ ), were significantly more comfortable during exercise ( $p < 0.05$ ), and felt less wet during the exercise and recovery periods ( $p < 0.05$  in both cases).

Heat storage during the experimental period was marginally significantly different between the two kinds of clothing ( $14.20 \pm 2.578$  kcal·m<sup>-2</sup> and  $11.39 \pm 1.611$  kcal·m<sup>-2</sup>, for UDC and DC, respectively; t-test,  $p = 0.058$ ), five out of the six subjects showing a higher heat storage with UDC clothing. The loss of body mass through the whole experimental period was significantly less



**Figure 6.** A comparison of subjective thermal sensation (a), comfort sensation (b) and clothing wetness (c) between UDC (thin line) and DC (thick line)

when wearing DC rather than UDC clothing ( $385.6 \pm 41.8$  g and  $298.2 \pm 25.0$  g, for UDC and DC, respectively; t-test,  $p < 0.05$ ).

## Discussion

The main results of this study were that, when wearing DC rather than UDC clothing, rectal and mean skin temperatures tended to be lower (Figures 3a and 3b) and mean body temperature was significantly lower throughout the whole experimental period (Figure 3c). Also, heart rate was significantly lower during the experimental period with DC clothing (Figure 4) and the loss of



body mass and heat storage were less with DC than with UDC clothing. These physiological responses suggest that light exercise in a warm environment induced a smaller heat stress to the body when wearing clothing made with cotton materials dyed with astringent persimmon extract rather than undyed materials.

In general, garments worn for sports or work should allow rapid transmission of metabolic heat and sweat from the body to the surroundings, so reducing internal heat stress and allowing exercise to be performed effectively (Hayashi & Tokura, 1999, 2000; Park et al., 2006). The properties of clothing materials relevant to heat and moisture transfer are thermal insulation, moisture absorption and water vapour permeability (Lotens, 1993; Lotens & Havenith, 1995; Park et al., 2005). In the present study, the fabric dyed with persimmon extract showed higher moisture regain, water vapour transmission and air permeability, and slightly lower thermal resistance than did undyed fabric, a result similar to that found previously (Park, 1995; Yi et al., 2007). Therefore, it seems that improved heat and moisture transmission in DC clothing materials reduced rectal and mean skin temperatures during the exercise and recovery periods, and reduced heat storage throughout the experimental period. Ha et al. (1995) reported that rectal temperature and pulse rate were lower during intermittent exercise at 24°C when wearing cotton clothing with higher moisture-absorption properties compared to polyester clothing. Also, Lee and Park (2006) found that mean skin temperature decreased when wearing a polyester clothing ensemble with higher air permeability and faster transfer of liquid water compared to a cotton clothing ensemble. In addition, Hayashi and Tokura (1999) reported that the gloves made of moisture-permeable fabrics could lower the microclimate temperature and humidity inside the gloves, suppressed the elevation of rectal temperature during exercise and rest, and increased the number of contractions made during a hand-grip exercise. Also, exercise performance was better and speed deviations in baseball pitching were less when wearing cotton clothing with higher water absorbency rather than polyester clothing (Park et al., 2006). All these results suggest that superior heat- and moisture-transfer properties of clothing can reduce heat stress and enhance exercise performance. Although exercise performance was not evaluated in this study, it seems possible that wearing DC clothing might enhance work efficiency.

Furthermore, the DC clothing materials showed higher values for stiffness (Koshi), anti-drape stiffness (Hari) and crispness (Shari) of the primary hand. These properties might favour the formation of a fuller, more expanded volume by the clothing, so allowing a wider air space between the skin and clothing. DC clothing with these properties would facilitate forced ventilation, especially during exercise, and reduce thermal resistance of the clothing due to promoting air exchange between the clothing microenvironment and the external environment (Bouskill et al., 2002; Havenith et al., 1990). Thus, wearing DC clothing could increase heat dissipation by convection, and this might account for the significantly lower microclimate temperature that was observed during part of the exercise and recovery periods, and lower microclimate humidity throughout the whole experiment (Figure 5). These suggestions and results might gain support from the findings of Chen et al. (2004) who demonstrated that, when the air gap between the body and garments exceeded a certain value, thermal insulation and vapour resistance decreased with the size of the gap. In addition, Lotens and Havenith (1988) reported that a windproof jacket worn with an air space between it and the body induced considerable ventilation, the effects of which were indistinguishable from air-permeable clothing. Moreover, Ueda et al. (2006) found that increased clothing ventilation soon after the onset of sweating had the advantage of keeping the wearer comfortable, by preventing an increase in skin moisture concentration. These results might explain the current observation that subjects felt less unpleasantly warm and more comfortable during exercise, and less humid both during exercise and recovery, when wearing DC rather than UDC clothing (See Figure 6).

## Conclusion

In this study, cotton materials dyed with astringent persimmon extract showed improved heat- and moisture-transfer properties such as moisture regain, water vapor transmission and air permeability, and increased stiffness in primary hand values. All these properties of the garments made by this eco-friendly production method might aid the effective transfer of exercise-induced metabolic heat and sweat from the body through the clothing to the surrounding air; they will also alleviate heat load

and increase subjective comfort when taking mild exercise in a warm environment.

In conclusion, the persimmon-dyed materials might be very desirable for outdoor work garments when considering both thermo-physiological and psychological comfort and concerns about eco-friendly manufacture in the textile and apparel industries.

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