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Ventilation Design of Combining Spacer and Mesh Structure in Sports T-shirt

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Ventilation Design of Combining Spacer and Mesh Structure in Sports T-shirts

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1. Descriptor

This body of work reports on the novel ventilation design in sports T-shirts, which combines both spacer and mesh structure, and experimental evidence on the advantages of design in thermal comfort improvement. Compared to conventional T-shirts designs, the new sports T-shirt design significantly increases air circulation next to the skin and spreads ventilation cooling, both during windy conditions or when the user is moving actively. Comparisons between the new T-shirt and conventional T-shirts were made by: 1) measuring their evaporative resistance (Re) and thermal insulation (Rc) with a sweating thermal manikin under three different air velocities. Moisture permeability index (im) was also calculated to compare the different designs; 2) conducting wearer trials comprised of 30 min of treadmill running followed by 10 minutes of rest. Skin temperature, skin relative humidity, heart rate, oxygen inhalation, and energy expenditure were all monitored, and subjective sensations were examined.

Results demonstrated that under windy conditions, the moisture permeability index (im) of the new T-shirt design with ventilation structures decreased about 11.1% compared to that of conventional ones. Under these real exercise situations, the sports T-shirt with the new ventilation design contributed to the reduction of heat accumulation, and the reduction of skin relative humidity, and the decrease of hot and chill discomfort. The variation of skin temperature and relative humidity was reduced up to 37% and 32% respectively.

Additionally, the wearer felt more comfortable with the novel ventilation designed garment during exercise, especially in the post-exercise phase. The new ventilation design also contributed to the reduction of 3.3% energy expenditure during exercise, which is expected to be applicable to active sportswear for jogging, racket sports, games, other exercises, and more.

2. Author Biography

Joe Au's research focus includes the development of fashion design theory and its application on different fashion domains. As a researcher and practitioner, he aims at solving design problems through adopting practice-based research methodology.

3. Research Outputs

The body of work comprises of:

- One T-shirt prototype made of single jersey fabric (Sample A as control sample).
- One T-shirt prototype made of single jersey fabric with spacer structure at the upper trunk area of the garment (Sample B).
- One novel T-shirt prototype made of single jersey fabric with spacer and mesh structures at the chest, shoulders and upper back area of the garment (Sample C).
- A refereed journal paper was published in May 2015.

4. Research Questions

The research sets out to investigate:

- How the design of ventilation features of a sports T-shirt can be improved without affecting its tactile comfort?
- What are the appropriate positions to apply the ventilation features of a sports T-shirt for improving the thermal comfort of the body?
- How does the thermal comfort of the novel T-shirt with mesh opening and spacer structure compare with the conventional sports T-shirts in terms of evaporative resistance, thermal insulation and subjective sensations?

5. Research Field & Key Works Referenced

- Different from daily wear, active sportswear tends to accumulate more sweat during exercise, which leads to heat stress and affects sport performance of athletes. Hence, thermal comfort is an important consideration when designing active sportswear.
- It has been recognized that efficient dry and evaporative heat transfer through clothing is critical to thermal comfort during exercises (McCullough et al., 1983; Fan, 1989). Past research revealed that air exchange between clothing microclimate and external environment has a significant effect on the wearer's evaporative and dry heat loss (Bouskill et al., 2002; Gao et al., 2012; Havenith et al., 1990).
- For a sweating man, the convection current accelerates the rate of convective heat transfer and the rate of evaporative cooling by wind or by pumping during body motion (Breckenridge, 1977; Oliveira et al., 2011). Therefore, in order to maintain thermal comfort of the body, it is important to improve ventilation cooling by use of ventilation features at appropriate positions of garments (Ruckman et al., 1999; Havenith et al., 2003).

5. Research Field & Key Works Referenced

The research sets out to investigate:

- Mesh opening, as a method to increase ventilation, has been widely applied in garments in order to maintain wearer comfort. Previous research showed that mesh opening design increases the total heat loss considerably during body movement (Bakkevig and Nielsen, 1995; Ho et al., 2008). However, the fabric still tends to stick to the skin (particularly in the chest, shoulder and upper back area of the body) after heavy sweating, which creates “clingy” discomfort and hinders the convection around the body.
- Ho and Fan (2011) developed a ventilation garment with mesh opening and additional arch-shaped spacer parts to address this problem. However, the additional spacers tend to create tactile discomfort for its undesirable big size and heavy weight, especially during exercises. Hence, it is desirable to develop a novel sportswear with ventilation features without affecting tactile comfort.
- In this study, a knitted fabric that combining spacer and mesh opening was fabricated and used at the chest and back area of the ventilation sports T-shirt to prop the garment up, thus improving air flow by reducing the contacting area between the fabric and human skin. It was hypothesized that the novel sports T-shirt contributes to sweat evaporation and thermoregulation. Both manikin tests and wearer trials were conducted to investigate the effectiveness of the garment in terms of thermal comfort, as well as the sweat accumulation, which is related to the potential of post-exercise chill.

6. Research Methods & Materials

Three different kinds of fabrics were knitted by circular knitting machine using polyester and nylon core-spun yarn (Fabric composition is 20% nylon and 80% polyester). The appearance of the fabrics is shown. The fabrics were tested in accordance with ASTM: D1776 by the Kawabata Evaluation System (KES).

The material used for the three garment samples is same, their size and weight (104 ± 2 g) are also similar, except for different fabric structures.

Sample A is made of a single jersey fabric (Fabric 1), which was used as a control sample.

Sample B is a combination of Fabric 1 and Fabric 2, where Fabric 2 was designed at upper trunk area of the garment.

Sample C is the **novel T-shirt** which is made of Fabric 1 and Fabric 3, where Fabric 3 was located at the chest, shoulders and upper back area.

6. Research Methods & Materials

The physical characteristics of the three fabrics are listed.

- Fabric 1 is a regular single jersey fabric.
- Fabric 2 is a single jersey based fabric with spacer structure.
- **Fabric 3 is a fabric combining of mesh opening and spacer structure.**

The spacer structure was knitted by successive float on a single needle. While mesh opening was achieved by float plating technique with elastic yarns.

Physical Characteristics of Three Different Fabrics

Physical characteristics		Fabric 1	Fabric 2	Fabric 3
Air permeability	Kpa s/m	0.184	0.133	0.045
Tensile	WT (gf.cm/cm^2)	8.52	7.83	9.42
	RT (%)	58.6	57.86	55.53
	EMT (%)	48.23	45.2	53.83
Shearing	G (gf/cm.deg)	0.33	0.31	0.27
Bending	B (gf.cm^2/cm)	0.0057	0.023	0.027
Surface	MIU	0.29	0.37	0.37
Compression	T_o (mm)	0.81	2.04	2.07
	T_m (mm)	0.63	1.26	1.21
Weight	g/m^2	117.5	154.75	135.5

6. Research Methods & Materials

The unique structure of novel T-shirt was derived from the combination of spacer and mesh structures. Spacer structure was knitted by successive float (12 courses) on single needle. Mesh structure was knitted by float plating with elastic yarns (spandex covered nylon yarn as ground yarn and COOLMAX®/ Cool Plus® as plating yarn).

The spacer structure lifted up the fabric to reduce the contact area and created a gap between the fabric and skin surface.

Mesh offered some ventilation holes allowing the exchange of warm air in the clothing microclimate and cool air in the environment.

6. Research Methods & Materials

A sweating thermal manikin-Walter (Fan and Chen, 2003; Fan and Qian, 2004) was used to measure the thermal property of different T-shirt samples.

Garment samples

Samples A, B and C (Novel T-shirt) were all used in sweating thermal manikin test. Before testing, all samples were laundered and air dried to eliminate any finishing chemicals in the fabric. In order to maintain consistency during testing, the same pair of gym shorts, made by 100% polyester knitted fabric, was used for all experiments.

Experimental condition

The tests were carried out in a climatic chamber controlled at a temperature of 20 ± 0.5^{0} C and a relative humidity of 65 ± 2%, aiming to simulate the indoor thermal environment of a gymnasium. They were conducted at three air velocities of 0.2 ± 0.1 m/s, 1.0 ± 0.1 m/s, and 2.0 ± 0.1 m/s, respectively. Since the effect of body movement on clothing thermal properties bears resemblance to the effect of wind on clothing thermal properties, as both increase convective air exchange, from the effect of air velocity, we can also understand the effect of exercise level on clothing thermal properties (Qian and Fan, 2006). The mean skin temperature of the manikin was set at 35^{0}C; all samples were conditioned in the chamber for 24 h before testing. All tests were repeated for three times, the samples were put off and on again between repetitions.

6. Research Methods & Materials

Subjects

Seven healthy male college students volunteered to take part in this study. Their physical characteristics were as follows: age of 22 ± 3, weight of 76 ± 8 kg and height of 1.74 ± 0.03 m.

Garment samples

The novel T-shirt (Sample C) and control sample (Sample A) were selected as testing samples to investigate the effect of spacer and mesh structure on wearer comfort during exercises.

Experimental procedure

The wearer trials were carried out in a climatic chamber at 20 ± 0.5^{o}C and 65.0 ± 5% RH. The test was divided into two periods, including 30 min run and 10 min rest. During the running period, the subjects ran on a treadmill with a speed of 6.0 km/h and an air velocity of 0.8 ± 0.1 ms^{-1} to simulate the body movement during exercise. During the rest period, the subjects sat in the chamber with an air velocity of 0.1 ± 0.1 ms^{-1} to simulate the static condition.

All subjects were asked to evaluate the subjective perceptions of their thermal sensation, moisture sensation and clingy sensation during the course of the experiment (before running and on 10th min, 20th min, 30th min, 35th min and 40th min, respectively).

7. Research Outcomes & Conclusions

The thermal insulation (R_c), evaporative resistance (R_e) and moisture permeability index (i_m) of the three samples under different air velocities are shown.

The effect of spacer and mesh structure (Sample C) on evaporative **heat loss becomes more significant with the increase of air circulation**. When there is no air circulation, more warm and moist air may be trapped by the increased air space between the fabric and skin, and it is difficult for them to be released from the mesh via natural convection (Ho et al., 2011).

However, when air is moving, **it is easy to ventilate from inside to outside due to the increase of the gap between the fabric and skin. Mesh in Sample C further enhances convective heat and moisture transfer.** Moreover, with the acceleration of the air flow, the impact of ventilation parts on evaporative heat transfer is getting increasingly apparent.

Experimental Result 1: Effect of ventilation design on clothing thermal properties in manikin test

Air velocity	Sample	R_c	SD	R_e	SD	I_m	SD
(m/s)		($_oC$ m^2 W^{-1})		(Pa m^2 W^{-1})			
0.2	A	0.131	0.005	19.285	0.212	0.410	0.020
	B	0.125	0.008	18.639	0.756	0.405	0.014
	C	0.123	0.010	18.159	0.927	0.411	0.019
1	A	0.063	0.005	5.890	0.246	0.652	0.067
	B	0.061	0.006	5.846	0.182	0.632	0.053
	C	0.060	0.000	5.514	0.232	0.662	0.033
2	A	0.058	0.001	4.878	0.195	0.719	0.034
	B	0.059	0.001	4.782	0.198	0.749	0.032
	C	0.060	0.002	4.576	0.183	0.799	0.038

7. Research Outcomes & Conclusions

Experimental Result 2: Effect of ventilation design on the change of temperature and relative humidity

The mean temperature and the mean relative humidity on the chest, shoulder and upper back during run and rest periods for Samples A and C are shown as below.

The results indicate that **the spacer and mesh structure (Sample C) tended to moderate the changes in the skin temperature. It avoided high skin temperature increase and decrease.**

Meanwhile, the spacers lifted the fabrics away from the skin surface, which caused the moist air escape easily via the mesh. **The ventilation parts reduced the accumulation of moisture in fabrics, which regulated the relative humidity of the microclimate around the body.**

		Temperature (o C)									Relative humidity (%)						
		Chest			Shoulder			Upper back			Chest			Shoulder			Upper back	
		Mean	SD		Mean	SD		Mean	SD		Mean	SD		Mean	SD		Mean	SD
Sample A	Run	30.55	0.86		32.13	0.33		31.59	0.86		44.50	4.58		43.93	3.11		48.50	9.15
	Rest	30.54	1.77		32.29	0.57		31.48	1.11		48.23	6.47		43.62	3.87		51.41	13.37
Sample C	Run	30.65	1.33		32.31	0.32		31.69	0.99		44.00	8.51		42.58	6.85		47.61	8.86
	Rest	30.18	2.81		32.03	1.05		31.41	1.45		48.60	9.77		43.75	7.41		51.43	12.80

7. Research Outcomes & Conclusions

It can be concluded that the **novel sports T-shirt design with a combined spacer and mesh structure, significantly increase the air circulation next to skin and ventilation cooling under windy condition and/or active body movement comparing to the conventional T-shirts designs.**

Under windy condition, **the moisture permeability index (i_m) of T-shirt with ventilation structures decreased about 11.1% compared to that of conventional one**.

Under the real exercise situation, the novel sports T-shirt with the new ventilation design **contributed to the reduction of heat accumulation, the increase of skin relative humidity, and the decrease of hot and chill discomfort. The variation of skin temperature and relative humidity reduced up to 37% and 32% respectively.** The wearer felt more comfort with the novel ventilation designed garment during exercise, especially in the post-exercise phase.

The new ventilation design also **contributed to the reduction of 3.3% energy expenditure during exercise**, which is expected to be applied on the active sportswear like those for jogging, racket sports, and ball games, etc.

8. Dissemination

[Refereed Journal Publication]

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