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Novel ventilation design of combining spacer and mesh structure in sports T-shirt significantly improves thermal comfort

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ABSTRACT

This paper reports on novel ventilation design in sports T-shirt, which combines spacer and mesh structure, and experimental evidence on the advantages of design in improving thermal comfort. Evaporative resistance (R_e) and thermal insulation (R_c) of T-shirts were measured using a sweating thermal manikin under three different air velocities. Moisture permeability index (i_m) was calculated to compare the different designed T-shirts. The T-shirts of new and conventional designs were also compared by wearer trials, which were comprised of 30 min treadmill running followed by 10 min rest. Skin temperature, skin relative humidity, heart rate, oxygen inhalation and energy expenditure were monitored, and subjective sensations were asked. Results demonstrated that novel T-shirt has 11.1% significant lower i_m than control sample under windy condition. The novel T-shirt contributes to reduce the variation of skin temperature and relative humidity up to 37% and 32%, as well as decrease 3.3% energy consumption during exercise.

1. Introduction

Different from daily wear, 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).

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

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human skin. We 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.

2. Materials and methods

2.1. Novel T-shirt description

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 in Fig. 1. The fabrics were tested in accordance with ASTM: D1776 by the Kawabata Evaluation System (KES). Some of the physical characteristics of the three fabrics are listed in Table 1. 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. The spacer structure lifts up the fabric to reduce the contact area and creates a gap between the fabric and skin surface, while mesh offers some ventilation holes which allow the exchange of warm air in the clothing microclimate and cool air in the environment.

The material used for the three garment samples (Fig. 1) 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.

2.2. Sweating thermal manikin test

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 (Fig. 2).

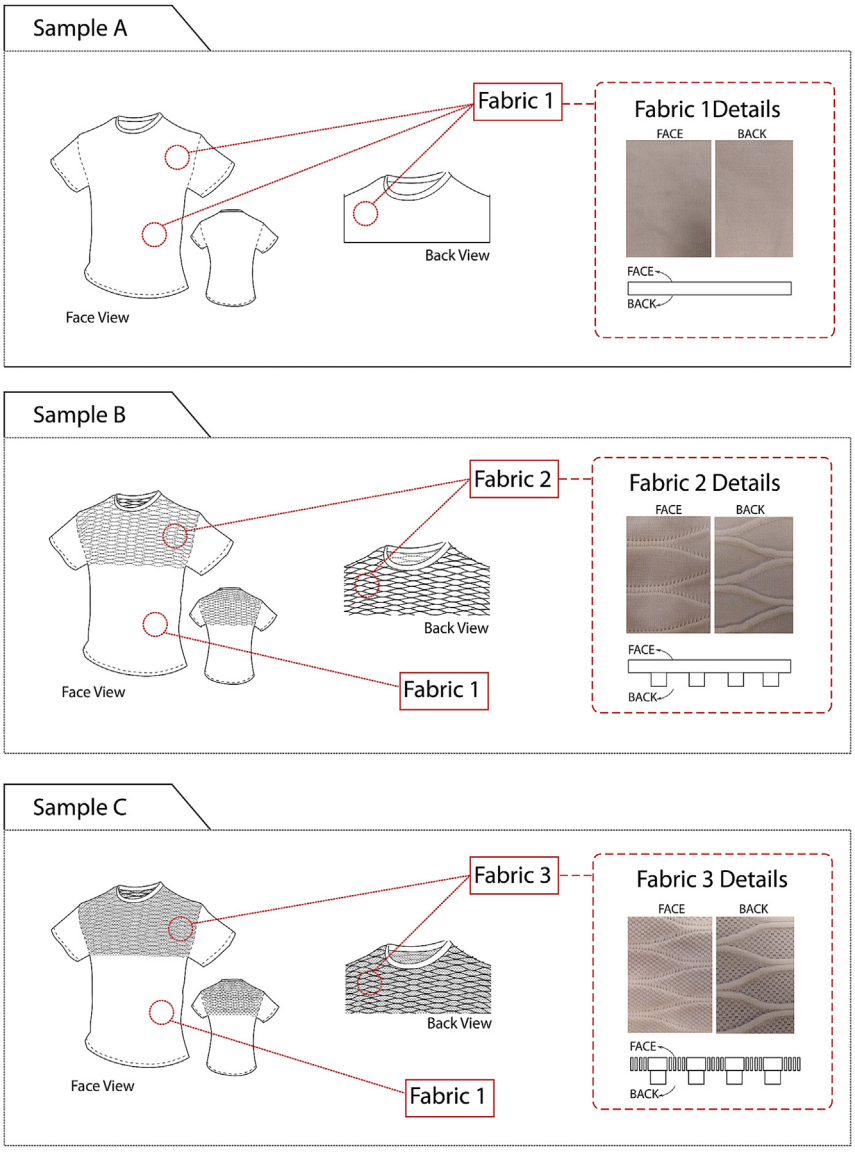

Fig. 1. Appearance of the three samples and the three fabrics.