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Research Article

Thermal Comfort Analysis of Moisture Management Treated Cotton Fabrics for Sportwear

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Abstract

Currently, health concern continues to increase in importance and leads people to exercise more. It also increases people's interest in purchasing athletic performance apparel that is promoted as superior apparel due to performance in moisture and heat transfer during exercising. This trend encourages more apparel companies to develop moisture management fabric. The aim of this study was to examine whether moisture management treated fabrics provide significant heat, moisture, and air transfers. Significant differences were found in air permeability among three different moisture management conditioned fabrics. There was no significant difference in heat and moisture transfers among them. However, statistically significant differences in heat, moisture, air transfers were found between two different fabric structures.

Keywords: Sportwear; Moisture management technology; Thermal comfort; Cotton; Knitted fabric

Introduction

With increased attention to living a healthy lifestyle, people tend to allocate more time to exercise and participate in sport and leisure activities [1]. Athletic people are interested in purchasing the most comfortable sportswear that must dry quickly, be most comfortable, and provide a wide range of motion to enhance athletic performance [2,3].

To satisfy the needs of athletic people, many apparel companies have invested a lot of time and effort to develop athletic performance apparel, which is referred to as moisture management apparel [4]. Moisture management apparel provides a greater degree of thermal comfort to the wearer especially during physical activity and performance since the moisture management property is effective to decide the comfort level of apparel [5,6].

The most important aspect of athletic apparel is how to transfer the heat, moisture, air from the body effectively [7-9]. This aspect assists in providing a comfortable environment for the wearers during exercising [10-12]. It also helps to maximize the wearer's performance by reducing discomfort and fatigue from the presence of heat and sweat on the microclimate of the body [13-15].

As shown in recent trends for athletic apparel, an important characteristic is the moisture management capacity of the fabric/apparel to improve the thermal functionality and comfort performance during exercise [16-20]. Moisture management technology has been applied to athletic apparel to provide effective moisture absorption and quicker drying theoretically [16, 21].

Several companies have patented moisture management treated fabrics designed to be the most comfortable athletic apparel that keeps human skin dry and comfortable [21]. Each manufacturer has produced a variety of different names or trademarks for athletic performance apparel to emphasize their own values such as quick moisture absorption and quick dry [22]. Nike used many high technology-based materials and developed

"Dri-fit" as a trademark of moisture management apparel, which emphasizes premium handling with reduced cling when wet [23]. It maximizes sweat to dry faster than regular fabric and increases the wearer's comfort level during their performance [24,25]. Champion also created "Double Dry," which employs a moisture management technology, "Wicking Windows" technology established by Cotton Incorporated, to speed up the moisture movement and the evaporation rate. It modifies the angles that contact the liquid surface and the fabric surface to transfer moisture quickly from the body to the environment through the fabric. Reebok (PlayDry), Adidas (ClimaCool), and Under Armour (CoolGear) have also developed similar textile technologies to compete in the athletic apparel industry.

Despite these trends, the amount of research related to the effectiveness of treatments on the thermal comfort of moisture management apparels is insufficient and lacking. These gaps have created many opportunities for research and development. Therefore, this study aims to examine if athletic apparel made with moisture management fabric provides significant heat, sweat, and air transfer from the body to the environment as promoted by popular athletic brands. Additionally, a comparison of dry thermal resistance, water-vapor resistance, and air permeability among three different moisture management conditions was conducted to verify effectiveness on the structure of fabric for thermal comfort. Dry thermal resistance (R_{ct}) for thermal resistance, water-vapor resistance (R_{et}) for thermal absorptivity, and air permeability for air transfer were employed as variables to determine the effects of moisture management technology and fabric structures with athletic apparel. Two hypotheses follow:

H1a,b,c: There are significant differences in (H1a) dry thermal resistance (R_{ct}), (H1b) water-vapor resistance (R_{et}), and (H1c) air permeability among three different moisture management conditions on cotton fabric for athletic apparels.

H2a,b,c: There are significant differences in (H2a) dry thermal resistance (R_{ct}), (H2b) water-vapor resistance (R_{et}), and (H2c) air permeability between two different fabric structures on cotton fabric for athletic apparels.

Experimental

Testing fabrics

100% knitted cotton fabrics with two different fabric structures, jersey and interlock, were chosen for the experiment. To test the effects of different moisture management technology with cotton fabrics, three moisture management applications were chosen for this study: None Moisture Management Technology (NMMT), Print Moisture Management Technology (PMMT), and Yarn Moisture Management Technology (YMMT). NMMT fabrics were not applied with any moisture management treatments. PMMT fabrics were treated with water repellent finishes through print application onto the skin side of cotton fabrics. Finally, YMMT fabrics used cotton yarns treated through a special process to make them water repellent before knitting. Thus, six fabric samples with two different fabric structures and three different levels of moisture management treatments were tested. The conditions of six fabric samples were provided with specific details such as weight and thickness (Table 1).

Table 1: Testing fabrics.

Fabric Structure	WPI	CPI	Weight(g/m^2)	Thickness(mm)	Moisture Management Conditions
Jersey	42	53	91.25	0.68	NMMT
Jersey	43	50	91.25	0.64	PMMT
Jersey	38	46	84.62	0.66	YMMT
Interlock	48	48	82.48	0.7	NMMT
Interlock	44	44	82.48	0.72	PMMT
Interlock	50	45	77.51	0.72	YMMT

Equipment

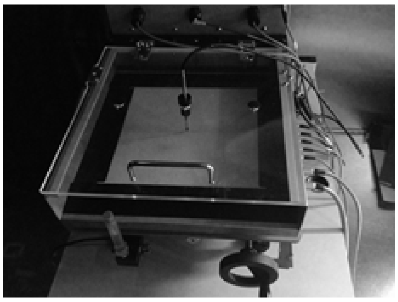

Figure 1: Sweating Guarded Hot-Plate manufactured by Measurement Technology Northwest.

Three specimens of each fabric, a total of 18 specimens, were cut 12 inches in length by 12 inches in width and pre-conditioned in the environmental chamber for 24 hours before testing. Each fabric specimen was tested by using the Sweating Guarded Hot-Plate (SGHP) (Figure 1) manufactured by Measurement Technology Northwest to conduct both dry thermal resistance (R_{ct}) and water-vapor resistance (R_{et}). According to the ASTM F1868-09, environmental chamber was pre-conditioned at the specific temperature and humidity for R_{ct} and R_{et}. Three repetitions of each test were collected. The collected R_{ct} and R_{et} values were calculated as the mean values with 5% of the standard deviation for the reliability of the study.

To measure the air permeability, the TEXTEST Air Permeability Tester (model: FX 3300 LabAir IV) was utilized. Ten specimens of each fabric, a total of 60 specimens, were cut according to the ASTM D737-04. The specimen was placed under the test head with no wrinkle. All measurements were repeated ten times for each specimen. ANOVA comparison of air permeability among three different moisture management conditions was run.

Results and Discussion

H1a,b,c: There are significant differences in (H1a) dry thermal resistance (R_{ct}), (H1b) water-vapor resistance (R_{et}), and (H1c) air permeability among three different moisture management conditions on cotton fabric for athletic apparels.

No significant differences were found in both R_{ct} (F (2, 17) = 3.002, p = .080) and R_{et} (F (2, 17) = .594, p = .565) according to three different moisture management conditions. However, a statistically significant difference in air permeability (F (2, 59) = 9.081, p = .000) was found (Table 2). It indicates that no differences exist among three different moisture treatment technology in transporting heat and sweat. However, a significant difference in air transfer among three different moisture treated fabrics was found from the body to the environment.

Table 2: ANOVA Table by Moisture Management Conditions on R_{ct}, R_{et}, & Air Permeability.

Source	Sum of Squares	df	Mean Square	F	P
Dry Thermal Resistance (R_{ct}) units: ºC·m²/W					
Between Groups	.000	2	.000	3.002	0.80
Within Groups	.000	15	.000		
Total	.000	17			
Water Vapor Resistance (R_{et}) units: Pa·m²/W					
Between Groups	0.107	2	0.054	0.594	0.565
Within Groups	1.356	15	0.09		
Total	1.463	17			
Air Permeability units: ft³/ft²/min					
Between Groups	22869.700	2	11434.85	9.081	.000*
Within Groups	71773.960	57	1259.192		
Total	94643.660	59			

Although no significant differences were found in R_{ct}, the mean value of NMMT (Mean = .019, SD = .004) for R_{ct} is higher than the mean values of PMMT (Mean = .022, SD = .001) and YMMT (Mean = .023, SD = .001) (Table 3). It means more heat remains between body and NMMT fabrics than other fabrics. However, for R_{et}, the mean values of all three different fabrics (NMMT: Mean = 3.361, SD = .424, PMMT: Mean = 3.452, SD = .265, & YMMT: Mean = 3.550, SD = .144) have the similar amount of moistures between garment and body under no significant difference on R_{et} (Table 3 & Figure 2).

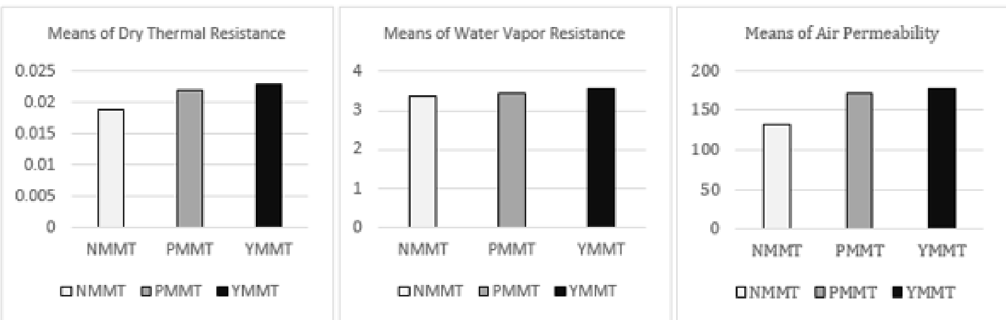

Figure 2: Mean Values of Dry Thermal Resistance, Water Vapor Resistance, & Air Permeability by Moisture Management Conditions.

Table 3: Means and Standard Deviations by Moisture Management Conditions on R_{ct}, R_{et}, & Air Permeability.

Moisture Management Conditions		R_{ct}	R_{et}	Air Permeability
NMMT	M	0.019	3.361	132.85
	SD	0.004	0.424	41.143
PMMT	M	0.022	3.452	170.6
	SD	0.001	0.265	36.453
YMMT	M	0.023	3.55	177.15
	SD	0.001	0.144	27.494

To see the group difference of air permeability, the LSD Post Hoc test was used (Table 4 & Figure 1). PMMT (Mean = 170.600, SD = 36.453) and YMMT (Mean = 177.150, SD = 27.494) were grouped together while NMMT (Mean = 132.850, SD = 41.143) were grouped together while NMMT (Mean = 132.850) remained in its own group. It indicated that no significant difference in moisture treated fabrics exits regardless to the moisture management treatment. However, a significant difference in air permeability between non-treated moisture management fabric and treated moisture management fabrics was found. PMMT and YMMT, which treated the moisture management on yarn and the top of the fabric, have higher air transfer than NMMT, which did not apply any moisture management technology.

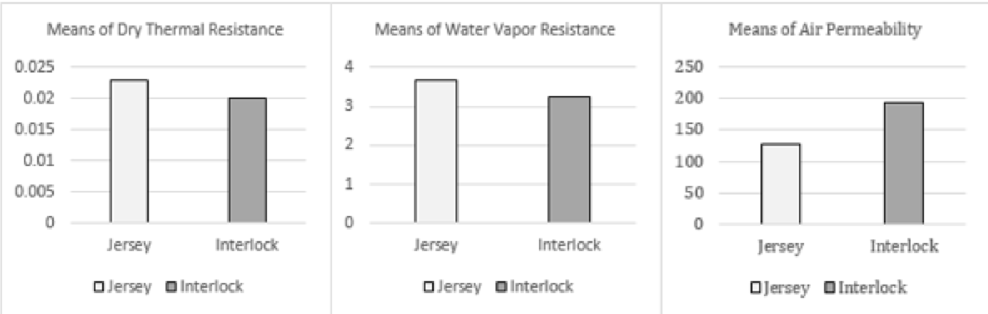

Figure 3: Mean Values of Dry Thermal Resistance, Water Vapor Resistance, & Air Permeability by Fabric Structures.

	NMMT	PMMT	YMMT
Air Permeability	132.850		
		170.600	177.150

Table 4: LSD Post Hoc Test Results by Moisture Management Conditions on Air Permeability.

H2a,b,c: There are significant differences in (H2a) dry thermal resistance (R_{ct}), (H2b) water-vapor resistance (R_{et}), and (H2c) air permeability between two different fabric structures on cotton fabric for athletic apparels.

As presented in Table 5, statistically significant differences were found in all of R_{ct} ($F(1, 17) = 4.663$, $p = .046$), R_{et} ($F(1, 17) = 24.820$, $p = .000$), and air permeability ($F(1,59) = 133.653$, $p = .000$) between two different fabric structures. It indicates that there are significant differences in dry thermal resistance, water-vapor resistance, and air permeability between two fabric structures, jersey and interlock.

Table 5: ANOVA Table by Fabric Structures on R_{ct}, R_{et}, & Air Permeability.

Source	Sum of Squares	df	Mean Square	F	P
Dry Thermal Resistance (R_{ct}) units: $^{o}C \cdot m^2/W$					
Between Groups	.000	1	.000	4.663	.046*
Within Groups	.000	16	.000		
Total	.000	17			

Water Vapor Resistance (R_{et}) units: Pa·m²/W					
Between Groups	0.89	1	0.890	24.82	.000*
Within Groups	0.574	16	0.036		
Total	1.463	17			
Air Permeability units: ft³/ft²/min					
Between Groups	66001.67	1	66001.67	133.653	.000*
Within Groups	28641.99	58	493.827		
Total	94643.66	59			

To see more detail in these differences, the means and standard deviations were conducted (Table 6 & Figure 3). For both R_{ct} and R_{et}, the mean values of jersey fabrics (R_{ct}: Mean = .023, SD = .001 & Ret: Mean = 3.677, SD = .153) is greater than the mean values of interlock fabrics (R_{ct}: Mean = .020, SD = .003 & R_{et}: Mean = 3.232, SD = .219). It indicates that more heat and moisture remain in jersey structured fabrics between body and garment than in interlock fabrics. Lastly, air permeability in interlock fabric structure (Mean = 193.366, SD = 17.625) has higher mean value than in jersey fabric structure (Mean = 127.033, SD = 26.019). It means that better air transfer in interlock fabrics occurred than in jersey fabrics.

Table 6: Means and Standard Deviations by Fabric Structures on R_{ct}, R_{et}, & Air Permeability

Fabric Structures		R_{ct}	R_{et}	Air Permeability
Jersey	M	.023	3.677	127.033
	SD	.001	0.153	26.019
Interlock	M	.020	3.232	193.366
	SD	.003	0.219	17.625

Conclusion

Many manufacturers and retailers promote to consumers that moisture management apparel has greater heat and sweat transfer properties than conventional sportswear, but this study has shown that the beneficial properties of moisture management fabrics are only seen in air transfer, not in heat and sweat transfer. Especially, two types of fabrics, PMMT and YMMT, which were differently treated for moisture management treatment, did not show a significantly differences of heat and sweat transfer than NMMT fabrics. However, although no significance showed in R_{ct} among three different fabrics, the descriptive analysis presented that PMMT and YMMT fabrics contained lower heat values which mean better heat transfer from the body to the outer portion of a T-shirt than NMMT fabrics. On the other hand, the R_{et} values of PMMT and YMMT fabrics are lower than NMMT fabrics, which means more sweat between body and T-shirt in NMMT fabrics remains than in PMMT and YMMT fabrics. It means that sweat in PMMT and YMMT fabrics is easily transferred from the body to the outer layers of the T-shirt and NMMT fabrics follow.

However, significant difference was found in air permeability test. NMMT has a significantly lower air permeability value than PMMT and YMMT which indicates moisture treated fabrics for athletic have better air transfer from the body to the environment than non-moisture treated fabrics. Thus, the athletic t-shirts made of both PMMT and YMMT fabrics provide better air transfer and ventilation than the athletic T-shirts made of NMMT fabrics.

Another major finding of this study is that there are statistically significant differences in dry thermal resistance, water-vapor resistance, and air permeability depending on types of fabric. These results support that fabric structures influence the thermal property of fabric such as heat, sweat, and air transfer. Two knitting structured fabrics, jersey and interlock, which are popularly used for athletic t-shirts, were employed for this research. According to the finding, the interlock structure has more effective heat, sweat, and air transfers than the jersey structure. It indicates heat, sweat, and air remain in jersey structures more than in interlock structures. It might be related to the weight of fabric that produces these different results.

Adding moisture management technology in athletic apparel has been widely promoted by many sportswear companies to provide quick heat, sweat, and air transfer effectively. Consumers tend to trust what popular companies promote and purchase their apparel by paying the premium price. However, as shown through this study, the effectiveness of moisture management technology on heat and sweat transfers is inadequate. The moisture management technology on air permeability only shows the significantly different air transfer on fabrics. A clearer description of effects on moisture management technology is relatively suggested and it will help to reduce consumers' misunderstanding and misguided purchase decisions. Also, using a certification mark after completing the appropriate tests should help consumers to understand more clearly about moisture management technology and build a positive image of a company promoting such athletic apparel.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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