

Exploring Thermal Comfort of Sports Shirts from the Price Difference Perspective

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Abstract

The purpose of this study was to examine the relationship between thermal comfort and price of athletic shirts. Three 100% polyester plain knitted sports shirts with three different prices were compared. Three hypotheses were developed to test the relationships between thermal comfort and price of the athletic shirt. The TEXTEST FX 3300 Lab Air IV was used to determine the air permeability of shirts based on (ASTM D737-04). The thermal manikin Newton was used for measuring thermal resistance and water vapor resistance of shirts based on (ASTM F1291-10) and (ASTM F2370-10) respectively. Analysis of Variance (ANOVA) and Post Hoc analysis were used to determine the relationship between price and thermal resistance, water vapor resistance as well as air permeability. A significant correlation was found between price and thermal resistance (R_{ct}) as well as air permeability. However, no significant difference was not found for water vapor resistance (R_{ev}) at different price levels.

Keywords — Sport, Price, Customer Satisfaction, Athletic Shirt, Thermal Comfort, Thermal Resistance, Evaporative Resistance, Air Permeability, Polyester.

I. INTRODUCTION

Exercise is one of the most heard words when we talk about health. The Immense importance of exercise was stated by many researchers in the past and known by all of us. People in the USA are aware of physical fitness as the statistics show 51.6 % of American exercised regularly [1]. A physically active lifestyle helps to reduce depression [2], [3], anxiety [4], [5] tension [2] and make people feeling good ([6], [7]). Moreover, long-term exercise is effective to reduce risk factors like obesity and hypertension [8], and health specialists consider lack of physical activity results in high risk of heart disease [9],[2]. Therefore, many studies assured that physical fitness is important for good health [10].

With significant health consciousness nationwide, it is also important to take clothing comfort during exercise into account. The ability of garment fabric to transfer heat, moisture, and perspiration from our body to the environment aims to equilibrium skin temperature with weather is considered as thermal comfort [11]. Many researchers stated comfort as a key feature of sportswear and

since it sits next to the skin, their attributes are important for wearers' performance and efficiency [12]–[15]. The Study found that the thermal and moisture comfort is drawing the attention of a number of the wearer while they buy sportswear or active wear [16]. The researcher examined that athlete with breathable clothing can perform better and longer than one doesn't [17]. The inner layer of garments which sits next to the skin is important for the physiological comfort of an athlete, and their thermal conductivity impacts the performance of the athlete [17][18].

There is a common understanding that the exchange of water vapor and heat through the garments may be are the most vital factors influencing clothing comfort. Scholar defined air permeability as the amount of air passes through the certain area of fabric surface at a certain pressure in a certain period [19]. The thermal resistance (R_{ct}) and evaporative resistance (R_{ev}) are the measures of the resistance to heat transfer and water vapor transfer from human skin to the environment respectively [20][21]. Researchers recognized many factors that affect clothing comfort during physical activity such as relative humidity [22], air permeability, evaporative resistance, thermal resistance [20][21], [23], [24] and moisture management [11], [23], [25], [26]. Since many studies found air permeability, evaporative resistance, thermal resistance are the most important factors from a comfort standpoint this study evaluated these parameters to determine comfort.

Sports companies like Nike, Adidas, Puma, Under Armour and many more trying to meet the customers' demand for sportswear by offering various product line like footwear, apparel, accessories and so on. For sports shirts, wicking, air permeability, thermal resistance, and evaporative resistance are the important factors to be considered. Sports companies offer products with different functionality in different prices. They exhibit a different level of thermal comfort. On the other hand, consumers always expect a better quality product when they pay the higher price [22]. The total revenue of the global sports apparel market projected was about 220 billion US dollars, whereas the revenue in the current year is 173.68 billion USD [27]. The sales of the sportswear market in the United States increasing since 2015. Projected sales of sportswear by 2020 is about 130

billion US dollars, whereas the figure is 115.61 billion US dollars in 2018 [28]. These meteoric rises in global revenue and US sportswear sales by years indicating the potential and competition of this sector in the future.

Scholar described customer satisfaction as a post hoc evaluation of consumption experience [29]. Customer satisfaction is the crucial factor for success in business. Researchers found that highly satisfied customers may also be more profitable since it is easy for companies to apply price increases with loyal customers [30]. Previous studies found that customers' satisfaction can result in brand loyalty and loyal customers are more profitable since they purchase the product or service more often [29], [31]–[34]. Researchers also found non-significant positive relationship customer profitability is positively associated with customer satisfaction though it was considered not significant statistically [35], [36].

Customers' satisfaction varied by different parameters. Researchers found customers satisfaction related with many factors such as price, value, loyalty [36]. A Study found the significant negative relationship of price sensitivity to preparation, relationship building, and information exchange [37]. They also found the insignificant negative relationship between intervention and price sensitivity. A researcher found that good service quality can make satisfied and loyal customers [38]. Several past studies had also found that a strong relationship exists among customer service, customer satisfaction and loyalty [39]–[43]. The study revealed that the lower price elasticities result in higher levels of customer satisfaction and the difference in elasticities between high and low satisfaction are very large, especially for a moderate price increase [41].

Some previous studies showed the inverse relationship between price and customer satisfaction. A researcher found customer satisfaction increase with the decrease of price elasticity of demand [44]. Customers commonly believe that higher price indicates higher quality [22]. Based on the price of products, consumers often develop a common ordering behavior, believing the expensive products have higher quality than cheaper product. Researcher found that consumers use price as an indicator of quality, especially when they have narrow knowledge of product offerings [45]. Overall price is one of the important variables that usually discussed in many kinds of literature as an effective extrinsic cue for consumers' assessment of product alternatives and their purchase decisions.

On the other hand, some studies insisted that there is no relation between price and customer perception and the actual relationship between price and quality is not really strong. A study stated that it seems that the price-quality relationship has somewhat decreased over time [46]. Many products are cheaper and performing better than the past. It represents that, consumers are less aware regarding

price-quality relationship than they were in the past. Another study found that consumers do not always 'get what they pay for' while inspecting the relationship between price and objective product quality [47].

In the past, many researchers studied thermal comfort for clothing where they tried to determine thermal comfort based on various aspects (i.e., such as physiological, psychological etc.). Modern technology has come up with different equipment to measure thermal comfort and several previous studies found the different factors that influence thermal comfort. Studies also discussed the relation between prices and perceived quality in case of clothing purchase but no published work investigated the relationship between price and thermal comfort in terms of thermal resistance, water vapor resistance, and air permeability. Thus, the purpose of this study was to investigate the relation between price and thermal comfort in terms of thermal resistance, water vapor resistance, and air permeability. Three hypotheses are developed to direct for this study as follows:

H1: Price of the athletic t-shirt has no effects on thermal resistance

H2: Price of the athletic t-shirt has no effects on evaporative resistance

H3: Price of the athletic t-shirt has no effects on air permeability

II. METHODOLOGY

A. Testing Garment

The reported study studied three male's athletic t-shirts, were purchased from local market. All three t-shirts are made of 100% polyester with three different prices; \$25.00, \$28.00, & \$45.00. The complete assembly of testing garments included one sports short sleeve t-shirt with one short (Fig I). Shirts were varied in style and price but shorts are all same.

TABLE I
Details of The Testing Garments

Assembly	Fiber content	Size	Price	Special function	
1	Top	100% Polyester	M	\$45.00	Sweat evaporation
	Bottom	100% Polyester	M	\$6.88	Moisture wicking
2	Top	100% Polyester	M	\$25.00	Sweat evaporation
	Bottom	100% Polyester	M	\$6.88	Moisture wicking
3	Top	100% Polyester	M	\$28.00	Sweat evaporation
	Bottom	100% Polyester	M	\$6.88	Moisture wicking

All t-shirts were belonging to the same brand and the shorts were from another brand. Shirts and shorts are not varied in material composition and

function to other. The details of testing garments are shown in Table I.

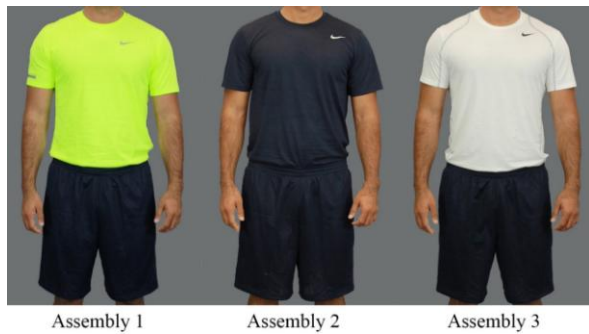


Fig I. Assembly of Testing Garments

B. Equipment

The details of equipments are described as follows.

1) Manikin:

The thermal manikin Newton was used in this study to measure thermal resistance and water vapor permeability. It has 46 individually controlled thermal zones. To simulate metabolic heat output rates, all thermal zones are equipped with heaters. For measuring skin temperature, Newton has scattered wire sensor. Through uniformly scattered fluid ports on its surface, each thermal zone has sweat control. The inner heater of the manikin pre-heat water before it is distributed to the ports on the manikin surface. The manikin zone divisions are shown as in Fig II.

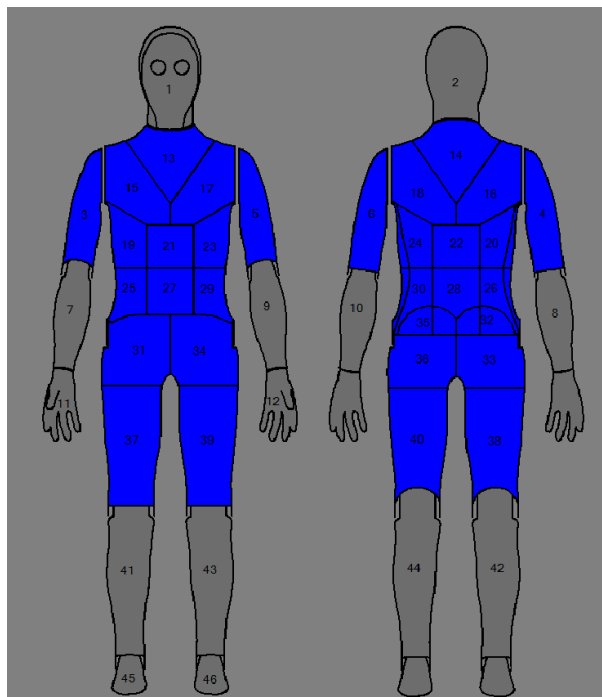


Fig II. Manikin Zone Divisions (blue zones were studied)

The outfit assembly used in this study only covered 32 zones on the thermal manikin. Therefore, the reported study evaluated only those 32 zones (Table II).

TABLE II
Details of Manikin Zone

Zone	Name	Zone	Name
3	R Up Arm Fr	25	R Front Oblique
4	R Up Arm Bk	26	R. Back Oblique
5	L Up Arm Fr	27	Lower Abdomen
6	L Up Arm Bk	28	Lower Back
13	Neck	29	L. Front Oblique
14	Trapezius	30	L. Back Oblique
15	R Pectoral	31	R Up Thigh Fr
16	R Shoulder	32	R Up Thigh Grd
17	L Pectoral	33	R Up Thigh Bk
18	L Shoulder	34	L Up Thigh Fr
19	R Front Rib	35	LUp Thigh Grd
20	R Back Rib	36	LUp Thigh Bk
21	Upper Abdomen	37	R Lwr Thigh Fr
22	Mid Back	38	R Lwr Thigh Bk
23	L Front Rib	39	L Lwr Thigh Fr
24	L Back Rib	40	L Lwr Thigh Bk

2) Chamber

The environmental chamber made by Russells Technical Products has used for this study and housed in Center for Merchandising and Design Technologies (CMDT) lab at Central Michigan University. The chamber controls temperature ranges from -20 F/-29°C to +180F/+82°C and a humidity range of 20% to 95% +/-5% RH. The internal working dimensions of this unit is 6'D x 11.5'W x 10'H; which can easily accommodate a piece of equipment with the researcher and the subject. Thus, the thermal manikin was placed in the environmental chamber to keep the stable temperature and humidity during the testing.

3) TEXTEST FX 3300 Lab Air IV

The TEXTEST FX 3300 Lab Air IV was used to measure the air permeability of each t-shirt. The dimensions of this unit are 39.4" D x 15.7" W x 38.6" H. It uses clamping mechanism and its fast release locking feature provides adequate support for specimens during testing. This equipment can measure in many units such as mm/s, ft3 /ft2 /min, cm3 /cm2 /s, l/m2 /s, l/dm2 /min, m3 /m2 /min, m3 /m2 /h, dm3 /s, Pa (pressure drop), mks rayl, and cgs rayl (air flow resistance). The reported study measured air permeability in ft3 /ft2 /min. It can test materials of 0-10 mm. Test head that used in the reported study is 38 cm² and the projection of clamping arm was 20".

C. Test Method

The reported study followed standard developed by American Society for Testing and Materials (ASTM).

1) Thermal and Evaporative Resistance:

All testing garments assembly were preconditioned for 12 hours before being tested in a

controlled chamber of $23 \pm 0.5^\circ\text{C}$ and $50 \pm 5\%$ RH and of $35 \pm 0.5^\circ\text{C}$ and $40 \pm 5\%$ RH prior thermal insulation and water vapor resistance test respectively. The mean value of skin surface temperature of manikin was maintained at $35 \pm 0.2^\circ\text{C}$ and $35 \pm 0.5^\circ\text{C}$ during a 30-minute test for thermal insulation and water vapor resistance test respectively. ASTM F1291-10 test method was used for measuring the thermal resistance and ASTM F2370-10 test method was used for measuring the evaporative resistance of clothing using a heated or sweating manikin subsequently.

The nude/bare manikin and the manikin with a sweat suit on were tested under the same environmental condition for thermal and evaporative resistance respectively. Bare tests took place at the beginning of each series of tests to determine the insulation provided by the air layer surrounding the bare manikin. Sports t-shirt and short were put on a standing manikin and the t-shirt was lightly bloused over waistband but the waistband wasn't cover completely. It was confirmed t-shirt was not crimped into the short. The short was loosely tied around the waist with the draw cord. Bring dressed manikin's skin temperature at steady-state of $35 \pm 0.2^\circ\text{C}$. After the assembly reaches at equilibrium conditions, manikin skin's temperature and air temperature recorded at every minute. The average of these measurements was taken over 30 minutes. Three independent fabric tests were conducted. Each assembly of sportswear was tested multiple times since only one set per assembly was available. Repetition of testing measurements was being ensured before measurements were taken.

2) Air Permeability:

All specimens were conditioned under $21 \pm 1^\circ\text{C}$ and $65 \pm 2\%$ RH for determining air permeability. 125 Pa (12.7 mm or 0.5 in. of water) water pressure differential was maintained for air permeability test. ASTM D737-04 (Reapproved 2012) test method was used for measuring the air permeability of garment. No specimen was required by the standard. Ten results were recorded from randomly selected ten different places of garments.

Machine calibration was verified for the range and achieve the expected water pressure differential for the samples to be tested. Conditioned garments were handled carefully thus they don't lose the natural state of the material. Placed each test sample onto the test head of the test instrument, then the test was performed as directed in manufacturer's operating manual. The total edge leakage through the sample and underneath was measured in a separate test, with the test sample covered by an airtight cover. The loss of air was far less than 10% hence the effect was ignored. The test was repeated 10 times at 10 different places of samples since only one sample was available.

Collected data were analysed by statistical means, Post Hoc, and Analysis of Variance

(ANOVA). All the calculations were carried out in Statistical Package for the Social Sciences (SPSS) software.

III.RESULT AND DISCUSSION

Total thermal insulation of the clothing system, including the air layer resistance (R_{ct}), was calculated by the following equation.

$$R_{ct} = (T_s - T_a) A / H \text{ (}^\circ\text{C}\cdot\text{m}^2/\text{W)}$$

Where R_{ct} is the total thermal insulation of the clothing ensemble and surface air layer, A is the area of the manikin's surface (m^2), T_s is the temperature at the manikin surface ($^\circ\text{C}$), T_a is the temperature in the air flowing over the clothing ($^\circ\text{C}$), and H is the power required to heat manikin (W).

The total evaporative resistance of the ensemble was calculated by the following equation.

$$R_{et} = [(P_s - P_a) A] / [H_e - (T_s - T_a) A / R_t] \text{ (kPa}\cdot\text{m}^2/\text{W)}$$

Where R_{et} is the total evaporative resistance of the clothing ensemble and surface air layer, P_s is the water vapor pressure at the manikin's sweating surface (kPa), P_a is the water vapor pressure in the air flowing over the clothing (kPa), A is the area of the manikin's surface that is sweating (m^2), H_e is the power required for sweating areas (W), T_s is the temperature at the manikin surface ($^\circ\text{C}$), T_a is the temperature in the air flowing over the clothing ($^\circ\text{C}$), and R_t is the total thermal resistance of the clothing ensemble and surface air layer ($^\circ\text{C}\cdot\text{m}^2/\text{W}$).

TABLE III
ANOVA Table by Shirt Prices on R_{ct} , R_{et} , and Air Permeability

Source	Sum of Squares	df	Mean Square	F	p
Thermal resistance (R_{ct}) units: $^\circ\text{C}\cdot\text{m}^2/\text{W}$					
Between Groups	0	2	0	6.4	0.033
Within Groups	0	6	0		
Total	0	8			
Water vapor resistance (R_{et}) units: $\text{kPa}\cdot\text{m}^2/\text{W}$					
Between Groups	0.526	2	0.263	0.6	0.574
Within Groups	2.585	6	0.431		
Total	3.111	8			
Air permeability units: $\text{ft}^3/\text{ft}^2/\text{min}$					
Between Groups	170644	2	85322	165	0
Within Groups	13927	27	515.8		
Total	184571	29			

The parallel method of determining the total thermal resistance and the total evaporative resistance were used. Where the area-weighted temperatures of all body segments sweating body segments are summed and averaged, the power levels to all body

segments are summed, and the areas are summed before the total resistance is calculated.

TABLE IV
Means and Standard Deviation of Evaluations

Garment		R _{ct}	R _{et}	Air permeability
\$25.00	M	0.0873	11.02	367.3
	SD	0.0015	0.918	37.798
\$28.00	M	0.0867	11.24	212.6
	SD	0.0015	0.6109	9.348
\$45.00	M	0.091	10.66	202.5
	SD	0.0017	0.2761	5.603

TABLE V
Post Hoc Test Results by Shirt Price on R_{ct} and Air Permeability

Tests	\$45.00 T-shirt	\$28.00 T-shirt	\$25.00 T-shirt
Thermal resistance (R _{ct})	0.091	0.087	0.087
Air Permeability	202.5	212.6	367.3

1) Hypothesis 1 (H1): Price of the athletic t-shirt has no effects on thermal resistance

Table III presents that the result of ANOVA comparing thermal resistance (R_{ct}) based on the price of the garment and shows the significant result ($p < .05$; R_{ct}: $p = .033$). It indicates that there was a difference among the thermal resistance value of three garments. Again Table IV indicates that the most expensive shirt (\$45) shows higher mean thermal resistance (R_{ct}). In table V, post hoc test results for the most expensive shirt on thermal resistance (R_{ct}) shows higher value (.091) than other 2 shirts. Other 2 shirts of \$25 (.087) and \$28 (.087) show similar values respectively. It indicates that most expensive shirt displays higher thermal resistance and support lower heat transfer. Therefore, H1 was not supported.

2) Hypothesis 2 (H2): Price of the athletic t-shirt has no effects on evaporative resistance

Comparison of water vapor resistance (R_{et}) and price of the garment shows the non-significant result ($p > .05$; R_{et}: $p = .574$) according to the result of ANOVA in table III. It means H2 was supported because there was no significant difference among the water vapor resistance value of three shirts. Most expensive (\$45) shirt has relatively lower mean value (10.66) on water vapor resistance (R_{et}) according to

table 3. Shirts of \$25 (11.02) and \$28 (11.24) showed similar values respectively. Although there is no significant difference but most expensive shirt displays lower water vapor resistance hence higher water vapor transfer which can increase thermal comfort.

3) Hypothesis 3 (H3): Price of the athletic t-shirt has no effects on air permeability

Result shows that there was a difference in the air permeability in three different garments of different values. Because table III exhibits that the result of ANOVA is significant ($p < .05$; $p = .000$) for air permeability and the price of the shirts. Table IV displays that, the most expensive shirt (\$45) has the lowest air permeability according to their mean value. Table V shows that the cheapest (\$25) shirt has a higher value (367.3) for post hoc test results on air permeability. On contrary, \$45 (202.5) and \$28 (212.6) shirts show similar values respectively. H3 was not supported, because result indicates that, the cheapest shirt displays higher air transfer than other two shirts which can enhance thermal comfort.

IV. CONCLUSIONS

Human's common perspective toward garment quality is directed by price. People strongly believe the higher price product has better quality, especially athletic wear which has the functional purpose of wearing. Consumers are price sensitive when it comes to quality[48]. Since athletic shirt uses many technologies (i.e. easy wicking, quick dry etc.) to increase thermal comfort hence athlete's performance which is costly to implement and added up the price. As the quality of athletic completely based on functionality, therefore when people pay more for sports shirts they expect a higher level of comfort. On the other hand, researchers proved that this common perception is not always true. Thus, this study investigated the relationship between price and thermo-physiological comfort of sports t-shirts, which are commonly used by athletes. To evaluate the performance of different priced sports t-shirt, thermo-physiological attributes for athletes such as thermal resistance, water vapor resistance, and air permeability was studied.

This study tested three hypotheses established based on literature review but only one of the hypotheses was supported by the test results. Three different hypotheses tested three different thermal comfort properties of the expensive and cheap athletic shirt. Thermal resistance, water vapor resistance, and air permeability were the thermal comfort properties under consideration for this study. All test samples were 100% polyester and plain knitted fabric. They all were specially made for athletes.

This study found that thermo-physiological comfort is not associated with the price of shirts. Price was not a determinant for R_{ct}, R_{et}, and air

permeability since the lower price shirt had lowest R_{ct} , and highest R_{et} , and air permeability value. This study proves that less expensive sports t-shirt has better heat transfer and air permeability over more expensive shirt. It also shows that, the most expensive shirt had better moisture transfer over cheaper shirts. This study suggests customer should not determine the quality of athletic shirt only based on price. It also suggests companies disclose test results on their garments' tag/label, thus customer can access them and easily understand which garment will be more suitable for them based on their physiological condition. Findings of this research will help companies to let their customer know actual performance of their products and achieve customer trust on them. Findings of this study will also add to the body of literature in other research/s which will be focused on the price-quality relationship. Future studies could explore the price-quality relationship of garments of other kinds.

V. LIMITATION AND FUTURE RESEARCH

The garments were tested by reported study sourced from the local market. Therefore, all attributes of testing garments were not being able to control by the researcher. The price range of garments used by the reported study was not too wide, it was based on what was available in the market of that time. The terms thermal resistance and thermal insulation, evaporative resistance and water vapor resistance were used interchangeably in previous research, which made confusion

Future research can be done with more controlled garments. More variety in the garment, fabric type, price, materials, and brand can have studied in future. Other comfort properties of fabric like wicking, porosity, breathability, heat transfer, sweat transfer can be added as the attribute and tested. Future study can also evaluate comfort properties by testing more zones of the manikin.

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