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**Influence of Sportswear Fabric Properties on the Health and Performance of Athletes**

**Abstract**

*The main goal of this work was to study the Influence of sportswear fabric properties on the physiological responses and performance of athletes. The influence of three different types of sportswear fabrics on the physiological response and performance of volunteers in sports conditions was investigated. The fabrics and garments tested were made of 100% cotton, a 65/35 polyester/cotton blend and 100% polyester fibres. Seven volunteer were selected to wear the sportswear during the physical exercise assigned and their physi- ological responses were tested. The results of the study show a statistically significant effect on the athletes’ physiological responses and performance parameters measured for the different types of sportswear tested. The sample with 100% polyester produced the best physiological responses and performance from the athletes. This effect can be related to better moisture management, which reflects the amount of relative water vapour perme- ability (68%) and lower thermal conductivity. This will enhance the body’s temperature regulation leading to increase athletes’ cardiorespiratory fitness and performance. The results also show the high correlation between the sportswear fabrics properties and ath- letes’ physiological responses and performance, except the relationship between the end- tidal partial pressure of oxygen (PETO2) and fabric thickness (h), air permeability (AP) and thermal resistance (r), which are not highly correlated. The other correlation values vary between (±0.62 and (±1).*

**Key words:** *sportswear fabrics, comfort properties, athletes’ physiological responses, per- formance of athlets.*

# Introduction



In active and endurance sports, the per- formance of a sportswear is synonymous with its comfort characteristics. The wear comfort of sportswear is an important quality criterion that affects perform- ance, efficiency and well-being. For in- stance, an active sportsperson that wears poor breathable sportswear will experi- ence an increase in their heart rate and rectal temperature more rapidly than one who wears breathable sportswear [1 - 3]. Hence fabric breathability (moisture and air permeability) and thermal proper- ties should be tailored in order to meet the requirements of sportswear. The type of fibre (natural, synthetic or blend), the fabric structure (woven or knitted) and fabric constructions (densities of yarns, fabric thickness, etc) are amongst the parameters that may affect the thermal and breathability properties of sports- wear fabrics. Studying these properties of sportswear fabrics is important, but, at the same time, it is so important to con- nect them with the performance of an athlete when wearing this kind of clothes during the course of exercise. Generally four different aspects can define wear comfort: physiological, psychological, ergonomic and skin sensorial aspects [4, 5]. Thermal insulation, breathability and the heat and moisture transportation process are a fabric’s physical properties that can affect the comfort sensation from a physiological point of view. The psy-

chological aspect can include personal preferences, fashion, ideology, etc. Ergo- nomic wear comfort depends mainly on the garment’s pattern and fabric elastic- ity, which influence the clothing fit and freedom of movement. Skin sensorial wear comfort characterises mechanical sensations caused by the direct contact of clothes to skin (e.g. softness, smooth- ness).

For sportswear one can find that the physiological aspect is extremely im- portant because of its major effect on the efficiency and performance of athletes. Thermal comfort refers to sensations of hot, cold, or dampness in clothes and is usually associated with environmen- tal factors such as heat, moisture, and air velocity [6]. Water/moisture vapour transmission and air permeability are important factors that affect the thermal comfort of sportswear. Fibre content and fabric geometry are two primary factors that may affect water/moisture vapour transmission [7]. Several stud- ies have been conducted on the role of determining thermal parameters in the human body during the performance of exercise [8]. Investigators have found that hydrophilic textiles, such as cotton seem to have beneficial influences on the thermal physiological response as well as on overall comfort during and after ex- ercise compared to hydrophobic textiles such as polyester, nylon and polypropyl-

ene. A rise in the core temperature, heart rate, amount of sweat, and metabolic heat production was found to be greater in subjects wearing clothing ensembles made of weak hygroscopic material ver- sus clothing ensembles made of strong hygroscopic material in various exercise conditions [9, 11].

Textile material used in underwear in a normal work garment has a small, but insignificant influence on the wet heat dissipation during intermittent exercise in a cool environment [10]. Investiga- tion of the influence of different types of sportswear made from cellulosic man- made fibers and polyester fibers on the energy cost of the effort of volunteers in sports conditions done by Malgorzata Zimniewska et al. [12].

The human body sweats during exer- cise to maintain its internal temperature, where its physiological activities can run efficiently. This process is called heat ac- climatisation, which improves thermal comfort, increases heat tolerance and re- duces heat strain [13]. On the other hand, the presence of moisture within cloth- ing can increase the wearer’s heat loss dramatically [14, 15]. Heat and mois- ture transport through clothing involves complex processes and is coupled with evaporation, condensation and the sorp- tion and desorption of moisture [16 - 18]. Transfer of heat away from the body is

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affected by various factors including air movement (i.e., wind), relative humidity, sunshine, and clothing. Clothing affects air circulation over the skin as well as evaporative cooling and moisture regula- tion. If moisture cannot evaporate from the skin, both the skin temperature and discomfort increase [19]. Adequate ven- tilation or air movement can reduce the insulation properties of clothing by 5 to 50% [20].

Researchers investigated the influence of different types of sportswear on the physiological parameters and energy cost of volunteers in sports conditions while wearing sportswear made from 100% TENCEL® fibres, 100% polyester fibres and TENCEL®/polyester blend. The study showed that garments made from a blend of Polyester and TENCEL® had the most favorable effect on the energy cost of physical work, as well as on the time of compensation and efficiency of the volunteers [21]. Other researchers compared the effect of wearing clothes made of natural fibres to clothes made of synthetic fibres on thermoregulation in humans. They found that the influence of the material type is especially seen during physical effort where muscular activity increases, resulting in an increase in heat produced by the body, which affects the heat balance in the human body [22, 23]. Some other research concerned measure- ments of body temperature, the heart rate, systolic and diastolic blood pressure, oxygen consumption, skeletal muscle activity and the reaction time [24 - 28]. Another research work focused on ana- lysing the influence of clothing materi- als on human physiology and thermal comfort. They compared the effect of wearing clothes made of natural fibres (wool) and synthetic fibres (acrylic) on some psychomotor parameters of human volunteers during and after physical ef- fort [29]. They found that the clothing material has an influence on the respira- tory and cardiovascular system, whereas there was no effect on psychomotor pa- rameters. In addition, the well-being feel- ing of wearing clothes made of acrylic fibres after the physical effort was worse compared to the woolen clothes [29]. An- other study examined the effects of wear- ing compression tights on oxygen cost and sensation responses during running exercise compared to the classic elastic variety and conventional shorts. They found that wearing compression tights during running exercise may enhance the overall circulation and decrease muscle

***Table 1.*** *Sample characteristics.*

oscillation to promote lower energy ex- penditure [30, 31].

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Samle No.** | **Fibre composition** | **Fabric porosity** | **Fabric thickness, mm** | **Fabric surface weight, g/m2** |
| 1 | 100% cotton | 0.85 | 0.725 ± 0.01 | 168 |
| 2 | 65% polyester/35% cotton | 0.81 | 0.743 ± 0.01 | 203 |
| 3 | 100% polyester | 0.79 | 0.598 ± 0.01 | 127 |

In this work, three samples of commer- cial sportswear were selected to repre- sent three different fibre compositions. All samples were made of single jersey knitted fabrics with 100% cotton fibres, 35/65 cotton polyester blend fibres and 100% polyester fibres. Thermal charac- teristics, air and moisture permeability properties were measured for all samples. Then group of volunteers, all sportsper- sons, were selected to wear the samples in order to evaluate their physical per- formance during the exercise assigned.

# Materials and methods



Fabric thermal resistance, thermal con- ductivity, thermal absorptivity, heat flow, relative water vapour permeability and air permeability are physical properties that need to be measured to obtain a bet- ter understanding of heat and water trans- portation through fabric. Three groups of knitted fabric samples made from fabrics that are commercially used for sports- wear were chosen for this work. The fi- bre composition of each group was 100% cotton fibres, 65/35 polyester/cotton blend fibres and 100% polyester fibres. The selection criterion of the fabric types was based on choosing fabrics with the same structure, same finishing process, relatively close fabric thickness and rela- tively close fabric porosity. All samples were dyed knitted fabrics with the same fabric structure - single jersey. The aver- age fabric porosity, fabric thickness and fabric weight per unit area for the three groups of samples are listed in ***Table 1***.

#### Measuring the thermal comfort properties of garments

Thermal properties are among the most important features of textiles. Most of the studies carried out have been devoted to measuring static thermal properties such as thermal conductivity, thermal resist- ance, and thermal diffusion. Kawabata & Yoneda pointed out the importance of the so-called ‘warm-cool feeling’ [32]. This property tells us whether a user feels ‘warm’ or ‘cool’ upon the first

brief contact of the fabric with the hu- man skin. Also, Hes introduced the term ‘thermal absorption’ as a measure of the ‘warm-cool feeling’ of textiles [33, 34]. The three samples of this study were tested using the computer-controlled ALAMBETA device to measure thermal resistance, thermal conductivity, thermal absorptivity, fabric thickness and heat flow. The ALAMBETA device enables rapid measurement of the steady-state and transient-state thermal properties of any plain compressible non-metallic ma- terials such as textile fabrics, plastic or rubber foils, and paper products [35, 36].

#### Measuring relative water vapour per- meability in %

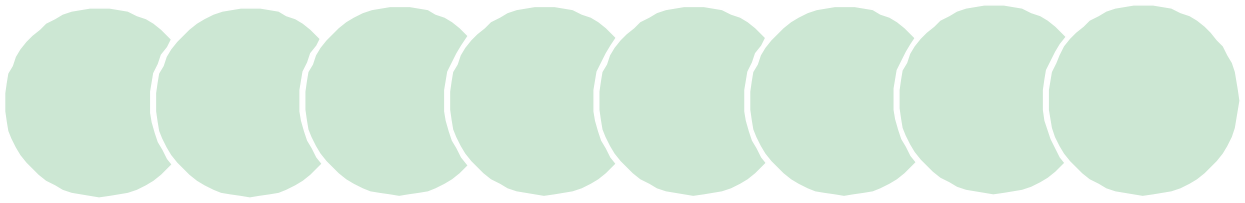
The samples were tested in a steady state isothermal condition to measure the relative water vapour permeability (RWVP%) using a PERMETEST device, which was developed by Hes [37, 38]. The PERMETEST is a new fast response measuring instrument (skin simulator) that measures the water vapour per- meability of textile fabrics, garments, nonwoven webs and soft polymer foils by measuring the evaporative heat re- sistance utilising heat flux sensing. The temperature of the measuring head is maintained at room temperature for iso- thermal conditions. Then heat supplied to maintain the temperature of the measur- ing head, where the water supplied gets evaporated, is measured. The heat sup- plied to maintain a constant temperature with and without the fabric mounted on the plate is measured.

#### Evaluating the physical effort of the athletes

Seven professional athletes, healthy males, were selected out of 16 profes- sional athletes volunteering their serv- ices to undergo the testing. All volunteers were informed about the aim of the ex- amination and its risk, and they agreed to participate in the study. Each subject was initially screened for major medical problems or prescription medication via a written questionnaire. A subject was deemed fit if he did not have a serious medical condition and if he regularly

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 3 min with a speed of | 2 min with a speed of | 2 min with a speed of | 2 min with a speed of | 2 min with a speed of | 2 min with a speed of | 3 min with a speed |
| 9.3 km/h | 9.3 km/h | 9.3 km/h | 9.3 km/h | 9.3 km/h | 9.3 km/h | reduction |
| with 0 | with 2.5 | with 5 | with 7.5 | with 10 | with 12.5 | at 3 km/h |
| degree of | degrees of | degrees of | degrees of | degrees of | degrees of | and 2 min |
| inclination | inclination | inclination | inclination | inclination | inclination | rest |

***Figure 1.*** *Experiment scheme.*



1. min rest and
2. min wamingup at 3 km/h

trained on a treadmill. After the subject was accepted as a potential candidate, his fitness was assessed on a treadmill using a progressive speed test to make sure that all the seven athletes had reached almost the same level of fitness to reduce the variability of the physiological response.

Seven volunteers aged 18 to 20 years with a similar body constitution, within a weight range of 65 : 75 kg and height range of 171 : 180 cm. The subjects were instructed to have no food for the three hours prior the exercise session and not to participate in any physical exercise for 72 hours prior to the exercise session. On the other hand, the subjects were in-

of the experiment scheme, shown in ***Fig- ure 1***.

Each subject covered a distance of 2.35 km during the exercise session. The meas- urement monitored the parameters of the respiratory and circulatory system to es- timate the physical performance of each subject wearing different types of sports- wear fabrics. Physiological performance was tested using a nSpire Health GmbH device, which gives detailed information during an exercise session about oxy- gen consumption (VO2), carbon dioxide production (VCO2), the end-tidal partial pressure of oxygen (PETO2), the end- tidal partial pressure of carbon dioxide

(PETCO2) and the heart rate.

meability (AP) is defined as the rate of air flow passing perpendicularly through a known area under a prescribed air pres- sure. The relative water vapor permeabil- ity (RWVP) is defined as the rate of wa- ter vapour transmission through a fabric. The results listed in **Table 3** show that the sample with 100% polyester fibres is the most permeable and has the highest value of water vapour permeability compared to the others. Fabric porosity (*FP*) for the three samples is calculated using data of the fabric thickness (*h*), weight per unit area (*W*), listed in ***Table 1*** (see page 83), and fabric density (*ρ*), following the rela- tion as follows:

 W (g/cm2 ) 

structed to maintain their regular fluid and food intake during the course of the investigation and to be normally hydrat-

*FP*  1   

 *hρ* (cm × (g/cm3)) 

*h ρ* (*cm*  (g/cm3)

 

# Results and discussion



ed prior to each exercise session. During the exercise session, each subject was attached to a heart rate monitor (nSpire Health GmbH). Every subject wore one type of test clothing during one day of the experiment and other types of clothes in the following two days. Each type of set was worn on three different days in hot weather (30 ± 2 °C and RH 60 ± 5 °C). Finally, seven full measurements were performed for each type of sportswear in accordance with the continuous 8 steps

***Table 2.*** *Thermal properties of fabrics.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Fabric type** | **Thermal conductivity (λ), W/mK** | **Thermal absorbtivity (b),**  **W.m-2s1/2.K-1** | **Thermal resistance**  **(r), K.m2/W** | **Heat flax density (q), W/m2** |
| **100% cotton** | 22.7 ± 0.07 | 56.0 ± 1.62 | 31.98 ± 0.60 | 0.0104 ± 0.00025 |
| **65% polyester 35% cotton** | 21.4 ± 0.08 | 51.3 ±2.36 | 34.44 ± 0.47 | 0.0094 ± 0.00024 |
| **100% polyester** | 19.3 ± 0.09 | 47.5 ± 2.02 | 27.74 ± 0.63 | 0.0088± 0.00025 |

#### Thermal and moisture characteristics

The thermal properties of the three types of sportswear fabrics were measured, the average values of which are listed in ***Ta- ble 2***. The results show that the sample with 100% polyester fibres has the low- est thermal conductivity (λ), thermal ab- rorbtivity (b), thermal resistance (r) and heat flow (q). In addition, air permeabil- ity (AP) and relative water vapor perme- ability (RWVP%) were measured for the three samples, listed in ***Table 3***. Air per-

Thermal conductivity (*λ*) indicates the ability of fabric to conduct heat. In gen- eral, the thermal conductivity of fibres is higher than that of entrapped air in fabric [39]. Therefore, as the amount of entrapped air in the fabric structure in- creases, the fabric provides lower ther- mal conductivity and higher thermal insulation. Thus the results in ***Table 2*** show that the sample with 100% poly- ester fibres has the lowest thermal con- ductivity and, hence, a higher amount of entrapped air compared to the other two samples. Therefore this sample has better thermal insulation compared to the other two samples.

Thermal absorptivity (*b*) indicates the warm-cool feeling of fabrics [40]. When a human touches a fabric that has a dif- ferent temperature from the skin, heat exchange occurs between the hand and fabric. If the thermal absorptivity of a

***Table 3.*** *Fabric relative water vapour permeability and air permeability for the three sam- ples.*

|  |  |  |
| --- | --- | --- |
| **Fabric type** | **Vapour and air permeability** | |
| **Air permeability, l/m2/s** | **Relative water vapour permeability, %** |
| **100% cotton** | 1403 ± 40.1 | 56.14 ± 0.289 |
| **65% polyester 35% cotton** | 1416 ± 18.1 | 52.98 ± 0.271 |
| **100% polyester** | 1670 ± 13.3 | 68.36 ± 0.710 |

fabric is high, it gives a cooler feeling at first contact [41]. Physically, thermal ab- sorptivity (*b*) is a function of the thermal conductivity, density and specific heat of a fabric (*c*) as follows: *b* = (λ ρ c)½ [42]. However, this relation applies only for a short time of thermal contact be- tween a fabric and skin. As time passes,

the heat flow (*q*) loses its dynamical (transient) character and its level falls to a steady state [43] and thermal resistance

(*r*) takes place for the thermal character- istics. Thermal resistance indicates the effectiveness of fabric insulation. Physi- cally, thermal resistance (*r*) is a function of the thermal conductivity (*λ*) and thick- ness (*h*) of a fabric (*r=h/λ*). The thermal resistance of a certain fabric is inversely proportional to its thermal conductivity [44]. At this point, it can be concluded that the sample with 100% cotton fibres has a higher thermal absorptivity (*b*) and a higher heat flow (*q*) as well, indicating a relatively cooler feeling when it touch- es human skin for a few seconds, which may give a more pleasant feeling com- pared to others. As time goes by, thermal resistance (*r*) takes place, which indicates the fabric’s insulation. Thus the sample with 100% cotton fibres has better ther- mal insulation compared to the others. This conclusion contradicts the previous one, which depends only on thermal con-

***Table 4.*** *ANOVA effect of dependance variable (fabric type) and athletes’ physiological responses and performance.*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | | **Sum of squares** | **df** | **Mean square** | **F** | **Sig.** |
| VCO2 | Between groups | 14.650 | 2 | 7.325 | 55.370 | 0.000 |
|  | Within groups | 2.381 | 18 | 0.132 |  |  |
|  | Total | 17.032 | 20 |  |  |  |
| VO2 | Between groups | 0.729 | 2 | 0.364 | 3.501 | 0.052 |
|  | Within groups | 1.874 | 18 | 0.104 |  |  |
|  | Total | 2.603 | 20 |  |  |  |
| RER | Between groups | 0.539 | 2 | 0.270 | 104.229 | 0.000 |
|  | Within groups | 0.047 | 18 | 0.003 |  |  |
|  | Total | 0.586 | 20 |  |  |  |
| VO2/kg | Between groups | 149.687 | 2 | 74.843 | 8.284 | 0.003 |
|  | Within groups | 162.626 | 18 | 9.035 |  |  |
|  | Total | 312.312 | 20 |  |  |  |
| PETO2 | Between groups | 38.000 | 2 | 19.000 | 4.0156 | 0.033 |
|  | Within groups | 82.286 | 18 | 4.571 |  |  |
|  | Total | 120.286 | 20 |  |  |  |
| PETCO2 | Between groups | 689.238 | 2 | 344.619 | 86.844 | 0.000 |
|  | Within groups | 71.429 | 18 | 3.968 |  |  |
|  | Total | 760.667 | 20 |  |  |  |
| HR | Between groups | 740.095 | 2 | 370.048 | 11.774 | 0.001 |
|  | Within groups | 565.714 | 18 | 31.429 |  |  |
|  | Total | 1305.810 | 20 |  |  |  |

ductivity. Therefore thermal conductivity

can be used to evaluate a fabric’s thermal insulation for the same fabric type. How- ever, thermal absorptivity (*b*), thermal resistance (*r*) and heat flow give more details to evaluate thermal insulation for different fabrics because of considering the specific heat of a fabric and its thick- ness. This conclusion also agrees with the values of fabric porosity calculated, listed in ***Table 1*** (see page 83).

Statistical analysis of variance (ANOVA) was conducted for all properties meas- ured to test the significance of differ- ences between the three samples. The re- sults listed in ***Table 4*** show that there are significant differences between the three samples for thermal absorptivity (*b*), thermal resistance (*r*) and heat flow (*q*). Thus, at this point it is statistically prov- en that there is difference between the ef- fective insulation of the three samples. In addition, there are highly significant dif- ferences between the three samples for air permeability (AP) and relative water vapor permeability (RWVP%).

Water or vapour permeability is an essen- tial property for fabrics used in sports- wear. The human body has its own mech- anism for cooling itself when overheating through sensible perspiration in the form of liquid sweat. Body heat evaporates the perspiration; however, if the vapor cannot escape to the surrounding atmos- phere, the relative humidity inside the clothing will increase, which will cause

a wet feeling on the skin and an uncom- fortable sensation [45, 46]. The sample with 100% polyester fibres has the high- est relative water vapour permeability, followed by the one with 65/35 polyes- ter cotton blended fibres. The sportswear made of 100% cotton fibres may absorb perspiration effectively but it keeps it close to the skin. When the wearer ex- erts physical effort (sports), the excess of sweat remains accumulated in the cotton fabric, causing thermal discomfort. Also the fabric might be soaked with sweat and has lost its thermal insulation.

#### Physiological response and performance

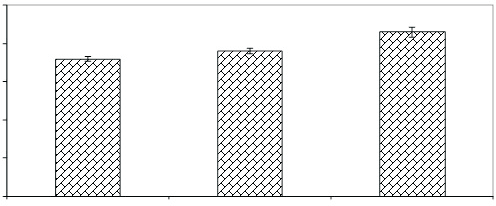
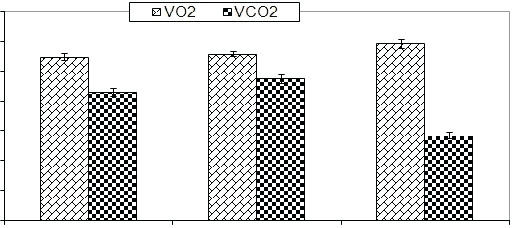
At this level, these properties are not suf- ficient to evaluate the three samples of sportswear. It was essential to evaluate the influence of the three samples on the performance of the athletes during the course of exercise. As mentioned previ- ously, the physiological performance of the athletes was tested using a nSpire Health GmbH device to understand the influence of the fabric composition. The device gives detailed information dur- ing the course of exercise about oxygen consumption (VO2), carbon dioxide production (VCO2), the end-tidal partial pressure of oxygen (PETO2), the end- tidal partial pressure of carbon dioxide (PETCO2), and the heart rate.

Oxygen consumption (VO2) is measured to indicate the volume of oxygen that is

used by human body to convert the ener- gy from eaten food into molecular energy, called Adenosine Tri-Phosphate (ATP), which is used at the cellular level. Dur- ing exercise, muscles work harder than normal and therefore they require more energy than normal. Hence, increasing the exercise intensity will lead to an in- crease in muscular oxygen demand and ultimately corresponds to an increasing VO2, which explains why breathing gets progressively faster and deeper as the exercise intensity increases [47, 48]. It is known that the absolute VO2 peak is strongly influenced by a change in body size, thus it is more appropriate to nor- malise the VO2 to the body mass since it will reveal the true oxygen consumption by fat free tissue [49].

Carbon dioxide output (VCO2) refers to the amount of carbon dioxide exhaled from the body per unit time. It continues to rise after the completion of exercise as the muscles continue to eliminate car- bon dioxide before returning to baseline levels after several minutes. Note that carbon dioxide output can differ from carbon dioxide production by the body’s metabolic processes, but in a steady state both are the same. The anaerobic me- tabolism supplies the excessive demand for energy, but it is accompanied by the production of carbon dioxide (CO2) and lactates. An excessive anaerobic metabo- lism reduces the stored energy faster than their renewal process. Carbon dioxide

***Figure 2.*** *Mean values of gas exchange (VCO2, VO2 and maxVO2/kg) for the three fabric types.*



7

6

5

4

3

2

1

85

76

67

58

49

0

100% cotton

a)

65% PE 35% C

Fabric type

100% polyester

40

100% cotton

b)

65% PE 35% C

Fabric type

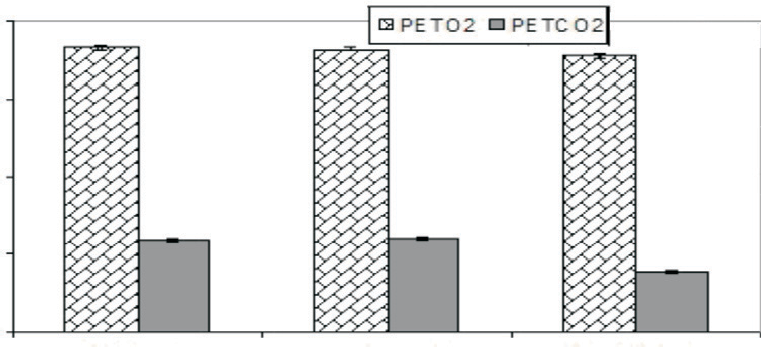
100% polyester

VO2 and VCO2, l/min

VO2/kg, ml/(kg.ml)

Heart rate, beats/min

***Figure 3.*** *Mean values of blood gases with standard error-bars for the three fabric types.*



120

90

60

30

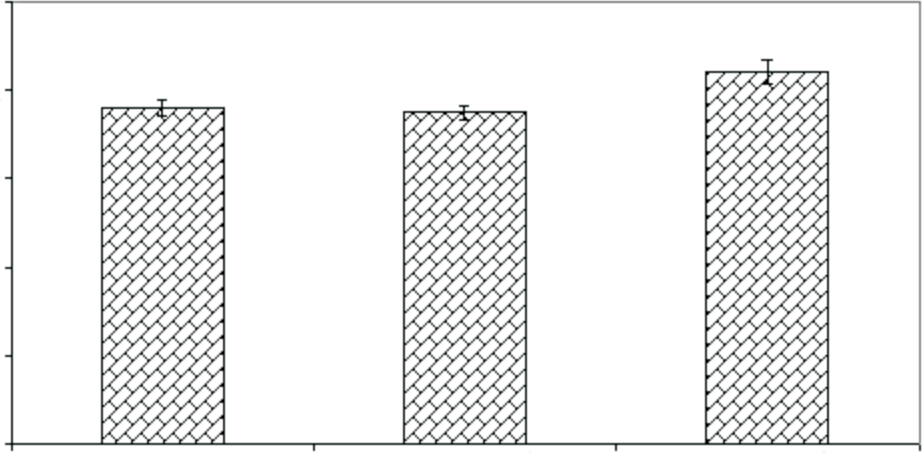
0

100% cotton

65% PE 35% C

Fabric type

100% polyester



200

180

160

140

120

100

100% cotton

65% PE 35% C

Fabric type

100% polyester

PETO2 and PETCO2, mmHg

***Figure 4.*** *Mean values of the heart rate with standard error-bars for the three fabric types.*

(CO2) and lactate production can inter- fere with the aerobic metabolism and lead to tiredness.

The End-Tidal Partial Pressure of Oxy- gen (PETO2) is measured at the end of exhalation in mm Hg. This value is typi- cally around 100 - 110 mm Hg at rest. In normal individuals it will remain at or near this level with progressive exercise until the ventilatory threshold is reached, then it will increase due to the increase in minute ventilation.

The End-Tidal Partial Pressure of Carbon Dioxide (PETCO2) is measured at the end of exhalation (mm-Hg). This value is typically around 35 - 40 mm Hg at rest. In normal individuals it will remain at or near this level with progressive exercise until the ventilatory threshold is reached,

then it will decrease. Failure to decrease or an increase in this value is a sign of person with limited ventilatory capacity or neuromuscular impairment. The lower the values thereof the better for the ath- lete for both PETO2 and PETCO2.

Results in ***Figure 2*** show that the sam- ple with 100% polyester fibres has the highest VO2/kg max (78.8 ml/(kgmin), VO2 (5.91 l/min), and the lowest VCO2 (2.84 l/min) and RER (0.48). The res- piratory Exchange Ratio (RER) is a parameter that represents the ratio be-

tween VCO2 and VO2 (VCO2/VO2). Carbon dioxide production during aerobic metabolism comes from the chemical combination of carbohydrate

or fatty acid with oxygen and the con- sequent production of carbon dioxide and water. The 100% cotton has the

lowest VO2/kg max (72.4 ml/(kg.min), and VO2 (5.47 l/min) and the middle value of VCO2 (4.28 l/min). This effect can be related to the better moisture man-

agement, which is reflected by its higher fabric relative water vapour permeability in %, 69.8%, fabric air permeability, and lower thermal conductivity, supporting the body’s temperature regulation and leading to an increase in the athlete’s cardiorespiratory fitness level and per- formance. From a physiological point of view, the higher the level of max VO2/kg and VO2, ATP and the lower the level of VCO2 and RER the more favorable for the human organism. This will allow the body to conduct more intensive physical exercise without disturbing homeosta- sis and reaching fatigue. The advantage of using 100% polyester over the other samples is that it provides athletes with a higher VO2 and lower VCO2.

***Table 5.*** *Correlation coefficients between the fabric thickness (h), fabric porosity (FP), rela- tive water vapour permeability (%) of the fabrics, and between the fabric air permeability (AP), thermal parameters and athletes’ physiological responses and performance (VO2/kg,*

*HR, VCO2,VO2 , RER, PETO2 and PETCO2).*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Fabric properties** | **Athletes’ physiological responses** | | | | | | |
| VO2/kg | HR | RER | VCO2 | VO2 | PETO2 | PETCO2 |
| **h** | -0.94 | -1.00 | 0.99 | 0.98 | -0.97 | -0.46 | 1.00 |
| **F p** | -0.95 | -0.75 | 0.70 | 0.66 | -0.92 | -0.91 | 0.78 |
| **AP** | 0.97 | 0.99 | -0.98 | -0.96 | 0.98 | 0.54 | -0.99 |
| **RWVP%** | 0.99 | 0.85 | -0.80 | -0.77 | 0.97 | 0.83 | -0.87 |
| λ | -1.00 | -0.88 | 0.84 | 0.82 | -0.99 | -0.79 | 0.90 |
| **b** | -0.96 | -0.78 | 0.73 | 0.69 | -0.94 | -0.89 | 0.80 |
| **r** | -0.79 | -0.96 | 0.98 | 0.99 | -0.83 | -0.15 | 0.95 |
| **q** | -0.93 | -0.72 | 0.66 | 0.62 | -0.90 | -0.93 | 0.75 |

***Figure 3*** shows the blood gases, which is a measurement of how much oxygen and carbon dioxide is in the subject’s blood, helping to determine the effective- ness of oxygen therapy. The test also pro- vides information about the body’s acid/ base balance, which can reveal important clues about lung and kidney functioning and the body’s general metabolic state. The values of PETCO2 for the 100% polyester clothing varies between 18 and 25 mm-Hg, showing a high reduc- tion in the PETCO2 level compared to

the other types of clothing. ***Figure 4*** shows the relation between the heart rate (beat/min) for the three different type of clothing. The maximum heart rate was for the 100% polyester clothing, fol- lowed by the 100% cotton clothing, and the lowest value was for the blended one.

Statistical analysis of variance (ANOVA) was conducted for all measured proper- ties to test the significance of differences between the three fabric types. The re- sults listed in ***Table 4*** (see page 85) show significant differences between the three samples for PETO2 and VO2. In addi- tion, there are highly significant differ- ences between the three samples for the remaining parameters.

The results in ***Table 5*** show the spearman correlation coefficients, calculated to study the correlation between attributes, which are assessed subjectively. The re- sults show a high correlation between fabric thickness, fabric porosity, fabric air permeability, the relative water vapour permeability, fabric thermal properties and athletes’ physiological responses and performance (VO2/kg, HR, VCO2,VO2, RER, PETO2 PETCO2), except the rela- tionship between PETO2 and *h*, *AP* & *r*, which is not highly correlated. The other correlation values vary between (± 0.62 and (± 1), which indicates a high and per- fect correlation, respectively.

# Conclusions



The results showed that the sample with 100% polyester fibres demonstrated better physiological responses and per- formance by athletes compared to the other two fabric types. This result was related to the better moisture manage- ment, which was reflected in the amount of relative water vapour permeability (68%) and lower thermal conductivity, which support the body’s temperature regulation. Better moisture management increased the athletes’ cardiorespiratory fitness and performance. The results also showed that the subjects who wore the sample with 100% polyester fibres had the lowest carbon dioxide production (VCO2), end-tidal partial pressure of carbon dioxide (PETCO2) and a higher respiratory exchange ratio (RER), which indicated better physical performance. Statistical analysis showed a high cor- relation between fabric thickness, fabric porosity, fabric air permeability, the rela- tive water vapour permeability, fabric thermal properties and athletes’ physio-

logical responses, except the relationship between the end-tidal partial pressure of oxygen (PETO2) and fabric thickness (*h*), air permeability (*AP*) and thermal resistance (*r*), which are not highly cor- related. Also there was a high correlation between both the moisture and thermal properties of sportswear and between the athletes’ cardiorespiratory fitness level and performance.

The sample made of 100% cotton fi- bres, which used to be favourable for sportswear, showed some shortcomings in terms of moisture management. Al- though perspiration is absorbed well, it remains close to the body, giving an unpleasant feeling, or thermal discom- fort in other words. Fabric soaked with sweat begins to lose thermal insulation, leading to so-called post-exercise chill. On the other hand, the sample with 100% polyester transports perspiration quickly and effectively away from the body as its relative water vapour permeability was higher than the other two samples. In ad- dition, it has the lowest thermal conduc- tivity, thermal absorbtivity, heat flow and has higher thermal diffusitivity.

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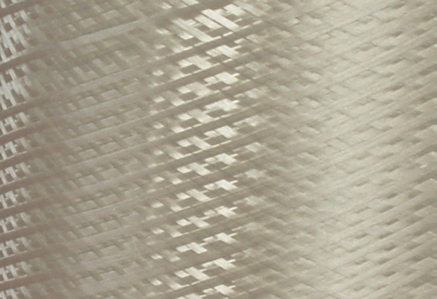
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