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Thermoregulatory evaluation of triathlon suits in regards to their physiological comfort properties

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Abstract

In this study 3 commercially available triathlon suits, one baseline level and 2 specialised suits, and their comprising materials are evaluated in terms of thermoregulatory performance, namely Dry Thermal Resistance, Evaporative Resistance and Permeability Index. Objective evaluation of thermal characteristic of these suits and materials is carried out by means of a Thermal Manikin where the data acquired in static, non-perspiring and perspiring conditions. Varied skin surface and sweating rates are allocated to different body zones relative to the triathlon activity, performance of the suits is evaluated, and the factors affecting their thermoregulatory characteristics are identified. The study demonstrated that the physiological comfort properties of triathlon suits are determined by both the fabrics and materials used and also the design and construction of the garments. It is possible by altering the design of the garment and, most importantly, by selection of the materials with relevant performance attributes, to engineer the garments with optimal performance.

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Keywords: Thriathlon; thriathlon suit; thermoragulation

1. Introduction

Wear comfort is an important aspect of clothing and thermophysiological function of clothing becomes even more important in active sportswear as it influences the wellbeing, efficacy, and performance of the athlete. In endurance activities such as triathlon, body temperature would rise considerably with the high potential of heat stress occurring, which would hinder the athlete's performance. The degree to which sport garments worn modify the heat exchange between the athlete and the environment depends upon the

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amount of the body surface area covered by the clothing, the characteristics of the component fabrics and the air trapped between the garment and the body and within the fabrics [1, 2, 3]. In triathlon the athletes compete in swimming, cycling and running sequentially, where sustainability of energy is paramount for the athlete's success. The immediate transition between activities with no change in clothing exposes the athlete to wetness from the swimming and sweating, wind current from cycling and running, as well as possible heat from the environment and activity in addition to the body heat generated.

For most competitors, an Olympic-distance triathlon typically takes between 2–4 hours to complete. This race begins with a swimming segment of 1500m. Given the wide variety of race venues found around the world, these swims occur in an assortment of water temperatures (from warm to cold) and conditions (from ocean surf to lake calm). Swimmers often exit the water in a state of moderate dehydration and hypothermia and then immediately start the 40km cycling leg. Many do so in their swimming attire. A wide variety of road surfaces, technically challenging topography, variable environmental conditions and dramatically changing velocities can be encountered on the cycle course. The race concludes with a 10km running leg. Since it is the final leg, it is often completed in higher ambient temperatures than those encountered at the start, with the athlete possibly running in a significant state of dehydration and fatigue [4].The mechanical, thermal and moisture interactions of the body and the triathlon suit worn influence the athlete's thermoregulatory responses [5] and thus the suitability of the suit for the intended end use where triathlon suits must enable and support thermoregulation of the body within varied range of environmental climates and physical activities.

Generally triathlons are held in water temperatures from 14ºC – 28ºC. In ambient temperatures >25ºC there is a risk of heat related illnesses. In shorter races this may not pose a problem but in long races such as the Ironman, the slowest competitors have up to 17hrs to complete the event. In the Hawaii Ironman for example, athletes may be running in hot, humid conditions where the temperature may be over 30ºC [4]. Although the area of quantification and assessment of the effects of indoor and outdoor "everyday", work and protective apparel on heat exchange [6] there is no extensive data on sport performance clothing and therefore, the purpose for this study was to evaluate and compare triathlon competition suits in regards to their thermo physiological comfort.

2. Study Design, Materials and Methods

Two elite endurance triathlon suits (suit A and suit B) and one of a base level suit C (Figure 1(a)) were investigated for their performance attributes relevant to the physiological comfort of the competing athlete wearing these suits in hot ambient conditions. All suits were commercially available, were of the same size, zoned construction and provided similar negative body fit. In this study, the garment design of each suit was driven by fabric physical parameters and characteristics relevant to their physiological comfort performance and type of physical activities performed during competition. The thermal resistance and evaporative resistance of these triathlon suits were evaluated using a heated sweating manikin in an environmental chamber.

2.1. Materials

The experimental triathlon suits used for this study consisted of the warp-knitted fabrics, some of different constructions, physical parameters and applied fabric treatments (Table 1). Fabrics comprising Suit C did not have a specific treatment applied, Suit A and B have different thermal treatments applied which are designed to be activated with moisture and increase thermal conductivity of the suits. The suits were washed on gentle washing cycle in a domestic washing machine and air-dried prior to testing.

Suit	Suit weight, g	Fabric	Fabric construction	Mass, g/m2	Fibre Composition, %	Thickness mm
Suit A	207.3	Fabric a	Tricot	229.6	Nylon 80, Elastane 20	0.50
		Fabric b	Tricot 4-bar	226.2	Polyester 80, Elastane 20	0.68
Suit B	199.4	Fabric c	Tricot	207.7	Nylon 80, Elastane 20	0.64
		Fabric b	Tricot 4-bar	226.2	Polyester 80, Elastane 20	0.68
Suit C	207.3	Fabric d	Tricot	246.1	Nylon 80, Elastane 20	0.69
		Fabric e	Tricot mock mesh	175.4	Nylon 80, Elastane 20	0.66

2.2. Methods

Fabric physical parameters and properties were evaluated objectively as follows: fabric mass per unit area was calculated as the mean mass per unit area of 3 specimens [7]; fabric thickness was measured as the distance between the reference plate and parallel presser foot of the thickness tester [8]. The measurements of Thermal Insulation and Evaporative Resistance of the experimental suits were carried out according to a standard method [9,10] in the climatic chamber at the School of Fashion and Textiles, RMIT University, Australia, using a male form Sweating Thermal Manikin consisting of twenty independently controlled thermal zones (Figure 1(b)), manufactured by the Measurement Technology Northwest, USA.

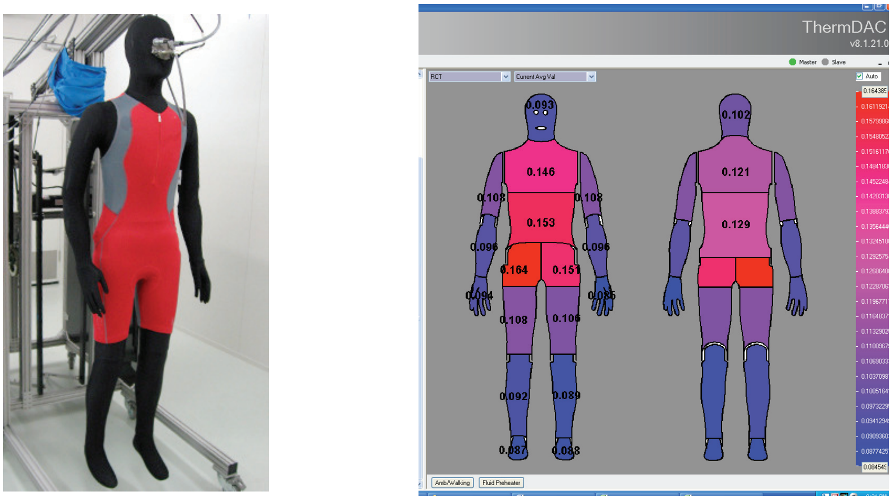

Fig. 1. (a) Measurement of Evaporative Resistance with manikin sweating skin – Suit C and (b) measurement of *Rct* at different zones – Suit A.

During the series of tests the mean skin temperature of the nude manikin was maintained at 35ºC with local deviations not exceeding ± 0.3 ºC., relative humidity at 50% for the Thermal Insulation test and 40 ± 5% for the Evaporative Resistance test; air temperature at 23 ± 0.5 ºC for the Thermal Insulation test and at 35 ± 0.5 ºC for the Evaporative Resistance Test (Isothermal Conditions).

Dry thermal resistance *Rct* calculated for each zone as:

$$Rct = (Tskin\text{-}Tamb).Q/A \tag{1}$$

Where Rct –Dry thermal resistance (m^2. ºC)/W, Tskin – Zone average temperature (ºC), Tamb – ambient temperature (ºC), Q/A – Area weighted heat Flux (W/m^2).

Thermal resistance of the garment is calculated as:

$$Rcf = Rct - (Rct_0/fcl) \tag{2}$$

Where *Rcf* – intrinsic thermal clothing insulation (m^2. ºC)/W, Rct_0 – nude resistance (m^2. ºC)/W, *fcl* – clothing area factor (dimensionless). In this study, *fcl*=1 as all the garments were of very close fit and thus did not increase the surface area and reduce the air layer resistance compare to the nude body.

Evaporative resistance Ret calculated for each zone as:

$$Ret = (Psat - Pamb)/(Q/A - [(Tskin - Tamb)/Rct]) \tag{3}$$

Where [(Tskin – Tamb)/Rct]=Dry Heat loss (W/m^2) can be omitted for isothermal conditions where Tskin=Tamb, Ret – Thermal resistance (m^2.Pa)/W, Psat – Saturation vapour pressure @ skin temperature (Pa), Pamb – Vapour pressure @ ambient temperature (Pa).

Evaporative resistance of the garment (intrinsic clothing insulation) is calculated as:

$$Ref = Ret - (Ret_0/fcl) \tag{4}$$

Where *Rcf* – clothing insulation (m^2.Pa)/W, Ret_0 – Nude resistance (m^2.Pa)/W or thermal insulation associated with the still air layer around the nude manikin.

The Im permeability index [11] indicates moisture-heat permeability through the textile material on a scale of 0 (totally impermeable) to 1 (totally permeable) normalized for the permeability of still air (naked skin). This parameter indicates the effect of skin moisture on heat loss as in case of sweating skin conditions:

$$Im = KRct/Ret \tag{5}$$

where *K=const* (60.6515 Pa/ ºC).

The parallel method of calculating the total thermal and total vapour resistance was used, where the area-weighted temperatures of all 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 [9,10]. Two group weighted averages were defined: all zones group and tri-suit group that included manikin zones of Chest, Shoulders, Stomach, Back, Right and Left Hip, and Right and Left Thigh.

Statistical analysis of results was performed and it was determined that CV% of results ranged from 0.91% to 2.17% for Dry Thermal Resistance and from 1.3% to 3.6% for the Evaporation resistance. The Thermal Resistance (Insulation) associated with the still air layer around nude manikin with dry sweating skin installed (Rct).

3. Results and Discussion

The insulation values for triathlon suits are presented in Table 2. The thermal resistance (insulation) associated with the still air layer around nude manikin with dry sweating skin installed Rct_0 was 0.104 m^2. ºC/W for all zones and 0.114 m^2. ºC/W for the nude tri-suit group.

Table 2. Thermal insulation and evaporative resistance values for triathlon suits

Suit	Total dry thermal resistance Rct (all zones), m2. ºC/W	Intrinsic dry thermal clothing insulation (suit zones) *Rcf,* m^2. ºC/W	Total evaporative resistance (all zones) *Ret,,* m^2.Pa/W	Intrinsic evaporative clothing insulation (suit zones) *Ref,* m^2.Pa/W	Permeability index (suit zones) *Im*
Suit *A*	0.113	0.013	21.90	1.01	0.34
Suit *B*	0.111	0.019	21.71	0.86	0.35
Suit *C*	0.108	0.012	20.63	0.89	0.33

The Ret_0 was 20.03 m^2.ºC/W and 21.94 m^2.ºC/W for all zones and tri-suit zones respectively. The results from Table 2 indicate that in terms of thermal insulation Suit C has the best performance relevant to hot climate as its Intrinsic thermal clothing insulation is 36% lower than that of Suit B and 8% lower than that of Suit A. This is mainly due to the thickness and density of the fabrics comprising each garment and, in part, total garment weight. Significant portion of suit C consists of the *fabric e* which has open mock-mesh construction. The mesh openings in the surface of the fabric allow the areas with little fibre cover to be open to the environment and thus to effectively transfer heat generated by the body of an athlete to the environment. This performance of *fabric e* offsets the high insulation of *fabric d* giving a good thermal insulation attributes to the suit C overall. In addition in Suit C there is less construction flatlock seams joining the garment panels, both in the stomach and back zones in Suits A and B. Comparing Suits A and B it is clear that the fabric thickness has a critical impact on the thermal insulation of the suits: despite the *fabric a* being heavier, due to it being thinner than *fabric c* it performs better in the suit construction.

In terms of the intrinsic evaporative clothing insulation for the tri-suit zones Suit B has the best performance: our results indicate that its *Ref* is 15% lower than that of Suit A and 3% lower than that of Suit C. This is due to the *fabric c* having less fibre density in its volume and also possibly due to the thermal treatment, applied to the main body fabric of Suit B, being more effective than the treatment applied to the main body fabric in Suit A.

Figure 2 demonstrates the different performance of the suit zones both in terms of their thermal insulation and Permeability index.

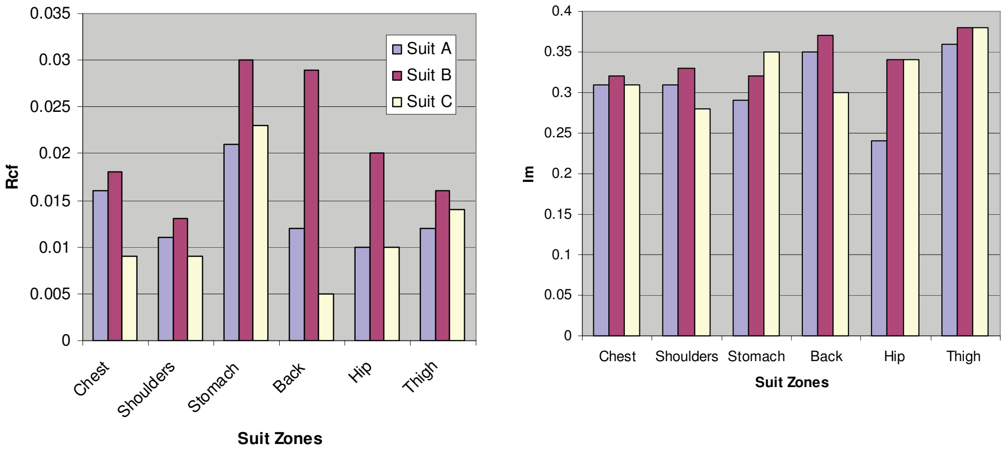

Fig. 2. (a) Thermal insulation of suit zones and (b) Permeability index of suit zones.

Results in Figure 2 and Table 2 indicate that zoned design of the suits have an implication on the performance of the different zones of the garment in terms of their thermal, evaporative resistance and Permeability Index. The most important human body areas for the thermal performance of a sport garment are the areas of the trunk or core: chest, shoulders, stomach and back. It is clear that the highest dry thermal insulation delivered by all suits is in the stomach zone followed by the zones of chest and shoulders. It is worth noting that the performance of Suit B consistently lower than performance of Suits A and C (Figure 2(a)), as for example its thermal insulation in the chest zone is 13% higher than that of the Suit A and 50% higher than that of the Suit C. Analyzing the design and construction of the suits it is possible to conclude that the insertion of the light open *fabric e* in the critical zones will improve the dry thermal insulation performance of the triathlon suit overall and in targeted zones.

It is important to note that due to the nature of triathlon competition it is important not only to consider the Dry thermal insulation but an overall performance of the suit using Permeability index *Im*. Analysis of the data in Figure 2(b) indicates that overall performance of the suits in specific zones is not as disparate as in case of Dry thermal insulation; with Suit B demonstrating the best Permeability index for all zones except stomach: its permeability is higher than that of Suits A and C in chest area by 5%, in the back area is higher by 6% than Suit A and by 19% higher than suit C.

4. Conclusion

This study demonstrated that the physiological comfort properties of triathlon suits are determined by both the fabrics and materials used and also the design and construction of the garments. It is possible by altering the design of the garment and, most importantly, by selection of the materials with relevant performance attributes, to engineer the garments with optimal performance.

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