Infrared thermography as a useful tool for improving the performance of athletes

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Sportswear for active athletes has various functions that perform certain features and help athletes achieve better athletic results. In any sportswear, the physiological aspect is of great importance as it has a great impact on the efficiency and performance of the athletes. In this paper, the interaction between the designed sportswear and the physiological responses of an athlete is described. In addition, it highlights the use of thermography as an important tool for evaluating sportswear and thus improving materials to enhance an athlete's athletic performance. The paper also reviews the research conducted in relation to the use of thermography for the evaluation of sportswear.
Keywords: *thermography; sportswear; physiological comfort*

1. Introduction

The consumption of textile fibres and fabrics intended for the production of sportswear and different sporting-related goods has seen a significant increase over the last decade. The forecast made by experts in the field for the upcoming period is even more positive. This increase in consumption is mainly directed due to the rising interest of the population worldwide in active indoor and outdoor sports, increased considerations of good health, as well as well-being.

In different active sports, the performance of sportswear is synonymous with the comfort characteristics of used sportswear. For different types of sportswear, the physiological aspect is extremely important because of its major effect on the efficiency and performance of athletes. In sportswear for outdoor use, the clothing should be capable of protecting the athlete from a number of external elements (for example rain, snow, wind, and sun). Additionally, the sportswear should be capable of maintaining the heat balance between the heat produced by the wearer, and the capacity to dissipate body heat and perspiration. In order to provide a comfortable microclimate for a specific athlete, designers must define specifics for each type of functional clothing as well as to obtain feedback from the athlete regarding specific issues [1].

This paper outlines the interconnectivity of the designed sportswear and the physiological responses of an athlete. Furthermore, it focuses on the use of thermography as an important tool for sportswear evaluation. Consequently, it outlines the need for the improvement of materials for increased performance of an athlete in sports, as well as increased well-being and discusses the results of previous scientific research related to use of thermography for body-mapping.

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2. Sportswear and skin response

Sportswear in active athletes has certain functions that meet certain characteristics and provide assistance to athletes to achieve great sports results. When sports activities take place in certain conditions, such as low and high temperatures, the functionality and comfort of sportswear are very important. Active athletes can produce up to 2.5 litres of sweat in extreme conditions. Sweat is through the textile through two related processes, wetting, and absorption [2]. When it comes in contact with textiles, wetting degree may vary. Wetting occurs when the liquids interact with the air in the pores of textile. To determine the degree of wetting, tests are based on measuring the contact angles at the textile surface since it changes at the interface due to textile properties. The possibility of wetting the textile fabric formations depends on the properties of the fibres and the surface properties of the material. The fluid is further transferred through a textile flat creation by capillary action or absorption. The absorbency depends on the type of fibre, yarn construction, the structure of the textile fabric, finishing, and humidity and temperature environment [3]. Related to the study of physiological warmth in athletes, comfort plays a very important role. According to the researchers, there are two physiological quantities. The amount of sweat on human skin determines the comfort of the skin in warm conditions, and the average skin temperature determines the comfort of clothing in colder conditions [4].

One of the groups of methods that are increasingly researched and used in sports are cooling methods. The most common methods of cooling after intense activity are immersion in cold water, contrast baths, cryogenic chambers, cooling vests, cold massages, and cold drinks [5]. Different methods also have different effect temperatures, and the magnitude of the effect depends on the water or chamber and the length of execution low temperatures, but also other features [6].

In conditions where there is high humidity and high temperature, cooling vests are used mostly before a lot of effort, competition or exercise. Highly intense activities in such conditions can lead to increased body temperature which can ultimately result in a drop abilities of the athlete. Vests are made of different materials and have laces to make the vest could weigh in to suit the athlete as best he could. Some research shows that such vests designed specifically for sports activities provide a significant advantage to athletes who perform repetitive physical activities in conditions of high temperature and humidity [7].

According to research in male athletes, before exercise, the average skin temperature was significantly lower when wearing a cooling vest at a temperature of 32 °C. In a hot environment, wearing a cooling vest can reduce body temperature by 3 to 7 °C [8]. Athlete fatigue is significantly less after wearing a vest. Some research has shown that using a cooling collar also helps reduce an athlete's body temperature. Listed research used only sensors to measure skin temperature on different parts of the skin [9, 10].

When consider cold environment, the athlete produces enough heat during exercise to maintain the overall heat balance [11]. However, at low temperatures, the extremities can be exposed to extreme cold, and various clothing items such as hats, scarves, gloves, and shoes are used. In extreme conditions (–25 °C) higher blood flow to the fingers resulted in the use of gloves and torso warmers [12]. According to research done by Song and Wang, where an electrically heated vest was used in a 2 °C environment, the heated vest showed a 2 °C higher temperature in the abdomen and back area compared to the unheated vest. Both methods led to an increase in body temperature and heat sensations [13]. The method that would be much more useful for measuring body temperature in athletes would be infrared thermography. A thermal camera would more accurately assess efficiency heating intervention or specific active clothing during exercise [14].

3. Thermography as a valuable evaluation tool of sportswear

Infrared thermography is a non-destructive measuring method for the determination of temperature distribution on the surface of objects. It is a common and popular measuring method among researchers in various scientific fields. In the field of textile engineering, this method may be used to observe the production process, textile material properties, clothing comfort, and product development.

Recently, much attention has been paid to the mapping of the body temperatures in order to adapt the fabric and garment to better meet the body's needs.

Back in 1975, German authors Keyl and Lenhart published the first research in the field of sports using infrared thermography. The research was conducted under the name "Thermography in sports injuries and lesions of the locomotor system due to sports." [15]. Thermography allowed trainers and athletes to observe changes in body temperature in specific parts of the body to prevent muscle injuries and be instructed in the health of athletes [16].

Furthermore, many studies related to infrared thermography have been conducted over the years in sports. P. Menezes et al. conducted research on twenty-one football players. Using infrared thermography, they took pictures of their muscles before activity and after 30 minutes of running. The results showed that skin temperature increased as a direct result of muscle activity [17]. Research has also been conducted in the field of hiking. Hiking is a very demanding and popular recreational activity. Given the weather conditions, hikers should have good and comfortable sportswear that protects them from adverse conditions [18, 19]. Research has been conducted that estimates the temperature of the skin under hikers 'clothing along the entire body at different stages. Women and men participated in the study. Participants wore pants, T-shirts, fleece, and a sports bra for women. Simulation of the morning walk (uphill, downhill and rest) showed that the average temperature in women was significantly lower than in men in the ascent and resting state. Also, layers of clothing have been shown to significantly affect skin temperature. The upper body, lower legs, and active muscles had a higher temperature than the arms (T-shirt), and in women the inner thighs [20]. This shows that thermography is extremely important when choosing the material of sportswear and adjusting the design [21].

Several different studies have also been conducted on runners [22]. Twelve active running athletes performed a 40-minute run, and infrared thermography estimates were obtained in 4 different phases. Before exercise, after 10 minutes of running, after 40 minutes of running, and after 10 minutes of rest. During all 40 minutes of running, it was shown that the body temperature in the area around the abdomen, sternum, thighs, neck, and cheeks, under the clothes was colder than the rest of the body. The area around the spine, the inside of the thighs, the leaves were significantly warmer [20]. J. I. Priego-Quesada et al. researched runners who wore graduated compressive stockings. The research was conducted on 44 runners, who performed 2x30min of running with and without graduated compressive stockings. They used infrared thermography and measured the skin temperature of runners before and after running. They concluded that there was a larger rise in temperature while wearing socks [23]. The knowledge of the thermal patterns under running clothes could be extended to a myriad of clothing conditions and exercise types in order to map the similarities and differences in skin temperature distribution. The aim of studying the impact of sports bras was to reduce breast movement as well as pain in the same during exercise [24, 25].

B. Ayres et al. investigated how the composition and layering of a sports bra affect skin temperature. The study involved eight women who wore a composite sports bra (65% nylon, 22% polyester 13% elastin) or a sports bra with 100% polyester. Using an infrared thermal camera, the skin temperature was measured, it was concluded that the temperature in the chest was lower than the temperature in the abdomen. With the sports bra, a decrease in the total skin temperature from the composite one could be noticed. It also turned out that a sports bra made of polyester had greater thermal comfort than a composite bra. The results also highlighted the importance of optimizing the design of sports bras to facilitate the cooling ability of the skin [26].

N. Ludwig et al. investigated the body temperature of cyclists using thermography. A maximum cycling test was performed to assess the reaction of their skin. The results showed a decrease in skin temperature during exercise, after which there was an increase in temperature in the exhaustion phase [27]. J. I. Priego-Quesada et al. have done various researches, one of them is related to infrared thermography. Research has been conducted on recreational triathletes. It was measured how training load can affect skin temperature after physical exertion. The results obtained showed an increase in mean and maximum skin temperature after the second day of training, and that this was directly related to muscle mass [28].

M. Chudecka et al. conducted a comparative study. Infrared thermography was used in the research, and it was used to measure the skin temperature in men when exercising on a rowing ergometer with two oars. Their skin temperature was compared to the muscle temperature of handball players. In rowers, the result showed that the mean temperature was lower after exercise than before exercise, in handball players the skin temperature in symmetrical areas above the asymmetrically working muscles showed statistically significant differences between the sides, which is related to functional training asymmetry. Research has shown that thermography would be very useful to coaches in assessing technical preparation in sports [29].

P. Gómez-Carmona et al. in 2020 did research using infrared thermography to detect muscle fatigue and overload in 24 football players. The research was conducted during the first preseason. It has been shown that infrared thermography can reduce the presence of injuries and identify potentially vulnerable footballers [30].

The latest research in the field of thermography was done by P. L. Valenzuela *et al*. They investigated changes in skin temperature in sixteen male weightlifters. The temperature of the biceps and pectoral muscles before, during, and after exertion was analysed. The results showed a significant decrease in temperature before warming up, and immediately after exercise [31].

4. Body temperature mapping

Infrared thermography is a useful tool to mapping temperature for large areas of the human body. In the field of sports, thermography is used to observe the changes in skin temperatures of players. During sports activity, exercising or playing, the core temperature of the body rises. Using a thermal camera, these changes can be easily noticed.

Examples of thermographic images taken by thermal camera are shown in Fig.1. These images show the temperature differences before and after sports activity.

In our previous study, the focus was on investigating the changes in body temperature during two typical football training sessions: condition training and tactical training. Both types of training lasted 60 minutes. Average temperatures were observed for the 9 anterior and 9 posterior zones of the upper body. The results showed that after condition training, body temperature decreases by up to 2 °C in the anterior upper arm and chest zones after condition training, while it increases by up to 1 °C in the anterior chest zone after tactical training. After both types of training, body temperature decreases by 1.2-3.7 °C in all posterior body zones [32].

The next study focused on measuring the surface temperature of participating futsal players after three types of training (elements of futsal game only, strength and endurance, and combined training of stretching and elements of futsal game). Each training session lasted 60 minutes. The measurements of the players' bodies were taken over a period of two months and the body maps of the measurements are shown in Fig.2. As can be seen from Fig.2, the measured temperatues increase slightly in most of the front zones after the training sessions focused exclusively on game elements. A significant temperature decrease is observed for zone 7, i.e. the zone of the medial abdomen. After strength and endurance training, temperature decreases in all observed anterior zones. This type of training is very complex and demanding, which triggered intense sweating of the body. Since the 100% PES fabric does not have absorbing capability, sweat accumulates on the surface of the skin, which affects the decrease in measured temperature.

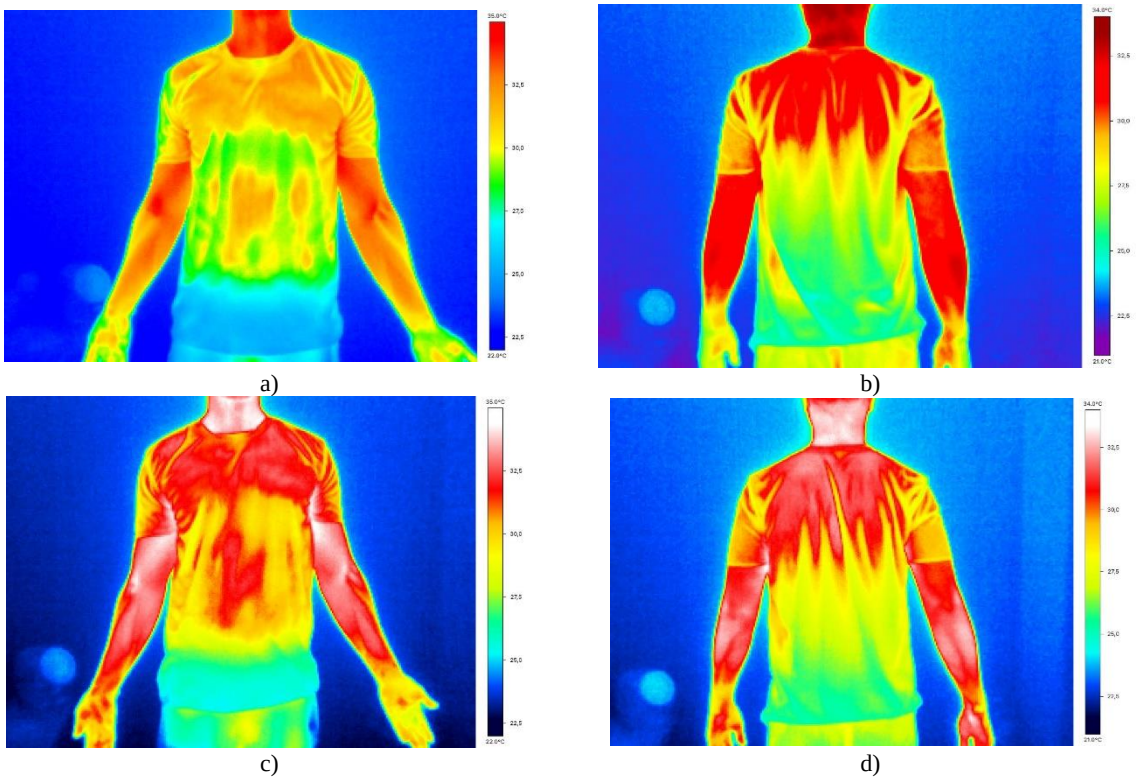

Fig.1 Examples of thermograms: a) anterior, before training, b) posterior, before training, c) anterior, after training, d) posterior after training

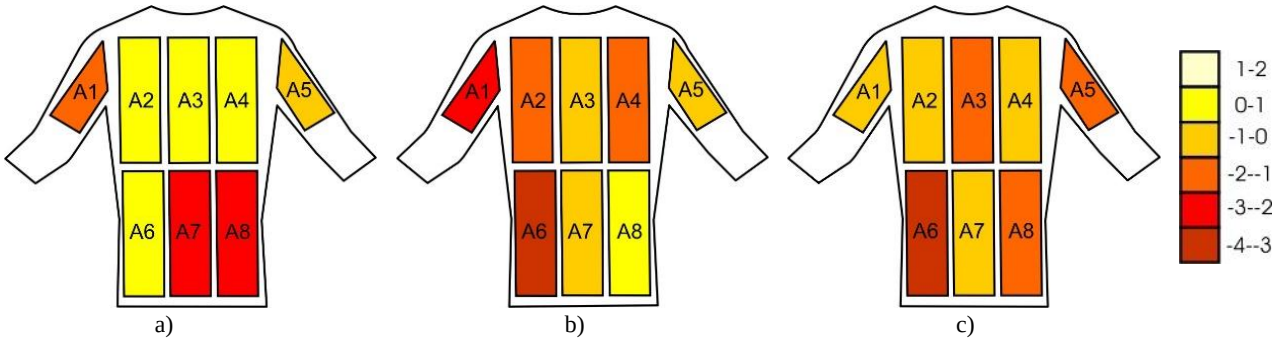

Fig.2 Body maps showing the differences in body temperatures after trainings (in °C) for different types of futsal training: a) training of elements of futsal game only, b) training of strength and endurance and c) combined training of stretching and elements of futsal game [33]

In the last type of training, after the combined training of stretching and elements of futsal game, the temperature increases in zones A1-A5, i.e. upper chest and upper arm zones. The results indicate that the body has warmed up due to the training activity, but the mechanism of body sweating has not yet been activated [33].

The research presented in next paper focuses to the influences of garment fit, activity level and gender to the changes of temperature on the clothing surface in moderate and cold thermal environments. This study implies that fit of garment plays an important role for the retention of heat between the textile material and skin. This applies in particular to the zone of both upper and lower shin. In the indoor environment, for female volunteer, tight model has significant influence on the average temperature in the zone of upper shin. This observation is even more highlighted in the outdoor environment. For the male volunteer, higher differences, between temperatures seen in the outdoor environment only.

Figs. 3 and 4 give graphical presentation (body maps) of average measured temperatures for observed body zones under different combination of influencing factors [34].

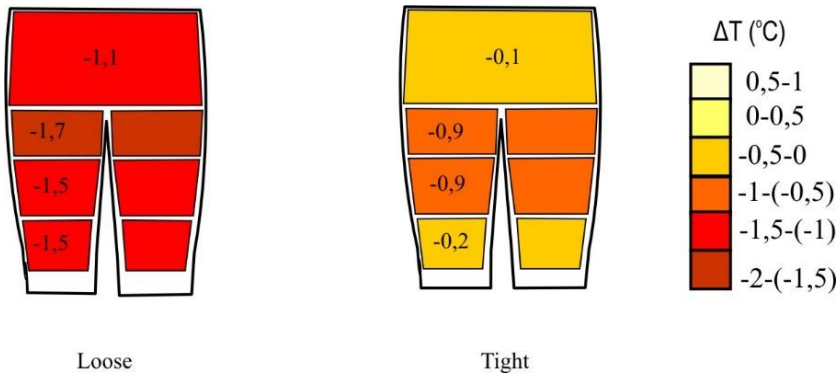

Fig.3 Body maps showing the differences in body temperatures after trainings in indoor environments for female

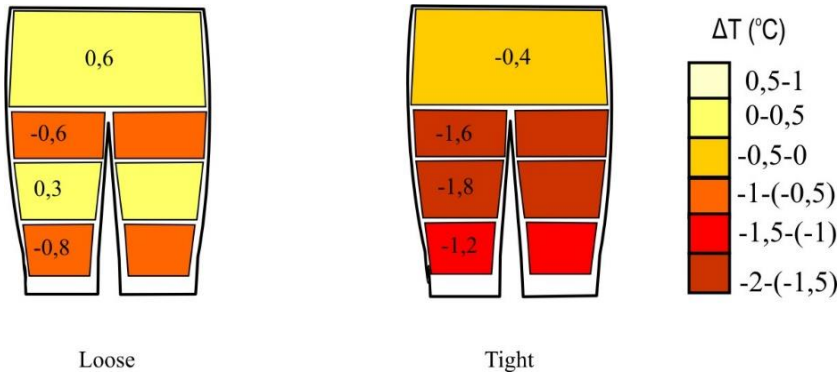

Fig.4 Body maps showing the differences in body temperatures after trainings in indoor environments for male.

5. Conclusion

Infrared thermography is an important and much used tool for the evaluation of a number of parameters in various scientific and professional fields. In the field of textiles, thermography can support the development of customized sports garments. In this context, the individual temperature patterns of an athlete can be useful to target heat loss or heat preservation. Nevertheless, it seems that infrared thermography is used to a limited extent in the field of sportswear ergonomics, especially when it comes to sportswear for specific sports and professional athletes. Considering the specificity of each sport and the need to improve athlete

performance, there are numerous examples where thermography could be used as an important assessment tool. Considering that the individual qualitative and quantitative information obtained through infrared thermography can be extremely valuable in evaluating the efficiency of sportswear, the importance of thermography is expected to be outlined in the following research.

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