Chapter 6
Infrared Thermography in Water Sports

Ricardo Vardasca, Adérito Seixas, Joaquim Gabriel and João Vilas-Boas

Abstract Likewise any other sport, water sports can also be objectively assessed through a physiological method such as thermal imaging. This particular type of sports present an extra parameter, which is the particular environment were it happens. In this chapter it is outlined the underlining concepts, challenges and methods, along with the related published research to date in the field with practical examples and future lines of research are proposed.

6.1 Introduction

Exercise training causes adaptations in the skin blood flow response to exercise, including changes in cutaneous microvascular reactivity. Increases in skin blood flow at a given exercise core temperature appear to be related with the expansion of blood volume and increased cardiac output that characterize the trained state. In contrast, adaptations in the cutaneous microvasculature are mediated by changes in

R. Vardasca (✉) · A. Seixas · J. Gabriel
LABIOMEP, UISPA/INEGI/LAETA, Faculty of Engineering,
University of Porto, Porto, Portugal
e-mail: rvardasca@fe.up.pt

A. Seixas
Faculdade de Ciências da Saúde, Universidade Fernando Pessoa, Porto, Portugal
e-mail: aderito@ufp.edu.pt

J. Gabriel
e-mail: jgabriel@fe.up.pt

A. Seixas · J. Vilas-Boas
LABIOMEP, CIFI2D, Faculty of Sport, University of Porto, Porto, Portugal
e-mail: jpvb@fade.up.pt

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the biological availability or activity of endothelium-derived vasoactive compounds [1]. Changes in skin temperature are known to be affected by blood flow [2], and skin temperature are passive of being passively captured and posteriorly analyzed through thermal imaging, a non-contact, non-invasive and non-ionizing imaging technique that registers the surface emitted thermal radiation into radiometric temperature maps [3].

Water sports, being swimming one of the major examples, induce changes in blood flow through the exercise, where heat is produced by the muscles, and the contact with water highly influences the skin thermoregulation. These two aspects can be object of monitoring using thermal imaging investigating skin temperature changes.

One of the basic functions of the human body is to keep core body temperature constant between 36 and 37.5 °C, keeping its vital functioning. This is maintained by the hypothalamus, which receives constant information from the autonomous nervous system, taking advantage in the different body thermal sensors, placed close to the vital organs internally and at the periphery at the skin dermis. The skin is the major organ of the human body and plays a major role in the interface with the surrounding environment. The neutral zone for the skin thermal body sensors is within an ambient temperature between 18 and 24 °C at a relative humidity of less than 50%. Below this value the temperature recovery mechanisms such as vasoconstriction, muscle shivering and increasing of the metabolic rate are activated. On the other hand above 24 °C the temperature release mechanisms are activated, consisting in vasodilatation and sweating [4, 5].

Water sports and in particular swimming, as any other sport, challenges the thermal balance of the human body, increasing the skin temperature [6] through a complex thermoregulation process that intends to preserve core temperature around 37.5 °C [7]. Despite the study of Wade and Veghte [8] and the increasing number of papers in sport research reporting the use of thermal imaging, its use in swimming research is limited and few researchers have informed the use of this technology in swimming activities [6, 9, 10].

6.2 Relationship Between Skin Temperature, Exercise and Water Exposure

Water is one of the most simple examples of matter that can easily change its state with the internal molecules activity. It is known that at temperature below 0 °C it solidifies, become solid, and at temperatures above 100 °C it boils, becoming a gas. Within this intervals the water stay in its liquid state, when in contact with it the human body starts to exchange thermal energy through forced convection. The physical properties of the water change according to its state, at a liquid state its emissivity value is of 0.97 [11], very close to the human skin value (0.98). However the presence of water in the skin causes an undesirable effect of blocking the spontaneous skin ability of radiating thermal energy. It worth also to mention that water is a much better heat conductor than air, about 25 times more effective [5]. The first major challenge of this type of research is to measure the thermal effect of any exercise, minimizing the water associated issues related to thermoregulation. Good understanding of how the water conditions and exposure can affect thermoregulation and the effect on human body core temperature is required to prevent undesired loss of physiological functions as presented in Fig. 6.1 [12].

In water temperatures of 25 °C and below, oxygen consumption (VO_2) increases at a faster rate than air at temperatures of 25 °C, and cardiac frequency is reduced [13, 14]. Oxygen consumption increases because the muscle tremor generates thermogenesis and possibly a decrease in mechanical ability during exercise. The cardiac output increases linearly with an increase in peripheral vasoconstriction in cold water. When water temperatures are at 30 °C and above, metabolic rate and cardiac frequency are the same in both air and water environments.

If the increase of pulses volume is due to the effects of hydrostatic pressure from the increasing peripheral vasoconstriction, then cardiac frequency could be depressed in warm water. Heat dissipates faster in cold water, and swimming in sub-maximal temperatures reduces the human body's core temperature, even if the metabolic rate increases [15]. The increase in metabolic rate is inversely proportionate to the increase in water temperature. The levels of lactic acid are increased during submaximal swimming distances in cold water, while muscle temperatures could alter physical and chemical functions in the muscle's interior during swimming, ultimately resulting in the reduction of mechanical ability in cold water [12].

Immersion of the skin in water results in a characteristic whitening and wrinkled appearance associated with the uptake of significant quantities of water. The rate of evaporation from hydrated skin surfaces is considerably in excess of that from

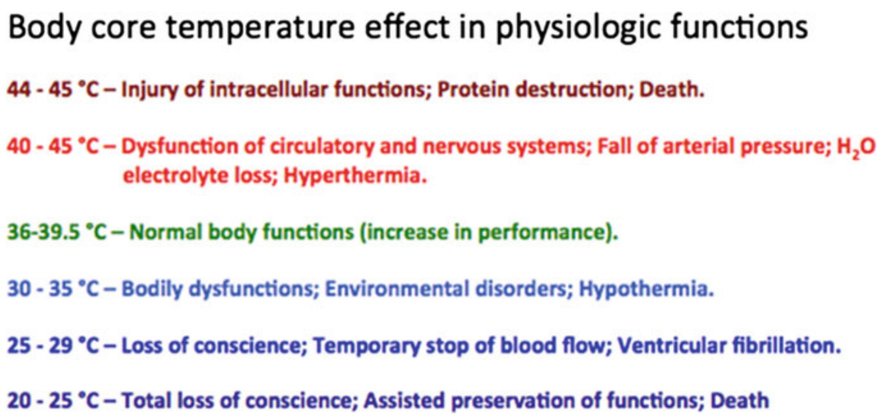


Fig. 6.1 Effect that body core temperature has in the physiological functions, describing its undesired risks

non-hydrated areas. Although, prolonged immersion suppresses sweating on the palm of the hands and feet sole [16], not being these areas recommended for skin temperature assessment with thermal imaging.

After stabilization of body temperature at rest in the coldest possible water (12 ° C), exercise reduced internal insulation only in muscular parts of the limbs. Exercise also increased heat loss elsewhere by exposing skin of protected regions such as flexural surfaces of joints. During exercise total heat production increased rather more than heat loss in unreactive subjects, but less than loss in subjects whose heat production had already risen to a high level when they were at rest in cold water [17].

In warm water (37 °C), tissue insulations were lower and much more uniform between subjects and between different body regions than in the cold. Even in the warm, however, insulations remained rather higher in fat than thin subjects, higher at rest than during exercise, and usually higher in the limbs than the upper trunk [17].

Repeated cold water immersion produces acclimation to cold air in humans and the cold acclimation is primarily of the insulative type in that skin temperatures are lower, probably due to greater sympathetic nervous system activation mediating stronger cutaneous vasoconstriction. The degree of cold acclimatization achieved is probably related to the intensity (frequency and duration of reduction in core temperature) of the acclimatization procedures employed [18].

Water and electrolyte balances are critical for a person's ability to thermoregulate and perform exercise in the heat. During exercise in the heat, water and electrolyte losses primarily occur from sweating. A person's sweating rate is dependent upon the climatic conditions, clothing worn and exercise intensity. Daily fluid requirements range (for sedentary to very active persons) from 2 to 4 l day in a cool climate up to 8–16 l/day in very hot climates. Over a 24 h period, fluid and electrolyte losses will be replaced if persons consume their normal diet. During exercise, sweat output often exceeds water intake, producing a water deficit or hypohydration. The water deficit lowers both intracellular and extracellular fluid volumes [19].

It also results in plasma hypertonicity and plasma hypovolemia, both of which adversely affect heat loss responses. Aerobic exercise tasks are likely to be adversely affected by hypohydration, with the potential effect being greater in warm environments. Hypohydration increases heat storage by reducing sweating rate and skin blood flow responses for a given core temperature. Hyperhydration provides no advantages over euhydration regarding thermoregulation and exercise performance in the heat [19].

A cold beverage taken in ecological conditions (i.e., small volumes taken regularly during training sessions) had a significant effect on body core temperature, thermal sensation, and heart rate during both training and high-intensity training in high-level swimmers in a tropical climate. The effects were optimal in the evening, certainly in relation with a more stressful environment and/or sensation. Because the aim of using cold water is to decrease the impact of stress to improve performance, studies exploring the effect of cold-water ingestion on performance

Water temperature effect on human body functions

33 – 34 °C – Thermal neutrality, maximal performance?

28 – 32 °C – Increase of central and peripheral temperature; Increase of vasodilatation; Increase of blood flow, maximal performance?

25 – 28 °C – Normal adaptations; Increase of VO_2 max; Increase of maximal performance.

20 – 25 °C – Disorders in operations; Increase of VO_2 max; Decrease of maximal performance.

16 – 20 °C – Decrease in core temperature; Decrease of VO_2 max; Decrease of heart rate; Decrease of muscle temperature.

10 – 16 °C – Decrease in core temperature; Decrease of VO_2 max; Decrease of heart rate; Decrease of muscle temperature; Hypothermia.

<10 °C – Decrease of muscle temperature; intense Hypothermia; Body defreezing.

Fig. 6.2 Effect of water temperature in human body functions

during real competitive events are needed, in both acclimated and unacclimatized high-level subjects [20].

The Fig. 6.2 shows the effects that water temperature has in the human body functions [12].

Water temperature immediately affects bodily functions upon entry into the water, throughout immersion and during swimming, gradually provoking changes, which affect the condition of the organism, as well as its overall performance. The increase or decrease of the water temperature beyond the normal range may act therapeutically, entertainly, or to enhance the body's physical fitness, but it does not contribute to the improvement of performance [12].

When the human body is immersed in water, body temperature changes. This change due to and influenced by several factors, such as: water temperature, air temperature, air currents, environmental moisture, the composition and percentage rate of tissues in the body, the percentage rate of fat tissue, and the percentage of immersion of the body in water. During exercise in water temperatures between 26 and 28 °C, in healthy adult individuals, a low and pleasant body temperature is observed. This temperature is present in most swimming pools and they have a strong effect on the human body, such as: only a few minutes after immersion of the body in water, skin temperature is equalized with water temperature (with a difference of approximately 1 °C), since heat conductivity is 25 times greater in water than in air [12].

In a state of rest-immobility, in water temperatures of 33–34 °C, the human body acquires thermal neutrality; this allows for mild swimming activities, with entertaining and therapeutic properties. These high temperatures are appropriate for mild activities for infants and children, the elderly, and fragile or injured individuals [12].

At water temperatures below 30 °C, hypothermia progressively sets in. In competitive swimming, any increase or decrease of the water temperatures beyond the normal [21], chain reactions and effects between organs, systems, mechanisms and substances are observed, on the surface and inside the body; these result in changes in their functions and/or activities, and strongly affect the outcome of the swimming effort [12].

The Table 6.1 presents the survival times of an average human subject immersed in cold water without protective clothing, characterizing the loss of dexterity, time of exhaustion or unconsciousness and expected time of survival [22].

When the water temperature is in the range from 28 to 32 °C, there is a tendency for performance to improve, primarily in speed events. However, at temperatures higher than that, performance decreases and other goals are pursued. In temperatures much higher than this range, staying in the water becomes impossible and pronounced phenomena of hypothermia occur [12].

At water temperatures ranging from 25 to 27 °C, there is a tendency for performance to improve, primarily in endurance events. However, at lower temperatures performance drops, and perhaps there is a need to investigate the appropriate temperature for marathon and hyper-marathon swimming [12].

Within the interval between 25 and 20 °C in water temperature, malfunctions appear in the organism, the swimming effort and performance is reduced and remaining in the water becomes difficult, with phenomena of hypothermia [12].

If the water temperature ranges between 20 and 12 °C, pronounced malfunctions appear in the organism, the swimming effort and performance is reduced and remaining in the water becomes difficult, with gradual phenomena of hypothermia. Only practiced, fit individuals can swim in these conditions [12].

When water temperatures drop below 12 °C, pronounced and immediate malfunctions appear in the organism, there is complete inability to swim or perform, inability to remain in the water for longer than 1 h, and pronounced phenomena of hypothermia and cooling of the body [12].

Table 6.1 The survival times of an average human subject immersed in cold water without protective clothing

Water temperature (°C)	Loss of dexterity with no protective clothing	Exhaustion or unconsciousness	Expected time of survival
>26.5	2–12 h	Indefinite	Indefinite
21–26.5	1–2 h	2–12 h	3 h to indefinite
15.5–21	30–40 min	2–7 h	2–40 h
10–15.5	10–15 min	1–2 h	1–6 h
4.5–10	Under 5 min	30–60 min	1–3 h
0.3–4.5	Under 3 min	15–30 min	30–90 min
<0.3	Under 2 min	Under 15 min	Under 15–45 min

6.3 Assessment of Skin Temperature in Water Sports

Acclimatization is important to achieve a pre-imaging thermal equilibrium between the body skin and surrounding environment [23] but the time required is not yet consensual and previous published research recommend time periods of 10 min [24], 15 min [25] and 20 min [26]. These authors suggest that acclimatization should be undertaken at rest in an examination room with controlled thermal environment to obtain baseline thermograms when using dynamic thermal imaging. In particular, swimming exercise is performed in the water and if baseline thermograms would be obtained in such conditions the analysis would be wrong and meaningless.

Water is an isotropic substance and opaque to skin radiation [27]. Therefore swimmers must be dried before thermal imaging acquisition. In this process skin friction must be avoided since it can influence local microcirculation and cause unwanted increase in the skin temperature values measured with the thermal images.

This issues where researched by Zaidi et al. [6], however their work was limited, further research is recommended.

The first known application of thermal imaging in water sports was performed by Wade and Veghte [8] on investigating the regional differences in skin temperature in 4 competitive swimmers of varying body compositions, prior to and after 5 min of immersion in water at 23.5 °C, and after a 500-m freestyle swim at a training pace. Decreases in skin temperature that correlated with skinfold thickness were seen post-immersion. After swimming, skin temperatures were highest in regions overlying active muscle masses (deltoids, trapezius, triceps and biceps brachi, and pectorals) and were independent of skinfold thickness. It was also found that thin swimmers were found to dissipate faster the heat than fat subjects.

Another study a few years later attempted to determine the thermal and metabolic effects of wearing a rubberized wet suit when compared with a competitive swimming suit while swimming for 30 min in 20.1, 22.7, and 25.6 °C water, with a 15 min resting period between them. Nine subjects were investigated and skin temperature was obtained not with thermal imaging but with skin temperature sensors (TX-4 Columbus instruments). The rubberized wet suit present a significant higher body temperature than the competitive swimming suit, that difference decreased when the water temperature become warmer [28].

Hue et al. demonstrated that training in a tropical climate significantly enhances performance in swimmers (400 m freestyle), 30 days after return to neutral climate [29]. A sample of 16 swimmers was used and the climates compared were the tropical and the neutral, there were 3 moments used, the baseline, 10 days after and 30 days after. No relation was obtained between the 10 and 30 days post training.

A preliminary experimental study was undertaken for studying the feasibility of using thermal imaging in the discipline of swimming and for quantifying the influence of the swimming technique (within the framework of a well defined protocol) on the distributions of skin temperatures [6]. They have used an uncooled

FLIR ThermaCAM FLIR SC1000 (sensor array size of 256 × 256, NETD of <70 mK at 30 °C and measurement repeatability of ±2% of the overall reading) and a cooled CEDIP TITANIUM HD 560 M (sensor array size of 640 × 256, NETD of <40 mK at 30 °C and measurement repeatability of ±2% of the overall reading) thermal cameras. Significant variations were found in the cutaneous temperature according to the swimming styles. From the examination of infrared thermography, the whole body surface, has respectively increased by 2.16 °C for the butterfly, 2.56 °C for the backstroke, 1.78 °C for the breaststroke and 2.00 °C for the freestyle, after the single participant had performed the 400 m test in each technique on different days. The swimmer had spent 10 min of acclimatization period in the pool with water at 27 °C. The thermal images were taken from swimmer after the period of acclimatization and after 100 m of each swimming technique (butterfly, backstroke, breaststroke and free style). Between each swimming technique performance there was a 10-min rest period to achieve thermal balance and the thermal imaging measurements were performed after this period were the baseline for the swimming technique performed after. The authors presented changes in skin temperature after each swimming technique and concluded that each technique changed the skin temperature differently. Although this study presented a new methodology to assess skin temperature after swimming exercise, some questions are still open, only one swimmer was assessed and the fact that all swimming techniques were performed in the same day since, with a 10-min resting period to achieve thermal balance between different exercises, is it enough? Does fatigue played any role in the observed temperature changes? Nothing was mentioned describing the velocity and intensity of each swimming technique, which may bias the presented results.

Another study compared the physical activities of swimming and practicing yoga in pregnant women [30]. It was found that swimming reduced the skin temperature in the breast and belly regions whereas yoga as presented an increase in most of the skin temperature areas, this may be due to the cooling effect of water. A FLIR T335 (sensor array size of 320 × 240, NETD of <50 mK at 30 °C and measurement repeatability of ±2% of the overall reading) uncooled thermal camera was used, the participants had engaged in a 10 min acclimatization period in a controlled environment room, the images after practice were taken 10 min after the exercise at the same conditions and in the swimming group after the participants dried the skin with towels without rubbing [30]. The acclimatization period and the drying method and subsequent 10 min waiting period may have bias the obtained results.

Five of twenty muscle regions have notable tendencies of increased temperatures, including a front part of deltoideus at right side which is very active by spreading arm forward and beginning of swimming stroke. In nine areas of main agonist swimmers movement forward included—triceps brachii, it was found no significant lowering temperatures. That can be due to the cooling effect of the swimmer in the water. A Fluke TiR (sensor array size of 160 × 120, NETD of <90 mK at 30 °C and measurement repeatability of ±2% of the overall reading) uncooled thermal camera was used. The water temperature was at 27 °C, it was no acclimatization in the water and the post exercise images were taken 15 min after coming out of the swimming pool and being dried with a towel avoid rubbing [31]. The use of an acclimatization period with different conditions from the exercise and a non-recommend low specifications thermal camera for human skin screening [32, 33] may have biased the obtained results.

A study investigated the possible relationship between energy expenditure and skin temperature during 2 × 300 m protocols (front crawl and backstroke), performed at the same intensity and velocity, by 2 male experimented swimmers [9]. Both swimming techniques increased skin temperature but with different thermal patterns. Higher values of energy expenditure during the 300 m backstroke test were found comparing with the values obtained for the same distance performed in front crawl and higher difference between skin temperatures values were associated with lower energy expenditure values. The swimmers have refrained an acclimatization period of 10 min immersed still in water at the pool till the head at a temperature of 27 °C. A FLIR A325sc (sensor array size of 320 × 240, NETD of <70 mK at 30 °C and measurement repeatability of ±2% of the overall reading) uncooled thermal camera was used.

A research conducted in Czech Republic has found that there is a significant increase (normalized units) 15 min after swimming in triceps brachii (on the right prior to swimming 0.950 and after swimming 0.994; on the left prior to swimming 0.947 and after 0.990), and in side, rear and front parts of the deltoid muscles [34]. On the contrary, there was a significant relative decrease in temperature in pectoralis, rhombic and lower trapezius, erector spinae lumbalis and latissimus dorsi. It can be concluded that swimming 1000 m breaststroke affected significant increase in the temperature of regions of interest, i.e., corresponding to agonists and synergists of upper extremities for the swimmer's forward motion. A relative decrease in temperature occurred rather in body muscles. The problem of biased results due to water-cooling was solved by using thermograms taken only in the 15th minute after getting out of water and calculating relative temperatures with normalized units. A Fluke TiR (sensor array size of 160 × 120, NETD of <90 mK at 30 °C and measurement repeatability of ±2% of the overall reading) uncooled thermal camera was used, which does not meet the minimum specifications for human skin screening [32, 33].

A study attempted to develop a methodology to investigate swimmers and verify whether there is a considerable change in skin temperature during different swimming techniques (7 × 200m protocol in front crawl and backstroke) and, if confirmed, to identify the most affected regions [10]. A FLIR A325sc (sensor array size of 320 × 240, NETD of <70 mK at 30 °C and measurement repeatability of ±2% of the overall reading) uncooled thermal camera was used. A total of 10 experienced swimmers had been investigated in two consecutive days at same time, performing in the first day the crawl technique and on the second day the backstroke technique.

The regions used were: For anterior view (Fig. 6.3), Anterior Neck Right; Anterior Neck Left; Anterior Torax Right; Anterior Torax Left; Anterior Arm Right; Anterior Arm Left; Anterior Forearm Right; Anterior Forearm Left; Anterior

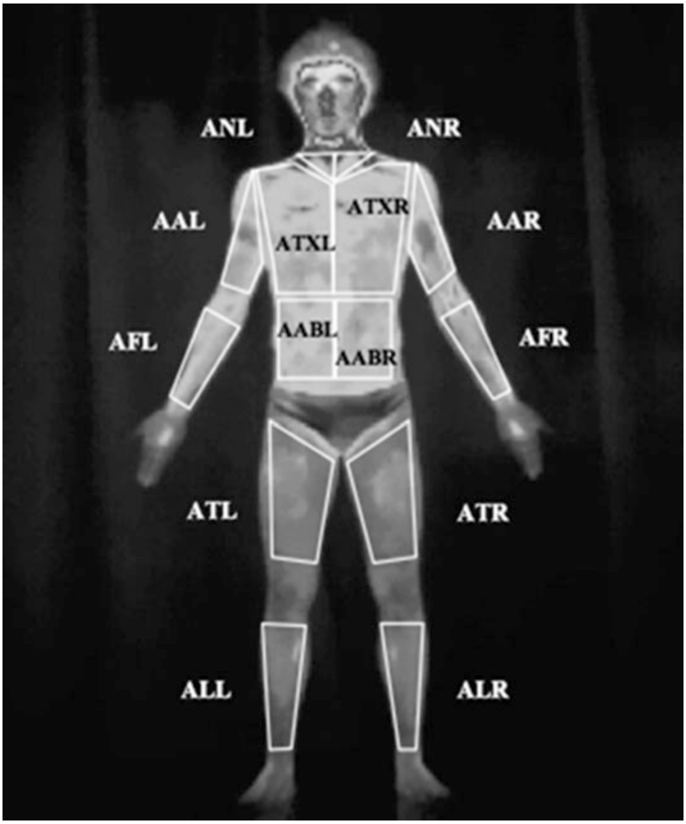


Fig. 6.3 Anterior regions of interest used in the study: Anterior Neck Right (ANR); Anterior Neck Left (ANL); Anterior Torax Right (ATXR); Anterior Torax Left (ATXL); Anterior Arm Right (AAR); Anterior Arm Left (AAL); Anterior Forearm Right (AFR); Anterior Forearm Left (AFL); Anterior Abdomen Right (AABR); Anterior Abdomen Left (AABL); Anterior Thigh Right (ATR); Anterior Thigh Left (ATL); Anterior Leg Right (ALR); Anterior Leg Left (ALL)

Abdomen Right; Anterior Abdomen Left; Anterior Thigh Right; Anterior Thigh Left; Anterior Leg Right; and Anterior Leg Left. For dorsal view (Fig. 6.4), Dorsal Neck Left; Dorsal Neck Right; Dorsal Upper Back Left; Dorsal Upper Back Right; Dorsal Arm Left; Dorsal Arm Right; Dorsal Middle Back Left; Dorsal Middle Back Right; Dorsal Forearm Left; Dorsal Forearm Right; Dorsal Lower Back Left; Dorsal Lower Back Right; Dorsal Thigh Left; Dorsal Thigh Right; Dorsal Leg Left; and Dorsal Leg Right (DLR).

There were collected half-body view images and full-body view images, being the fist collected at a distance of 2 m and the second at 4 m. In both type of views the ROIs were analyzed in terms of mean temperature and between bilateral ROIs, the thermal symmetry [35] was analyzed.

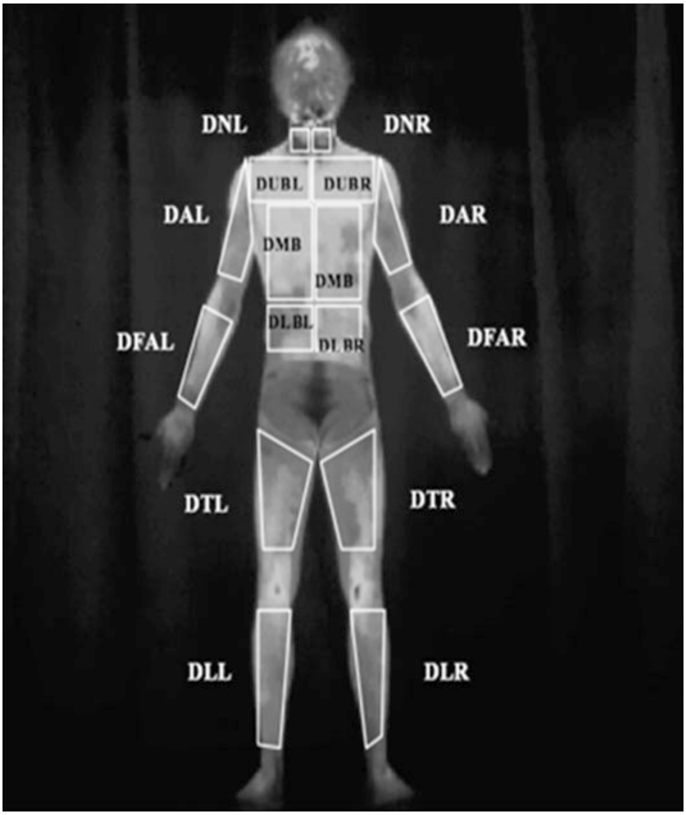


Fig. 6.4 Dorsal regions of interest used in the study: Dorsal Neck Left (DNL); Dorsal Neck Right (DNR); Dorsal Upper Back Left (DUBL); Dorsal Upper Back Right (DUBR); Dorsal Arm Left (DAL); Dorsal Arm Right (DAR); Dorsal Middle Back Left (DMBL); Dorsal Middle Back Right (DMBR); Dorsal Forearm Left (DFAL); Dorsal Forearm Right (DFAR); Dorsal Lower Back Left (DLBL); Dorsal Lower Back Right (DLBR); Dorsal Thigh Left (DTL); Dorsal Thigh Right (DTR); Dorsal Leg Left (DLL); Dorsal Leg Right (DLR)

Thermal Symmetry was defined as the ‘degree of similarity’ between two ROIs, mirrored across the human body’s longitudinal main axes which are identical in shape, identical in size and as near identical in position as possible. The degree of similarity is measured in terms of the respective mean temperatures obtained in the ROIs [35].

The capture protocol consisted of the swimmer being subjected to a 10 min acclimatization period in the pool, maintaining a static position and immersing all parts of the body, except the head. To avoid the negative influence of water in thermograms, the swimmer was quickly dried with microfiber towels, avoiding any friction (Fig. 6.5).

Fig. 6.5 Example of participants drying without any friction using microfiber towels

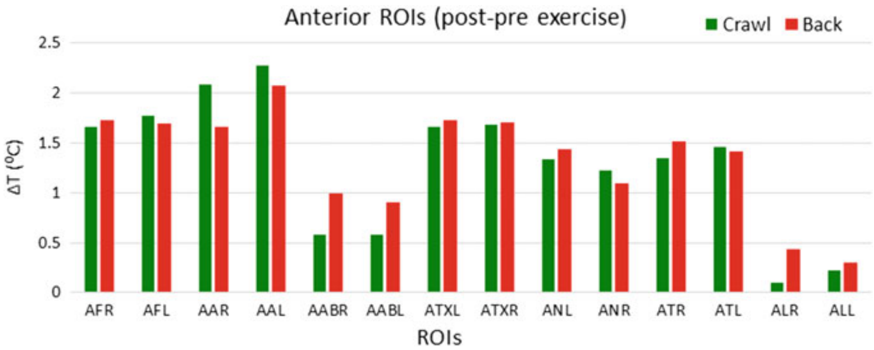


Fig. 6.6 Anterior half-body views regions of interest variation post-pre exercise for both swimming techniques. Anterior Forearm Right (AFR); Anterior Forearm Left (AFL); Anterior Arm Right (AAR); Anterior Arm Left (AAL); Anterior Abdomen Right (AABR); Anterior Abdomen Left (AABL); Anterior Torax Right (ATXR); Anterior Torax Left (ATXL); Anterior Neck Right (ANR); Anterior Neck Left (ANL); Anterior Thigh Right (ATR); Anterior Thigh Left (ATL); Anterior Leg Right (ALR); Anterior Leg Left (ALL)

Regarding the differences in temperature distribution associated with exercise. In all studied regions the temperature variation was greater than zero, which indicates an increase in skin temperature, as can be seen in Fig. 6.6 for anterior ROIs of half-body views in both swimming techniques, and in Fig. 6.7 for posterior ROIs.

The regions with higher temperature increase, for both techniques, are the upper limb (arm and forearm) and upper trunk region (thoracic, upper back and middle back). Although the abdomen and lower back are located in the trunk, they do not indicate significant differences in temperature, as well as, in the neck and leg regions. Example full-body view images, including pre and post swimming technique exercise) are presented from Figs. 6.8, 6.9, 6.10, 6.11, 6.12 and 6.13.

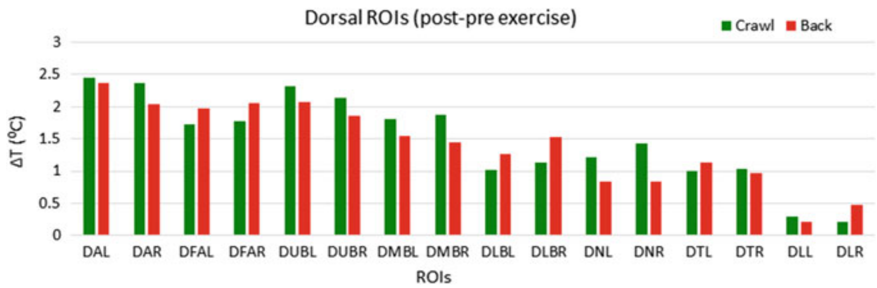


Fig. 6.7 Dorsal half-body views regions of interest variation post-pre exercise for both swimming techniques. Dorsal Arm Left (DAL); Dorsal Arm Right (DAR); Dorsal Forearm Left (DFAL); Dorsal Forearm Right (DFAR); Dorsal Upper Back Left (DUBL); Dorsal Upper Back Right (DUBR); Dorsal Middle Back Left (DMBL); Dorsal Middle Back Right (DMBR); Dorsal Lower Back Left (DLBL); Dorsal Lower Back Right (DLBR); Dorsal Neck Left (DNL); Dorsal Neck Right (DNR); Dorsal Thigh Left (DTL); Dorsal Thigh Right (DTR); Dorsal Leg Left (DLL); Dorsal Leg Right (DLR)

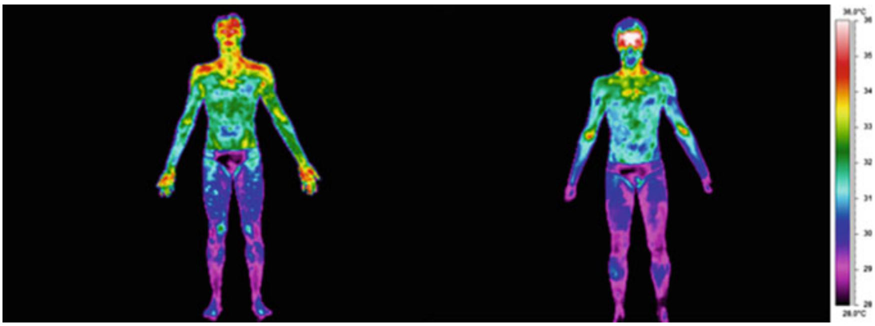


Fig. 6.8 Example of thermal images of pre (*left*) and post (*right*) exercise in full body anterior view

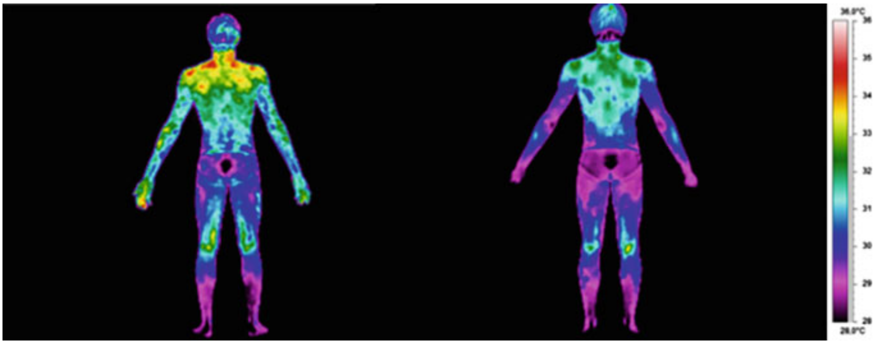


Fig. 6.9 Example of thermal images of pre (*left*) and post (*right*) exercise in full body dorsal view

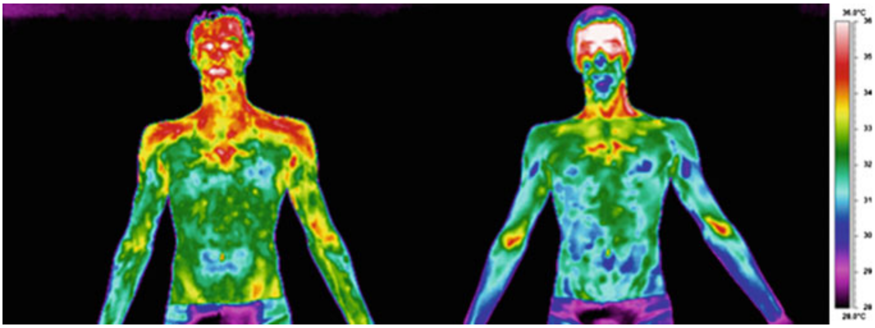


Fig. 6.10 Example of thermal images of pre (*left*) and post (*right*) exercise in half body anterior-top view

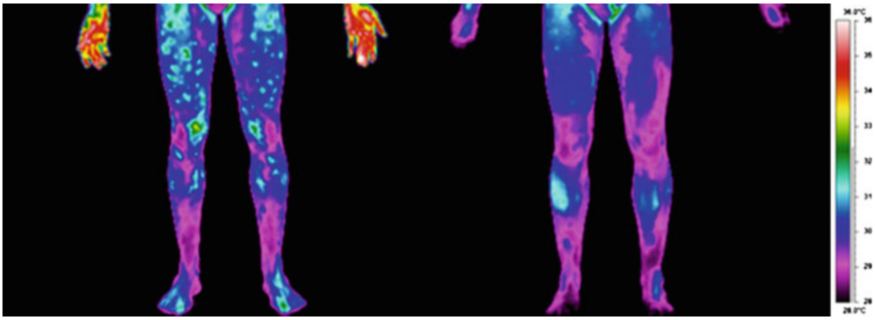


Fig. 6.11 Example of thermal images of pre (*left*) and post (*right*) exercise in half body anterior-bottom view

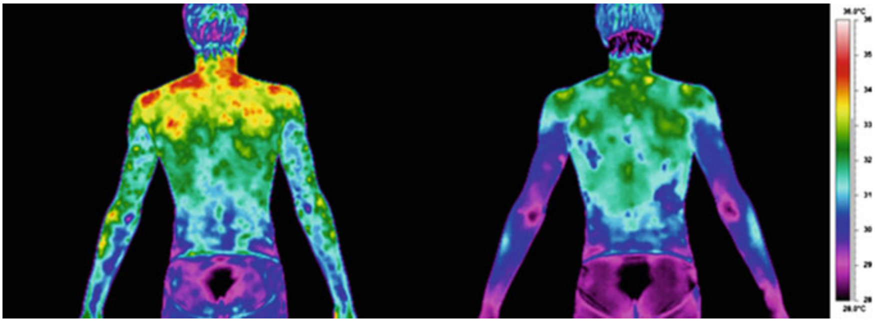


Fig. 6.12 Example of thermal images of pre (*left*) and post (*right*) exercise in half body dorsal-top view

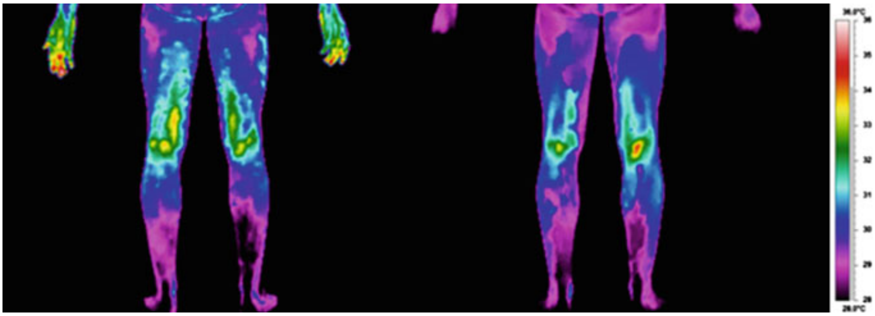


Fig. 6.13 Example of thermal images of pre (*left*) and post (*right*) exercise in half body dorsal-bottom view

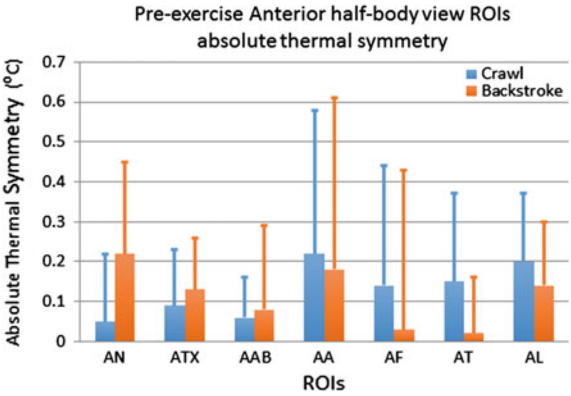


Fig. 6.14 The thermal symmetry absolute values (*left–right* ROI) for both swimming techniques pre-exercise in anterior half-body view. Anterior Neck (AN); Anterior Torax (ATX); Anterior Abdomen (AAB); Anterior Arm (AA); Anterior Forearm (AF); Anterior Thigh (AT); Anterior Leg (AL)

The temperature difference between left and right regions did not exceed more than 0.5 °C for all ROIs. These differences were expected due to the health condition of athletes and also because the swimming techniques performed were symmetrical, only small noticeable changes were found in the arms (for crawl swimming technique) and thighs (for backstroke swimming technique) regions (Figs. 6.14, 6.15, 6.16 and 6.17). There was no significant variation between full and half body view, although the usage of half body views is recommended, because it allow bigger regions of interest and future better discrimination in the case of any pathology.

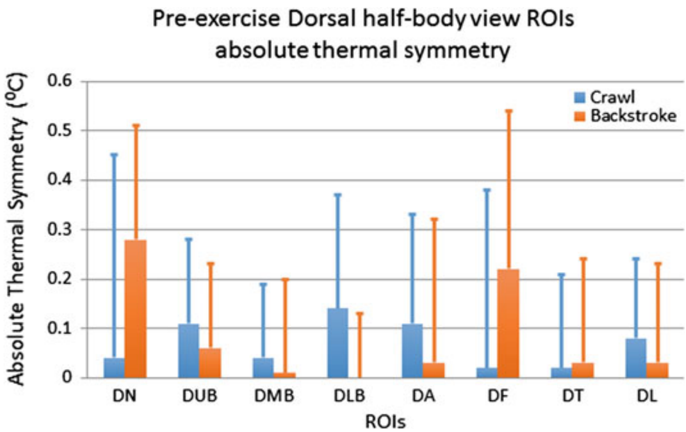
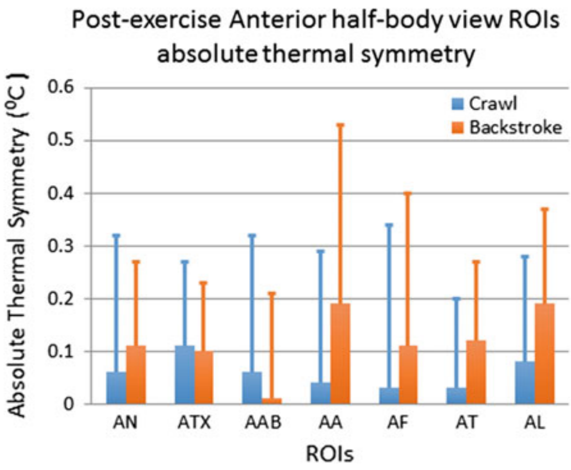


Fig. 6.15 The thermal symmetry absolute values (*left–right* ROI) for both swimming techniques pre-exercise in dorsal half-body view. Dorsal Neck (DN); Dorsal Upper Back (DUB); Dorsal Middle Back (DMB); Dorsal Lower Back (DLB); Dorsal Arm (DA); Dorsal Forearm (DF); Dorsal Thigh (DT); Dorsal Leg (DL)

Fig. 6.16 The thermal symmetry absolute values (*left–right* ROI) for both swimming techniques post-exercise in anterior half-body view. Anterior Neck (AN); Anterior Torax (ATX); Anterior Abdomen (AAB); Anterior Arm (AA); Anterior Forearm (AF); Anterior Thigh (AT); Anterior Leg (AL)



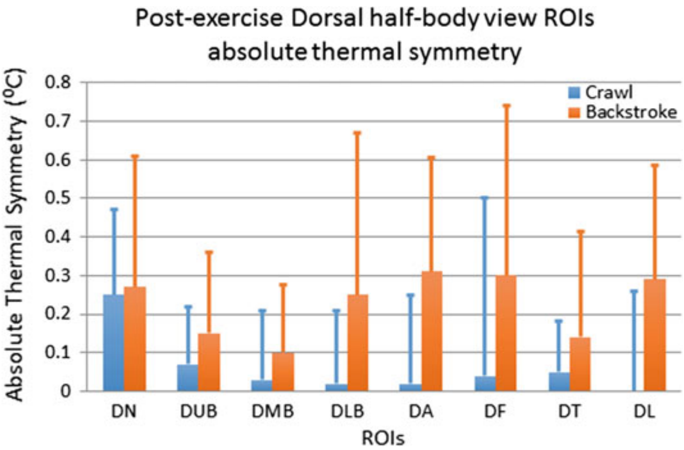


Fig. 6.17 The thermal symmetry absolute values (*left–right* ROI) for both swimming techniques post-exercise in dorsal half-body view. Dorsal Neck (DN); Dorsal Upper Back (DUB); Dorsal Middle Back (DMB); Dorsal Lower Back (DLB); Dorsal Arm (DA); Dorsal Forearm (DF); Dorsal Thigh (DT); Dorsal Leg (DL)

One weakness of this research was not having the participants again inside water during the time of swimming practice for better estimation of the difference between effect of exercise and water immersion.

Both swimming techniques significantly increased skin temperature in every ROI ($p < 0.05$), however technique discrimination was not possible since no significant differences were found. From the analysis through the Related-Samples Wilcoxon Signed Rank Test it is possible to observe that there is statistical evidence ($p < 0.05$) for every ROI between pre and post exercise in half-body views. Differentiating swimming techniques through the ROIs and their differences in mean temperatures (post-pre exercise) was not possible due the absence of statistic evidence in avoiding the null hypothesis ($p > 0.05$) with the Independent-Samples Kruskal-Wallis Test. No significant statistical evidence of differences was found between the two studied swimming techniques [10].

6.4 Proposed Methodology for Measuring Skin Temperature in Water Sports

Based in the previously described existing literature, it is known that skin temperature is influenced by several factors. Assessing skin temperature in water sports upon on the internationally accepted human body thermal imaging capture protocols ([23, 36, 37], which specify subject preparation previously and during examination, recording equipment preparation and examination room preparation, there are other intrinsic aspects related with water immersion related exercising.

The athletes should refrain from having a heavy meal, smoking, intaking alcohol or drugs, having tea or coffee in the 2 h before examination, having oil or ointments in the skin, using any jewelry, the recording equipment must be switched on at a safe interval to prevent the startup drift [38], and at the local of examination there should be take actions to prevent any unwanted thermal reflection from any possible source.

Instead of having the acclimatization period at room constant air environment, since the activity takes place in the water, its temperature value has to be constant and depends on the exercise type and research question, but it can be assumed the for most exercises the recommended value would be 27 °C, the subject must stay sill during that period, which is in line with the proposed knowledge [12]. The challenge after acclimatizing in water and after performing the water activity is to dry the skin surface with minimal effect of the whole process, that can be achieved through having minimal contact with highly absorbent microfiber towels, but it has to been done in a minima time (typically 1 min) and using the same direction and speed to reduce the influencing variables. This action with limit the cooling and evaporation effect that water exposure has on skin surface. For a better understanding of the exercise skin temperature influence, it is recommended that the subjects perform a test of staying still at the same condition of the exercise test and during the same time. It is also recommended to use half-body views and keep a distance of about 2 m from the target and use a 90 angle for images capture. The images should be assessed using regions of interest over the muscular areas and

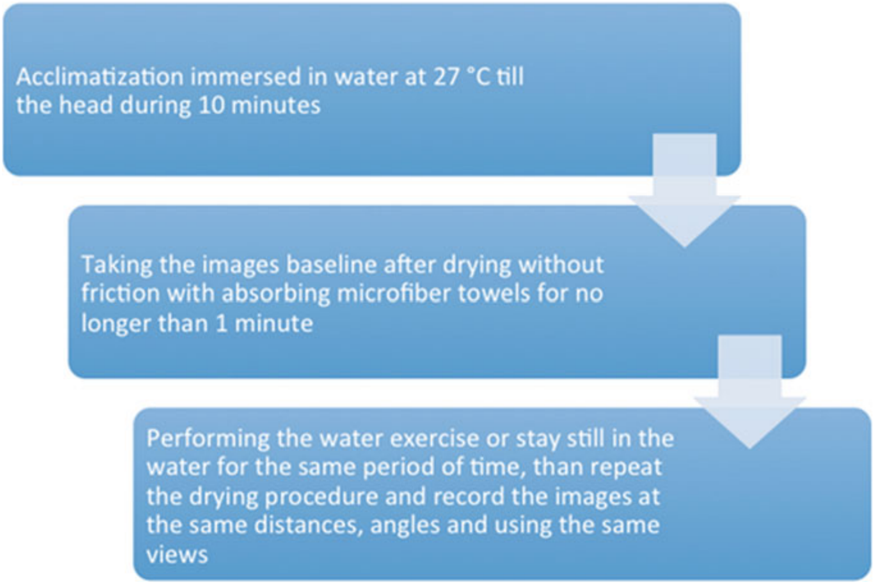


Fig. 6.18 The main points of the proposed methodology for water sports screening with thermal imaging

measuring the mean, minimum and maximum temperatures and standard deviations along with the histograms. Based in the literature, distal extremities such as hand and feet should not be considered because of the higher effect that water contact has on them. The Fig. 6.18 resumes the main points of the proposed methodology for water sports screening with thermal imaging.

6.5 Future Research Directions in Water Sports

Future research is needed and suggested for any water activity involving body immersion for a period of time higher than 5 min. In the particular case of swimming, it is required to know if it has any influence in total skin temperature or in the temperature of individual ROIs, the existing studies [6, 8–10, 28–31, 34, 39] give that indication but had a limited number of participants to take wider and accurate conclusions. The influence of the swimmer level and specialization is another issue that needs to be explored, as the influence of age, gender and body composition on the thermal response. The intensity of the swimming technique, the different types of swimming techniques and its effect in skin temperature also needs to be addressed.

An aspect that worth attention is the determination of the appropriate water immersion acclimatization period duration. Other is the ideal method to dry the skin without affecting the exercise effect in the skin temperature.

There is a lot of opportunities in research in this particular field, most till now were based in swimming but there are other water activities that worth attention and interest such as: hydrotherapy, sauna, Turkish bath, diving, water polo, water jogging and any other emerging underwater activity.

6.6 Conclusion

In this chapter the reasons for measuring skin temperature changes during water sports and underlining physiological aspects were outlined. The aspects of the relationship between water contact, exercise and skin temperature were addressed. Example of applications of skin temperature assessment with thermal imaging involving effect of different body masses in water immersion [8], using different types of swimming suits [28], training at different climates [29], assessing different swimming techniques with water acclimatization [6, 10, 39], relating that with energy expenditure [9], comparing yoga and swimming in pregnant women [30] and fifteen minutes in muscle areas after breaststroke swimming [31, 34]. All of these research studies involved small samples but presented interesting and promising results.

A new investigation methodology for thermal imaging screening in water sports was proposed based in the previous studies findings. A future challenge can be repeating some of the described applications with larger samples for confirming the initial results and conclusions.

One thing is certain, using standardized medical thermal imaging has proven to be a useful tool to evaluate temperature differences after sports activity and only implementing it, it is possible to contribute for its development, growing usage and credibility, attracting new users.

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