The influence of swimming type
on the skin-temperature maps of a competitive
swimmer from infrared thermography

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This work aims to study the usability of infrared thermography in swimming for the purpose of quantifying the influence of the swimming style on the cartographies of cutaneous temperatures of a swimmer.

Only one subject took part in the experimental protocol, who was to accomplish a 4×100 m 4 medley. Thermal acquisitions followed by one period of recovery with return to thermal balance were carried out between particular strokes.

IR thermography made it possible to discuss the influence of the swimming style on the distributions of cutaneous temperatures in various body zones. This process seems to be completely adaptable to the development of future statistical studies.

Key words: new swimming performance method, skin temperature, infrared thermography

1. Introduction

Swimming, like any sports activity, induces a complex thermoregulation process where part of heat is given off by the skin of a swimmer. As not all the heat produced can be entirely given off, there follows a muscular heating resulting in an increase in the cutaneous temperature. This study arose from two extremely simple questions: what is the skin temperature of a swimmer during his activity and what influence does the swimming style exert on the temperature distribution? The answers to these are of importance since they constitute the thermal boundary conditions in the numerical modelling of the flow around a swimmer.

A close examination of the literature shows that no study has been devoted to these problems. Though, for example, BRANDT and PICHOWSKI [1] determined the temperature of a swimmer to be 33 °C after exercise, it was a local measurement only, therefore very partial, obtained by means of a thermocouple placed at the deltoid. In the same way, HUTTUNEN et al. [4] studied variations in the internal temperature of long distance swimmers in cold water. In no way did they study the cutaneous temperature.

To mitigate this lack of data, we opted for a total acquisition of the distributions of temperature by infrared thermography. Whereas this technique is usually used under thermal conditions of living [5], no mention of its application to swimming can be found in the literature. The study was carried out in a swimming pool. The temperature of water in the pool is a significant parameter, which conditions the evolution of physiological parameters such as, for example, the production of lactate or the heart rate [7], which have a direct influence on the process of body thermoregulation. An analysis carried out by ROBINSON and

Sommers [8] showed that in swimming, the optimal temperature of water for 20 minutes of freestyle must range between 21 and 33 °C, with an optimal break-even point at 29 °C. This value is slightly higher than the one we measured at the time of the study in the swimming pool. The investigation being a preliminary study, only one male swimmer took part in it.

It is advisable to specify that the present work is not a statistical study. The results obtained in this study cannot be considered to have a universal character since only one subject was taken into account for our experimentation. The objectives of this preliminary study are, on the one hand, to show the applicability of IR thermography to swimming and, on the other hand, to show up to what point the cutaneous temperatures are influenced by the swimming style. This method will enable us, in the long term, to quantify the heat loss according to the swimming style, and to consider the muscular and energy outputs during the stroke. We make a point of underlining the originality of this study that consists in dissociating the segments of the body of the swimmer according to the constraints of each swimming style.

2. Material and methods

2.1. The subject

The subject taking part in this study is a swimmer of national level specialist in the 400 m medley who is training on average 10 to 12 hours per week. The principal anthropometric characteristics of the subject are summarized in Table 1.

Table 1. Morphometric data for the swimmer

	Age	Height (m)	Mass (kg)	Body fat (%)
Swimmer (man)	19	1.78	67	12.4

2.2. Body decomposition

In order to better assess the influence of the swimming style on the muscular heating, the cutaneous surface was divided into closed polygonal surfaces A, B, ..., J, according to the distribution represented in Figure 1.

The limb extremities and the joint regions, which represent poorly the contribution of the body thermoregulation process, were excluded from this geometrical body cutting. The body cutting used in our study allows for the elementary geometry approach adopted by Yanai [9] for the swimmer representation to numerical simulation purposes.
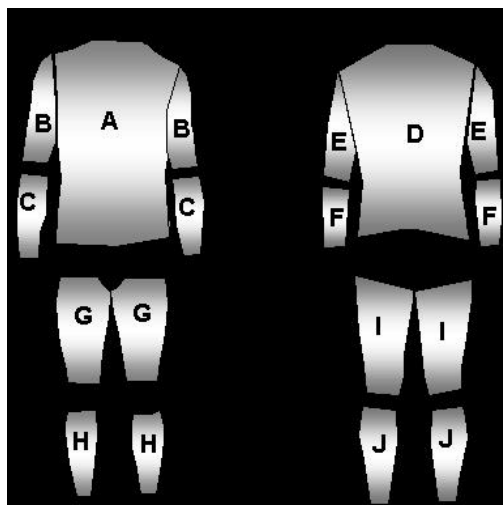

Fig. 1. Body zone definitions: frontal view (1) and dorsal view (2)

2.3. The thermal camera

The cutaneous temperature field was acquired using a digital short wave infrared (IR) camera (FLIR, SC1000) sensitive to radiation in the 3.0–5.0 μm wavelength band. The human skin having an emissivity of 0.97, whatever its degree of pigmentation [2], the minimum detectable temperature difference in the spectral band is lower than 0.1 °C. The thermal images were taken at a distance of 4 m from the subject. Four successive acquisitions make it possible to map the cutaneous temperature of the swimmer. The trunk and the upper limbs, then the lower limbs, are studied both face on (A, B, C–G, H) and from behind (D, E, F–I, J).

2.4. Protocol

The experimentation took place in a covered swimming pool of 25 m in length, in the morning. The temperature of the water was 27 °C and that of the ambient air was 24 °C. The experimental protocol, summarized in Table 2, is defined as follows: at the beginning, the swimmer is immersed up to the neck in the static position for 10 minutes. At the end of this period, the swimmer leaves water and then is rapidly dried (water is opaque to infrared radiation). The following task was the first recordings of the body surface thermal maps, which constitutes the thermal ref-

Table 2. Infrared thermography data acquisition

	Thermal balance	100 m butterfly	Thermal balance	100 m backstroke	Thermal balance	100 m breast stroke	Thermal balance	100 m free style	End test
Duration of sequences	10'	1'03	10'	1'08	10'	1'22	10'	1'03	–
Test chronology									
Data acquisition	x (reference)		x		x		x		x

erence level of the swimmer at rest. Next, the swimmer executes his first 100 m butterfly, leaves water, is dried and then is subjected to a second set of thermal acquisitions that will provide the cartography of the body surface temperatures after the exercise. Once these thermographies are obtained, the swimmer is immersed in water again. The duration between two swimming series is sufficiently long (10 minutes) to allow a return to the thermal balance of the swimmer. This cycle is reproduced for the three other strokes. It is to be specified that the swimmer was subjected to a test during the period of recovery according to his training program, which explains the average results obtained during the test of a 4 × 100 m medley with a departure in water.

3. Results and discussion

3.1. Reference temperatures

The histogram of the cutaneous temperatures of the swimmer at rest is shown in Figure 2. These temperatures were measured after the swimmer had remained for 10 minutes in the water at 27 °C. They constitute the case of reference of the study. There appear disparities in the distribution of the average temperatures of the zones; the highest temperatures correspond to the zones closest to the vital organs of the swimmer (abdomen, chest, back), whereas the lowest are those of the forearms of the swimmer. The maximum variation observed is about 1.7 °C.

3.2. Influence of the swimming style

The various infrared cartographies established for the four styles according to the protocol defined previously are presented in Figures 3 and 4. Notable differences appear in the images, which allows us to predict a considerable influence of the swimming style on the distributions of the cutaneous tempera-

tures. To quantify this influence, let us introduce the average temperature difference (ΔT) defined as the difference between the temperature measured after effort and that measured at rest. The corresponding histograms are shown in Figure 5.
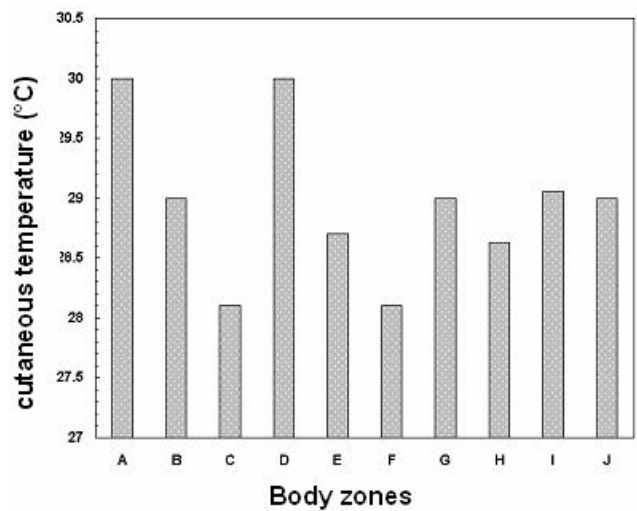

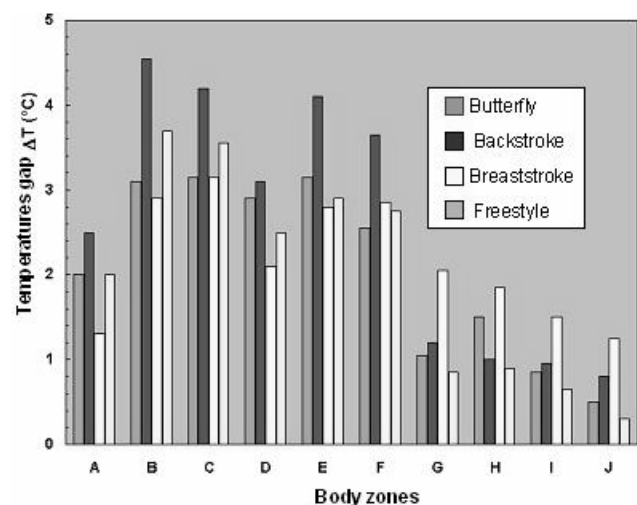Fig. 2. Cutaneous temperatures of the different swimmer zones

Fig. 3. Influence of the swimming style on the temperature gaps measured after effort and at rest
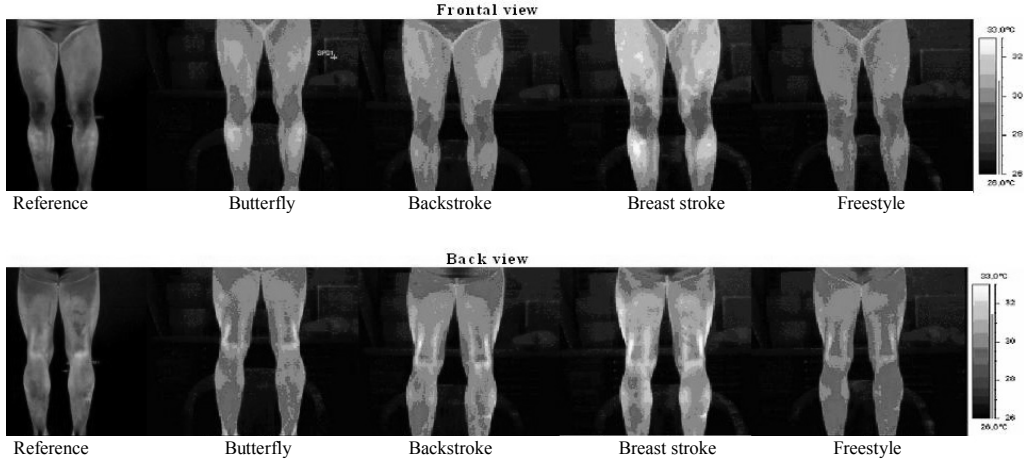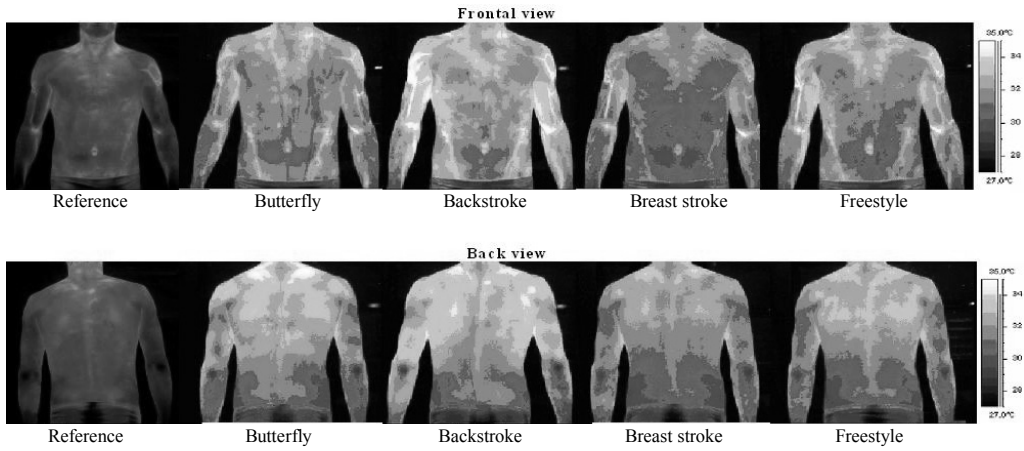
Fig. 4. Infrared cartographies of the lower limbs

Fig. 5. Infrared cartographies of the trunk and the upper limbs

Table 3. Synthesis of results

	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F	Zone G	Zone H	Zone I	Zone J
ΔT max	Back-stroke	Breast stroke	Back-stroke	Back-stroke	Back-stroke	Back-stroke	Breast stroke	Breast stroke	Breast stroke	Breast stroke
ΔT min	Breast-stroke	Breast stroke	Breast stroke butterfly	Breast stroke	Breast stroke	Butterfly	Freestyle	Freestyle	Freestyle	Freestyle

The histograms indicate that a significant increase in the cutaneous temperature is possible in accordance with the swimming style and the body zone considered. Indeed, it appears that the highest temperature is reached in the upper part of the body corresponding to zones A, B, C, D, E, F for the backstroke with $2.50 \pm 0.10 \leq \Delta T \leq 4.55 \pm 0.10$, whereas on the level of zones G, H, I, J, corresponding to the lower limbs, it is the breast stroke that generates the greatest increments in the cutaneous temperature, with $1.25 \pm 0.10 \leq \Delta T \leq 2.05 \pm 0.10$. On the contrary, freestyle induces the weakest variations in temperature on the lower limbs, with $0.30 \pm 0.10 \leq \Delta T \leq 0.90 \pm 0.10$. Obviously, these results appear to be adequate to the intensity of the muscular activity related to the type of stroke. These are summarized in Table 3.

3.3. Global cutaneous temperature

We were interested in defining a global average cutaneous temperature $\overline{T}_{\text{overall}}$ calculated over of the zones as a whole. It is given by the relation:

$$\overline{T}_{\text{overall}} = \frac{\sum_{i=A}^{J} T_i S_i}{\sum_{i=A}^{J} S_i}, \qquad (1)$$

Table 4. Overall cutaneous temperature values

	Butterfly	Backstroke	Breast stroke	Freestyle
$\overline{T}_{overall}$ (°C)	31.73 ± 0.10	32.14 ± 0.10	31.43 ± 0.10	31.58 ± 0.10

where S_i is the number of pixels defining each polygonal zone and T_i is the average temperature for each zone. Table 4 contains the global temperatures obtained.

HOLMER [3] carried out experiments in the experimental pool of Stockholm. At a given speed, significant differences in energy expenditive were observed between the four swimming styles. Techniques with alternate locomotive cycles (crawl and backstroke) were more efficient than techniques with simultaneous cycles (butterfly and breast stroke). Thereafter, these results were confirmed by LAVOIE and MONTPETIT [6].

From the results of Table 4, one can note that the highest global average temperature corresponds to the backstroke case. This stroke seems to show, as for this study, the greatest expenditure of energy. The lowest temperature corresponds to the case of the breast stroke whose overall expenditure of energy seems to be the least. In the present case and according to the protocol drawn up, the temperature difference induced by the practice of these two strokes is 0.78 ± 0.10 °C. One should point out that by no means can our results be compared with those of HOLMER [3] and LAVOIE and MONTPETIT [6], which were established statistically on the basis of different experimental protocol.

4. Conclusions

A preliminary experimental study was undertaken, on the one hand, for studying the feasibility of using IR in the discipline of swimming and, on the other hand, for quantifying the influence of the type of stroke (within the framework of a well defined protocol) on the distributions of cutaneous temperatures. To the best of our knowledge, it is for the first time that such a study has been undertaken.

In particular, this study shows significant variations in the cutaneous temperature according to the swimming styles. From the examination of infrared thermographies, one can note that the temperature, averaged over the whole body surface, is respectively increased by 2.16 °C for the butterfly, 2.56 °C for the backstroke, 1.78°C for the breast stroke and 2.00 °C for the freestyle, after the practised test.

One should recall that these conclusions cannot be considered as universal as far as only one subject, a male swimmer of national level, took part in this study. Nevertheless, the conclusions make us think of considering a statistical study that would also account for the initial temperature of the water in the swimming pool.

References

[1] BRANDT R.A., PICHOWSKY M.A., *Conservation of energy in competitive swimming*, Journal of Biomechanics, 1995, 28, 925–933.

[2] COHEN M.L., *Measurement of the thermal properties of human skin – a review*, Journal of Investigative Dermatology, 1977, 69, 333–338.

[3] HOLMER I., *Energy cost of arm stroke leg kick and the whole stroke in competitive swimming styles*, Europ. J. Appl. Physiol., 1974, 33, 105–118.

[4] HUTTUNEN P., LANDO N.G., MESHTSHERYAKOV V.A., LYUTOV V.A., *Effects of long-distance swimming in cold water on temperature, blood pressure and stress hormones in winter swimmers*, Journal of Thermal Biology, 2000, 25, 171–174.

[5] JANSKY L., VAVRA V., JANSKY P., KUNC P., KNZKOVA I., JANDOVA D., SLOVACEK K., *Skin temperature changes in humans induced by local peripheral cooling*, Journal of Thermal Biology, 2003, 28, 429–437.

[6] LAVOIE J.M., MONTPETIT R., *Applied physiology of swimming*, Sport Med., 1986, 3, 165–189.

[7] MOUGIOS V., DELIGIANNIS A., *Effect of water temperature on performance, lactate production and heart rate at swimming of maximal and submaximal intensity*, J. Sports Med. Phys. Fitness, 1993, 33, 27–33.

[8] ROBINSON S., SOMERS A., *Temperature regulation in swimming*, J. Physiol., 1971, 63, 406-409.

[9] YANAI T., *Rotational effect of buoyancy in frontcrawl: does it really cause the legs to sink?* Journal of Biomechanics, 2001, 34, 235–243.