Infrared thermography for non-invasive monitoring of swimmers' body temperature after ice swimming

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Abstract

Ice swimming is a very demanding sports discipline requiring extraordinary body adaptation to harsh environmental conditions. Athletes cover different distances in low water temperature without wetsuits or any additional warming elements spending anywhere from one minute to several hundred minutes in the cold water. During that time, the body cools down rapidly, causing the body temperature to drop, even to mild hypothermia levels. This paper proposes a method for ice swimmers' physical condition assessment and time-in-the-water estimation based on the analysis of the thermograms recorded just before and after the swimming session.

1. Introduction

Ice swimming is a very demanding sports discipline. The International Ice Swimming Association (IISA) rules require water temperature to be below 5 ℃ during the entire swimming session. Athletes cover distances from 100 m to as much as 6 km in these conditions without wetsuits or any additional warming elements spending anywhere from one minute to several hundred minutes in the cold water. During that time, the body cools down rapidly, causing the body temperature to drop, even to mild hypothermia levels. The temperature difference between individual, selected body parts after the session might carry broad information about the thermoregulative behaviour of the body, allowing further enhancement and understanding of the swimmers' performance [1]. This paper proposes a method for ice swimmers' physical condition assessment and time-in-the-water estimation based on the analysis of the thermograms recorded just before and after the swimming session. Thermography, as a non-invasive, non-contact, and rapid method, enables the recording of skin temperature distribution across large areas of the body without interfering with natural physiological processes or impacting swimmers' comfort [2]. Compared to traditional skin temperature measurements, thermography allows for the detection of local temperature gradients, temperature asymmetries, and differences between selected skin areas.

2. Methodology

The study aims to verify the feasibility of monitoring ice swimmers' body cooling patterns after the swim session in a non-invasive way. Thanks to the courtesy of the swimming club, the Authors obtained thermal images from 19 ice swimmers from which 16 were males aged $(\mathbf{38.12 \pm 7.59})$ years and 3 were females aged $(\mathbf{44.33 \pm 6.03})$ years. All the swimmers were healthy and agreed to use their randomized personal data for research purposes. External conditions such as water or ambient temperature were measured before and after each swim trial. The experimental protocol was executed during ice swimmers' regular trainings and can be divided into three stages (swim preparation in a hot environment (thermal images **not** available); proper swim; after swim resting period (thermal images available))

During the first stage, the swimmers remained still in a heated car – temperature was equal to (39.73 $\pm$ 1.89) ℃. Afterwards, before the proper swim, thermal images of the front, back and face of the volunteers have been taken. The face thermal images have been taken from up close, whereas front and back images have been taken from a tripod placed 7 meters from the volunteer (before immersion phase BM). Due to individual preparation and athleticism of volunteers swim times varied from (91 – 2 025) s. After the swim, the participants have been patted dry gently with a towel in order to take front, back and face thermal images again (after immersion phase AM).

All thermal images were taken with FLIR E50 thermal camera, emissivity factor 0.95 and best image sharpness the Authors could get in a non-laboratory setup. Water temperature T_W and ambient temperature T_A were measured just before and after each swimming attempt with a thermometer calibrated by ISO/IEC 17025 accredited calibration laboratory. For all swim trials T_W varied from 1.73 ℃ to 1.94 ℃ and T_A -2.53 ℃ to 2.98 ℃.

3. Results

The raw thermal data was extracted to MATLAB environment for further analysis. The original images resolution was equal to (320x240) px. It was digitally enhanced to (1280x960) px to improve clarity. The custom deterministic algorithm was used to detect human silhouette on the whole-body thermal images. The detection algorithm block diagram has been presented in Figure 1. It must be noted that some of the swimmers wore one-piece swimsuits which could disturb the temperature distribution, especially at the torso.

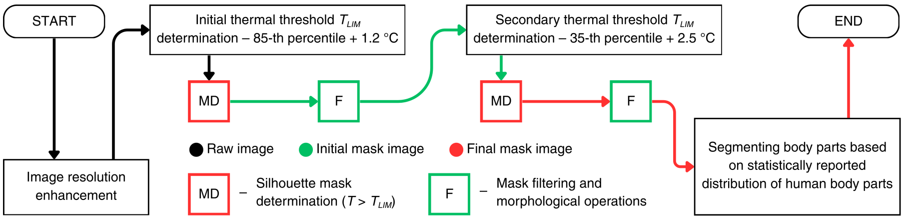

Fig. 1. *Human silhouette detection algorithm block diagram.*

After detecting the silhouette the Authors calculated the temperature differences between the AM and BM phases readings of the lower limbs, upper limbs, torso and head. Two expressions were identified as temperature differences indicators: mean temperature of the region $(\bar{T})$ and standard deviation of the temperature distribution in the region (SD_T). In order to verify the interdependency between the swim time and subsequent body parts cooling, the Spearman correlation of $(\bar{T})$ and (SD_T) to swim time was calculated for all the regions. None of the factors exhibited a significant correlation to swim time – the minimum of all p-values calculated among all the anatomical sites equaled 0.41, whereas the median equaled 0.86. A manual assessment of the thermal images revealed the potential for analyzing the popliteal fossa (kneepit) and the orbit. The custom algorithm for knee line and eye orbit detection have been developed separately. The exemplary detections have been presented in Figure 2a and 2b respectively.

(a) **(b)**

Fig. 2. *Exemplary results of knee line **(a)** and eye orbit **(b)**.*

4. Conclusion

The proposed study demonstrates the potential of using thermal imaging for rapid and non-invasive diagnosis of whole-body temperature distribution in swimmers. However the presented work exhibits a few important limitations. Foremost, the analysis was executed at the limited number of subjects (19). Although the results were non ambiguous, the volunteers group was not statistically representative, that is why it is recommended to continue the data acquisition process. Secondly, the volunteers exhibited different postures, fat percentage level and athleticism, which can introduce additional errors to non-contextual analysis. Although regions of the popliteal fossa (kneepit) and the orbit seemed promising due to a great temperature gradient to the surrounding body parts, the proposed Spearman metric showed no significant correlation. It lets the Authors believe that the interdependency between the swim time and body cooling in ice swimmers can either be non linear or does not exist at all. It requires more complex, non deterministic methods to verify this relationship. The future work should focus on using convolutional deep learning methods combined with contextual survey allowing for individual traits differentiation.

References

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