



Research article

Behavior of skin temperature during incremental cycling and running indoor exercises



Tatiane Lie Igarashi^{a,b}, Tiago Lazzaretti Fernandes^c, Arnaldo José Hernandez^c,
Carlos Eduardo Keutenedjian Mady^{a,*}, Cyro Albuquerque^a

^a Department of Mechanical Engineering, Centro Universitário FEI, Humberto de Alencar Castelo Branco Avenue, 3972-B - Assunção, 09850-901, São Bernardo do Campo, SP, Brazil

^b School of Mechanical Engineering, University of Campinas, 200 Mendeleev Street, Cidade Universitária, 13083-970, Campinas, SP, Brazil

^c Sports Medicine Group of the Department of Orthopedics and Traumatology, University of São Paulo Medical School, São Paulo, Brazil

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ABSTRACT

The study of the human body's energy behavior has received more attention over the past years. The development of thermal infrared cameras brought new possibilities for evaluating physical exercise performance. This work aims to study the skin temperature distribution during treadmill running and cycle ergometer tests with a graded load exercise until exhaustion. Eight amateur athletes performed both tests. In addition, the ventilatory and metabolic data were measured by indirect calorimetry. The thermoregulatory system is highly requested to maintain the internal body temperature. Consequently, the average skin temperature decreased during running and cycling tests, although with a higher variation in running. It was observed that the lower limbs had a similar performance for both exercises; on the other hand, the upper limbs had a higher temperature decrease for running. This may be explained by increased body energy transfer to the environment due to higher degrees of freedom during the test. The main contribution is comparing the thermal behavior of the person's skin performing two different activities, constructing a basis for future energy and exergy analysis of the human body under physical activities complementary to the literature.

1. Introduction

The thermoregulatory system allows the human body to work in a narrow temperature range [1, 2]. The body has sensors located at the skin's surface and deeper areas, e.g., the hypothalamus that detects environmental and physiological modifications [3]. A control system maintains the body in a narrow range of temperatures to function accordingly for different environmental temperatures, activity levels, or pathologies [4, 5].

The environmental conditions influence the athletes' performance with a decrease in extreme environments [6, 7]. Thus, understanding how the athlete behaves when subjected to a specific stimulus in different environments or levels of physical activity has been the focus of many types of research [6]. In addition, the knowledge of internal temperature is crucial at these circumstances [2], where there is a unique equation of the esophagus temperature (T_{es}) as a function of the maximum and instantaneous oxygen consumption. Moreover, higher environmental temperatures increase the internal body temperature during physical activities [8].

Thermographic images have matured into a popular tool for human body skin temperature evaluation [9] due to its relatively low cost and the possibility of analyzing large areas simultaneously. Further, it is a non-invasive method that does not cause distress to the patients of the test [10, 11]. For example [12], analyzed the thermographic picture for the knee on ski athletes and concluded that the lesions might present a hyperthermic pattern. Price and Campbell [13] compared the skin temperature map among two groups, paraplegic and able-bodied. Both men and women have the same temperature distribution pattern [14]; nonetheless, females presented lower magnitudes. Finally, lower environmental temperatures lead to a higher disparity in skin dimensions [8].

One usual discovery is that the average skin temperature has a negative trend during physical activities [15]. This temperature adaptation can be related to the metabolic muscle increase [16] and the necessity of higher energy losses. Zontak et al. [17] analyzed the behavior of the hand temperature during a bicycle exercise with a constant and incremental load. Merla et al. [14] performed a test for a gradual load running. They found that the average skin temperature and the region of

* Corresponding author.

E-mail address: cekmady@fei.edu.br (C.E. Keutenedjian Mady).

interest (trunk, thigh, and forearm) decreased during the exercise. Aki-mov and Sonkin [15] tested the forehead temperature and compared it with the blood lactate threshold during a gradual load cycling, aiming at finding some correlation [18].

This article focuses on analyzing the same patient skin temperature for running and stationary bicycle tests with protocols typical for obtaining cardiorespiratory performance parameters. A distinguishing feature of this article is comparing the temperature distribution of the same individual between two different exercises. There is no consensus regarding the infrared measurements of the skin temperature [19], making this comparison a compelling contribution to this path. Moreover, few articles in the literature correspond the skin temperature with physiological variables such as metabolism and oxygen consumption for the same subject during two different tests. redFinally, to properly apply the second law of thermodynamics to the human body, it is necessary to evaluate both physical activities, since in cycling tests, there is an easiness to calculate the performed work [4], and on the treadmill, the heat and mass exchange phenomena are more prominent [5]. This purpose is in agreement with the reasoning proposed by [7].

2. Materials and methods

The tests were carried out at the Sports Medicine Group of the Department of Orthopedics and Traumatology, University of São Paulo Medical School, São Paulo, Brazil. As a result, the Research Ethics Committee approved the project of the Clinics Hospital of the University of São Paulo Medical School, São Paulo, Brazil (CAAE 2.477.702). These experiments were conducted according to established ethical guidelines, and informed consent obtained from the participant. They occurred between February and May 2018. This would not be an issue when the hot

climate in São Paulo would not interfere as much as in extreme conditions, although the laboratory has a climatization infrastructure. Still, we saw differences in internal temperature due to the size of the environment. The air temperature was 24.2 ± 3.8 °C, with a relative humidity of $63 \pm 8\%$ for the running exercise tests, and 26.6 ± 3.1 °C with a relative humidity of $58 \pm 5\%$ for cycling tests. No significant differences were found between the environmental conditions during the cycling and running tests (unpaired t-test, $p = 0.21$ for temperature, and $p = 0.13$ for humidity). The barometric pressure of the site was 688 mmHg. Eight amateur athletes with regular training and participation in sports competitions were studied. All patients participated in running and cycling on different dates. The anthropometric characteristics of the individuals, maximum oxygen consumption are in Table 1. This manuscript is a logical progression of work developed by the research group, where each method is available in [4, 5].

All athletes underwent the same warm-up and recovery regimen. However, the exercise duration varied according to each individual. The recovery phase began as soon as the athlete signaled that he/she had reached exhaustion. The application of this condition is according to the Borg Scale for subjective perception of exertion [20].

As usually carried out in the laboratory, these protocols are used in both tests for amateur athletes. A warm-up is arranged at the beginning of the test, lasting 4 min; the speed increase occurs every 1 min. After that, the speed is increased by 1.2 km/h every 2 min. The 2-minute stage duration was also used in the cycling protocol, with a 2-minute warm-up period in the beginning. In both circumstances, the exhaustion is signaled, and a recovery period begins. Figure 1 shows an example of the experiment. A more precise description can be seen in references [4, 5]

The metabolism by means of oxygen consumption and carbon dioxide production are shown on Figure 2 (a) and (b), which also includes the

Table 1. Subjects characteristics: subject ID, birth sex, mass, lean mass, height, and maximum oxygen consumption for running and cycling.

ID	Sex	Age	Mass [kg]	Lean mass [kg]	Height [m]	$V_{O_2,max}$ (running) [$\text{mlmin}^{-1} \text{kg}^{-1}$]	$V_{O_2,max}$ (cycling) [$\text{mlmin}^{-1} \text{kg}^{-1}$]
1	M	41	73.2	34.2	1.78	51.0	56.6
2	M	47	80.9	37.5	1.80	43.5	42.0
3	M	34	67.2	32.0	1.70	64.1	53.3
4	M	41	56.8	27.2	1.60	38.9	55.4
5	F	30	57.5	23.2	1.60	46.8	44.8
6	F	47	56.3	20.4	1.55	50.1	41.9
7	F	27	64.3	27.0	1.57	41.9	43.2
8	F	30	66.5	28.8	1.65	44.8	38.5
Average		37	65.3	28.8	1.66	47.6	47.0
Standard Deviation		8	8.7	5.6	0.09	7.8	7.0

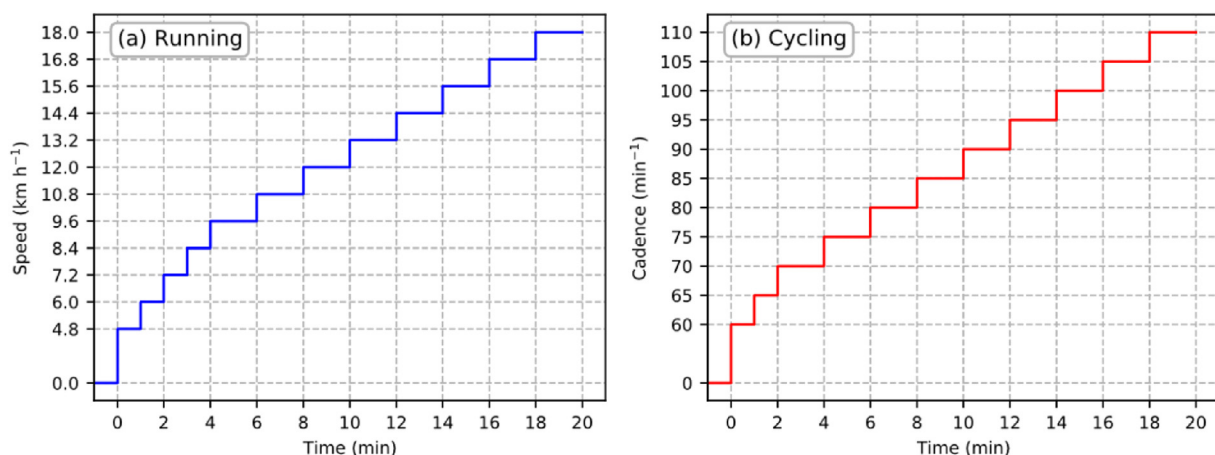


Figure 1. Protocol used for both tests: (a) running; (b) cycling.

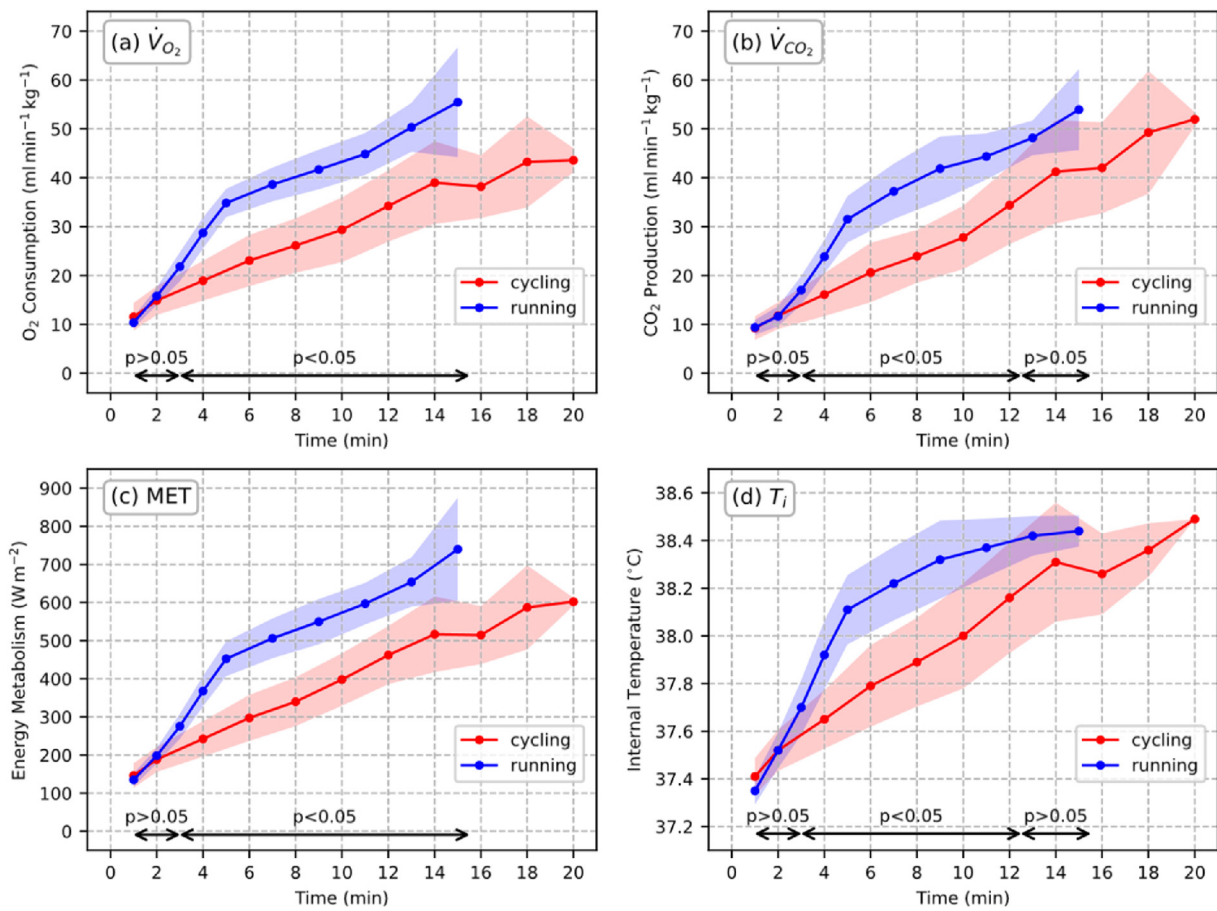


Figure 2. Metabolism, oxygen consumption, carbon dioxide production and internal temperature of the body over time.



Figure 3. Pictures using a thermal camera during cycling tests. The system was calibrated before each test with a 3-L calibration syringe and reference O₂ and CO₂ gases. Heart rate was obtained from an electrocardiogram (6.4, HeartWare™, BH, Minas Gerais, Brazil) with a 12-leads configuration. Blood pressure was measured every 2 min.

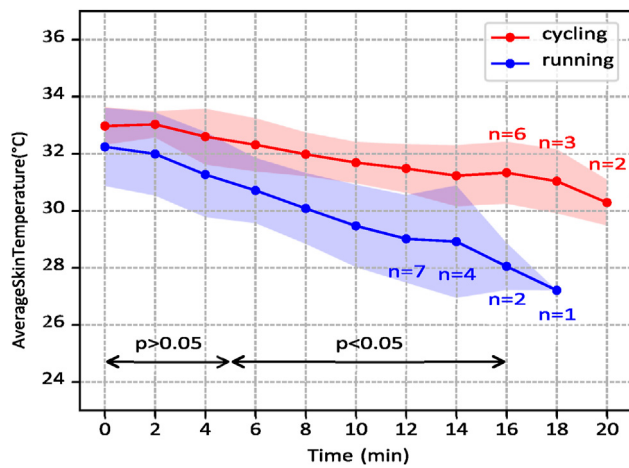


Figure 4. Average skin temperature. The dots indicate the average values of the athletes at each speed, and the colored bands indicate the standard deviation between the subjects. The number of subjects that reached the last points is indicated in the graphs. The other points are composed of the whole sample, except for the following instants for males, due to data loss: running from 0 to 4 min (n = 3); cycling at 0 min (n = 3) and 2 min (n = 2).

metabolic rate and the esophagus temperature (Figures 2(c) and (d)) using the Equation from [2]. The increase of the metabolism was higher during the running exercise. Moreover, the esophagus temperature is higher for this activity. This increased metabolism results (ante internal temperature) show the patient's need to release more energy into the environment. The intensification of energy transfer is observed by increasing the intensity of the sweat evaporation and convection mechanisms (body parts movements) higher to running tests.

At the last minute of each activity level, a video was recorded using a FLIR Camera model E60 to evaluate the skin temperature the distance between camera and subject was always the same (around 1 m). This camera measures the temperature from -20°C to 650°C, with accuracy of 2% and the cam resolution is 320 × 240 pixels. According to reference [9] the 45 works presented, 18 use the FLIR E-60 model, 40% of the articles. Figure 3 presents a thermal image taken in one of the experiments. Based on the proposal of [21], with a correction of the regions based on [22], the average skin temperature was calculated. Thus, 12 points of the body were selected, each one representative of an area. We also conducted a modification to consider that the subject is wearing tennis shoes, so the foot temperature was not considered in the

evaluation. It is important to highlight that the factors used to calculate the average temperature do not distinguish between women and men, as it is not usual in the works found in the literature. As can be seen in [22], each has a large variability between authors.

3. Results and discussion

Results indicate the skin temperature profile and its behavior over time for each test: cycling and running. For illustration, Figures 4, 5, and 6 show the skin average and temperature trends. Colored bands highlight the values between individuals and the standard deviation. The p-values for unpaired t-test comparing cycling and running groups or between males and females were included in the graphs. Values smaller than 0.05 suggest that there must be differences between the groups. It is possible to remark that the same group of individuals running in ergometric (indoor) tests achieved lower surface temperatures than cycling. Although running tests is more energy-intensive for the body, the average skin temperature is lower than cycling tests (Figure 4). One of the critical reasons is the necessity to release more heat to the environment associated with higher oxygen consumption (metabolism), and the other reason is associated with more body parts with movement. A better investigation of the first statement is in Figure 2, whereas Figure 6 compares the skin temperature of different body segments.

Figure 5 indicates the temperature of the skin for males and females over the test, where it is possible to infer that the temperature behavior is similar for both genders. These differences were also not observed in the temperatures of all limbs (p between 0.098 and 0.998 for all instants, p > 0.05); even though the data on the characteristics of the subjects (Table 1) indicate that there may be differences between genders in lean mass (p = 0.034), height (p = 0.045), and $\dot{V}_{O_{2,max}}$ in cycling (p = 0.036). Because of the similarity in temperatures, all individuals were considered as a group to compare the temperature of cycling and running activities. The mean skin temperature data at each moment, and sample with all individuals, suggest the hypothesis of normality (Shapiro-Wilk test, p between 0.066 and 0.85 for all instants, p < 0.05) and homogeneity between groups of each activity (Levene test, p between 0.054 and 0.41 for all instants, p < 0.05).

Figure 6 shows an analysis of different limbs demonstrating that the body needs to release more energy to the environment for running tests - another evidence of the skin temperature being higher over the exercise tests for running. The 16 tests performed have a long duration, and samples close to this one are usually present in other studies of this type in the literature, as can be seen in the recent systematic review by [9].

The central body parts, such as the head and trunk, have higher temperatures (Figure 6), while the more peripheral body members have

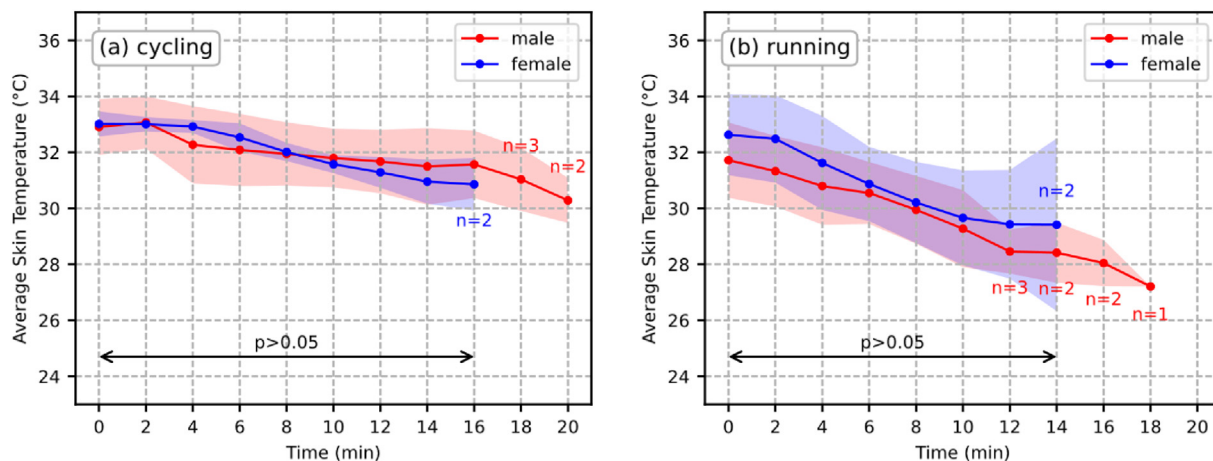


Figure 5. Average skin temperature for males and females. The dots indicate the average values of the athletes at each speed, and the colored bands indicate the standard deviation between the subjects.

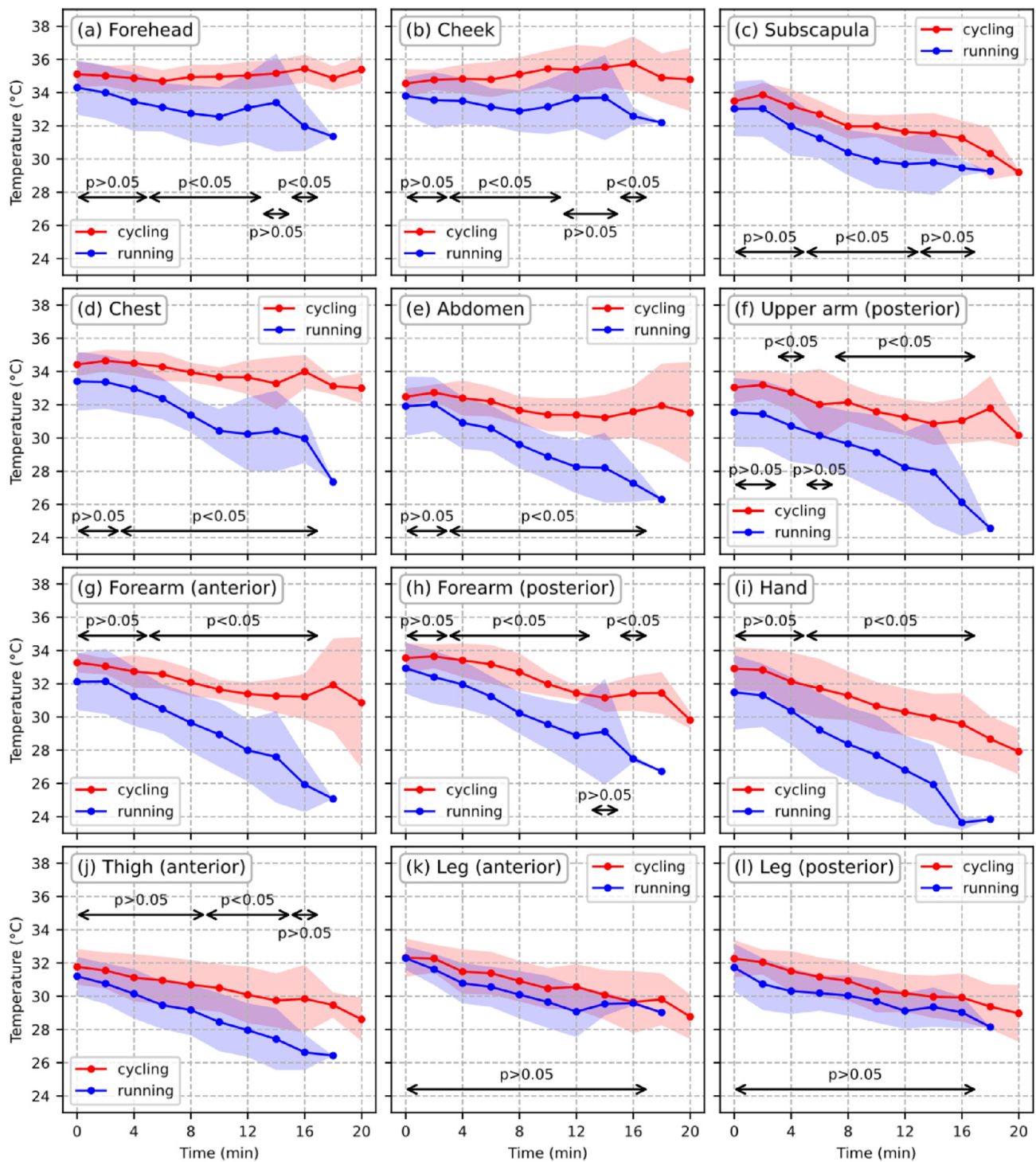


Figure 6. Skin temperature of the body's member. The dots indicate the average values of the athletes at each speed, and the colored bands indicate the standard deviation.

lower temperatures, e.g., forearms and hands. Compared with the other body areas, the hand presented the lowest temperatures. The cheek region presented an increased profile during the bicycle test, although the temperature was practically constant for the running test. Conduction of future analyses to focus on understanding this behavior may be considered. This result contradicts the thermoregulatory system actuation to increase sweat and vasodilatation capillaries at this moment. During cycling, the forehead and cheeks temperature showed a negligibly increasing pattern; nevertheless, the temperature decrease was more pronounced for the running protocol. Regarding Figure 6 (c)–(j), the skin

temperature presented a decreasing pattern for both activities. In addition, both activities for the legs (anterior and posterior) led to similar values of skin temperature outcomes.

A comparison of Figure 6(d) that shows the temperature of the chest over time with (i) highlights the contrast of temperature of the hand and trunk, making it clear that the metabolism is higher in the central area. Moreover, the members that move have a trend of temperature decrease with the member speed, which shows that the movement of the hands during the exercise decreases its temperature because there is an increase in the global heat transfer coefficient. Moreover, blood circulation is one

of the main mechanisms of the thermoregulatory system. In the central part, the blood has a higher temperature, in an adequate range for the functioning of the organs. On the other hand, arterial blood loses heat to travel to the extremities. Similar results and trend are found in accordance to references [8] and [17]. Figure 6 (k) and (l) show the increase of the convection mechanism of heat transfer because, in both tests, these were the members with higher velocities.

The temperature of the thigh region decreased for both exercises; for running, the subjects had a sharp reduction (Figure 4). One viable explanation for that might be related to the muscle activation for cycling, more pronounced in this region. Nevertheless, a phenomenological explanation, such the one carried by [23], is related to the member speed, which increases the heat transfer coefficient of the leg. This increase makes the body lose heat at a higher rate at this part, e.g., $Q = h_{conv}A_{body}(T_{skin} - T_{environment})$, where the heat transfer coefficient is h_{conv} , which grows with velocity. Interestingly, there were no significant differences in skin temperature for both the activities, assumably due to a balance among increased muscle activation and intensified heat transfer with the environment due to leg movement.

4. Concluding remarks

This article analyzed the effect of two indoor activities with calorimetry measurement with relation to time. This kind of comparison is seldom found in literature since the infra-red camera is spreading as a tool to evaluate most lesions herein there is an intent to properly evaluate these parameters to future provide an energy balance for the body. The same athletes carried out two different physical activities, cycling and running, following a similar graded protocol. This comparison is already a distinguishing feature of this article. One point of improvement is to increase the number of subjects for future analysis.

Nevertheless, from the range of the results, it was possible to conclude that:

- The skin temperature of the same athletes was higher for cycling than running, although the average metabolism was higher for the runners. The reason is related to the transfer of more energy to the environment connected with the movement of more body segments.
- For both practices, the cheek region presented a similar trend of the skin temperature over time. Interestingly the forehead delivered a matching behavior.
- The members that move have a trend of temperature decrease with its velocity. This negative trend can be related to the intensification of convection in these body parts.
- The metabolism was higher for runners. In addition, their evaluated internal temperature showed that the body's active mechanism acuates to increase the energy transfer to the environment—higher internal temperatures and lower skin temperatures, displaying a more elevated temperature gradient.

Declarations

Author contribution statement

Tatiane Lie Igarashi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Tiago Lazaretti Fernandes; Arnaldo José Hernandez: Conceived and designed the experiments; Analyzed and interpreted the data.

Carlos Eduardo Keutenedjian Mady: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Cyro Albuquerque: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare the following conflict of interests: The first author, Tatiane Lie Igarashi, is performing her PhD thesis in this area. The group from medical school (Professors Lazaretti and Hernandez) are helping us with the measurements, data analysis. The Professors from Centro Universitario da FEI (Professor Mady and Albuquerque) are Tatiane advisors, and we are helping her in each step of the process.

Additional information

The clinical trial described in this paper was registered at University of São Paulo, under the registration number "CAAE 2.477.702".

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