Time required to stabilize thermographic images at rest

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HIGHLIGHTS

- Standardizing the acclimatization time is crucial for a right T_{SK} assessment by IRT.
- Time for reaching T_{SK} balance in rest is different for young men and women.
- 10 min is enough for acclimatization when the external temperatures are not extreme.

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ABSTRACT

Thermography for scientific research and practical purposes requires a series of procedures to obtain images that should be standardized; one of the most important is the time required for acclimatization in the controlled environment. Thus, the objective of this study was to identify the appropriate acclimatization time in rest to reach a thermal balance on young people skin. Forty-four subjects participated in the study, 18 men (22.3 ± 3.1 years) and 26 women (21.7 ± 2.5 years). Thermographic images were collected using a thermal imager (Fluke®), totaling 44 images over a period of 20 min. The skin temperature (T_{SK}) was measured at the point of examination which included the 0 min, 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20. The body regions of interest (ROI) analyzed included the hands, forearms, arms, thighs, legs, chest and abdomen. We used the Friedman test with post hoc Dunn's in order to establish the time at rest required to obtain a T_{SK} balance and the Mann–Whitney test was used to compare age, BMI, body fat percentage and temperature variations between men and women, considering always a significance level of $p < 0.05$. Results showed that women had significantly higher temperature variations than men ($p < 0.01$) along the time. In men, only the body region of the abdomen obtained a significant variance ($p < 0.05$) on the analyzed period, both in the anterior and posterior part. In women, the anterior abdomen and thighs, and the posterior part of the hands, forearms and abdomen showed significant differences ($p < 0.05$). Based on our results, it can be concluded that the time in rest condition required reaching a T_{SK} balance in young men and women is variable, but for whole body analysis it is recommended at least 10 min for both sexes.

1. Introduction

In humans, core body temperature (CT) is maintained nearly constant by physiological mechanisms that maintain a balance between the internal heat and heat released to the environment [1]. These adjustments are essential to maintaining an inner temperature of approximately 37 °C, thus preserving vital metabolic functions. However, skin temperature (T_{SK}) varies widely, ranging from 10 to 42 °C [2]. The factors that affect T_{SK} include exposure to certain environmental conditions, such as extreme temperatures, humidity and solar radiation [3] for long periods performing exercise [4] and the presence of pathological conditions, such as fever [5] or cancer [6].

A cold environment causes vasoconstriction of the skin to preserve the internal heat of vital organs [1]. Under extreme heat conditions, the opposite occurs; vasodilatation facilitates heat loss,

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and the T_{SK} is elevated [7]. During exercise, when the CT is high, it is necessary to increase the mechanisms for releasing the excess body heat to avoid hyperthermia. One of the main mechanisms is increasing skin circulation, while the systolic volume is decreased. Increased flow of blood to the skin promotes heat exchange mediated by the evaporation of sweat and may increase the T_{SK} to 38 °C [8,9]. However, in a neutral thermal environment and at rest, T_{SK} tends to stay in balance, and a significant increase or decrease in its normal levels may indicate a pathological state.

The analysis of temperature using skin thermometry (thermography) is promising method in studies designed to examine the T_{SK}. Skin thermography is an objective and non-invasive procedure that measures temperature distribution using a thermal imager that receives and processes the infrared radiation emitted by the body surface [10]. The scientific use of thermography began in medical research, in which it has been used to diagnose vascular disease [11], inflammation [12], tumors [6,13], metabolic disorders and abnormalities in body temperature [12]. In the field of physical activity and sports, some studies have used the technique to study differences in thermogenesis between young and elderly people [14], the effect of exercise on hand temperature [8], and the distribution and variation of T_{SK} during progressive exercise [4].

Thermography for scientific research and practical purposes requires standardized procedures to obtain reliable images. In 2000, Ring and Ammer [15] conducted a review in which they proposed a methodology for collecting accurate thermal images. An important factor in their methodology is the time required for acclimatization in a controlled environment, which may be defined as the time necessary to achieve adequate stability in the subject's blood pressure and skin temperature. The authors recommend waiting 15 min for the optimal stabilization of T_{SK}, with a minimum of 10 min. However, when acclimatization exceeds 30 min, temperature oscillation can occur, creating an asymmetry between the left and right sides of the subject. Roy and collaborators [16] performed a study in which thermography was used to analyze the time necessary for the temperature in the region of the spine to stabilize and suggested a minimum time of 8 min and maximum of 16 min for reliable measurements [16]. The recommended acclimatization time varies between studies of skin thermometry, with periods of 10 min [14,17], 15 min [8] and 20 min [4] suggested for the subject to remain at rest in a room with controlled temperature and humidity. This variation may be influenced by environmental conditions, especially by the temperature outside the test room.

This lack of consensus [4,8,14–17] makes it difficult to determine the optimal acclimatization protocol because each study recommends a different acclimatization period to achieve a stable T_{SK} to ensure the homogeneity of results and allow consistent interpretation and comparison of results between studies. Consequently, the objective of this study was to identify the time required to achieve a stable T_{SK} at rest in a group of young men and women.

2. Materials and methods

2.1. Sample

A convenience sample of 44 physical education students at the Federal University of Viçosa participated in the study: 18 men (age: 22.3 ± 3.1 years; height: 177.3 ± 4.9 cm; body mass: 76.1 ± 9.1 kg; body mass index [BMI]: 24.3 ± 3.3 kg/m^2; and% of body fat [%BF]: 19 ± 6.2%) and 26 women (age: 21.7 ± 2.5 years; height: 163 ± 5.2 cm; body mass: 56.8 ± 5.3 kg; BMI: 21.4 ± 1.8 kg/m^2; and%BF: 28 ± 5.4%). The subjects did not report any pain or problems in their daily activities and did not consume any medication for 2 weeks before the measurements. The exclusion criteria were smoking and any pathological condition that could alter skin temperature. These requirements were verified in advance with a questionnaire. All subjects signed an informed consent form, and the ethics committee of the Viçosa Federal University approved the study procedures.

2.2. Procedures

The subjects were instructed not to consume alcohol or caffeine after breakfast, use any type of moisturizer or cream in the 6 h preceding the measurements or perform vigorous physical exercise in the 24 h preceding the measurements. The subjects were informed of these requirements when they enrolled, and their adherence to the requirements was verified with a questionnaire administered immediately before the data were collected. All measurements were performed in the morning. The T_{SK} of the regions of interest (ROI) of the body was analyzed from thermographic images following the criteria described by Ring and Ammer [15].

The evaluations were performed at the Human Performance Laboratory (LAPEH) of the Federal University of Viçosa from October to November of 2010 (spring in Brazil). The average temperature outside was 23 °C with 60% relative humidity. The subjects were instructed to change clothes into a swimsuit or shorts (men) or a top and shorts (women). They were then directed to an air-conditioned room (temperature: 19 °C ± 0.3 °C and humidity: 65.8 ± 3.8%) where the thermographic images were collected. Forty-four thermograms were recorded for each subject at 0, 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 min.

Every 2 min, 4 images were recorded, including two images (of the lower limbs and upper limb and trunk) of both the anterior and posterior sides of the body. After entering the air-conditioned room, the subject was instructed to stand on a rubber mat 4 m from the infrared imager. The subject remained standing in the anatomical position for 20 min while images were collected. The subjects were asked to avoid moving during the procedure, including sitting, crossing their arms or scratching. The ROIs analyzed included the hand, forearm, upper arm, thigh, leg and left and right sides. Additionally, the chest, abdomen, lower back and upper back were also analyzed. The average T_{SK} of each rectangular ROI was collected using Smartview software (Fluke, Everett, USA). The configuration of the rectangles was determined using anatomical landmarks as follows: (a) the hand ROI was measured from the junction of the 3rd metacarpal with the 3rd proximal phalanx to the ulnar styloid process; (b) the forearm ROI was measured from the distal forearm to the cubital fossa; (c) the arm ROI was measured from the cubital fossa to the axillary line; (d) the abdomen ROI was measured from the xiphoid process to 5 cm below the umbilicus; (e) the chest ROI was measured from the nipple line to the top edge of the sternum; (f) the thigh ROI was measured from 5 cm above the superior border of the patella to the inguinal line; and (g) the leg ROI was measured from 5 cm below the inferior border of the patella to 10 cm above the malleolus. The corresponding points on the posterior of the body were marked using a tape measure encircling the analyzed region parallel to the ground. Fig. 1 shows an example of the images taken of a single subject after 20 min with the ROIs labeled. Finally, the temperatures obtained were collected in an Excel spreadsheet (version 2010).

ATIR-25 camera (Fluke, Everett, USA) with a measurement range of −20 to +350 °C, accuracy of ±2 °C or 2% of the measurement, sensitivity of ⩽0.1 °C, infrared spectral band from 7.5 μm to 14 μm, refresh rate of 9 Hz and resolution of 160 × 120 pixels FPA (focal plane array) was used to obtain the thermograms. Before the data collection, the camera was running for the same period of acclimatization than the subject, this provided time enough for the camera sensor to make a calibration. A fixed area of the black

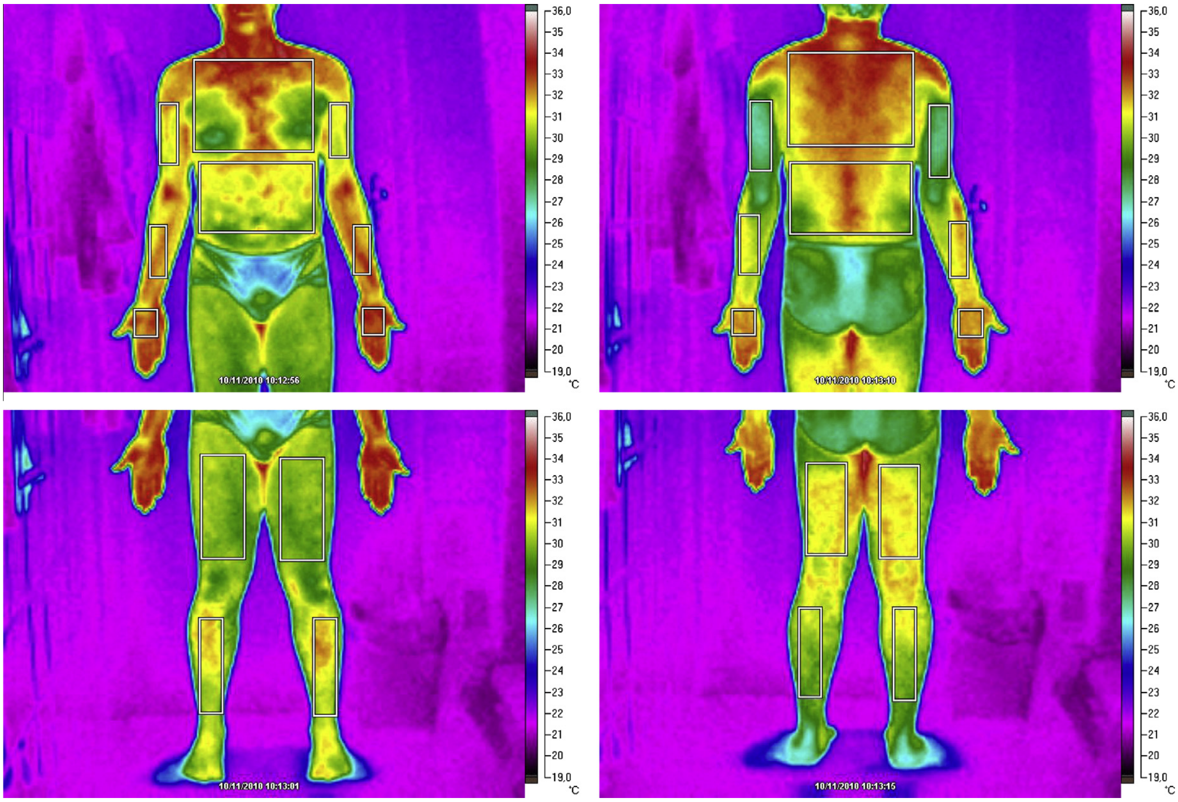

Fig. 1. Thermographic images of a 21-year-old human volunteer with ROIs highlighted.

background was taken as the reference temperature. The images were obtained using a degree of emissivity of 0.98 [18].

After collecting the thermographic data, the subjects were directed to the Division of Health at the Federal University of Viçosa, where their body composition was measured using dual energy X-ray absorptiometry (DXA) on a Lunar Prodigy Advance DXA system (GE Healthcare, Diegem, Belgium; software version 13.31) by an accredited radiology technician. Their weight was measured with an ID-M weight scale (Filizola, São Paulo, Brazil), and their height was measured with a standard wall stadiometer (Sanny, São Bernardo do Campo, Brazil).

2.3. Statistical analysis

We calculated the descriptive statistics, including the means and standard deviations, for data presentation. The sample was tested for normality using the Shapiro–Wilk test and for homogeneity of variances using the *F*-test. We used Friedman's test with Dunn's post hoc test to establish the time required to obtain T_{SK} at rest. The Mann–Whitney *U* test was used to compare age, BMI, body fat percentage and temperature between the genders. A significance level of $p < 0.05$ was used in all calculations, which were performed using SigmaPlot 11.0 software.

3. Results

The male and female samples were similar in age, but the males had a higher BMI ($p < 0.05$), and the females had a higher body fat percentage ($p < 0.05$). The T_{SK} values of the analyzed ROI and temperature differences between the start (0 min) and end (20 min) of the acclimatization period are shown in Tables 1 and 2. The female subjects had greater temperature variations than the male subjects ($p < 0.05$).

Table 1
Skin temperature (°C) of the male subjects ($n = 18$).

ROI	Minute 0	Minute 20	Δ Absolute	Δ Relative (%)
Anterior region				
Right hand	30.1 ± 1.2	30.3 ± 2.0	0.2	0.7
Left hand	30.1 ± 1.2	30.5 ± 2.0	0.4	1.3
Right forearm	30.8 ± 1.1	30.8 ± 0.9	0.0	0.0
Left forearm	30.8 ± 1.1	31.0 ± 0.8	0.2	0.6
Right arm	31.0 ± 1.2	30.9 ± 0.9	−0.1	−0.3
Left arm	30.9 ± 1.2	30.8 ± 1.0	−0.1	−0.3
Abdominal	31.7 ± 1.1	30.7 ± 0.8*	−1.0	−3.2
Pectoral	31.9 ± 0.9	31.4 ± 0.6	−0.5	−1.6
Right thigh	30.3 ± 1.2	29.7 ± 0.9	−0.6	−2.0
Left thigh	30.4 ± 1.3	29.9 ± 0.9	−0.5	−1.6
Right leg	30.3 ± 1.3	30.4 ± 1.0	0.1	0.3
Left leg	30.4 ± 1.3	30.6 ± 0.8	0.2	0.7
Posterior region				
Right hand	29.9 ± 1.6	29.9 ± 1.4	0.0	0.0
Left hand	29.6 ± 1.7	29.5 ± 1.4	−0.1	−0.3
Right forearm	31.0 ± 0.8	30.4 ± 0.8	−0.6	−1.9
Left forearm	30.7 ± 0.8	30.0 ± 0.7	−0.7	−2.3
Right arm	29.5 ± 1.3	29.0 ± 0.9	−0.5	−1.7
Left arm	29.2 ± 1.3	28.7 ± 0.9	−0.5	−1.7
Lower back	31.6 ± 0.8	30.6 ± 0.7*	−1.0	−3.2
Upper back	32.3 ± 0.8	31.7 ± 0.7	−0.6	−1.9
Right thigh	30.6 ± 1.2	30.3 ± 0.9	−0.3	−1.0
Left thigh	30.6 ± 1.2	30.3 ± 0.9	−0.3	−1.0
Right leg	30.4 ± 1.2	30.2 ± 0.8	−0.2	−0.7
Left leg	30.2 ± 1.1	30.1 ± 0.8	−0.1	−0.3

ROI: region of interest; Δ: difference between minute 20 and minute 0; mean values ± standard deviation.
* Significant difference ($p < 0.05$).

In the male subjects, there was a significant difference only in the T_{SK} of the abdomen during the period analyzed, both in the anterior ($p < 0.05$) and posterior ($p < 0.05$) regions (Table 1). In

Table 2
Skin temperature (°C) of the female subjects ($n = 26$).

ROI	Minute 0	Minute 20	⊿ Absolute	⊿ Relative (%)
Anterior region				
Right hand	28.9 ± 1.6	27.8 ± 2.1	−1.1	−3.8
Left hand	28.9 ± 1.6	28.0 ± 2.3	−0.9	−3.1
Right forearm	30.5 ± 1.1	30.3 ± 0.9	−0.2	−0.7
Left forearm	30.5 ± 1.2	30.3 ± 0.9	−0.2	−0.7
Right arm	30.7 ± 1.3	30.3 ± 0.8	−0.4	−1.3
Left arm	30.7 ± 1.3	30.4 ± 1.0	−0.3	−1.0
Abdominal	31.7 ± 1.2	30.5 ± 1.1*	−1.2	−3.8
Right thigh	28.6 ± 1.0	27.8 ± 0.6*	−0.8	−2.8
Left thigh	28.8 ± 1.2	28.0 ± 0.6*	−0.8	−2.8
Right leg	29.6 ± 1.3	29.5 ± 0.7	−0.1	−0.3
Left leg	29.7 ± 1.2	29.7 ± 0.7	0.0	0.0
Posterior region				
Right hand	29.1 ± 1.7	27.7 ± 1.7*	−1.4	−4.8
Left hand	28.8 ± 1.8	27.3 ± 1.7*	−1.5	−5.2
Right forearm	30.9 ± 1.1	29.9 ± 0.7*	−1.0	−3.2
Left forearm	30.8 ± 1.2	29.5 ± 0.8*	−1.3	−4.2
Right arm	28.6 ± 1.4	27.9 ± 1.0	−0.7	−2.4
Left arm	28.5 ± 1.4	27.6 ± 1.0	−0.9	−3.2
Lower back	31.8 ± 1.1	30.3 ± 0.8*	−1.5	−4.7
Right thigh	29.2 ± 0.9	28.7 ± 0.6	−0.5	−1.7
Left thigh	29.2 ± 0.9	28.7 ± 0.6	−0.5	−1.7
Right leg	29.0 ± 0.8	28.6 ± 0.6	−0.4	−1.4
Left leg	28.9 ± 0.8	28.5 ± 0.6	−0.4	−1.4

ROI: region of interest; ⊿: difference between minute 20 and minute 0; mean values ± standard deviation.
* Significant difference ($p < 0.05$).

the female subjects, there were significant differences in the T_{SK} of the abdomen ($p < 0.05$) and left and right thighs (right: $p < 0.05$; left: $p < 0.05$) in the anterior region and right hand ($p < 0.05$), left hand ($p < 0.05$), right forearm ($p < 0.05$), left forearm ($p < 0.05$) and lower back ($p < 0.05$) ROIs in the posterior region during the recording period (Table 2).

Figs. 2 and 3 show the evolution of the temperature during the experiment in the ROIs in which statistical differences were identified.

4. Discussion

Tables 1 and 2 show that some body regions had variations in T_{SK} greater than other regions during the 20 min of acclimatization. In the male subjects, the main changes were found in the core area, with a decrease of 3.2%. In the female subjects, differences were focused in the anterior abdomen (−3.8%) and right hand (−3.8%) and posterior right hand (−4.8%), left hand (−5.2%) and lower back (−4.7%), where the temperatures registered the largest variations. These data suggest that the stabilization period varies depending on the body region, which must be considered in thermographic analyses. Although not all body regions showed statistical differences, a clear tendency of the temperature to decrease during the 20 min period can be seen in Figs. 2 and 3. These results reveal that there are thermal adjustments in the skin; consequently, it is important to include an appropriate acclimatization period in thermographic protocols to obtain correct baseline temperature

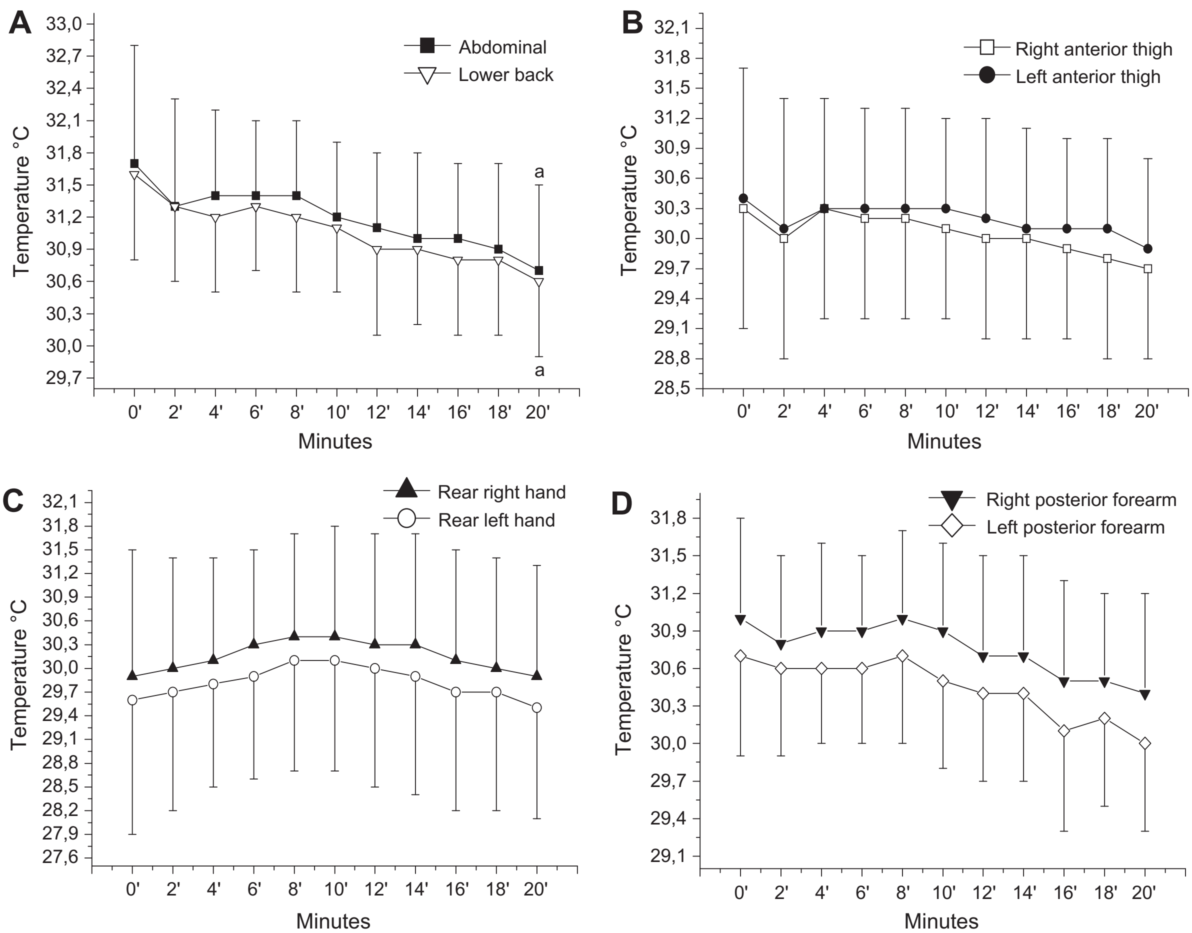

Fig. 2. Average T_{SK} for women ($n = 26$) in the abdominal region and lower back (A), right and left anterior thigh (B), right and left posterior hand (C) and right and left posterior forearm (D). [a]Significantly different from T_{SK} at 0 min; [b]significantly different from T_{SK} at 2 min; [c]significantly different from T_{SK} at 4 min;[d]significantly different from T_{SK} at 6 min;[e]significantly different from T_{SK} at 8 min; all $p < 0.05$.

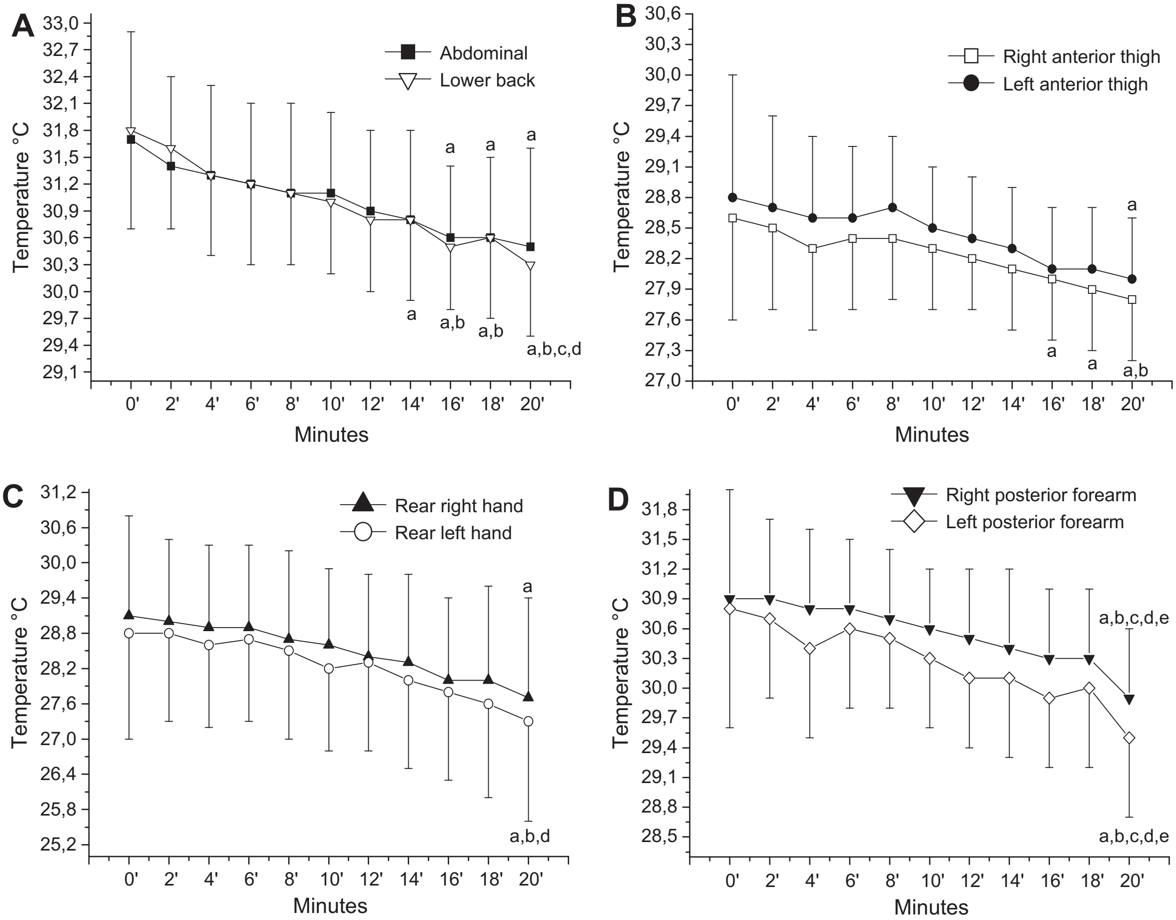

Fig. 3. Average T_{SK} for women ($n = 26$) in the abdominal region and lower back (A), right and left anterior thigh (B), right and left posterior hand (C) and right and left posterior forearm (D). [a]Significantly different from T_{SK} at 0 min; [b]significantly different from T_{SK} at 2 min; [c]significantly different from T_{SK} at 4 min;[d]significantly different from T_{SK} at 6 min;[e]significantly different from T_{SK} at 8 min; all $p < 0.05$.

records and reduce the effects of the external environmental conditions, as recommended in previous studies [15,16].

The central body regions (i.e., the abdomen and chest) exhibited higher temperatures than the peripheral regions (i.e., the hand, forearm, upper arm, thigh and leg). In the resting position, the body shifts blood flow to central regions, where vital organs such as the heart and lungs are located [1]. This behavior of the human thermoregulatory system can result in higher T_{SK} values in the central region. Our results are in agreement with previous studies because these studies also found higher T_{SK} values in the abdomen of children [19] and the elderly [20]. Kolosovas-Machuca and González [19] conducted a study to establish the T_{SK} distribution in Mexican Children (10 female and 15 male) with a thermographic camera. They reported that temperature distribution between girls and boys is very similar. On the contrary, there was a lower T_{SK} variation among children than among adults.

There was a greater decrease in T_{SK} in females than males. During the acclimatization time analyzed in this study, a significant decrease was observed in the abdominal temperature in both males and females, but only females showed significant decreases in the extremities. The higher percentage of body fat in women could be a factor influencing this result. There is evidence in the literature that regions with a greater accumulation of body fat have a lower T_{SK} [21,22]. In a thermographic survey, Savastano and collaborators [23] compared the T_{SK} of normal and obese subjects and found colder abdominal temperatures and warmer fingertip temperatures in obese subjects. The results in Table 2 do not show higher T_{SK} in the extremities of women; however, factors such as the age, body fat percentage and frequency of exercise of the sample make it difficult to compare our results with other studies.

The ability to collect reliable data in a shorter time period facilitates the use of thermography in professional activities because a long acclimatization time may be a limiting factor for the use of thermography in athletes, factory workers and hospitalized patients.

Moreover, this difference in the acclimatization time of males and females and between the central and peripheral regions suggests that the minimum time necessary to obtain a stable T_{SK} should be determined according to the goal of the measurement. Studies in the field of thermography have evaluated only the lower limbs [14], hands [8] or whole body [4]. The results of this study suggest different acclimatization times for different body areas. A shorter time may be acceptable in a study that examines only the lower limbs in males [14] than in a study that examines the whole body [4] without altering the quality of the results. The possibility of collecting reliable data in less time primarily facilitates the use of thermography in professional scenarios, because the time of acclimatization may be a limiting factor in studies of sports teams, factory workers and hospitalized patients.

The data from this study indicate an acclimatization time of at least 2 min in all regions of the men. In the women, we found acclimatization times of 4 min for the anterior thighs, 8 min for the anterior abdomen, lower back and posterior hands, 10 min for the posterior forearms and 2 min for the other regions. To facilitate the application of thermography in practice, it is recommended to choose the appropriate acclimatization time for the target.

A minimum acclimatization time of 10 min is required to investigate the whole body for both males and females. Despite clear evidence that some body parts have acclimatization times of less than 10 min, especially in males, the mechanisms that cause the different acclimatization times between genders are still unclear.

Some evidence [20,24,25] suggests that the time of exposure to the external environmental conditions influences the acclimatization time. A comparison of normative T_{SK} data collected in Taiwan [20] with values from Scandinavian regions [25] demonstrated temperature differences that were attributed to the time of exposure to cold. Exposure to either extreme cold or solar radiation can increase the time required for acclimatization [25]. It should be noted, however, that the variations in temperature are greater when the stress is generated by cold temperatures [24], suggesting that longer acclimatization times are needed in areas with a cold winter. When the subject is exposed to an external environment that is extremely cold or hot, the acclimatization time will be different from the time observed in this study, in which the external conditions were a tropical environment, and the room conditions were a temperature of 19° ± 0.3 °C and humidity of 65.8 ± 3.8%.

The use of thermography in sports medicine has focused primarily on the early detection of lesions by evaluating the temperature difference between the injured limb and contralateral uninjured limb [26]. This study provides evidence that in some areas, it is possible to reduce the acclimatization time when infrared thermography is used frequently during training periods.

Apart from the external temperature out of the laboratory, there are some physiological foundations suggesting that children [19] and senior [27] patients should have different acclimatizing times compared with adults due to the existence of thermoregulatory adjustments. Additionally, many protocols of studies, in which sample are people with certain diseases (as, for example, diabetes), they use to set the acclimatizing time on 15 min [28].

The need for a minimum acclimatization period of 10 min for the stabilization of the T_{SK} of the whole body [15] was confirmed only in females. When performing bilateral comparisons as a means of assessing the risk of injury, the time required for acclimatization may be shorter. We have found that even with a reduced acclimatization period, data collection can be performed without altering the data analysis. It should be noted that before obtaining the thermographic record, it is necessary to carefully evaluate the factors that influence the adaptation time, including the body region being assessed, patient's gender and purpose of the study.

5. Conclusion

Based on these results, we conclude that the time required in the resting state to achieve a stable T_{SK} in college-aged men and women is variable. To analyze the whole body, an acclimatization time of 10 min is recommended for both sexes. although some body parts have acclimatization times of less than 10 min, especially in males. Therefore, acclimatization time may be shorter when analyzing specific body parts. Our results may contribute to the development of methods for using thermography in scientific studies and professional practice.professional practice.

Conflict of interest

The authors declare that there are no conflicts of interest.

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