Daily rhythm of skin temperature of women evaluated by infrared thermal imaging

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ABSTRACT

It is well known that skin temperature varies due to circadian rhythm. Although there is information available for men, little is known about women's circadian rhythm in the analysis of skin temperature (Tsk) using infrared thermography. The objective of this study is to identify Tsk variations on different body regions in women through infrared thermography during the day. The sample consisted of 20 female (mean age of 20.5 ± 1.3 years, body weight of 62.2 ± 9.2 kg and height of 165.0 ± 4.7 cm). One-way ANOVA for repeated measures, and Cosinor analysis was used to determine the MESOR, amplitude and acrophase of Tsk. The regions of the forearm, upper arm and anterior and posterior legs in the lower limbs, as well as the chest and scapulae in the upper limbs showed higher variability throughout the day. In general, distal regions had lower values compared with the central regions, and the pectoral region had the lowest standard deviation values. Tsk of the analyzed regions at different times show significant differences between periods of the day in young active women, showing the minimum absolute values for both Tsk in the early morning. These results highlight the need to consider the time of day when analyzing women's skin temperature. Future studies should report the time of day when the images were collected, as well as consider the circadian rhythm when making comparisons.

1. Introduction

Daily circadian rhythms are not only associated with a response to changes in the physical environment during 24-h, they are generated by an internal system and allow for anticipation and preparation for changes related to night-time and daytime periods (Vitaterna et al., 2001). The suprachiasmatic nucleus (SCN) located in the anterior hypothalamus is responsible for this internal circadian rhythm that comes through the transcription-translation feedback of genes that act in the nucleus neurons (Siepka et al., 2007), resulting in circadian oscillations observed in organs and tissues such as the heart, lungs, liver, intestines, adrenal gland and adipose tissue (Garaulet and Madrid, 2009).

In order to study the physiological circadian oscillations of human body, the MESOR (Midline Estimating Statistic of Rhythm), acrophase and circadian rhythm amplitude are generally used (Refinetti et al., 2007). These indicators have been applied to indentify changes driven by the biological rhythm in measures such as the rest-activity cycle (Carvalho Bos et al., 2003), melatonin level, cortisol production and core body temperature (Tc) (Holstra and de Weerd, 2008).

The study of Tc has important implications for determining changes in circadian rhythm due mainly to its representative capacity of biological rhythms in general (Waterhouse, Fukuda et al., 2012). The influence of circadian rhythms on Tc fluctuations are probably related to the action of the Central Nervous System (CNS) on the hypothalamic thermoregulatory centers, changing the thresholds for cutaneous vasodilation and sweating (Weinert and Waterhouse, 2007).

In participants with a normal lifestyle, the Tc has higher values between 14 h and 20 h, the acrophase around 17 h, and the bathypase at 5 h (Krauchi and Wirz-Justice, 1994). Rectal temperature (Trectal) (Dijk et al., 2012; Monk et al., 1995; Thomas et al., 2004), axillary temperature (Taxillar) (Edwards et al., 2002; Thomas et al., 2004), gastrointestinal temperature (Tgastrointestinal) (Edwards et al., 2002), oral
temperature \(T_{\text{mean}}\) (Edwards et al., 2008) and skin temperature \(T_{sk}\) (Fronina and Rybakov, 2011) are often used to establish specific curves of circadian variation in body temperature. However, it has been impossible for us to identify works applying infrared thermography (IRT) to establish the \(T_{sk}\) profile of women throughout the day.

IRT captures and processes the infrared radiation from the body surface by a thermal imager (Vainer, 2005), being considered a non-invasive procedure that can be used as an important alternative technique for studying daily temperature variation. Its advantages are the absence of physical contact with the evaluated subject and allows for an immediate general or specific analysis focused on a certain part of the body.

Early studies using IRT in humans were aiming to diagnose vascular disease (Soulen et al., 1972), determination of burn depth (Medina-Preciado et al., 2013), inflammation (Anbar, 1998), tumors (Acharya et al., 2012; Levy et al., 2010), metabolic disorders such as diabetes (Martínez-Jiménez et al., 2013), and abnormalities in body temperature (Anbar, 1998). Recently, our laboratory used IRT to establish the thermographic profile of football players (Marins et al., 2014b), to compare \(T_{sk}\) between genders of the population (Marins et al., 2014a), to compare different methods to measure \(T_{sk}\) in exercise situations (Fernandes et al., 2014), and to determine daily oscillations of skin temperature in military personnel (Costa et al., 2016; Marins et al., 2015). These studies were conducted only for the purpose of assessing \(T_{sk}\) at a single time of day in order to avoid the bias of circadian rhythms; thus, setting the daily thermal changes of skin in women can contribute to better understanding the results of upcoming studies, both in the medical field as well as in sports.

Therefore, the aim of this study is to establish daily \(T_{sk}\) variations and to identify MESOR, amplitude and acrophase of \(T_{sk}\) in different regions through infrared thermographic technique during the circadian rhythm of active young women.

2. Materials and methods

2.1. Participants

The sample consisted of twenty young women [age: 20.5 ± 1.3 years, height: 165.0 ± 4.7 cm, weight: 62.2 ± 9.2 kg, BMI: 22.8 ± 3.1 kg/m², and body fat: 20.8 ± 4.4% body fat] who volunteered without receiving any financial reward after being informed about the study dynamics and signed a free and informed consent form. The ethics committee of the Federal University of Viçosa approved the study procedures, with the registration number 40928260540, which followed the principles outlined by the World Medical Assembly Declaration of Helsinki.

The evaluated participants did not report any pain or problems with their daily activities, were not consuming any medication that could interfere with Tsk in the two weeks before the measurements, they performed the same physical training for at least six months, were non-smokers, and did not report any pathological condition that could alter the Tsk. Menstrual cycle phase was not controlled during the experimental session. However, the stage of menstrual cycle in each participant was noted and a range of stages was tested during the experiment, thus providing a representative sample of menstrual states in the results.

2.2. Procedures

The same daily routine was employed to homogenize dynamic data collection. The exclusion criteria were (a) any bone, muscle or joint injury in the two months prior to data collection; (b) history of kidney problems due to fluid accumulation in the body, causing inflammation in several body regions; (c) currently undergoing physiotherapy treatment; (d) tobacco or drug consumption (antipyretics or diuretics), or food supplements that might interfere with homeostasis hydration or body temperature in the previous two weeks; (e) burns on the skin, regardless of their degree; (f) undergoing any local treatment with creams,ointments or lotions; and (g) pain, fever symptoms, or sleeping disturbances in the previous seven days; (h) consumption of alcohol or caffeine, moisturizing the skin or conducting any vigorous exercise in the 24-h period before the first collection period of thermographic images.

The participants were also asked to wear light clothes that would not influence Tsk on the day of the test, but wear shorts and a top during the period in which they were in the laboratory room for recording the thermal images. They were asked to avoid the influencing factors related to IRT measurement (alcohol beverages, smoking, caffeine, large meals, ointments, cosmetics and showering), which were confirmed verbally before each assessment (Moreira et al., 2017).

Samples were collected in the campus infirmary laboratory at five periods of the day, with an interval of 4 h between periods. The collection times were at 7, 11, 15, 19 and 23 h, so that there was no interference with mealtimes, having periods of at least 2 h between meals and thermal data collection.

After arriving to the data collection room, the participants remained at rest in a sitting position for five minutes, and then were led to a heated room (temperature: 23.0 ± 1 °C; humidity: 50.0 ± 5%), where they remained standing for ten minutes to stabilize their Tsk (Marins et al., 2014c). During the acclimation period, participants were instructed and supervised to remain standing without crossing their arms, to avoid any sudden movements, scratching or rubbing their hands. After the acclimation period, they were asked to position themselves on a platform at a distance of 4 m from the imager to record four thermograms at the five collection periods (7 h, 11 h, 15 h, 19 h and 23 h), two thermograms of lower limbs and two thermograms of upper limbs. The camera was positioned perpendicular to the region of interest. Moreover, the same evaluator collected the thermal images and selected the ROIs. Fig. 1 shows the considered regions in the anterior and posterior areas of the lower and upper body.

The temperature was obtained for each region following the criteria described by Ring and Ammer (Ring and Ammer, 2000). Analyzed body regions were chest, abdomen, lower back and right and left scapulas, anterior and posterior right and left hands, and forearms and arms in the upper body; furthermore, anterior and posterior thigh and leg on the right and left sides were selected in the lower limbs. These regions were selected through SmartView software, as shown in Fig. 1.

The following anatomical limits were determined for configuration of the areas: a) hand: the junction of 3rd metacarpal with the 3rd proximal phalanx and styloid process of the ulna; b) forearm: first distal third of the forearm and cubital fossa; c) arm cubital fossa and axillary line; d) abdomen: xiphoid and 5 cm below the umbilicus; e) chest: 5 cm above nipple line and top edge of the sternum; f) thigh: average thigh line and 5 cm above the upper edge of the patella; g) leg: 10 cm below the lower edge of the patella and 10 cm above the malleolus. The corresponding points of the posterior region of the body were marked with a tape measure parallel to the floor, making a circumference of the analyzed region. Fig. 1 shows an example of thermograms with all the considered regions. Finally, the temperatures were tabulated in a spreadsheet for further analysis where the mean skin temperature of each ROI was used.

The device used to obtain the thermographic images was the TIR-25 Imager (Fluke®, Everett, USA), with a measuring range of −20 to +350, a precision of ±2 °C or 2%, sensitivity ≤0.1 °C, infrared spectral band of 7.5–14 µm, 9 Hz refresh rate, and a resolution of 160 × 120 pixels. The images were subsequently analyzed using SmartView® software, version 2.1. The images were obtained setting the emissivity of the recorded surface at 0.98 (Anbar, 1998).

After the thermographic data first collection, participants remained in the room to measure anthropometric data according to the methodological guidelines proposed by the International Society for the Advancement of Kinanthropometry (International Society for
Advancement in Kinanthropometry- ISAK (Marfell-Jones et al., 2012). The triceps, suprailiac and medium thigh skinfolds were obtained with a Lange skinfold caliper, and weight and height were measured with a R-110 scale (Welmy, Santa Barbara d’Oeste, São Paulo, Brazil). All the anthropometric material was properly calibrated before use.

2.3. Statistical analysis

Descriptive statistics with mean and standard deviation values of regions were calculated. Normality and homogeneity of the data variance was tested by the Shapiro-Wilk test and F-test, respectively indicating normal data allowing for a One Way ANOVA for repeated measures analysis followed by post-hoc Tukey test to determine significant differences between the different times of the day for each regions. A significance level of p < 0.05 was adopted for all calculations.

Next, Cosinor analysis was used to determine MESOR, amplitude and acrophase for Tsk during the 24-h period. Acrophase is a measure of time elapsed between a time (phase) of reference and the stage where there is the greatest probability of a higher value of the variable being found from the sine-shaped data curve. MESOR is the average value of the rhythmic function (e.g. cosine curve) fitted to the data. Amplitude is the distance between the maximum of the fitted curve and the MESOR (Refinetti et al., 2007). Cosinor Periodogram 2.7 software was used for Cosinor analysis, and the SigmaPlot 11.0 software was used for all other calculations.

3. Results

The Figs. 2 and 3 show the mean, standard deviation and variations of Tsk for anterior and posterior regions at different periods of the day. There was a statistically significant effect of time on Tsk for all regions of interests (p < 0.001). The right hands and anterior and posterior left hands were the regions that showed the greatest differences in Tsk values between the hours 07 h and 23 h, with fluctuations of 3.1–3.0 °C and 2.7–3.0 °C, respectively. The region of the forearm, upper arm and anterior and posterior legs were the regions that showed the most variability throughout the day, as well as the chest and scapula regions. Average values are lower in the distal regions of the hands and forearms, and also in areas of the anterior and posterior thighs compared with regions of the chest, abdomen, scapulas, lower back, while the chest had the lowest standard deviation values.

Tsk at 11 h, 15 h, 19 h and 23 h were all significantly different (p < 0.05) from the measurement at 7 h in the forearm, upper arm, thigh, anterior and posterior legs, scapulae, and abdominal and pectoral muscles, showing an increase of Tsk in the morning until 15 h, and subsequently a decrease, but Tsk in the posterior right arm was not significantly different (p = 0.063) between 11 h and 7 h.

Except for the anterior hands and left anterior forearm (Fig. 2A, B), the temperature reduction between the 23 h and 15 h was statistically significant (p < 0.05) in the right anterior forearm, anterior arms, chest, abdomen, thighs and anterior leg regions, while in the posterior view this behavior was repeated in the forearms, arms, scapulae and legs. The largest absolute difference in °C between 15 h and 23 h occurred in the anterior and posterior region of the arms, with 1.1 and 0.9 °C in the right side, and 1.0 and 1.1 °C in the left side. Furthermore,
the smallest difference between 15 h and 23 h occurred in the posterior thigh with a difference of 0.4 °C.

Figs. 4A and B show the percentage of cases of lowest temperature recorded at different times of the day for the anterior (A) and posterior (B) regions respectively, indicating that both anterior and posterior regions presented a lowest Tsk at the 7 h.

Fig. 5 shows the mean temperature values of the skin (TMsk) obtained using the Tsk of four regions (abdomen, the right anterior thigh, right posterior arm and right posterior leg). There was a statistically significant effect of time on TMsk (p < 0.001). The results show that TMsk for 7 h are statistically lower (p < 0.05) than other times. The lower TMsk values were obtained in the early morning, with increases in the afternoon and a peak temperature at 15 h; after this maximal value, there was a drop in TMsk, presenting a significant difference (p < 0.05) between 15 h and 23 h.

Table 1 presents the data of average and standard deviation of the temperatures obtained in the different moments of the day and the results of cosinor analysis obtained through means. The MESOR values indicate a similarity in Tsk values between the left and right side of the body, while the largest amplitude values are in the hands. Acrophase
Fig. 3. Average $T_a$ in the posterior ROIs of women ($n = 20$); R = right; L = left. (a) Significant differences compared to 7 h. (b) Significant difference compared to 11 h. (c) Significant difference in relation to 15 h. (d) Significant differences compared to 19 h. ($p < 0.05$). Legend (1) letters and standard deviation above the graph line; (2) letters and standard deviation below the graph line.
results shows that regions have higher Tsk near the beginning of the night.

4. Discussion

The Tsk obtained by IRT during different periods of the day show variations in all the regions, which corroborates other studies that also found variations in Trectal (Dijk et al., 2012; Monk et al., 1995; Thomas et al., 2004), Taxillar (Edwards et al., 2002; Thomas et al., 2004), Tgastrointesinal (Edwards et al., 2002), Toral (Edwards et al., 2008) and Tsk (Pronina and Rybakov, 2011) during the day characterized by circadian rhythms. Unlike most of the aforementioned studies that monitored only one site or variable (i.e. core temperature), this study reports that circadian variation occurs in different magnitudes in every regions, and not equally across the body surface. So, given the statistical variations presented, it seems clear that each body region responds in a specific way according to the time of day (Figs. 2 and 3).

The lowest Tsk values were consistently obtained in the morning (7 a.m.) in the right anterior thigh, posterior right and left thighs at 7 h for all women evaluated (Figs. 4A and B); on the other hand, 23 regions showed the highest Tsk at 15 h. Lower Tc in the morning followed by an increase in the afternoon was also found by Edwards et al. (2002). When Tsk was compared with Trectal to identify Tc during the circadian rhythm, the authors concluded that both variables had similar behavior during the circadian rhythm, but average values of Tsk were smaller than Trectal (Edwards et al., 2002).

The work of Monk et al. (1995) using Trectal in young and old adults, Edwards et al. (2008) who used sublingual clinical thermometer and Pronina and Rybakov (2011) who obtained Tsk through a sensor attached on the shoulder of children and young adults are all examples of papers that used different thermal recording techniques and also had lower temperatures in the morning and increases in the afternoon. Thus, the similarity between our findings and the results of these studies indicate a clear signal that the IRT technique may be an important tool for evaluating the thermal variations not only for the whole body, but especially in certain body regions when a local analysis is required.

A lower temperature in the morning compared to other times of the day is related to several metabolic adjustments. For Dijk et al. (2012), endocrine responses of melatonin and cortisol are factors involved in the process of temperature changes (Dijk et al., 2012). The body temperature decreases, while cortisol and melatonin elevation during the night are related to physical and mental restoration during sleep (Dijk and Lockley, 2002). The increased body temperature, low melatonin secretion levels, and high cortisol levels during the day phase promote high physical and cognitive performance (Wright et al., 2002).

Daily variations of Tsk found in our study suggest different thermoskin adjustments depending on regions. Despite the variations registered throughout the day in the central region and in the extremities, especially in hands (Figs. 2A and 3A), these variations can be justified by the fact that the hands are areas with a higher vasomotor function of heat loss (Machado-Moreira et al., 2008).

Even when Tsk variations have been registered in regions located on the trunk (chest, abdominal, lower back and scapulas), Tsk increments in these regions have not exceeded the Tsk increases in distal regions during the circadian rhythm. The causes of increased temperature in the central regions may be related to the concentration of the major organs in the abdominal and thoracic region, which are the main heat producer in resting conditions (Campbell, 2011). Other studies corroborate the results obtained in this work, showing greater Tsk values in the abdomen of children (Kolosovas-Machuca and Gonzalez, 2011), adults and the elderly (Niu et al., 2001). These results are important because they indicate that the thermography technique is also sensitive to capture this type of body heat distribution behavior, with higher temperatures in the central regions and lower temperatures in the extremities.

The peak Tc at approximately 17 h has been previously observed through Tsk in proximal regions and Trectal (Krauchi and Wirz-Justice, 1994), as well as by Tsk (Edwards et al., 2008). This time is close to what was found in the present study, in which 23 of the 25 analyzed
regions showed their acrophase between 17 h and 19 h. Only the anterior region of the hands presented their acrophase after 19 h. Statistically, one can also consider the existence of a thermal plateau between 15 h and 23 h for identifying Tsk variability throughout the day.

The distribution of Tsk should display a contralateral symmetry between the hands, forearms, upper arms, thighs and legs (Herry and Prize, 2004). This symmetry appears to also occur during the circadian rhythm. The results of this study showed a balance of Tsk in hemobodies in the examined regions, which may be justified due to a balanced neural response for thermoregulatory adjustments in both hemobodies. An example of this thermal bilateralism is that few sites, especially the upper distal limbs, showed a difference greater than 0.5 °C (Table 1) between the right and left sides of the body, which is a critical difference for thermal asymmetry according to Niu et al. (2001).

IRT is used in sport to detect possible contralateral Tsk differences between right and left hemispheres in order to predict an injury risk (Hildebrandt et al., 2010). Thus, due to circadian variations in Tsk presented in this study, the professionals who use IRT for longitudinal monitoring of Tsk should always perform the evaluations at the same time of day and register the time when the image was recorded in order to avoid errors in thermogram interpretation.

Average skin temperature (TMsk) is often used to compare and establish a relationship with Tc (Wakamura and Tokura, 2002). The estimation is obtained by a number of temperature sites on the skin, since
it is often not feasible to determine the $T_{sk}$ throughout the whole body surface. After employing the formula proposed by Choi et al. (1997), modified for calculating the $T_{Ma}$ from IRT results and determining the circadian variation of $T_{Ma}$ throughout the day (Fig. 5), the differences observed indicate the importance of setting the same time of day to estimate $T_{Ma}$, in the same way as when using the partial $T_{sk}$ values of the regions used in the equation.

The absence of similar studies using IRT makes it difficult to compare our results with others found in the literature. Previous studies using contact sensors has shown a circadian variation of $T_{sk}$, however, these studies evaluated only one or few regions (Promina et al., 2015; Bracci et al., 2016; Cuesta et al., 2017). Although thermocouple is the most widely used method to measure $T_{sk}$, its functioning is different from IRT. The principle of thermocouple is based on the phenomenon known as the Seebeck effect (Childs (2001), which occurs when there is a potential difference between materials of two conductors (or semi-conductors) at different temperatures. It is important to consider that the temperatures measured by IRT differ from thermocouple devices when individuals are at rest in a thermo-neutral environment and this difference increases when exposed in hot environments, physical exercise or pathologies (Bach et al., 2015). In our study, the absolute differences exhibited lower $T_{Ma}$ and $T_{sk}$ in the early morning, and higher values followed by an increase in the afternoon, with maximal values between 17 and 19 h in most of the considered regions. In this way, the use of IRT confirms the findings of other studies that used different methods to measure $T_{Ma}$ and $T_{sk}$.

This study has some limitations. The results should be analyzed with caution because it was considered only the variations of $T_{sk}$ between 7 h and 23 h, which may have some implications. Firstly, as a less than a full cycle was analyzed, the results of MESOR may be affected; and secondly, the impact of sleep time on $T_{sk}$ variation cannot be analyzed. It is important to note, however, that it is not the sleep time but rather the awake time which is most influenced by exogenous agents that may impact circadian rhythm (Weinert and Waterhouse, 2007). In this way, the data presented provide a portrait of the $T_{sk}$ circadian rhythm during the day, considering a normal routine. In addition, the participants did not have their menstrual cycles controlled, however the various stages of the menstrual cycle in the analyzed participants dilutes this possible influence on the data. Given the complexity of thermoregulatory responses against other internal and external factors, it is suggested that further work be conducted to investigate the daily $T_{sk}$ profile recorded by IRT in women of various age groups at different stages of the menstrual cycle and menopause.

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Conflict of interests

The author(s) declare(s) that there is no conflict of interest.

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