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Journal of Thermal Biology

Thermal body patterns for healthy Brazilian adults (male and female)

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A B S T R A C T

The aim of this study was to establish the skin temperature (T_{sk}) thermal profile for the Brazilian population and to compare the differences between female and male Brazilian adults. A total of 117 female and 103 male were examined with a thermographic camera. The T_{sk} of 24 body regions of interest (ROI) were recorded and analyzed. Male T_{sk} results were compared to female and 10 ROI were evaluated with respect to the opposite side of the body (right vs. left) to identify the existence of significant contralateral T_{sk} differences (ΔT_{sk}). When compared right to left, the largest contralateral ΔT_{sk} was 0.3 °C. The female vs. male analysis yielded significant differences ($p < 0.05$) in 13 of the 24 ROI. Thigh regions, both ventral and dorsal, had the highest ΔT_{sk} by sex (≈ 1.0 °C). T_{sk} percentile below P_5 or P_{10} and over P_{9o} or P_{95} may be used to characterize hypothermia and hyperthermia states, respectively. Thermal patterns and T_{sk} tables were established for Brazilian adult men and women for each ROI. There is a low T_{sk} variation between sides of the body and gender differences were only significant for some ROIs.

Keywords:

Infrared thermography

Skin temperature

Thermal symmetry

Brazilian profile

Highlights

Establishing a standard thermographic profile is crucial for an appropriate interpretation.

Standardization of the protocols leads to obtain comparable results.

Gender seems to be a determining factor for the skin temperature of the thigh, calf and dorsal arm.

We suggest the value of 0.5 °C as a normal limit for contralateral $\Delta T_{sk.}$

1. Introduction

Infrared Thermography (IRT) is a technique that allows visualization of the heat radiated from a body using infrared emission, a spectrum that is not visible to humans (Hildebrandt et al., 2010; Pascoe et al., 2008). This technology is used in the medical field, where it can provide doctors with information about the physiological responses associated with skin temperatures (T_{sk}) to identify different types of pain syndromes (Al-Nakhli et al., 2012), changes in the T_{sk} (Park et al., 2012, Howell et al., 2009, George et al., 2008), vascular deficiencies (Huang et al., 2011; Brioschi et al., 2003), or neurological problems (Zaproudina et al., 2006); provide assistance in cardiac interventions (Brioschi et al., 2003); or help in cancer diagnosis and monitoring (Arora et al., 2008). Recently, thermography has also been proposed as a way to prevent sports injuries (Sillero-Quintana et al., 2011; Gomez-Carmona et al., 2011), control training load (Akimov et al., 2010), or study thermal responses during and after exercise (Hildebrandt et al., 2010; Merla et al., 2010; Marins et al., 2012$_{ab}$; Merla and Romani 2008; Garagiola and Giani, 1990). Most thermography studies evaluate contralateral T_{sk} differences (ΔT_{sk}) existing in pathological conditions such as cancer (Acharya et al., 2012; Arora et al., 2008) or spinal disorders (Ammer, 2010). In those cases, contralateral ΔT_{sk} is usually the main focus. A good thermal state of the body structure is based on thermal symmetry between symmetrical parts of the body always between a temperature range. Higher contralateral differences in Tsk could mean an imbalance or impairment between symmetrical parts of the body.

There are clear indications that thermography is a valid (Ammer and Ring, 2008; Zaproudina et al., 2006) technology, which is both non-invasive and low-cost, that rapidly produces a non-contact recording of the energy irradiated from the body (Han et al., 2010; George et al., 2008; Jiang et al., 2005). It has been recently shown that a high resolution thermal image can provide interesting information about the complex thermoregulation system of the body (Pascoe el al., 2008). The development of fast and easy IRT monitoring tools allows us to obtain a general or local thermal profile of humans, including their main body regions of interest (ROI).

For an appropriate interpretation of an individual thermographic profile, it is necessary to establish a reference thermal pattern for each population group (for example, by age group, by race or for a particular disease). Although these types of studies are uncommon, some studies in adult populations with different ethnic characteristics such as Chinese (Zhu and Xin, 1999), Finish (Zaproudina et al., 2008), Portuguese (Vardasca, 2011), Taiwanese (Niu et al., 2001), or Mexican children (Kolossovas-Machuca and Gonzales 2011) have attempted to establish population thermal patterns. Having a thermal reference allows us to evaluate normal T_{sk} in different body segments and the proportion of bilaterally (side-to-side). According to Niu et al. (2001) and Uematsu (1985), a ΔT_{sk} greater than 0.5 °C between two body segments strongly indicates a functional disorder in the assessed ROI.

Thermographic records also show the complex physiological response to strength training involving the skeletal muscle (metabolism), the cardiovascular system (blood flow), the nervous system (central and local) and the adrenergic system (Johnson and Kellogg, 2010; Cheuvront et al., 2010). The regulation of body temperature to maintain internal temperature at adequate levels is complex. The hypothalamus and multiple sensors and effectors act together, providing feedback to control the system (Werner et al., 2010) and consequently affect the T_{sk}.

To adequately interpret thermographic data, a set of internal factors such as age (Falk and Dotan, 2011; Charkovduran, 2010; Niu et al., 2001), gender (Falk and Dotan, 2011), level of fitness (Magalhaes et al. 2010; Merla et al, 2005), and external factors including the degree of hydration (Charkovduran, 2010), clothing (Gonzales et al., 2011) or environmental conditions (Moris et al., 2005) should be considered. Furthermore, an appropriate protocol for infrared imaging is crucial to obtain quality thermographic images (Ammer and Ring, 2008). Our study has followed their guidelines considering the dark background, the distance from the camera, the position of the camera, the range of temperature and the resolution.

Data for T_{sk} can help to establish standards of normality in different parts of the body. Establishing the standard thermal patterns in different population groups may help to identify hyperthermic or hypothermic areas, to detect contralateral ΔT_{sk} as signs of functional problems or diseases and to determine the relationships between central and peripheral temperatures, thus reducing the subjectivity in the evaluation. Establishing the values for normal resting conditions may also contribute to understanding the thermal changes of the skin during and after any physical activity.

Local thermal information is relevant not only for practitioners but also for sports physiotherapists, dieticians and coaches who advise and provide training and therapy to normal people or athletes.

Given that age factor (Kolosovas-Machuca and Gonzales, 2011; Niu et al., 2001) is crucial in thermal responses, specific data by gender for well-defined age groups such as children, adolescents, adults and elderly people are required. Therefore, the aims of this study were (a) to establish the T_{sk} data for Brazilian adults and (b) to compare ΔT_{sk} between males and females.

2. Material and methods

2.1. Participants

A sample of two hundred and twenty young adults participated in the study, 103 men [age: 21.3 ± 2.19 years, height: 1.78 ± 0.7 m, body mass: 72.5 ± 7.8 kg, and Body Mass Index (BMI): 23.0 ± 2.3 kg/m^2] and 117 women [age: 21.9 ± 2.2 years, height: 1.64 ± 0.05 m, body mass: 59.8 ± 7.1 kg, and BMI: 22.2 ± 2.4 kg/m^2]. They did not report any pain or problems in their daily activities and did not consume any medication in the 2 weeks prior to the measurements. Exclusion criteria were smoking or any pathological condition that could alter the T_{sk}. All individuals signed a consent inform and the ethics committee of the Viçosa Federal University, Brazil approved the study procedures.

2.2. Procedures

Before the assessment, subjects were instructed to avoid consuming alcohol or caffeine, using any type of moisturizer or cream and performing vigorous physical exercise in the 24 hours preceding the measurements. These recommendations were given on the day of enrollment and were assessed via questionnaire immediately before the early morning data collection.

The T_{sk} of the body ROI were obtained from thermographic images following the criteria described by Ring and Ammer (2012; 2008). Evaluations were performed at the Human

Performance Laboratory (LAPEH) of the Federal University of Viçosa from October 2010 to March 2011 (spring and summer season in Brazil). Subjects were instructed to change clothes, using a swimsuit or shorts (men) or a top and shorts (women). Soon after, they were directed to a conditioned room (Temperature: 21 °C ± 0.3 °C and humidity: 67.8 ± 3.8%) where, after 15 minutes of adaptation to the room conditions, four thermograms for each subject were recorded including two images each (lower limbs and trunk/upper limb) of the anterior and posterior sides of the body.

Just after entering the data collection room, the subject was instructed to stand on top of a rubber mat that was 4 m away from the infrared imager and 0.4 m from the wall. The wall was covered with a black background to avoid any kind of reflection. Subjects were asked to refrain from making any type of movement, sitting, crossing their arms or legs, or scratching throughout the procedure.

The T_{sk} analysis included the left and right sides of the hand, forearm, upper arm, thigh and leg. In addition, T_{sk} data of the chest, abdomen, lower back and upper back were also collected. The T_{sk} averages from 24 ROI were collected by the software Smartview® (Fluke®, Everett, USA). The ROI were rectangles determined by anatomical landmarks, namely: a) hand: the junction of the 3rd metacarpal with the 3rd proximal phalanx and the ulnar styloid process, b) forearm: the distal forearm and cubital fossa c) arm: cubital fossa and axillary line, d) abdomen (and low back): xiphoid process and 5 cm below the umbilicus; e) chest (upper back): nipple line and top edge of the sternum; f) thigh: 5 cm above the superior border of the patella and the inguinal line; g) leg: 5 cm below the inferior border of the patella and 10 cm above the malleolus. The points corresponding to the posterior region of the body were marked using a tape measure parallel to the ground. Figure 1 shows an example of images taken of the evaluated ROI.

The thermographic imager was a TIR-25 camera (Fluke®, Everett, USA) with a measurement range of -20 to +350 °C, an accuracy of ± 2 °C or 2% of the measurement, a sensitivity below 0.1 °C, an infrared spectral band from 7.5 µm to 14 µm, a refresh rate of 9 Hz and a resolution of 160 x 120 pixels FPA (Focal Plane Array). Images were obtained assuming a skin emissivity of 0.98 (Ring and Ammer, 2012) and analyzed using the Smartview ® software, version 3.1.

After thermographic data collection, the subjects were weighed with an ID-M scale (Filizola®, São Paulo, Brazil), and their heights were measured with a standard wall-stadiometer (Sanny®, São Bernardo do Campo, Brazil).

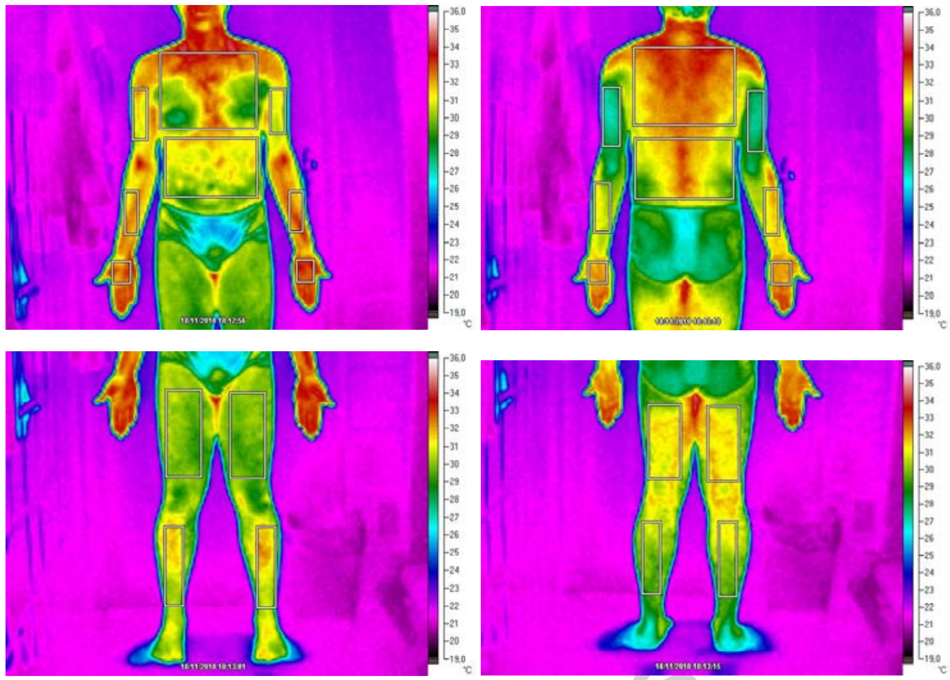

Fig. 1. Front and back infrared thermograms of a male subject and the location of the 24 measured ROI.

2.3. Statistical analysis

We applied descriptive statistics including the means and standard deviations for data presentation. General and by gender absolute regional contralateral ΔT_{sk} were calculated for each of the 10 ROI pairs by subtracting the mean T_{sk} of the left side from the mean T_{sk} of the right side.

After confirming the normal distribution of the variables using a Shapiro-Wilk test, significant differences between the 10 contralateral ΔT_{sk} values were calculated by a paired samples Student's t-test, and the differences between the T_{sk} of the 20 gender-common ROI by an independent samples Student's t-test. A significance level of $\alpha = 0.05$ was set for the statistic tests in the software SigmaPlot 11.0 (Systat, Chicago, USA).

We also calculated the ΔT_{sk} percentage distribution in seven ranges of temperatures (< 0.25 °C; 0.26 to 0.50 °C; 0.51 to 0.70 °C; 0.71 to 1.00 °C; 1.01 to 1.25 °C; 1.26 to 1.50 °C and > 1.51 °C) for the 10 contralateral paired ROI. Finally, the percentiles P_5, P_{10}, P_{50}, P_{90} and P_{95} were obtained to establish T_{sk} values for the 24 ROI.

3. Results

Table 1 shows the averages and standard deviations for the 24 ROI of the 220 Brazilian adults by gender as well as the mean ΔT_{sk} between the 10 paired ROI. The hand region is the area of lowest T_{sk} in both men and women. The hottest regions were the chest (anterior view) and upper back (posterior view) in men, while in women they were the abdomen (anterior view) and lower back (posterior view). In most of the ventral areas, males and females showed higher T_{sk} averages in the left side, whereas in the dorsal areas showed higher T_{sk} averages in the right side.

Table 1
Mean T_{sk} (°C) and standard deviations of the 24 measured ROI, considering contralateral and gender differences (ΔT_{sk}).

ROI		Male (n= 103) Average ± SD	Male (n= 103) Mean ΔT_{sk} (R *vs.* L); *p*	Female (N = 117) Average ± SD	Female (N = 117) Mean ΔT_{sk} (R *vs.* L); *P*	(Male *vs.* Female) Mean ΔT_{sk}; *P*
Ventral Hand	R	28.17 ± 2.61	- 0.17;	28.40 ± 2.2	- 0.20;	0.23; $p = 0.48$
	L	28.34 ± 2.62	$p = 0.00$	28.60 ± 2.2	$p < 0.00$	0.26; $p = 0.42$
Ventral Forearm	R	30.75 ± 1.2	- 0.21;	30.39 ± 1.2	- 0.20;	0.36; $p = 0.03$*
	L	30.96 ± 1.1	$p = 0.00$	30.59 ± 1.2	$p < 0.00$	0.37; $p = 0.03$*
Ventral Arm	R	31.25 ± 1.3	- 0.07;	30.75 ± 1.2	- 0.33;	0.40; $p = 0.00$*
	L	31.32 ± 1.4	$p = 0.13$	31.08 ± 1.3	$p < 0.00$	0.24; $p = 0.19$
Ventral Thigh	R	29.70 ± 1.1	- 0.05;	28.62 ± 1.3	- 0.10;	1.08; $p < 0.00$*
	L	29.75 ± 1.2	$p = 0.11$	28.72 ± 1.3	$p < 0.00$	1.03; $p < 0.00$*
Ventral Leg	R	30.21 ± 1.4	0.02;	30.18 ± 1.2	0.07;	0.03; $p = 0.86$
	L	30.19 ± 1.4	$p = 0.51$	30.11 ± 1.2	$p = 0.04$	0.08; $p = 0.65$
Chest		31.80 ± 1.0	--	--	--	--
Abdomen		31.56 ± 1.1	--	31.39 ± 1.4	--	0.17; $p = 0.33$
Dorsal Hand	R	28.06 ± 2.1	0.06;	28.37 ± 1.8	0.15;	0.31; $p = 0.25$
	L	28.00 ± 2.1	$p = 0.27$	28.22 ± 1.8	$p = 0.00$	0.22; $p = 0.40$
Dorsal Forearm	R	30.61 ± 1.1	0.31;	30.20 ± 1.2	0.25;	0.41; $p = 0.01$*
	L	30.30 ± 1.1	$p < 0.00$	29.95 ± 1.1	$p < 0.00$	0.35; $p = 0.02$*
Dorsal Arm	R	29.36 ± 1.2	0.14;	28.59 ± 1.4	0.11;	0.77; $p < 0.00$*
	L	29.22 ± 1.2	$p = 0.00$	28.48 ± 1.4	$p < 0.01$	0.74; $p < 0.00$*
Posterior Thigh	R	30.28 ± 1.1	0.08;	29.26 ± 1.1	0.11;	1.02; $p < 0.00$*
	L	30.20 ± 1.2	$p = 0.01$	29.15 ± 1.1	$p = 0.45$	1.05; $p < 0.00$*
Calf	R	29.97 ± 1.3	0.09;	29.16 ± 1.0	0.15;	0.81; $p < 0.00$*
	L	29.88 ± 1.3	$p = 0.00$	29.01 ± 1.1	$p < 0.00$	0.87; $p < 0.00$*
Upper Back	-	32.14 ± 0.9	--	--	--	
Low Back	-	31.56 ± 1.0	--	31.30 ± 1.4	--	0.26; $p = 0.12$

Note: R = Right; L = Left

Below are the percentage distributions of ΔT_{sk} for the 10 paired ROI analyzed in men (Figure 2) and women (Figure 3) separated into seven temperature ranges. In the Figures 2 and 3, the hands of both men and women (13.6% in men and 14.5% in women) in the anterior view and the forearm in the posterior view for both men and women (9.7% and 10.3%, respectively) were the regions that registered the highest percentage of cases with ΔT_{sk} greater than 1.0 °C; moreover, the anterior and posterior thigh and leg were the ROI in men and women with the lowest incidence of abnormal asymmetries, always below 2% of cases. The ranges of

ΔT_{sk} in the normal limits for young adults were between 53 and 89% of males and between 59% and 81% of females in the anterior view and between 63 and 92% of males and between 57% and 85% of females in the posterior view, depending on the considered ROI.

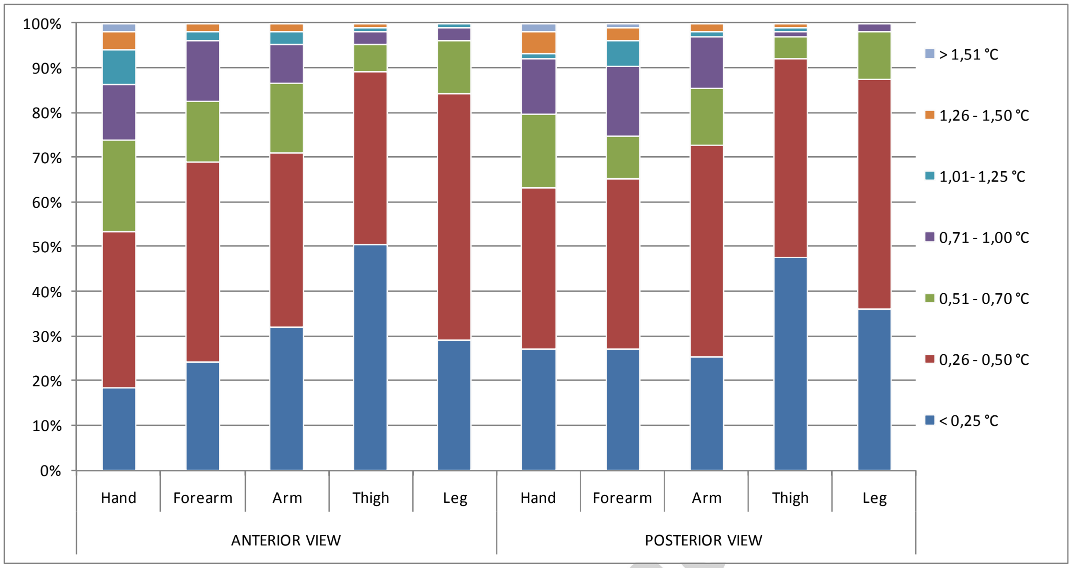

Fig. 1. Percentage distribution of ΔT_{sk} for selected paired ROI in men (n= 103)

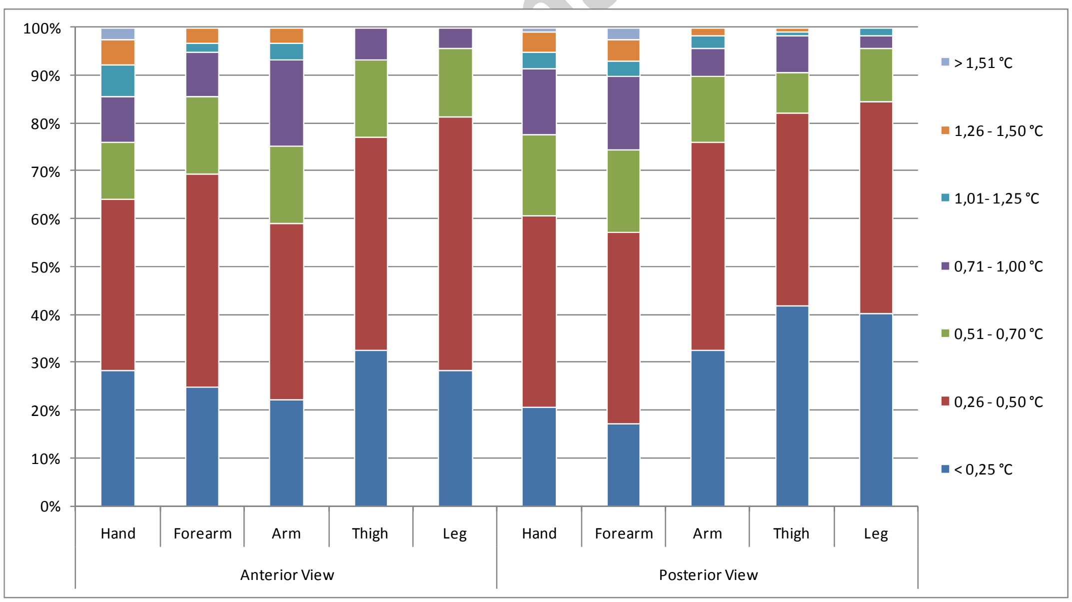

Fig. 3. Percentage distribution of ΔT_{sk} for selected paired ROI in women (n= 117)

4. Discussion

A thermal image can be interpreted in two ways: qualitatively and quantitatively. For a qualitative analysis, the evaluator requires experience to identify abnormal hotspots and cold areas. A quantitative analysis, however, can objectively determine the existence of any thermal imbalance with more accuracy. data for T_{sk} on each ROI are crucial for a proper analysis of the thermogram, allowing a clearer evaluation of the subject not only in a clinical setting but also for physical therapy or even professional sports.

Quantitative analysis can be performed in two ways: first, by considering the bilateral ROI when comparing contralateral ΔT_{sk} (Zaproudina et al.,2008; Uematsu et al., 1988; Zhu and Xin, 1999; Niu et al., 2001; Vardasca, 2010; Kolosovas-Machuca and González 2011; Ben-Eliyahu, 1992) and second, by establishing the percentile values for each ROI, which has a specific thermal profile (Cabrera et al., 2008; Zaprudina et al., 2008; Niu et al., 2001).

These analyses may help interpret the data obtained for a subject. A good thermal report should identify thermal imbalances for each ROI compared with its contralateral side, and additionally, whether the patient is experiencing hyperthermia or hypothermia of each ROI. Although the thermographic results are not conclusive enough to make a definitive diagnosis, they provide the professional with some clues for carrying out further diagnostic tests to establish the causes of this abnormal T_{sk} behavior.

4.1. Contralateral Analysis

Thermal bilateral symmetry is justified by the concept of proportionality between contralateral body areas (Brioschi et al., 2003). Our average T_{sk} results are consistent with other works in the literature identifying standard right vs. left thermal differences in healthy populations (Zaproudina et al., 2008; Uematsu et al.,1988;; Zhu and Xin, 1999; Niu et al., 2001; Vardasca, 2010; Kolosovas-Machuca and González (2011). Table 2 compares our contralateral ΔT_{sk} with those reported by some authors who have analyzed the same ROI.

Table 2
Mean contralateral ΔT_{sk} in different studies with healthy people.

Gender	Males		Females	Males and Females			
ROI	Our study (n = 103) Brazilian	Zaproudina et al. (2008) (n = 16) Finish	Our study (n = 117) Brazilian	Niu et al. (2001) (n = 37) Taiwanese	Uematsu et al. (1988) (n = 90)	Kolosovas-Machuca and González (2011) (n = 25) Mexican children	Zhu and Xin (1999) (n = 223) Chinese
Ventral Hand	0.17	0.22	0.20	0.24	0.3	0.1	0.3
Ventral Forearm	0.21	0.19	0.20	0.25	0.21	0.1	0.21
Ventral Arm	0.07	0.21	0.33	0.27	1.19	0.1	1.19
Ventral Thigh	0.05	0.15	0.10	0.24	0.18	0	0.18
Ventral Leg	0.02	0.17	0.07	0.27	ND	ND	ND
Dorsal Hand	0.06	0.22	0.15	0.31	0.36	0.1	0.36
Dorsal Forearm	0.31	0.19	0.25	0.31	0.26	0.1	0.26
Dorsal Arm	0.14	0.24	0,11	0.39	0.37	0.1	0.37
Dorsal	0.08	0.14	0.11	0.23	0.25	0	0.25

Thigh							
Dorsal Calf	0.09	0.21	0.15	0.29	0.18	ND	0.18

*ND = Data not available.

The results in the table above show that our absolute side-to-side ΔT_{sk} never exceeded 0.4 °C, confirming the previously measured value of 0.5 °C as the maximum normal value for contralateral ROI (Niu et al., 2001; Uematsu, 1985).

Quantitative analysis using IRT is a fast, non-invasive and safe tool (Hildebrand et al., 2010) for general clinical analysis. When IRT results show a contralateral thermal imbalance, they can indicate disturbances in the autonomic nervous system (Herry and Frize, 2004) and peripheral blood flow (Hildebrand et al., 2010) as well as pain syndromes (Al-Nakhli et al., 2012; Zaproudina et al., 2006). A good example of the applicability of IRT was shown previously when up to 85.7% of physiological syndromes had diagnosis confirmed through T_{sk} asymmetries in contralateral evaluations (Zhu and Xin, 1999). At the moment, IRT can detect some physiological disturbances, but more elaborate clinical trials should be carried out to directly relate thermal asymmetries with their causes.

It has been suggested that a ΔT_{sk} over 1 °C can be considered a strong indicator of abnormality (Ben-Eliyahu 1992), requiring further diagnostic protocols to identify the cause of this difference.

Other authors are more rigorous and set values of 0.62 °C (Feldman et al., 1984) or 0.5 °C (Niu et al., 2001; Uematsu's, 1985) as the reference points for abnormal contralateral ΔT_{sk}. In the present study, the highest mean ΔT_{sk} values were 0.5 °C for women in the ventral hand and dorsal forearm and 0.3 °C for men in the dorsal forearm.

Figures 2 and 3 provide interesting information concerning the limit value of 0.5 °C as a normal contralateral ΔT_{sk}. It should be noted that the thigh and leg regions were those with the most thermal symmetry. The data from this study indicate a consistent symmetrical distribution of the human T_{sk} (Figures 2 and 3).

Kolosovas-Machuca and Gonzalez (2011) evaluated 42 measurement points and considered the maximum average ΔT_{sk} in children to be 0.7 °C. In our study, the highest average ΔT_{sk} recorded in adults was 0.3 °C (see Table 1); these values are clearly lower than those obtained by Zhu and Xin (1999) in China, who reported a maximum of 1.8 ° C. Other studies indicate a maximum average ΔT_{sk} of 0.5 °C (Niu et al., 2001), 0.67 ° C in the toe region (Uematsu et al., 1988), or 0.64 °C in the heel region (Zaproudina et al., 2008). These reported differences make clear the need for large population studies, as certain characteristics of a race or physiological responses may affect the thermal behavior of each ROI and consequently the normal range of T_{sk}.

Some studies (Sivanandam et al., 2012; Ring et al.,2004; Huygen et al., 2004; Zhu and Xin, 1999; Ben-Eliyahu, 1992) have focused on comparing the thermal profile of healthy people to that of people with an established diagnosis. The ΔT_{sk} in healthy people was found to usually be below 0.5 °C. However, in people with a diagnosed injury, contralateral ΔT_{sk} tend to be higher, with ΔT_{sk} values up to 5.9 °C (Zhu and Xin, 1999).

The evaluation criteria for contralateral ΔT_{sk} may also vary depending on the type of analysis that is attempted. Han et al. (2010) propose an upper threshold of 0.6 °C to indicate herpes zoster infection both in the face and trunk. Raschner and Hildebrandt (2010) identified an asymmetrical T_{sk} as a predictor for pre-symptomatic identification of overuse injuries and considered IRT as an effective injury prevention method. This application was implemented in a Spanish professional football team with positive results over a preseason, with a 90% reduction in the number of days absent from training caused by injury among the players (Gomez-Carmona et al., 2011).

We did not record the subjects' hand and foot dominances, however, there is some evidence of increased T_{sk} in the dominant limb both in normal subjects (Smith et al., 1986) and in athletes (Gomez-Carmona et al., 2009; Arnaiz-Lastras et al., 2011). Determination of dominant side asymmetries could be important for better understanding the normal thermal profiles of athletes with high unilateral physical workload (i.e., tennis or fencing) but might be less relevant in other sports such as cycling.

Our data suggest that, for a healthy population of Brazilian adults, normal contralateral mean ΔT_{sk} should be considered 0.3 °C or less, similar to that observed in the Chinese population (Zhu and Xin, 1999).

4.2. Data

Thermographic data are important to establish baselines, but factors such as specific population characteristics, evaluated ROI, the cameras used and their operation and environmental conditions can affect the results. These factors should be considered when comparing with data from different studies.

Our average values for the 24 monitored ROI approximate the data obtained by Niu et al. (2001) and Zaproudina et al. (2008) however, they are lower than the results presented by Zhu and Xin (1999), Cabrera et al. (2008) and Sivanandam et al. (2012). These differences in results may be based on a number of influencing factors such as the data collection time, room temperature (Ammer & Ring, 2008), type of camera used (Nguyen et al., 2010) and race of the subject (Zhu and Xin, 1999). For a better comparison of data in future studies, it is important to indicate the criteria and conditions for data collection and to identify the cameras used.

The results from Table 1 indicate a ΔT_{sk} of approximately 3 - 4 °C between the central and distal regions of the body. This condition is considered normal because the central regions have a higher T_{sk} than the extremities (Niu et al., 2001; Cabrera et al., 2008; Zhu and Xin, 1999). T_{sk} differences are mainly caused by sympathetic neural activation in the acral regions, which is controlled by adrenergic vasoconstrictor nerve activity (Pascoe et al., 2008). Additionally, central regions have temperatures 5 to 6 °C higher than distal body parts because they contain organs such as the heart, liver and intestines, which generate a large amount of metabolic heat (Campbell, 2008).

The T_{sk} values differ depending on the study. Niu et al. (2001) observed that the highest T_{sk} was on the neck (31.9 ± 0.6 °C) and the lowest was on the toes (27.5 ± 2.0 °C). Another example was presented by Cabrera et al. (2008) who found the highest T_{sk} on the shoulders (34.2 ± 2.7 °C) and the lowest on the dorsal feet (29.8 ± 3.4 °C), which represents a ΔT_{sk} of 4.32 °C between the maximum and minimum T_{sk} values of the body. There is strong evidence for considering the forehead, upper trunk and anterior neck as the regions with the highest T_{sk}; the lowest T_{sk} are located on the toes and the soles of the feet (Cabrera et al., 2008).

After evaluating 84 ROI in 25 children, Kolosovas-Machuca (2011) also observed this trend by establishing 5.1 °C as the maximum T_{sk} variation in the cranio-caudal axis and 0.7 °C in the transversal axis. Zhu and Xin (1999) assessed adult Chinese to find ΔT_{sk} up to 9.0 °C on the y-axis and up to 1.8 °C on the x-axis. Vardasca (2010) proposed a normality condition considering the maximal thermal sagittal symmetry as 0.49 ± 0.29 °C. It seems clear that greater ΔT_{sk} values can be expected in adults than in children.

There is marked individual variation in T_{sk} at rest. ΔT_{sk} values have been observed in the palm of up to 9.1 °C (Zaproudina et al., 2008), and in the fingers of up to 9.5 °C (Niu et al., 2001). It therefore becomes necessary to establish a specific T_{sk} reference for each body region. It would be a mistake to establish a unique range of normal T_{sk} for the whole body as has been established for core temperature.

Cabrera et al. (2008) proposes clear data for 28 ROI including muscle and joint regions, but they present only averages without providing any comment about gender and age factors. However, their work is interesting as a starting point for the interpretation of a thermal image.

Our study shows five percentile values for each ROI that can help to determine when an area is within the normal range or in a state of slight hypothermia ($<P_{10}$), hypothermia ($<P_5$), slight hyperthermia ($>P_{90}$) or hyperthermia ($>P_{95}$). Considering the variety of joints and muscle groups, it seems necessary to provide specific thermal profiles including these areas. Most works in the literature (Zaproudina et al., 2008; Uematsu et al.,1988; Zhu and Xin, 1999; Niu et al., 2001; Vardasca 2010; Kolosovas-Machuca and Gonzalez, 2011) report only the mean and standard deviation data, which are important but are not sufficient for an accurate analysis of thermal data.

Our work considers only 24 ROI, although there are studies that subdivide the body into more ROI (Uemtsu et al., 1988, Niu et al., 2001; Zaproudina et al., 2008; Cabrera et al., 2008), with up to 84 ROI evaluated by Kolosovas-Machuca and Gonzales (2011). Regardless of the number of ROI, it becomes necessary to determine the expected thermal behavior for each region evaluated. Knowing the expected thermal behavior is important for practical analysis, as in the case of a physician who is evaluating a patient with a shoulder bursitis, a physical therapist who is involved in the reco of a knee after a long period of immobilization, or a coach who is evaluating the reco of an athlete by T_{sk} after performing an exercise. data such as that presented in this study may be a useful tool for establishing the normal T_{sk} ranges or to encourage the investigator to find the factor that is causing the abnormality (in the examples above, inflammation of the shoulder, poor neural activation or muscle activity, or an overload in a concrete muscle group of the athlete, respectively) considering the data for the specific population group (bursitis patients, knee convalescent, or athletes) or, even better, the previous records of the same subject.

4.3. Male vs Female

Our results (Table 1) aim to consider gender as a determining factor for T_{sk} because 59% of the 22 considered ROI showed significant differences by gender at a p <0.05 level. Regions without significant differences were the ventral and dorsal hand, ventral leg, abdomen and lower back. These data suggest that for only the indicated ROI, a unique T_{sk} reference would be valid for both men and women.

Results from Niu et al. (2001) were similar to our data, showing non-significant differences in the dorsal hand and abdomen by gender. Moreover, the anterior and posterior hypochondrium and the feet were indicated by Zhu and Xin (1999) as the regions with the highest ΔT_{sk} between men and women.

Kolosovas-Machuca and Gonzalez (2011) also compared T_{sk} by gender, but in children. The largest ΔT_{sk} obtained was 0.8 °C in the cheek and neck, but in 58.3% of the 84 evaluated ROI, the ΔT_{sk} were equal to or lower than 0.5 °C; Therefore, the authors concluded that T_{sk} in children were independent of gender. These results also agree with Agarwal (2010), who did not see an influence from gender after evaluating the T_{sk} of 50 healthy subjects (29 females and 21 male; aged 32.8 years).

However, data from our study indicate that in most of the evaluated ROI, absolute differences were less than 0.5 °C (Table 1). In the thigh region (dorsal and ventral), the ΔT_{sk} were elevated ($\Delta T_{sk} \approx 1.0$ °C), followed by the calf ($\Delta T_{sk} \approx 0.8$ °C) and the dorsal arm ($\Delta T_{sk} \approx$ 0.7 °C). Despite the lack of data about body composition, the ΔT_{sk} on these areas may be caused by a greater accumulation of body fat in women or higher muscle mass development in men. Thus, it is inappropriate to use the same T_{sk} reference values in these regions. We recommend the design of specific T_{sk} tables for these regions that consider gender.

Further research about the influence of gender on the recorded T_{sk} is required to fully understand the skin thermal response and to set specific values for both men and women.

5. Conclusion

Different T_{sk} for each ROI and many incident factors provide particular thermal profiles, making specific reference tables necessary to establish the normal conditions for each population group. There is a marked state of thermal equilibrium for contralateral ROI. We suggest the value of 0.5 °C as a normal limit for contralateral ΔT_{sk}. Gender seems to be a determining factor for the T_{sk} of the thigh, calf and dorsal arm, making it necessary to apply specific tables for analyzing the T_{sk} of these regions by gender. However, the hands, ventral leg, abdomen and lower back reference values are similar in both sexes.

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Appendix 1

T_{sk} (°C) percentiles (P_5, P_{10}, P_{50}, P_{90} and P_{95}) for female and male Brazilian adults.

ROI		MALE					FEMALE				
		P_5	P_{10}	P_{50}	P_{90}	P_{95}	P_5	P_{10}	P_{50}	P_{90}	P_{95}
Ventral Hand	R	24.02	24.84	27.80	31.70	33.04	24.38	25.14	28.60	31.02	31.60
	L	24.54	25.04	28.00	32.12	33.06	24.79	25.20	28.70	31.32	32.01
Ventral Forearm	R	28.80	29.40	30.60	32.16	32.60	28.28	28.78	30.40	32.02	32.20
	L	28.82	29.34	31.00	32.32	32.78	28.69	29.10	30.50	32.40	32.60
Ventral Arm	R	29.14	29.50	31.30	32.76	33.08	28.50	29.00	30.80	32.40	32.80
	L	29.04	29.60	31.40	33.06	33.40	28.78	29.28	31.20	32.82	33.02
Ventral Thigh	R	27.62	28.08	29.80	31.10	31.40	26.20	26.58	28.70	30.10	30.53
	L	27.52	28.10	29.80	31.30	31.58	26.30	26.98	28.80	30.22	30.51
Ventral Leg	R	27.82	28.34	30.30	31.80	32.20	27.59	28.48	30.20	31.72	31.91
	L	27.80	28.24	30.30	31.96	32.28	27.89	28.38	30.30	31.64	32.10
Chest		30.02	30.06	31.90	32.86	33.26	--	--	--	--	--
Abdomen		29.80	30.08	31.50	33.06	33.40	28.99	29.50	31.30	33.32	33.62
Dorsal Hand	R	25.02	25.40	27.90	30.96	32.24	25.30	25.86	28.60	31.22	31.70
	L	24.40	25.30	27.70	30.70	31.54	25.40	25.68	28.10	30.90	31.51
Dorsal Forearm	R	28.96	29.50	30.70	31.86	32.30	27.89	28.40	30.30	31.62	32.10
	L	28.62	28.94	30.40	31.60	31.86	27.69	28.48	30.10	31.40	31.70
Dorsal Arm	R	27.30	27.78	29.40	30.86	31.52	25.67	26.88	28.60	30.32	30.66
	L	26.94	27.64	29.30	30.56	30.90	25.58	26.90	28.50	30.24	30.72
Posterior Thigh	R	28.30	28.80	30.40	31.70	32.10	27.09	27.68	29.40	30.70	31.01
	L	28.04	28.64	30.30	31.76	32.08	27.00	27.28	29.40	30.52	30.82
Calf	R	27.42	28.10	30.20	31.56	31.90	27.20	27.88	29.20	30.60	30.70
	L	27.62	27.90	30.10	31.52	31.80	26.88	27.60	29.00	30.40	30.60
Upper Back		30.44	31.10	32.30	33.10	33.38	--	--	--	--	--
Low Back		29.84	30.14	31.60	32.76	33.28	29.49	29.80	31.10	33.10	33.54

Note: R = Right; L = Left

TABLE 1.

Mean T_{sk} (°C) and standard deviations of the 24 measured ROI, considering contralateral and gender differences (ΔT_{sk}).

ROI		Male (n= 103) Average ± SD	Male Mean ΔT_{sk} (R *vs.* L); *p*	Female (N = 117) Average ± SD	Female Mean ΔT_{sk} (R *vs.* L); *P*	(Male *vs.* Female) Mean ΔT_{sk}; *P*
Ventral Hand	R	28.17 ± 2.61	- 0.17;	28.40 ± 2.2	- 0.20;	0.23; $p = 0.48$
	L	28.34 ± 2.62	$p = 0.00$	28.60 ± 2.2	$p < 0.00$	0.26; $p = 0.42$
Ventral Forearm	R	30.75 ± 1.2	- 0.21;	30.39 ± 1.2	- 0.20;	0.36; $p = 0.03$*
	L	30.96 ± 1.1	$p = 0.00$	30.59 ± 1.2	$p < 0.00$	0.37; $p = 0.03$*
Ventral Arm	R	31.25 ± 1.3	- 0.07;	30.75 ± 1.2	- 0.33;	0.40; $p = 0.00$*
	L	31.32 ± 1.4	$p = 0.13$	31.08 ± 1.3	$p < 0.00$	0.24; $p = 0.19$
Ventral Thigh	R	29.70 ± 1.1	- 0.05;	28.62 ± 1.3	- 0.10;	1.08; $p < 0.00$*
	L	29.75 ± 1.2	$p = 0.11$	28.72 ± 1.3	$p < 0.00$	1.03; $p < 0.00$*
Ventral Leg	R	30.21 ± 1.4	0.02;	30.18 ± 1.2	0.07;	0.03; $p = 0.86$
	L	30.19 ± 1.4	$p = 0.51$	30.11 ± 1.2	$p = 0.04$	0.08; $p = 0.65$
Chest		31.80 ± 1.0	--	--	--	--
Abdomen		31.56 ± 1.1	--	31.39 ± 1.4	--	0.17; $p = 0.33$
Dorsal Hand	R	28.06 ± 2.1	0.06;	28.37 ± 1.8	0.15;	0.31; $p = 0.25$
	L	28.00 ± 2.1	$p = 0.27$	28.22 ± 1.8	$p = 0.00$	0.22; $p = 0.40$
Dorsal Forearm	R	30.61 ± 1.1	0.31;	30.20 ± 1.2	0.25;	0.41; $p = 0.01$*
	L	30.30 ± 1.1	$p < 0.00$	29.95 ± 1.1	$p < 0.00$	0.35; $p = 0.02$*
Dorsal Arm	R	29.36 ± 1.2	0.14;	28.59 ± 1.4	0.11;	0.77; $p < 0.00$*
	L	29.22 ± 1.2	$p = 0.00$	28.48 ± 1.4	$p < 0.01$	0.74; $p < 0.00$*
Posterior Thigh	R	30.28 ± 1.1	0.08;	29.26 ± 1.1	0.11;	1.02; $p < 0.00$*
	L	30.20 ± 1.2	$p = 0.01$	29.15 ± 1.1	$p = 0.45$	1.05; $p < 0.00$*
Calf	R	29.97 ± 1.3	0.09;	29.16 ± 1.0	0.15;	0.81; $p < 0.00$*
	L	29.88 ± 1.3	$p = 0.00$	29.01 ± 1.1	$p < 0.00$	0.87; $p < 0.00$*
Upper Back	-	32.14 ± 0.9	--	--	--	
Low Back	-	31.56 ± 1.0	--	31.30 ± 1.4	--	0.26; $p = 0.12$

Note: R = Right; L = Left

TABLE 2.

Mean contralateral ΔT_{sk} in different studies with healthy people.

Gender	Males		Females	Males and Females			
ROI	Our study (n = 103) Brazilian	Zaproudina et al. (2008) (n = 16) Finish	Our study (n = 117) Brazilian	Niu et al. (2001) (n = 37) Taiwanese	Uematsu et al. (1988) (n = 90)	Kolosovas-Machuca and González (2011) (n = 25) Mexican children	Zhu and Xin (1999) (n = 223) Chinese
Ventral Hand	0.17	0.22	0.20	0.24	0.3	0.1	0.3
Ventral Forearm	0.21	0.19	0.20	0.25	0.21	0.1	0.21
Ventral Arm	0.07	0.21	0.33	0.27	1.19	0.1	1.19
Ventral Thigh	0.05	0.15	0.10	0.24	0.18	0	0.18
Ventral Leg	0.02	0.17	0.07	0.27	ND	ND	ND
Dorsal Hand	0.06	0.22	0.15	0.31	0.36	0.1	0.36
Dorsal Forearm	0.31	0.19	0.25	0.31	0.26	0.1	0.26
Dorsal Arm	0.14	0.24	0,11	0.39	0.37	0.1	0.37
Dorsal Thigh	0.08	0.14	0.11	0.23	0.25	0	0.25
Dorsal Calf	0.09	0.21	0.15	0.29	0.18	ND	0.18

*ND = Data not available.

Thermal body patterns for healthy Brazilian adults (male and female)Highlights

Establishing a standard thermographic profile is crucial for an appropriate interpretation.

Standardization of the protocols leads to obtain comparable results.

Gender seems to be a determining factor for the skin temperature of the thigh, calf and dorsal arm.

We suggest the value of 0.5 °C as a normal limit for contralateral $\Delta T_{sk.}$