



Normative surface skin temperature changes due to blood redistribution: A prospective study

Phillip Shilco^a, Yulia Roitblat^b, Noa Buchris^c, Jacob Hanai^d, Sabrina Cohensedgh^{a,e},
Eden Frig-Levinson^{a,e}, Jacob Burger^f, Michael Shterenshis^{a,*}

^a Science Research Department, Alexander Muss High School in Israel (AMHSI) affiliated to the Alexander Muss Institute for Israel Education (AMIIE), Hod HaSharon, Israel

^b Department of Sciences, Belkind School for Special Education, Rishon-LeZion, Israel

^c Dept. of Sciences, El Camino Real Charter High School, Woodland Hills, CA, USA

^d Dept. of Sciences, Montgomery Bell Academy, Nashville, TN, USA

^e Science Research Department, Milken Community High School, Los Angeles, CA, USA

^f Department of Anatomy and Physiology, Sharon High School, Sharon, MA, USA

ARTICLE INFO

Keywords:

Skin temperature
Blood redistribution
Infrared thermography
Screening

ABSTRACT

The continuing development and manufacture of infrared devices, together with improvements in thermal body mapping techniques have simplified surface skin thermography which is being used more extensively than ever before. Normative thermography data, however, remains incomplete. A normative blood redistribution range of skin temperatures was established for use as a reference for laboratory infrared thermography (IT), thermal body mapping, and mass fever screenings. 500 healthy volunteers participated in this prospective study. To determine the maximum range of the skin temperature changes due to the posture-related physiological blood redistribution, the volunteers were asked to keep one extremity up and another extremity down whilst lying, sitting, and standing. We obtained 6000 hand and 400 foot temperature readings. The normal temperature was 29.1 ± 0.6 °C for the middle fingers and 27.8 ± 0.7 °C for the toes. The physiological temperature change during body position changes ranged from 4 to 6 °C (fingers: 27–31 °C; toes: 26–32 °C). At normal room temperature, the surface skin temperature may vary within this range due to blood redistribution. These changes reflect the individual variability of vasomotor activity. This physiological range of temperatures should be taken into account during IT and other thermography-involved investigations.

1. Introduction

The continuing development and manufacture of infrared devices, together with improvements in thermal body mapping techniques have simplified surface skin thermography which is being used more extensively than ever before. Among numerous medical applications, the current usage of medical infrared thermography (IT) includes screening febrile passengers in airports, detection of patients with inflammatory processes, mammary gland tumor screening, diagnosis of sinusitis, and for preliminary diagnostics of skin tumors, disorders, and lesions (Godoy et al., 2017; Oya et al., 2016; Fink and Haenssle, 2016; Gurjarpadhye et al., 2015; Nishiura and Kamiya, 2011; McBride et al., 2010; Sun et al., 2014; Kalaiarasi et al., 2018). If the current general health care trend continues, surface skin thermography screening will be used more widely and more frequently in busy settings such as

emergency rooms or as a component of early warning surveillance systems in epidemic situations (Ataş Berksoy et al., 2018; Chang et al., 2018; Ko et al., 2018). For practitioners, thermography-based blood flow imaging is a means for the non-contact monitoring of the blood supply in cases of nervous peripheral lesions, diabetes, and peripheral vascular diseases.

In addition to investigative and clinical IT, thermal body mapping provides information which can be used as a supplementary indicator for both the diagnosis and monitoring of disease and for assessing the effects of global warming. Human skin temperature mapping techniques have been advancing since the 1980s (Griffiths and Ahmed, 1987; Astrahan, 1989). Currently, they are widely used in clinical practice as well as for screening healthy subjects (Liu et al., 2018; Kleesz et al., 2012; Filingeri et al., 2014). Finally, MRI-based thermography has become an additional established clinical tool (Włodarczyk et al., 1999;

* Correspondence to: Aliyat HaNoar 9, Hod HaSharon 45102, Israel.

E-mail address: mshterenshis@amhsi.org (M. Shterenshis).

<https://doi.org/10.1016/j.jtherbio.2019.01.009>

Received 28 October 2018; Received in revised form 8 January 2019; Accepted 8 January 2019

Available online 09 January 2019

0306-4565/ © 2019 Elsevier Ltd. All rights reserved.

Rieke and Butts Pauly, 2008). Finally, the ongoing process of climate change has significantly increased interest in thermoregulation and surface skin temperature issues among physicians and physiologists. Normative thermography data, however, remains incomplete.

A precise knowledge of normative surface skin temperature data is paramount for diagnostic investigations. For MRI, in particular, measurements give a temperature change relative to a baseline condition and reducing temperature measurement artifacts is highly desirable. The normative database, however, should not be a set of fixed numbers for various body regions as usually presented in the literature. Several studies performed in the 1940s and 50s helped to differentiate between normative skin temperature changes due to blood redistribution and pathological changes resulting from inflammation or hyperthyroidism (Stewart and Evans, 1940; Cooke et al., 1953). In the following decades, similar studies were repeated from time to time but their results did not find their place in general IT guidelines (Thermography guidelines, 2002; American Academy of Thermology, 2015, 2016).

Due to individual variation the first necessary step in any IT investigation is to establish a personal profile of the normative range of surface skin temperature changes for any given person. This scale may provide an IT practitioner with an understanding of what is normal and what is abnormal for a given patient. It has been demonstrated that the sympathetic skin response and the vasomotor reflex vary in different cases (Park et al., 1994). The response and the reflex by themselves are not pathological, but physiological phenomena. The blood redistribution in the skin is a normal process that changes the surface skin temperature.

We hypothesize that the currently generally accepted presentation of normal peripheral temperatures as fixed numbers, with or without standard deviation, provides an incomplete set of reference temperatures and, therefore, should be accompanied by a normative range of skin temperature changes. The aim of the current study was to establish this normative range of skin temperature changes due to normal blood redistribution that can be used as a reference during laboratory IT investigations, thermal body mappings, and mass skin temperature screening.

2. Methods and subjects

The research was designed as a prospective international multicenter study and took place from September 2016 to May 2018. The study was approved by the Institutional Review Boards (USA – AMIIE, Israel – AMHSI) as both non-invasive and non-interventional.

2.1. Participants

For establishing the truly normative database, we recruited young, healthy volunteers of both sexes (age 18–30, mean age 24 ± 3.3 , $n = 500$, Males 238, Females 262). To keep the margin of error below 5%, we initially planned the sample size of 400 (the margin of error 4.9% with a confidence level of 95%) that is suitable for large population screenings. However, while we encountered numerous variations and peculiarities of the skin temperature during the tests that are assessed below in the Results, the decision was made to expand the sample size to 500 participants. All participants gave their written informed consent. Volunteers with known and documented disorders and conditions that can alter cutaneous blood supply and circulation, such as diabetes mellitus, hypertension, use of beta-blockers, Raynaud's syndrome, Rett syndrome, etc. were excluded from the study. We also excluded smokers, persons who worked with vibrating instruments (who may be suffering from hand-arm vibration syndrome) (Youakim, 2010), and piano players (Mohamed et al., 2011) because the hands were our main object of investigation. The hands remain the primary area of interest for thermography since IT was introduced in the 1970s (Buchwald et al., 1973; Krasemann, 1973). The rationale of choosing these target areas for the current study is based on the fact that apart

from studying peripheral vascular diseases the hands are widely used for the assessment of the relationship between skin blood flow and skin temperature dynamics in general (Scolnik et al., 2016; Sagaidachnyi et al., 2017; Tse et al., 2016). We included volunteers with a BMI of 18–29 (normal mass and mass over) to the study, and the volunteers with a BMI of less than 18 or more than 30 were excluded. The rationale for this exclusion was based on the fact that the amount of fatty tissue and obesity, in general, can significantly alter the surface skin temperature (Savastano et al., 2009; Bertsch et al., 1998; Ang et al., 2017).

2.2. Study design and protocol

The study consisted of two stages. During Stage 1, the normative temperature of the areas of interest (tips of the middle fingers of both hands and the first toes of both feet) was to be established for sitting participants, with their hands on a table and feet on the floor. We randomly selected 100 volunteers (20% of the cohort) for Stage 1 investigations. The effect of clothing was also assessed during this stage. The readings taken from participants dressed in long pants and short sleeve T-shirts ($n = 50$) were compared with the readings taken from participants dressed in long pants and long sleeve shirts ($n = 50$). All the readings were taken between 8:00 and 10:00 A.M.

During Stage 2, we planned to establish the normative database for the skin temperature changes due to blood redistribution and to calculate the correction factors (coefficients) for different body postures (standing, sitting, reclining). The second objective was to determine the time needed for complete blood redistribution when the body position was changed. For this purpose, the temperature readings were monitored after the body position was changed until the moment when the reading remained constant ($\pm 0.1^\circ\text{C}$) for the following 15 s. To determine the maximum range of the surface skin temperature changes due to normal blood redistribution, the volunteers were asked to recline with one arm up and another arm down. (Fig. 1A). In such a position, the tip of the middle finger of the upper arm was the highest part of the body and the tip of the middle finger of the lower arm was its lowest part. This is an ideal position for the normal blood redistribution investigation. If reclining is not possible (mass fever IT screening, airport passenger screening, etc.) a person may be screened whilst standing (Fig. 1B) or sitting (Fig. 1C) and all our 500 participants were tested in all three body positions. Our last aim was to check any temperature differences between hands and feet (whichever are chosen as the areas of interest). For this purpose, the volunteers were asked to recline with one leg up and another leg down. (Fig. 1D). The tip of the first toe was chosen as the area on which the camera would focus. If it was hard for a participant to keep one leg raised for several minutes, an assistant held the heel and supported the leg. It did not alter the temperature reading from the toe. All the participants were dressed in shorts during the foot testing.

The main part of the study was performed on all 500 volunteers and temperature readings were taken in the above mentioned positions. Two sets of readings were obtained from each volunteer (right arm up – left arm down; left arm up – right arm down) and 3000 readings were obtained from the hands. To reduce the effect of measurement error, all the tests were performed twice (total hand temperature 6000 readings) and the test-retest reliability coefficients were calculated. The foot temperature changes were measured for 100 randomly selected participants (200 toe readings $\times 2 = 400$ readings). The research was performed in different locations and the temperature measurements were taken either by the ThermoVision SC6000 Science-grade infrared camera (sensitivity 0.05°C) (FLIR Systems, Inc., Wilsonville, OR, USA) or by 1024×768 resolution T1030sc, FLIR R&D/Science IR camera (sensitivity 0.02°C) (FLIR Systems, Inc., USA).

2.3. Technicalities

The IT readings were performed adhering strictly to the IT

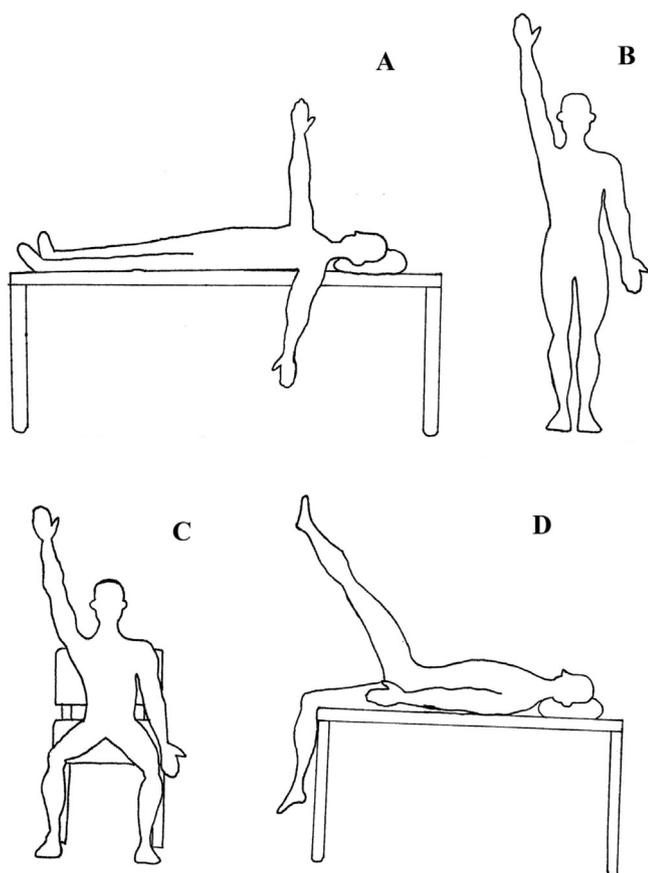


Fig. 1. a. The main test position to assess surface skin temperature changes due to normal blood redistribution. The temperature readings should be taken from the tips of the middle fingers of both hands. b. If reclining is not possible during IT screening, an investigated person may remain standing or c. sitting. d. The skin temperature readings can be taken from the feet if the latter are taken as areas of interest. For this purpose, a person should recline with one leg up and another leg down. The tip of the first toe is taken as the area of the camera focus.

guidelines for neuromusculoskeletal disorders published in 2015 by the [American Academy of Thermology \(2015\)](#). Following these guidelines, emissivity was set to 0.98 (human skin) and the temperature range was set to cover temperatures within the range of human emissions (20–45 °C). Infrared studies were performed in the imaging room with an air conditioning system set at 25 °C (no direct airflow towards a participant) and relative humidity was maintained at 60% ($\pm 5\%$) (Yk-302, 12 V Microcomputer Digital Temperature Humidity Controller; You Kong, China). Thermal drift caused by the internal heating of equipment during normal operation was avoided by switching off the IT camera for 10 min after each 20 min of operation. Maintenance of detector uniformity and correction was performed via calibration. The distance between the camera and the object of focus (the tip of a middle finger from the palmar side, the tip of the big toe) was preset for 50 cm and this distance was maintained at all times. The quantitative differential temperature analysis was performed with a precision of ± 0.1 °C. To speed up the study process, a second room with an air temperature of 25 °C and relative humidity of 60% was used for the volunteers and they were equilibrated in it for 15–20 min prior to imaging. To maintain a strict 25 °C in the imaging room, the air conditioning system was preset to 23 or 24 °C because the room temperature was elevated in the presence of people.

2.4. Analysis

In addition to analysis of temperature readings taken during the above mentioned five positions, the correlation analysis was performed with sex. While both age and BMI were used as selection criteria, they were not included in further analyses. Therefore, the following 11 variables (V) were analyzed:

- V1 - normative finger temperature, hands on a table (100 participants, 200 readings),
- V2 - reclining, right arm up - left arm down (500 participants, 1000 readings),
- V3 - reclining, left arm up - right arm down (500 participants, 1000 readings),
- V4 - sitting, right arm up - left arm down (500 participants, 1000 readings),
- V5 - sitting, left arm up - right arm down (500 participants, 1000 readings),
- V6 - standing, right arm up - left arm down (500 participants, 1000 readings),
- V7 - standing, left arm up - right arm down (500 participants, 1000 readings),
- V8 - reclining, right leg up - left leg down (100 participants, 200 readings),
- V9 - reclining, left leg up - right leg down (100 participants, 200 readings),
- V10 - time needed for complete blood redistribution (6000 and 400 readings),
- V11 - sex (500 participants).

A within-group repeated measures experimental statistical analysis was used to test the variables. Normal probability plots and basic descriptive statistics (mean, standard deviation (SD), min, and max) were calculated for every variable except for sex. The data obtained from the left extremity and from the right extremity were compared. A non-parametric Mann-Whitney *U*-test was used to analyze those variables that were measured more than once (V2 – V9) except for V10. For V10, while decimal statistics is not applied to minutes and seconds, SPSS TIME.HMS function was used (SPSS, Chicago, IL, 2007). For V11, the Pearson χ^2 criterion using 95% confidence interval was applied for assessing correlations of the readings with sex. The level of significance for all analyses was set at $p < 0.05$.

3. Results

3.1. Stage 1 findings

The normative temperature of the tips of the middle fingers from the palmar side of both hands for a person sitting with hands on a table, was 29.1 ± 0.6 °C with an individual lateral difference of ~ 0.6 °C at the environmental temperature of 25.4 ± 0.4 °C. Differences in clothing (short sleeve/long sleeve) did not significantly alter the readings from the tips of the middle fingers ($p = 0.7$). For the toes, this temperature was 27.8 ± 0.7 °C for the same body position, with feet on the floor. No strong correlation with sex was detected ($r = 0.38$).

3.2. Stage 2 findings

The time needed for complete blood redistribution in the reclining position was $2 \text{ min } 15 \text{ s} \pm 45 \text{ s}$ but the range was relatively wide: from $1 \text{ min } 05 \text{ s}$ to $4 \text{ min } 25 \text{ s}$. Thus the average rate of temperature change was $0.01 - 0.02$ °C/s. No correlation with sex was detected for this variable ($r = 0.31$). The reclining position was chosen as the main one for a statistical comparison with the temperature readings for the sitting and the standing positions. In all these three positions, the readings for the upper arm were almost identical ($p = 0.88$ reclining vs. standing,

Table 1

The changes of the surface skin temperature for hands and feet in °C due to physiological blood redistribution. P values are given for Upper extremity reading / Lower extremity reading.

Variables	Average Up/Down	Max Up/Down	Min Up/Down	P vs. V1	P vs. V2(V3)
V1	29.1 ± 0.6	31		27.8	–
V2	27.1 ± 1/31.1 ± 0.9	29.9/33.3	25.3/26.5	0.03/0.02	–
V3	27.1 ± 1.1/31.1 ± 1	29.8/33.3	25.2/26.8	0.03/0.02	–
V4	27.1 ± 1/30.6 ± 0.8	29.6/33	25/26.9	–	0.98/0.92
V5	27 ± 1.2/30.5 ± 0.8	29.5/33	25.1/27	–	0.96/0.92
V6	27 ± 0.8/30.3 ± 0.9	29.4/32.8	25.6/27	–	0.9/0.88
V7	27.1 ± 1/30.3 ± 1	29.5/32.9	25.7/27.2	–	0.9/0.87
V8	26.5 ± 1/31.7 ± 1	28.3/33.8	25.6/28.4	–	–
V9	26.4 ± 1/31.7 ± 1.1	28.4/34.1	25.4/28.6	–	–

Abbreviations: V1 - normative finger temperature, hands on a table, V2 – reclining, right arm up – left arm down, V3 – reclining, left arm up – right arm down, V4 – sitting, right arm up – left arm down, V5 – sitting, left arm up – right arm down, V6 – standing, right arm up – left arm down, V7 – standing, left arm up – right arm down, V8 – reclining, right leg up – left leg down, V9 – reclining, left leg up – right leg down.

p = 0.95 reclining vs. sitting). For the lower arm, the average temperature of a sitting volunteer was 2% less than in the reclining position (30.5 ± 0.8 °C vs. 31.1 ± 1 °C), and the average temperature of a standing volunteer was 3% less than in the reclining position (30.3 ± 1 °C vs. 31.1 ± 1 °C). Therefore, the correction factors (coefficients) for different body postures were calculated as 1.02 for a sitting person and 1.03 for a standing person. For foot testing, the average temperature of the upper toe was 7% lower than the average temperature of the upper middle finger (25.4 ± 1 °C vs. 27.3 ± 1 °C) and the temperature of the lower toe was 2.5% higher than the temperature of the lower middle finger (31.8 ± 1 °C vs. 31 ± 1 °C, p = 0.72). No correlation with sex was detected for this variable (r = 0.26).

The skin temperature results for hands and feet are summarized in Table 1. The time needed for complete blood redistribution after the body position changed is presented in Table 2. No significant lateral differences were detected (hands left/right: p = 0.73; legs left/right: p = 0.48). The test-retest agreement was 0.82. The main findings are summarized in Fig. 2.

3.3. Unusual physiological findings

Further analysis of the data obtained from the investigated cohort revealed certain unusual findings in some of the participants. In 4.6% of all participants (n = 23), the temperature of the upper and the lower hands remained the same during the test taking. The temperature of the upper hand was higher than the temperature of the lower hand in 1.8% of cases (n = 9). In 3.2% of cases, the difference between the upper and the lower hand temperatures exceeded 6 °C (n = 16). In one case the difference was 8 °C (25.6 °C – the upper hand, 33.3 °C – the lower hand). Some of the subjects screened had a larger difference between readings in the standing position than in the reclining position (n = 85, 17%). Redistribution correction physiological maneuver (baroreceptor reflexes? nonthermoregulatory reflexes?) was observed in 7.2% (n = 36). In a reclining position, during the initial one or two minutes of the test, the difference between the upper and the lower readings increased, but during the subsequent one or two minutes, the difference became smaller until it stabilized. While the lateral difference between hand skin temperatures rarely exceeded 0.6 °C, when the hands were in the

Table 2

Time needed for complete blood redistribution after the changes in the body position.

Position/area	average time ± SD	min/max time range	P against position I
I. reclining, hands	2'15" ± 45"	1'5" – 4'25"	–
II. sitting, hands	2'15" ± 35"	1'15" – 3'15"	0.97
III. standing, hands	2'02" ± 35"	1'15" – 2'45"	0.88
IV. reclining, feet	3'10" ± 1'05"	1'45" – 4'30"	0.32

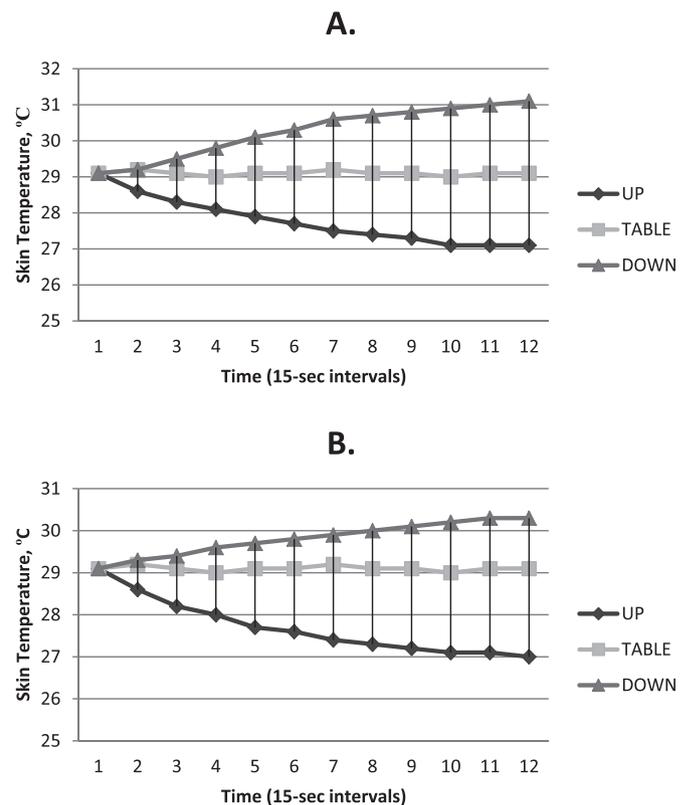


Fig. 2. A. The time/temperature relations during complete blood redistribution in reclining persons (UP – the upper hand, TABLE – hands are on the table, DOWN – the lower hand). X-axis – time, twelve 15-sec periods (3 min); y-axis – surface skin temperature, °C. B. The time/temperature relations during complete blood redistribution in standing persons. While the readings from the upper hand are almost similar to the readings of the reclining person, the readings from the lower hand show lesser changes.

same position on a table, in the hand up/hand down position this difference could exceed 1 °C. The test with the left arm up and the test with the right arm up may indicate significantly different temperatures at the tips of the middle fingers in 18.4% (n = 92). The temperature readings during retesting of the same person differed from initial readings by more than 1 °C in 12.8% of all participants (n = 64).

4. Discussion

Our main finding is that the surface skin temperature may vary within a range of approximately 4–5 °C (from 26–27 °C to 31–32 °C in extremities) due only to physiological blood redistribution in the body.

While a physiological phenomenon, this range of temperatures is specific for each person and should be assessed on an individual basis.

Human thermoregulation and cutaneous blood flow are well-researched topics. Thermoregulatory reflexes, however, are usually tested by some *external* stimulation methods that include body heating, local application of heat or cold (cold provocation test), blood pressure occlusion, and pharmacological stimuli (acetylcholine, sodium nitroprusside) (Park et al., 1994; Scolnik et al., 2016; Dupuis, 1987; Norrbrand et al., 2017; Cherniack et al., 2003). In addition to various pathological influences, there are three *internal* physiological conditions that may change the surface skin temperature, namely, normal blood redistribution due to body posture changes, temporary physiological changes within endogenous metabolism processes, and emotional situations. It has been proven for the latter that emotionally important situations may lead to skin vasodilatation/vasoconstriction and therefore may change the surface skin temperature (the pale – blushing situations) (Kret, 2015; Graef et al., 2017). In the current study, we concentrated on a normative range of skin temperature changes due to normal blood redistribution.

By choosing young healthy BMI-good nonsmokers as a cohort of “ideal” volunteers, we aimed to establish a normative range of surface skin temperature changes due to physiological blood redistribution. This range, which we call the Blood Redistribution Temperature scale (the BRT-scale), shows surface skin temperature more realistically than the fixed temperature readings for various parts of the body even if they were presented with standard deviations. We suggest that any set of reference temperatures for skin locations should be accompanied with the reference BRT-scale. We presume that most of the temperature changes within this scale are physiological, and temperature variations outside this scale may be regarded as pathological. It is possible that hypovascular skin tumors or avascular or hypovascular breast tumors may present temperatures within the BRT-scale range (González, 2007; Herman and Cetingul, 2011; Buzug et al., 2006) but such readings will remain a localized phenomenon while the temperature change because of fever is a generalized phenomenon. We suggest that those temporary skin temperature changes of endogenous metabolism origin, if they remain within physiological limits, might still be within the BRT-scale range because vasodilatation/vasoconstriction mechanisms are involved in such processes as well. Numerous studies indicate that metabolism-related physiological temperature changes rarely exceed 1.5 °C (Pastukhov and Ekimova, 2011; Whittle, 2012; Maslov et al., 2014; Celi et al., 2015; Montanari et al., 2017). The same is true for circadian rhythms in body temperature (Honma, 2013; Kiehn et al., 2017; Riede et al., 2017).

Assessing the results of Stage 1, we confirm previous reports indicating that the normative surface skin temperature of the palmar side of the hand is within the 28–30 °C range (Scolnik et al., 2016; Dupuis, 1987; Norrbrand et al., 2017; Symons et al., 2015). The recent study of Fernandes Ade et al. (2016), however, indicates a “hands anterior view” temperature of 32 °C, but the readings were taken from the middle of the palm. It has been shown that within the hand, the tip of a finger, the fingernail bed, and the middle of the palm provide different readings (Norrbrand et al., 2017; Sagaidachnyi et al., 2017; Leijon-Sundqvist et al., 2017). It was reported that the vasomotor innervation of the skin and cutaneous vasoconstriction/vasodilatation activity vary from individual to individual (Scolnik et al., 2016; Dupuis, 1987; Norrbrand et al., 2017; Cherniack et al., 2003; Park et al., 1994) and our results support this statement.

Discussing Stage 2 findings, we believe that the subjects can be tested in a sitting or standing position if normative clinical testing is impossible to perform. In such cases, the above-mentioned coefficients could be applied. For example, if a reading taken from the lower hand of a standing person was 33 °C, the real upper end of the BRT-scale for him/her will be $33 \times 1.03 = 34$ °C. Another finding from Stage 2 revealed that the BRT test performed on legs provided a somewhat wider range of temperatures. However, while it is harder to perform such a

test during mass IT screening, it may serve as an additional tool when pathological conditions are assessed in a hospital setting.

The BRT-scale for the extremities may be presented in the following way:

$$\text{Pathological hypothermia} \leftarrow 26\text{--}27\text{ }^{\circ}\text{C} \leftarrow \text{normal BRT} \rightarrow 31\text{--}32\text{ }^{\circ}\text{C} \\ \rightarrow \text{pathological hyperthermia}$$

This scale was calculated for an environmental temperature of 25 °C and 60–65% relative humidity and correction coefficients must be applied for different environmental conditions. The aim of our upcoming research will be a calculation of such coefficients. For the facial and trunk temperatures, the lowest and the highest marks of the scale will be different but we believe that the range itself will remain 4 °C or less if no external factors are involved.

The results of the seven reported physiological anomalies (Results, 3.3) are not statistically significant. Within the whole cohort of 500 participants that provided 6000 readings, the reported extremes mostly balanced each other out leaving the average numbers unchanged. Yet, the existence of the anomalies is important. We wish to stress the fact that the BRT-scale is specific for each person. Although we report the normative data we obtained, we need to keep in mind that about a third of the participants had the above mentioned physiological vasodilatation/vasoconstriction anomalies. Furthermore, while the test-retest agreement of 0.82 can be considered acceptable, it still leaves an 18% intra-personal difference in the readings. Therefore, an individual approach is paramount for any skin thermography investigation even during mass IT fever screening procedures.

The accuracy of IT as a screening tool for febrile passengers in airports and for breast cancer screening was recently questioned by several authors (de Jesus Guirro et al., 2017; Fitzgerald and Berentson-Shaw, 2012; Shterenshis, 2017). We consider IT in itself as an effective diagnostic tool but the protocols have not yet been perfected. The implementation of the BRT-scale concept in the IT investigations may help to avoid false-positive results during mass fever screenings. As for thermal body mapping, the BRT-scale for a given patient should be established before the procedure started and the obtained results should be assessed against it. Laboratory blood test reports usually indicate the precise reading for an investigated element of the blood followed by a normative range in parenthesis (for example: glucose 106 mg/dl [70–110]). We believe that the thermography should follow the same pattern and its reports should indicate the observed reading and the BRT-scale for a given investigated patient.

4.1. Limitations

While modern IT devices are usually standardized, some differences in readings may still occur when various skin temperature sensors are used. The data in this study were obtained from “ideal” young healthy volunteers; children, the elderly and people with disease may have different readings. Different environmental temperatures and relative humidity may alter the results. During IT screenings at airports and other crowded places, the face temperature is usually the object of interest. Additional studies are needed to adjust the BRT-scale to the face because pale – blushing variations, while also of vasoconstriction/vasodilatation matter, may have different physiological pattern.

The BRT-scale cannot be applied to the orbital area, the external ear canal, the genital area, and the axillary area because the temperature of these areas is close to the core temperature.

5. Conclusion

At a room temperature of 25 °C, the surface skin temperature may vary within a range of approximately 4–5 °C due only to physiological blood redistribution in the body. The Blood Redistribution Temperature scale is specific for each individual due to the individual variability of

vasomotor activity. This physiological range of normal skin temperatures should be taken into account during any IT investigation.

Acknowledgments

The authors sincerely thank Mordechai Cohen, Rachel Sevitt, Orit Rome, Leor Sinai, Geoffrey P. Jacobs, and Alex Lasky in Israel, and USA-based Kimberly Schwartz, Roger Kassebaum, Damon Scoville, Pauline Kim, Omri Chaspher, and Ethan Suman for assistance.

Conflict of interest

The authors declare that they have no conflict of interest.

Competing interests

This research did not receive any grants from funding agencies in the public, commercial, or nonprofit sectors.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jtherbio.2019.01.009](https://doi.org/10.1016/j.jtherbio.2019.01.009).

References

- American Academy of Thermology – AAT, 2015. Guidelines for dental-oral and systemic health infrared thermography. *Pan Am. J. Med. Thermol.* 2 (1), 44–53. <https://doi.org/10.18073/2358-4696/pajmt.v2n1p44-53>.
- American Academy of Thermology – AAT, 2016. Guidelines for neuromusculoskeletal infrared thermography sympathetic skin response (SSR) studies. *Pan Am. J. Med. Thermol.* 2 (1), 35–43. <https://doi.org/10.18073/2358-4696/pajmt.v2n1p35-43>.
- Ang, Q.Y., Goh, H.J., Cao, Y., et al., 2017. A new method of infrared thermography for quantification of brown adipose tissue activation in healthy adults (TACTICAL): a randomized trial. *J. Physiol. Sci.* 67 (3), 395–406. <https://doi.org/10.1007/s12576-016-0472-1>.
- Astrahan, M.A., 1989. Thermal mapping with multisensor probes. *Strahlenther. Onkol.* 165 (10), 746–750.
- Ataş Berksoy, E., Bağ, Ö., Yazici, S., Çelik, T., 2018. Use of noncontact infrared thermography to measure temperature in children in a triage room. *Medicine (Baltim.)* 97 (5), e9737. <https://doi.org/10.1097/MD.00000000000009737>.
- Bertsch, F., Mattner, J., Stehling, M.K., et al., 1998. Non-invasive temperature mapping using MRI: comparison of two methods based on chemical shift and T1-relaxation. *Magn. Reson. Imaging* 16 (4), 393–404.
- Buchwald, W., Habighorst, L.V., Hülse, R., 1973. Thermography in blood circulation disorders of the extremities. *Radiologe* 13 (8), 329–334.
- Buzug, T.M., Schumann, S., Pfaffmann, L., Reinhold, U., Ruhlmann, J., 2006. Functional infrared imaging for skin-cancer screening. *IEEE Eng. Med. Biol. Soc.* 1, 2766–2769.
- Celi, F.S., Le, T.N., Ni, B., 2015. Physiology and relevance of human adaptive thermogenesis response. *Trends Endocrinol. Metab.* 26 (5), 238–247. <https://doi.org/10.1016/j.tem.2015.03.003>.
- Chang, C.J., Chen, C.S., Tien, C.J., Lu, M.R., 2018. Epidemiological, clinical and climatic characteristics of dengue fever in Kaohsiung City, Taiwan with implication for prevention and control. *PLoS One* 13 (1), e0190637. <https://doi.org/10.1371/journal.pone.0190637>.eCollection 2018.
- Cherniack, M., Brammer, A., Meyer, J., Morse, T., Peterson, D., Fu, R., 2003. Skin temperature recovery from cold provocation in workers exposed to vibration: a longitudinal study. *Occup. Environ. Med.* 60 (12), 962–968.
- Cooke, J.V., Goldring, D., Kahn, L.I., 1953. The occurrence of changes resembling the inflammatory in skin injured and incubated after excision. *J. Exp. Med.* 97, 651–662.
- de Jesus Guirro, R.R., Oliveira Lima Leite Vaz, M.M., das Neves, L.M.S., et al., 2017. Accuracy and reliability of infrared thermography in assessment of the breasts of women affected by cancer. *J. Med. Syst.* 41 (5), 87. <https://doi.org/10.1007/s10916-017-0730-7>.
- Dupuis, H., 1987. Thermographic assessment of skin temperature during a cold provocation test. *Scand. J. Work Environ. Health* 13 (4), 352–355.
- Fernandes Ade, A., Amorim, P.R., Brito, C.J., Sillero-Quintana, M., Bouzas Marins, J.C., 2016. Regional skin temperature response to moderate aerobic exercise measured by infrared thermography. *Asian J. Sports Med.* 7 (1), e29243. <https://doi.org/10.5812/asjsm.29243>.
- Filingeri, D., Fournet, D., Hodder, S., Havenith, G., 2014. Body mapping of cutaneous wetness perception across the human torso during thermo-neutral and warm environmental exposures. *J. Appl. Physiol.* (1985) 117 (8), 887–997. <https://doi.org/10.1152/jappphysiol.00535.2014>.
- Fink, C., Haenssle, H.A., 2016. Strategies for the noninvasive diagnosis of melanoma. *Hautarzt* 67 (7), 519–528. <https://doi.org/10.1007/s00105-016-3796-0>.
- Fitzgerald, A., Berentson-Shaw, J., 2012. Thermography as a screening and diagnostic tool: a systematic review. *NZ Med. J.* 125 (1351), 80–91.
- Godoy, S.E., Hayat, M.M., Ramirez, D.A., Myers, S.A., Padilla, R.S., Krishna, S., 2017. Detection theory for accurate and non-invasive skin cancer diagnosis using dynamic thermal imaging. *Biomed. Opt. Express* 8 (4), 2301–2323. <https://doi.org/10.1364/BOE.8.002301>.
- González, F.J., 2007. Thermal simulation of breast tumors. *I Rev. Mex. Fis.* 53, 323–326.
- Graef, J.E., Rief, W., Nestoriuc, Y., Weise, C., 2017. The more vivid the imagination the better: the role of the vividness of imagination in vasoconstriction training and vasodilatation training. *Appl. Psychophysiol. Biofeedback* 42 (4), 283–298. <https://doi.org/10.1007/s10484-017-9373-1>.
- Griffiths, H., Ahmed, A., 1987. Applied potential tomography for non-invasive temperature mapping in hyperthermia. *Clin. Phys. Physiol. Meas.* 8 (Suppl. A), 147–153.
- Gurjarpadhye, A.A., Parekh, M.B., Dubnika, A., Rajadas, J., Inayathullah, M., 2015. Infrared imaging tools for diagnostic applications in dermatology. *SM J. Clin. Med. Imaging* 1 (1), 1–5.
- Herman, C., Cetingul, M.P., 2011. Quantitative visualization and detection of skin cancer using dynamic thermal imaging. *J. Vis. Exp.* (51). <https://doi.org/10.3791/2679>. (2011 May 5).
- Honma, K., 2013. Circadian rhythms in body temperature and sleep. *Nihon Rinsho.* 71 (12), 2076–2081.
- Kalaiarasi, R., Vijayakumar, C., Archana, R., et al., 2018. Role of thermography in the diagnosis of chronic sinusitis. *Cureus* 10 (3), e2298. <https://doi.org/10.7759/cureus.2298>.
- Kiehn, J.T., Tsang, A.H., Heyde, I., 2017. Circadian rhythms in adipose tissue physiology. *Compr. Physiol.* 7 (2), 383–427. <https://doi.org/10.1002/cphy.c160017>.
- Klees, P., Darlenski, R., Fluhr, J.W., 2012. Full-body skin mapping for six biophysical parameters: baseline values at 16 anatomical sites in 125 human subjects. *Skin Pharmacol. Physiol.* 25 (1), 25–33. <https://doi.org/10.1159/000330721>.
- Ko, L.N., Raff, A.B., Garza-Mayers, A.C., et al., 2018. Skin surface temperatures measured by thermal imaging aid in the diagnosis of cellulitis. *J. Invest. Dermatol.* 138 (3), 520–526. <https://doi.org/10.1016/j.jid.2017.09.022>.
- Krasemann, P.H., 1973. Examination methods in peripheral arterial blood circulation disorders with special reference to thermography. *Med. Mon.* 27 (12), 537–544.
- Kret, M.E., 2015. Emotional expressions beyond facial muscle actions. A call for studying autonomic signals and their impact on social perception. *Front. Psychol.* 6, 711. <https://doi.org/10.3389/fpsyg.2015.00711>.eCollection 2015. (2015 May 27).
- Leijon-Sundqvist, K., Tegner, Y., Olsson, F., Karp, K., Lehto, N., 2017. Relation between dorsal and palmar hand skin temperatures during a cold stress test. *J. Therm. Biol.* 66, 87–92. <https://doi.org/10.1016/j.jtherbio.2017.04.003>.
- Liu, W., Jia, D., Chao, J., et al., 2018. An optical fiber based data-driven method for human skin temperature 3-D mapping. *IEEE J. Biomed. Health Inform.* <https://doi.org/10.1109/JBHI.2018.2854734>. (Epub ahead of print).
- Maslov, L.N., Vychuzhanova, E.A., Gorbunov, A.S., Tsybul'nikov, S., Iu, Khaliulin, I.G., Chauski, E., 2014. Role of thyroid system in adaptation to cold. *Russ. Fiziol. Zh. Im. I. M. Sechenova.* 100 (6), 670–683.
- McBride, W.J., Buikstra, E., FitzGerald, M., 2010. Investigation of febrile passengers detected by infrared thermal scanning at an international airport. *Aust. N.Z. J. Public Health* 34 (1), 5–10. <https://doi.org/10.1111/j.1753-6405.2010.00466.x>.
- Mohamed, S., Frize, M., Comeau, G., 2011. Assessment of piano-related injuries using infrared imaging. *Conf. Proc. IEEE Eng. Med. Biol. Soc.* 2011, 4901–4904. <https://doi.org/10.1109/IEMBS.2011.6091214>.
- Montanari, T., Pošćić, N., Colitti, M., 2017. Factors involved in white-to-brown adipose tissue conversion and in thermogenesis: a review. *Obes. Rev.* 18 (5), 495–513. <https://doi.org/10.1111/obr.12520>.
- Nishiura, H., Kamiya, K., 2011. Fever screening during the influenza (H1N1-2009) pandemic at Narita International Airport, Japan. *BMC Infect. Dis.* 11, 111. <https://doi.org/10.1186/1471-2334-11-111>.
- Norrbrand, L., Kölegård, R., Keramidas, M.E., Mekjavic, I.B., Eiken, O., 2017. No association between hand and foot temperature responses during local cold stress and rewarming. *Eur. J. Appl. Physiol.* 117 (6), 1141–1153. <https://doi.org/10.1007/s00421-017-3601-5>.
- Oya, M., Takahashi, T., Tanabe, H., et al., 2016. Low-temperature infiltration identified using infrared thermography in patients with subcutaneous edema revealed ultrasonographically: a case report. *Drug Discov. Ther.* 10 (2), 117–122. <https://doi.org/10.5582/dtd.2016.01033>.
- Park, E.S., Park, C.I., Jung, K.I., Chun, S., 1994. Comparison of sympathetic skin response and digital infrared thermographic imaging in peripheral neuropathy. *Yonsei Med. J.* 35 (4), 429–437.
- Pastukhov, Iu.F., Ekimova, I.V., 2011. Thermophysiology of the paradoxical sleep. *Russ. Fiziol. Zh. Im. I. M. Sechenova.* 97 (4), 351–373.
- Riede, S.J., van der Vinne, V., Hut, R.A., 2017. The flexible clock: predictive and reactive homeostasis, energy balance and the circadian regulation of sleep-wake timing. *J. Exp. Biol.* 220 (Pt 5), 738–749. <https://doi.org/10.1242/jeb.130757>.
- Rieke, V., Butts Pauly, K., 2008. MR thermometry. *J. Magn. Reson. Imaging* 27 (2), 376–390. <https://doi.org/10.1002/jmri.21265>.
- Sagaidachnyi, A.A., Fomin, A.V., Usanov, D.A., Skripal, A.V., 2017. Thermography-based blood flow imaging in human skin of the hands and feet: a spectral filtering approach. *Physiol. Meas.* 38 (2), 272–288. <https://doi.org/10.1088/1361-6579/aa4eaf>.
- Savastano, D.M., Gorbach, A.M., Eden, H.S., Brady, S.M., Reynolds, J.C., Yanovski, J.A., 2009. Adiposity and human regional body temperature. *Am. J. Clin. Nutr.* 90 (5), 1124–1131. <https://doi.org/10.3945/ajcn.2009.27567>.
- Scolnik, M., Vasta, B., Hart, D.J., Shipley, J.A., McHugh, N.J., Pauling, J.D., 2016. Symptoms of Raynaud's phenomenon (RP) in fibromyalgia syndrome are similar to those reported in primary RP despite differences in objective assessment of digital microvascular function and morphology. *Rheumatol. Int.* 36 (10), 1371–1377. <https://doi.org/10.1007/s00296-016-3483-6>.
- Shterenshis, M., 2017. Challenges to global implementation of infrared thermography

- technology: current perspective. *Cent. Asian J. Glob. Health* 6 (1), 289. <https://doi.org/10.5195/cajgh.2017.289>. eCollection 2017.
- Stewart, H.J., Evans, W.F., 1940. Peripheral blood flow in hyperthyroidism. *Am. Heart J.* 20, 715–720.
- Sun, G., Saga, T., Shimizu, T., Hakozaki, Y., Matsui, T., 2014. Fever screening of seasonal influenza patients using a cost-effective thermopile array with small pixels for close-range thermometry. *Int. J. Infect. Dis.* 25, 56–58. <https://doi.org/10.1016/j.ijid.2014.03.1398>.
- Symons, F.J., Byiers, B., Hoch, J., Dimian, A., Barney, C., Feyma, T., Beisang, A., 2015. Infrared thermal analysis and individual differences in skin temperature asymmetry in rett syndrome. *Pediatr. Neurol.* 53 (2), 169–172. <https://doi.org/10.1016/j.pediatrneurol.2015.03.018>.
- Thermography guidelines, 2002. Standards and Protocols in Clinical Thermographic Imaging (September <<http://www.iactorg.org/professionals/thermog-guidelines.html#/imaging>>).
- Tse, J., Rand, C., Carroll, M., et al., 2016. Determining peripheral skin temperature: subjective versus objective measurements. *Acta Paediatr.* 105 (3), e126–e131. <https://doi.org/10.1111/apa.13283>.
- Whittle, A., 2012. Searching for ways to switch on brown fat: are we getting warmer? *J. Mol. Endocrinol.* 49 (2), R79–R87. <https://doi.org/10.1530/JME-12-0080>.
- Wlodarczyk, W., Hentschel, M., Wust, P., et al., 1999. Comparison of four magnetic resonance methods for mapping small temperature changes. *Phys. Med. Biol.* 44 (2), 607–624.
- Youakim, S., 2010. Infrared thermometry in the diagnosis of hand-arm vibration syndrome. *Occup. Med. (Lond.)* 60 (3), 225–230. <https://doi.org/10.1093/occmed/kqq004>.