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Original Article

Skin temperature behavior after a progressive exercise measured by infrared thermography

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Abstract:
The main objective of this study was to verify the behavior of skin temperature in different body regions of interest before, after and during a progressive submaximal exercise. Thermal images were recording following the recommendations proposed by the European Association of Thermology. The exercise protocol consisted of brief warm-up period followed by increase in speed of 1 km/h on the treadmill every 2 minutes until they reached 85% of the estimated maximum heart rate. Results shows a is a clear response in the skin temperature with a significant reduction after finishing the submaximal exercise compared to resting values in most of the different body regions of interest with the exception of the head and front and back leg, which the largest reductions taking place in the upper limbs.
Keywords: body temperature; infrared thermal imaging; physical exercise, recovery.

Introduction

The exercise execution requires acute organic adaptations, such as changes of autonomic, cardiovascular, pulmonary and metabolic systems in order to adapt to new demands caused by the exercise (Johnson, 2010). An important physiological response to exercise is the redistribution of blood flow in different body regions. In the active muscles that demands larger volume of oxygen occurs vasodilatation, while in inactive areas, such as the system digestive and renal, occurs vasoconstriction (Johnson, 2010; Johnson & Kellogg, 2010). The skin is also affected by these adjustments due to physical exercise be a disturbing agent of thermal homeostasis (Johnson & Kellogg, 2010; Gonzalez-Alonso, Crandall & Johnson, 2008), thereby changing the blood flow. The human cutaneous circulation is extremely variable and may vary from almost zero in extreme local or whole body cooling conditions up to 8 l/min under thermal stress (Charkoudian, 2010). Cutaneous blood flow has a direct correlation with the temperature of the skin (T_{skin}). With low blood flow conditions are recorded the lower values of T_{skin} and with high blood flow there are observed greater T_{skin} (Sawka, Cheuvront & Kenefick, 2012). The adjustments of the blood flow are made through mechanisms of vasodilation and vasoconstriction. The cutaneous vasoconstriction is controlled by the adrenergic sympathetic nervous system and modulated by the action of noradrenergic neurotransmitters such as norepinephrine and neuropeptide Y (Charkoudian, 2010; Gonzalez-Alonso et al., 2008; Johnson & Kellogg, 2010). Already, the cutaneous vasodilation is modulated by the cholinergic sympathetic nervous system, as well as the actions of nitric oxide, acetylcholine, vasoactive intestinal peptide (VIP) and P substance (Johnson, 2010; Johnson & Kellogg, 2010).

At the regions of non-glabrous skin ("with hair", comprising most of the body surface) is known the presence of sympathetic nerves responsible for vasoconstriction and vasodilatation (Charkoudian, 2010; Johnson, 2010; Johnson & Kellogg, 2010). However, in regions of the glabrous skin (hairless) as the palms and feet soles, is there only the adrenergic system innervation that controls vasoconstriction, thus the process of vasodilation in this region is modulated mainly by the withdrawal of vasoconstrictor tone (Gonzalez-Alonso et al., 2008; Johnson & Kellogg, 2010; Johnson, 2010; Kellogg, 2006; Charkoudian, 2010). Due to these physiological characteristics it is probable that in these areas the T_{skin} responds differently to the physical

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exercise. In the onset of dynamic exercise occurs a cutaneous vasoconstriction that is related and accompanied with an acute T_{skin} reduction (Charkoudian, 2010; Johnson & Kellogg, 2010). Such reductions are related to exercise intensity, amount of muscle mass involved in the activity and type of exercise (dynamic or isometric) (Johnson & Kellogg, 2010). Thus, redistribution of cutaneous and visceral blood flow requires higher levels of vasodilatation on the active muscles to be able to receive redistributed the blood flow (Johnson & Kellogg, 2010). Different studies have been conducted for establish the T_{skin} adjustments related to physical exercise, using mostly thermo sensors of contact (Schlader, Simmons, Stannard & Mündel, 2011; Levels, Koning, Foster & Daanen, 2012). However, this monitoring technique registers only the temperature at the sensor contact point, not allowing to record T_{skin} of the complete monitored segment. In the study of Hunold, Mietzsch & Werner (1992), for example, it was observed that within a distance of few inches can be found differences in T_{skin} higher than 3°C and differences in skin microcirculation of up to 300%. Thus, depending the sensor positioning, different values of T_{skin} can be recorded and hamper to compare across studies.

Another common methodology used to study the T_{skin} is based on the average skin temperature (AvT_{skin}). registered at different pre-established anatomical regions which subsequently are introduced into an equation. In this type of analysis, the number of body regions that comprises each formula varies widely(Choi, Miki, Sagawa & Shiraki, 1997) and can, for example, consider four (Ramanathan, 1964) or eight (Nadel, Mitchell & Stolwijk, 1973) body regions which can result, depending on the specific physiological response of each body region in physical exercise, in different AvT_{skin} according to the formula chosen. This kind of analysis is widely used in studies related to thermoregulation (Schlader et al., 2011; Levels et al., 2012); however, it is not so common in studies of T_{skin} recorded by infrared thermography.

An interesting methodological strategy to evaluate the T_{skin} is infrared thermography (IRT), this technique extends human vision through the infrared spectrum and allows visualization of local or whole body surface T_{skin} without physical contact with the assessed (Fernandes et al., 2012; Merla, Mattei, Di Donato & Romani, 2010). Some studies have performed T_{skin} monitoring using IRT in situations of progressive exercise until the maximal aerobic capacity (Akimov & Son'kin, 2011; Merla et al., 2010; Zontak, Sideman, Verbitsky & Beyar, 1998; Akimov et al., 2010; Hunold et al., 1992). These studies indicate reduction of T_{skin} in different body regions during and immediately after physical exercise. However, none of these studies have separated glabrours and non-glabrous in the analysis and the AvT_{skin} formulas (Ramanathan, 1964; Nadel et al., 1973) were not used. The variation measured by IRT, which allows comprehensive analysis different of body regions of interest (ROIs) in the anterior and posterior view, during and after submaximal progressive exercise requires further research, thus leaving a gap in specific knowledge of this technique.

Thus, the present study established three objectives: a) verify the variations of T_{skin} in different ROIs after a submaximal exercise with progressive increment of intensity; b) compare the pre- and post-exercise AvT_{skin} obtained through formulas that consider four and eight ROIs; c) compare the T_{skin} behavior in the non-glabrours skin regions (dorsal hand) and glabrous skin regions (palms) in pre- and post-exercise moments.

Materials & Methods

The study was conducted in three stages: preparation, exercise and rest phases.

Preparation phase

Were selected 12 participants with mean age of 22.4±3.3 years, height 177.0±0.8 cm, body mass 74.8±6.2 kg, body fat percentage 12.7±3.5%, body surface area 1.92±0.1 m^2 and VO^2max of 48.7±4.9 $ml.kg.min^{-1}$.

The participants were selected complying with the criteria for inclusion/exclusion cited in sequence. As the T_{skin} may suffer interference due to external and internal factors, it was considered as exclusion factors the following characteristics: smoker, history of kidney problems, osteo-myo-articular injury in the last two months or lodge any symptoms; present a skin burn; symptoms of pain in any body region; sleep disorders; fever in the last seven days; Therapy or dermatological treatment with creams, ointments or lotions for local use; and use of antipyretics or diuretic medications, or any dietary supplement with potential interference in water homeostasis or body temperature in the last two weeks.

All volunteers were apparently healthy through the Physical Activity Readiness Questionnarie (PARq) (Shephard, 1988), and with low coronary risk classification according to the proposal from Michigan Heart Association. Considering the dynamics of the proposed exercise, were included subjects classified as “physically active” according to the criteria of the American College of Sports Medicine (ACSM)(Garber et al., 2011) for holding regular physical training sessions at least 3 times a week in the last four months.

During this step the volunteers were submitted to the dynamics of the study, as well as conduct procedures for the second and third stages. All participants signed a free and informed consent. This study was approved by the Ethics Committee for Research with Human Beings of the Federal University of Viçosa (Case 134). During this step also were measurements performed of body mass (Filizola®, Star 300/4) and height (American Medical®, ES2020), following the recommendations of International Society for the Advancement of Kinanthropometry (Marfell-Jones, Olds, Stewart & Carter, 2006). The body surface area was calculated from the anthropometric measurements performed, according to DuBois and DuBois (1916). To estimate body density, we used equations with the sum of seven skinfolds (pectoral, subscapular, midaxillary, triceps, supra-iliac, abdomen and thigh) developed by (Jackson & Pollock, 1978).

The maximum oxygen consumption ($VO_{2máx}$) was estimated based on the ACSM(American College of Sports, Thompson, Gordon & Pescatello, 2010) recommendations using a submaximal treadmill test, to preserve the safety of the volunteer. In this methodology, individual equations to estimate the $VO_{2máx}$ were formulated by linear regression using the heart rate values (HR) and VO_2 (ml.kg.min^{-1}) obtained during exercise with analysis of respiratory gas exchange. For the oxygen consumption evaluation was used a metabolic gas analyzer (Medical Graphics Corporation®, VO2000), for evaluating the HR a heart monitor (*Polar® RS800CX) and for determining the linear regression was used the software* SigmaPlot®, 12.0.

Exercise phase and resting phase

For the thermal images recording, the recommendations proposed by the European Association of Thermology (Ring & Kurt, 2006) were followed. Considering that body temperature varies with the day time, we chose to perform all thermographic images in the afternoon at 14:00 hours.

The experiment was carried out in a properly prepared environment in with artificial lighting and controlled temperature conditions (Komeco®, Split Hi-Wall). The average ambient temperature remained at 23.1±07°C and relative humidity of 62.2±5.7%, both recorded by digital anemometer (Instrutherm®, AD-250). These environmental conditions are in accordance with the Ring and kurt (2006) recommendations for perform a correct thermal imaging. The conditioner airflow was not directed to the area of exercise execution or thermographic images collection, in these sites, wind speed was measured by digital anemometer and it was null. Room was artificially illuminated by fluorescent lamps, where the reflected temperature has been properly measured and recorded at 23°C.

The evaluated remained standing for a 30-minute adaptation period in the test room with controlled temperature before starting the evaluations, enough time to occur T_{skin} stabilization forward to the laboratory conditions of registration according to the recommendations of suggesting a minimal adaptation time of 10 minutes (Marins et al., 2014). During this step the volunteers used only tennis, swimming trunks and heart monitor. After this adjustment period, the evaluated were oriented to indicate the thermal sensation through a nine-point scale (Yasuoka, Kubo, Tsuzuki & Isoda, 2012), and thermal comfort in seven-point scale used previously in study of Yasuoka et al. (2012).

Thermal images were performed on six different times: pre-exercise (after 30' of acclimatizing), immediately after exercise and at the 5, 10, 15 and 20 minutes post-exercise recovery. At this stage, the volunteer was standing positioned in anatomical position facing the imager to perform the thermal images of the anterior regions, turning back later to execute the thermal imaging of the posterior regions (see figure 1).

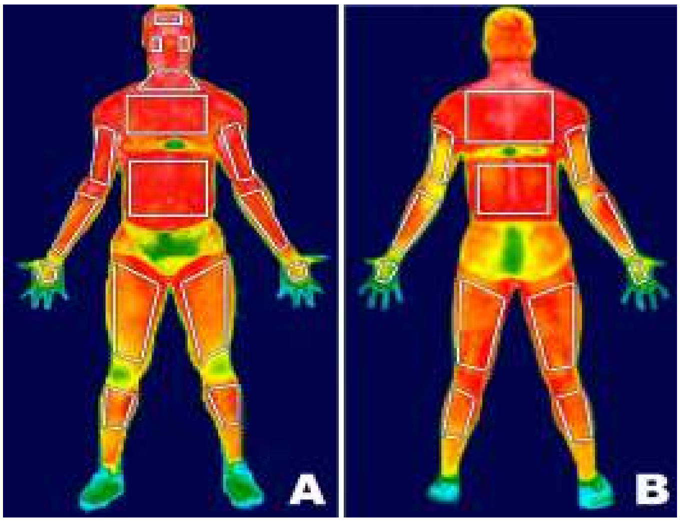

Fig 1. Location of the considered ROI in the frontal and posterior views.

To define better the analyzed ROI several reference anatomical points were established in the anterior part of the body and to determine areas of the posterior ROIs they were considered the corresponding landmarks in the anterior ROIs.

Therefore, the rectangles configuration was determined as follows: (a) Forehead: in the forehead; (b) Cheeks: Between the zygomatic and infraorbital region, including part of the buccal region; (c) Neck: in the anterior cervical region, including part of the sternocleidomastoid region, the small supraclavicular fossa, the lateral cervical region and greater supraclavicular fossa; (d) Hand: from the junction the metacarpal 3rd with the proximal phalanx 3rd to the ulnar styloid process; (e) Forearm: from the distal forearm to the cubital fossa; (f) Arm: from the cubital fossa to the axillary line; (g) Abdomen: from the xiphoid process to 5 cm below the umbilicus; (h) Chest: from the nipple line to the top sternum edge; (i) Thigh: from 5 cm above the patella superior border to the inguinal line; and (j) Leg: from 5 cm below the patella inferior border to 10 cm above the malleolus.

The equipment used to obtain thermal images was the thermal imager (Fluke®, TIR-25), with a measuring range of -20 to +350°C, accuracy of ± 2°C or 2%, sensitivity ≤ 0.1°C, spectral band of infrared 7,5 µm a 14 µm, refresh rate of 9 Hz and System FPA (Focal Plane Array) of 160 x 120 pixels. The camera was adjusted for the emisivity values adopted for human skin (0.98) (Jones, 1998; Costa et al., 2015; Marins, Formenti, Costa, Fernandes & Sillero-Quintana, 2015).

After collecting the thermal images, it was possible to establish the thermal values for the 28 considered ROIs (forehead, cheeks, neck, chest, abdomen, back, lumbar, and still, hand, forearm, upper arm, thigh, leg, the right and left sides) using the specific software Smartview®, 3.1.

To calculate the average skin temperature (AvT_{skin}) two different equations were used as described in Table 1: the first was the porposed by Ramanathan (1964), including four registration points, while the second was proposed by Nadel et al. (1973) and included eight registration points.

Table 1. Equations to calculate AvT_{skin}.

References	Equations
Ramanathan (1964)	$0.3 \times T_{chest} + 0.3 \times T_{arm} + 0.2 \times T_{thigh} + 0.2 \times T_{leg}$
Nadel et al.(1973)	$0.21 \times T_{forehead} + 0.1 \times T_{chest} + 0.17 \times T_{abdomen} + 0.11 \times T_{dorse} + 0.12 \times T_{arm} + 0.06 \times T_{forearm} + 0.15 \times T_{thigh} + 0.08 \times T_{leg}$

The exercise protocol started with a warm-up of three minutes in the treadmill (Ecafix®, EG 700x) with the speed maintained at 5 km/h; after this period, the speed was increased by 1 km/h every two minutes until the subjects reached 85% of their maximum heart rate (MHR) previously calculated using the equation proposed by Tanaka, Monahan & Seals (2001) [MHR =208 - (0,7 x age)]. The treadmill inclination was set at 2% throughout the test. The cold-down period was 2 minutes with the speed maintained at 3 km/h and and inclination of 0%.

Resting phase

During the 20 minutes of recovery we followed the same methodological procedures to record thermal images of the previous steps, but the subjects remained in a standing position without sitting down, drying or scratching their skin at any time.

Statistical Analysis

For statistical calculations were considered the average of sum T_{skin} registered in both body segments of the hands, forearms, arms, legs and thighs, just as in the face region with forehead and cheeks areas. It was used the Shapiro-Wilk test to confirm the normal distribution of the data, followed by descriptive statistics as mean and standard deviation (SD). For T_{skin} comparison between the different moments pre, post-exercise, 5, 10, 15 and 20 minutes of the resting period and AvT_{skin} values the ANOVA One-Way for repeated measures was used followed by post-hoc Holm-Sidak.

We used the paired samples T-test to compare the T_{skin} of non-glabrous and glabrous regions, as well as to compare the results of the AvT_{skin} formulas of Ramanathan (1964) and Nadel et al. (1973) in the different studied moments. The significance level was set always at $\alpha < 0.05$. All analyses were conducted in the statistical program Sigmaplot®, version 12.0.

Results

The average of thermal sensation was -0.3±1.2 points, the thermal comfort 2.0±1.1 points, the ratings of perceived exertion (RPE) 14.0±1.4 points, the HR 163.5±1.9 beats·min^{-1}, the exercise total time 11.8±2.2 min and the top speed 9.5±1.2 km/h.

Figures 2 and 3 show the T_{skin} mean values of the analyzed ROIs, in different moments of the data collection in the front view and posterior view respectively.

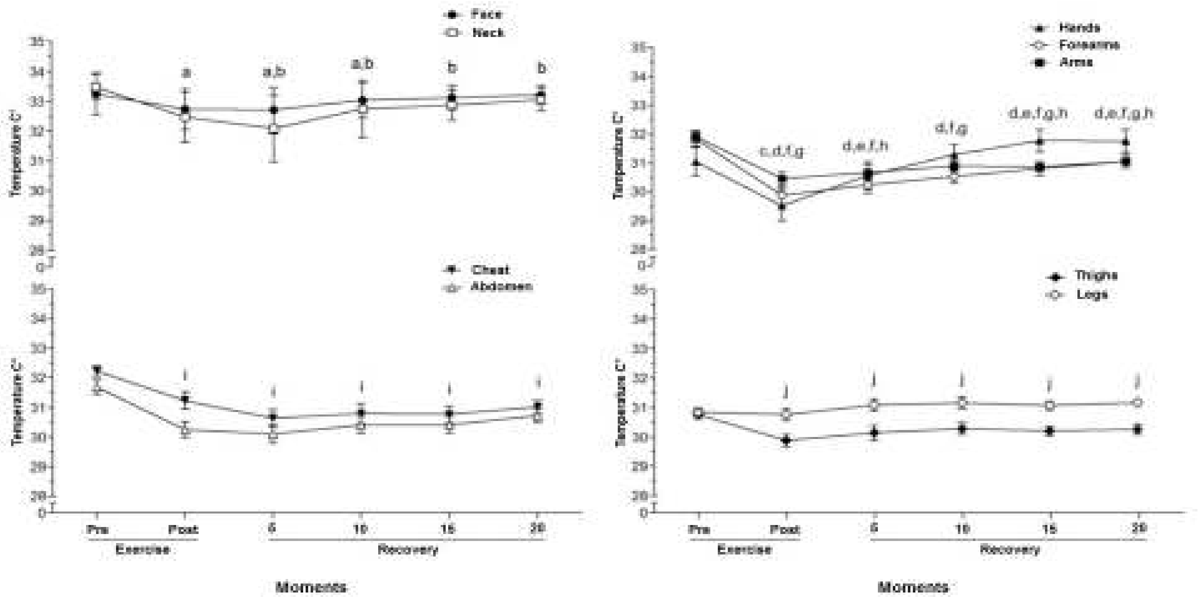

Fig 2. Values of T_{skin} in ROI of the face, neck, hands, forearms, arms, chest, abdomen, thighs and legs on pre and post exercise, minutes 5, 10, 15 and 20 recovery in anterior regions. Results presented as mean and standard deviation.

[a] *sig. dif. pre-exercise VS post-exercise, 5 e 10 at the neck.* [b] *sig. dif. 5 minutes VS 10, 15 e 20 minutes at the neck.* [c] *sig. dif. pre-exercise VS post-exercise at the hands.* [d] *sig. dif. post-exercise VS 5, 10, 15 e 20 minutes at the hands.* [e] *sig. dif. 5 VS 15 e 20 minutes at the hands.* [f] *sig. dif pre-exercise VS post-exercise, 5, 10, 15 e 20 minutes at the forearm and arm.* [g] *sig. dif. post-exercise VS 10, 15 e 20 minutes at the forearm.* [h] *sig. dif. 5 VS 15 e 20 minutes at the forearms.* [i] *sig. dif. pre-exercise VS post-exercise, 5, 10, 15 e 20 minutes at the chest and abdomen regions.* [j] *sig. dif. pre-exercise VS post-exercise, 5, 10, 15 e 20 minutes at the thigh.*

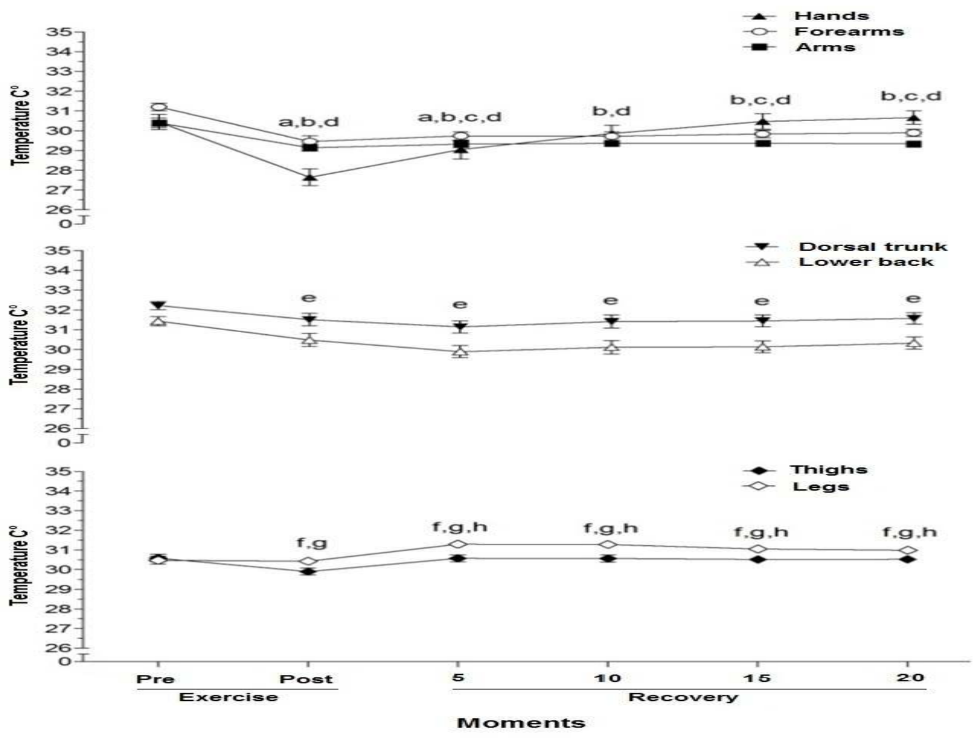

Fig 3. Values of T_{skin} in ROI of the hands, forearms, arms, dorsal trunk, lower back, thighs and legs on pre and post exercise, minutes 5, 10, 15 and 20 recovery in posterior regions. Results presented as mean and standard deviation.

[a] *sig. dif. pre-exercise VS post-exercise e 5 minutes at the hands.*

[b] *sig. dif. post-exercise VS 5, 10, 15 e 20 minutes at the hands.*

[c] *sig. dif. 5 VS 15 e 20 minutes at the hands.*

[d] *sig. dif. pre-exercise VS post-exercise, 5, 10 15 e 20 minutes at the arm and forearm regions.*

[e] *sig. dif. pre-exercise VS post-exercise, 5, 10 15 e 20 minutes at the dorse and lower back regions.*
[f] *sig. dif. post-exercise VS pre-exercise, 5, 10, 15 e 20 minutes at the thigh region.*
[g] *sig. dif. post-exercise VS 5, 10, 15 e 20 minutes at the leg regions.*
[h] *sig. dif. pre-exercise VS 5, 10, 15 e 20 minutes at the leg regions.*

Figure 4 shows the AvT_{skin} values of Ramanathan (1964) and Nadel et.al. (1973) equations calculated for the following moments: 1) before and after exercise; and 2) in minutes 5, 10, 15 and 20 of recovery.

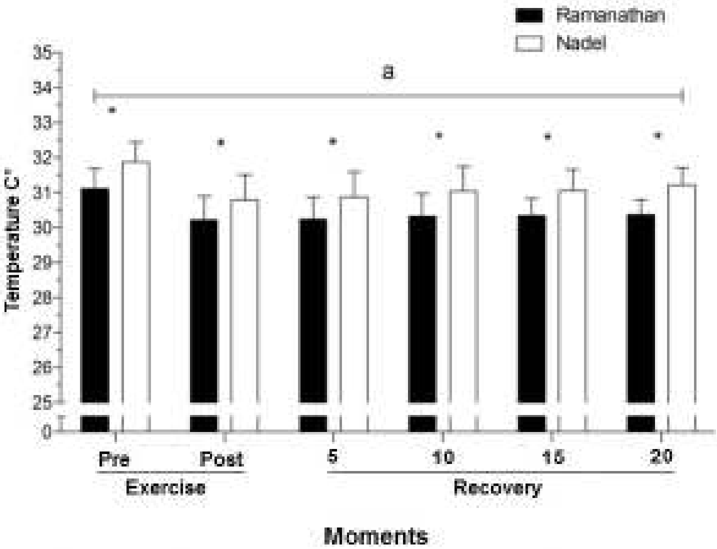

Fig 4. Values of AvT_{skin} calculated through the formulas Ramanathan (1964) and Nadel et al.(1973) pre and post exercise and in minutes 5, 10, 15 and 20 of recovery. Results presented as mean and standard deviation.
[a] *sig. dif. pre-exercise VS post-exercise, 5, 10, 15 e 20 minutes of formulas Ramanathan and Nadeletal; * sig. dif. between of formulas Ramanathan e Nadel.*

Figure 5 shows the T_{skin} comparison at the non-glabrous and glabrous regions of the skin: 1) before and after exercise; and 2) in minutes 5, 10, 15 and 20 of recovery.

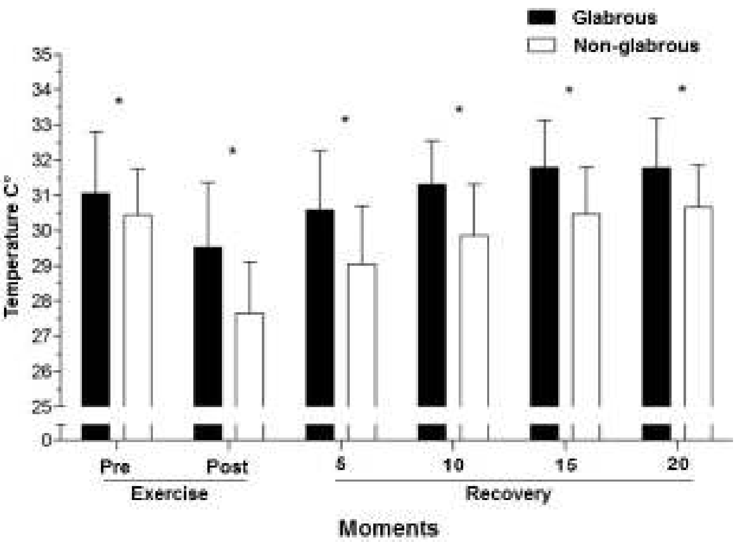

Fig. 5. Values of T_{skin} in non-glabrous and glabrous regions pre and post exercise and in minutes 5, 10, 15 and 20 of recovery. Results presented as mean and standard deviation.
* *sig. dif. between of* non-glabrous and glabrous regions

Discussion

The main study findings suggest that while performing a short duration and progressive exercise occurs an acute blood flow redistribution on the skin regions corresponding to active muscles due to the action of strong vasoconstrictor mechanisms (Johnson & Kellogg, 2010; Charkoudian, 2010). Thus, for a short progressive exercise in thermo neutral environment, is more important for body to meet the metabolic demands of the exercised muscles than exchanging heat with the environment by directing the blood flow to the skin.

The results of T_{skin} in the assessed ROI indicate significant reduction between the T_{skin} values obtained in pre-exercise time compared to those recorded immediately after exercise in almost all ROI analyzed. The exceptions were the face region, and the anterior and posterior legs regions (Figures 2 and 3). The main reductions occurred in the upper limbs, with a magnitude of 1.8°C, followed by the central regions (chest, abdomen, back and lower back) and also in the thighs regions. These results reinforce the concepts of blood flow redistribution from the skin region to the active muscles (Johnson & Kellogg, 2010; Johnson, 2010; Gonzalez-Alonso et al., 2008), where the body segments, arms, forearms and especially hands, seem to significantly contribute to this process.

The reduction of T_{skin} values immediately after exercise has been previously reported by other authors such as Merla et al. (2010) and Zontak et al. (1998) where the assessed performed a progressive load exercise up to maximum aerobic capacity. This drop in T_{skin} was justified by the start of heat loss through evaporation, but mainly by a physiological vasoconstrictor cutaneous response controlled by the adrenergic sympathetic nerves and modulated by action of noradrenergic neurotransmitters such as neuropeptide Y and noraepenefrina (Charkoudian, 2010; Gonzalez-Alonso et al., 2008; Kellogg, 2006; Johnson & Kellogg, 2010).

This vasoconstrictor mechanism possibly acts with higher intensity in the ROI of the upper limbs, especially hands, where T_{skin} decreases after exercise 1.6°C (4.9%) in the anterior view and 2.8°C (9.2%) in posterior view. These results are similar to other studies in literature (Merla et al., 2010; Nakayama, Ohnuki & Kanosue, 1981; Torii, Yamasaki, Sasaki & Nakayama, 1992; Zontak et al., 1998). It is important to note that during the post-exercise periods, the T_{skin} took upward trend in the ROI of the upper limbs returning quickly to resting values at the time 10-minute. This T_{skin} oscillatory behavior shows that even at submaximal intensity there is a quick response from thermoregulatory system.

In the analysis of the ROI corresponding to the lower limbs, we identified significant statistically reduction of T_{skin} between pre and post-exercise time in the anterior and posterior regions of the thigh, and this reduction is maintained only in the anterior region during the recovery process. A similar result but with higher magnitude was found in the study of Merla et al. (2010), where T_{skin} was reduced by 4.6°C. It should be noted that in the revised study, subjects underwent a progressive loading protocol up to the maximum, while the effort levels measured in this study remained at submaximal levels, this point could explain the discrepancy on the magnitude of T_{skin} differences between the two studies. Other studies (Zontak et al., 1998; Torii et al., 1992; Merla et al., 2010; Nakayama et al., 1981) also reported T_{skin} reduction in short duration exercise, being the reduction inversely proportional to the intensity of the load, supporting our less marked T_{skin} reduction after performing a submaximal exercise.

The T_{skin} behavior of the anterior legs showed no statistical difference in the different assessed moments, thereby indicating a temperature balance in this site. Similar results were recorded in posterior view when pre- and post-exercise values are compared; however, there was a significant statistically increment on T_{skin} when comparing pre-exercise with 5, 10, 15 and 20 minutes of recovery values. This T_{skin} increment may have occurred because of the blood flow redirection from muscle to skin in order to facilitate the heat exchange with environment (Merla et al., 2010).

The AvT_{skin} calculated by Nadel et al. (1973) and Ramanathan (1964) formulas also shows a significant reduction between pre-exercise values and the other assessed moments independently of the formula used (Figure 4). This result reinforces the role of vasoconstrictor mechanisms as the main responsible for these T_{skin} reductions and agrees with previously published works of Torii et al (1992) and Nakayama et al. (1981), where T_{skin} decrement happens at the beginning of the exercise even without the presence of sweating.

Another important consideration is the existence of a significant difference at all studied moments when comparing the two considered formulas to determine the AvT_{skin}, obtaining higher AvT_{skin} values with 8 ROIs Nadel's equation. In order to minimize estimation errors, our results indicate that AvT_{skin} comparisons should be held out with studies that used the same equations. Choi et al. (1997) compared AvT_{skin} results obtained by 16 different formulas and concluded that to obtain a reliable result, one should choose equations involving more than T_{skin} evaluation points. Based on that statement, we suggests in further studies the use of Nadel et al. (1973) equation with 8 registration points.

The non-glabrous (hair) regions have vasodilators and vasoconstrictor nerves, while the glabrous (hairless) regions only receives vasoconstrictor innervations (Johnson & Kellogg, 2010). Thus, even when the dynamics of the skin thermal response after exercise is similar, in the dorsal region of the hand, T_{skin} is always higher compared to the palmar region (Figure 5). This may be due to the vasodilator mechanisms in the back of the hand that do not exist in the glabrous region (Johnson & Kellogg, 2010). Furthermore, it is known that non-glabrous region produces larger amount of sweat that the glabrous regions, which may have contributed to the greater T_{skin} reduction in the back of the hands (Smith & Havenith, 2011). In post-exercise period T_{skin} rose more sharply in glabrous areas, probably due to its more effective vasoconstriction mechanisms, which creates immediate rise in blood flow on this area (Johnson & Kellogg, 2010). According to Johnson and Kellogg (2010), vasoconstrictor nerve activity in non-glabrous regions leads to modest increases of blood flow compared to glabrous region; however, this mechanism is still unclear.

We would like point out that the registered T_{skin} responses are valid for the environmental conditions of this study, which may be considered as tempered or "thermoneutral", being assessed by the participants as "neutral" (thermal sensation) and "confortable" (thermal comfort). Under extreme environmental conditions the results could be different.

In this study there were presented average T_{skin} values in different ROI from many areas of the body surface, allowing greater understanding of T_{skin} responses in submaximal exercise. As study limitations it should be considered not evaluating the core temperature or T_{skin} while performing the running test, which could have provide us with very interesting information about the thermal dynamics during exercise.

Conclusion

The results obtained by IRT showed that during the progressive loading running exercise there is a post exercise T_{skin} reduction compared to pre-exercise values with emphasis on upper limbs and the trunk, while this behavior was not observed in anterior and posterior legs regions.

The AvT_{skin} results also indicate a post-exercise reduction compared to the pre-exercise values, independently of the equation used equation. There is a difference between the AvT_{skin} results according to the formula used, being always lower when using the four points Ramanathan's equation.

Finally, the dynamics of thermal response after exercise was similar in glabrous and non-glabrous areas of the hand; however, the T_{skin} was always higher on glabrous region in all the studied moments.

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Conflict of interests

The author(s) have no conflicts of interest relevant to this article.

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