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Original Article

Measuring of skin temperature via infrared thermography after an upper body progressive aerobic exercise

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Abstract:

The aim of this study was to evaluate the skin temperature (Tsk) response to progressive exercise of upper limbs. Sixteen young active men (22.5±2.1 yrs.) performed a progressive test up to 85% of HRmax. Thermograms of the trunk, Upper Limbs (UL) and Lower Limbs (LL) were recorded at rest (REP), immediately after exercise (PEX) and every 15 minutes during 60 minutes of recovery (R15 to R60). Ten regions of interest (ROIs) were manually selected from each thermogram. A repeated measures ANOVA was applied to assess thermal variations over time. There was a significant decrease in temperature in Chest, Abdomen, Superior Back, Lumbar, Anterior and Posterior Thigh, Anterior and Posterior Leg PEX (Δ≤-1.5oC vs REP; p<0.001 for all comparison); however, the Tsk increased after 15 minutes of recovery in these same ROI (Δ≤0.7oC vs REP; p<0.05 for all comparisons, except Anterior Thigh; p=0.167). All Arm ROIs showed the opposite behavior, where there was a progressive increase in Tsk up to 15 min post-exercise (Δ≤1.0oC vs REP; p<0.01 for all comparison), followed by a progressive decrease. The progressive submaximal upper limbs exercise increased the Tsk in active areas (arms) and induced a significant decrease of Tsk in others.

Key words: thermography; temperature skin; thermoregulation; arm ergometer.

Introduction

Infrared thermography (IRT) can be considered an emerging alternative methodology in studies involving skin temperature (Tsk) analysis (Jiang *et al.*, 2005; Vargas *et al.*, 2009). IRT is a technique that extends the human eye through the infrared spectrum by means of a camera which allows you to record the temperature of the body surface in real time with a sensitivity up to 0.025°C, and an accuracy reaching 1.0% without any physical contact (Vargas et al., 2009). It is worth noting to point out that this technique quantifies temperature from the infrared radiation released by the skin, differing from contact thermosensors which register skin temperatures by conduction, and not only from the skin but also from deeper tissues (Vargas et al., 2009). The use of (ITR) at resting condition is well described in the literature, including works that established normative data in adult populations (Marins, Fernandes, et al., 2014; Vargas et al., 2009; Zaproudina, Varmavuo, Airaksinen, & Närhi, 2008; Zhu & Xin, 1999), children (Kolosovas□Machuca & González, 2011), and gender differences (Marins, Fernandes, et al., 2014; Niu et al., 2001). However, ITR can be considered an innovative methodology in studies involving Tsk analysis for exercising (Jiang et al., 2005). Moreover, there is an increase in metabolic rate and consequent increase in the internal heat during exercise (Schlader, Stannard, & Mündel, 2010; Shibasaki, Wilson, & Crandall, 2006). This changes the thermal equilibrium between the subject and the environment, making it necessary to activate mechanisms for compensating heat loss mediated by the hypothalamic complex feedback system (Shibasaki et al., 2006). Other changes involve a redistribution of blood circulation from inactive to active areas during exercise. Continued physical activity subsequently redirects the blood flow to the skin for the purpose of exchanging heat with the environment (Charkoudian, 2010). Thus, exercise is considered a disturbing agent of thermal homeostasis (Crandall, Wilson, & Kregel, 2010).

It seems important to establish how thermal Tsk adjustments occur during various forms of exercise on different types of ergometers, considering the movement patterns and the body mass involved which could generate different and specific metabolic responses. Most of the work done in the area of thermography and exercise in laboratory conditions were performed using a treadmill (Clark, Mullan, & Pugh, 1977; de Andrade Fernandes et al., 2014; de Andrade Fernandes, dos Santos Amorim, Brito, Sillero-Quintana, & Marins, 2016; Merla, Mattei, Di Donato, & Romani, 2010) or cycle ergometer (Akimov & Son'kin, 2010; Hayashi, Kawashima, & Suzuki, 2012; Levels, de Koning, Foster, & Daanen, 2012) and eventually with strength training

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in a gym (Hani H, Jerrold S, Michael S, & Lee S, 2012). It was evident that there are specific thermal adaptations depending on the type of exercise and the execution technique. However, settings for describing the effects of exercises performed with an arm ergometer on Tsk have not been related. Thus, it is interesting to identify the body heat dissipation processes both in general, and considering different regions of interest (ROIs) of the body. This information is important to understand how body heat adjustments during exercise take place, which may contribute, for example, to developing new sports clothes that facilitate heat loss under stress conditions, or retain heat in a cold environment. The aim of this study was to analyze the thermographic behavior of different regions of the skin immediately after an aerobic arm exercise and during one hour of the recovery process. We hypothesized that the exercised region (upper limbs) will present a temperature difference in comparison to the non-exercised region (lower limbs).

Materials & methods

Participants

The inclusion criteria for the present study were as follows: a) being physically active, b) between 18 and 30 years of age, c) male, d) a college student; and e) at present a negative coronary risk (PAR-q). We obtained 16 volunteers. They then went through an initial screening with the following exclusion criteria recommended by Fernández-Cuevas et al. (2015): smoking, history of kidney problems, osteomioarticular injury in the last two months or any symptoms at present; burns on the skin; symptoms of pain in any body region; sleep disorders; fever in the last seven days; physiotherapy or dermatological treatment with creams, ointments or lotions for local use; and consuming drugs such as antipyretics or diuretics, or some food supplement with potential interference in water homeostasis or in body temperature in the last two weeks. Therefore, the final sample of this study was composed of 16 young males (22.5±2.1 yrs., 1.8± 0.1 ht., 76.2 ± 9.7 kg, 11.6 ± 5.1% BF).

Procedures

After screening, the volunteers completed the PAR-Q questionnaire and coronary risk table proposed by the Michigan Heart Association (Thomas, Reading, & Shephard, 1992). The participants were considered “apparently healthy” if they presented a "negative response" to all questions of the PAR-Q questionnaire and coronary risk rated "below average". Subjects were considered “physically active” when they were engaged in regular physical activity at least three times a week, according to the American College of Sports Medicine recommendation (Garber et al., 2011). All subjects were informed of the study objectives and signed a free and informed consent form, thus meeting the requirements of the federal law 466/12 for experiments with humans. This study was approved by the Local Ethics Committee of the University where the experiment was conducted (protocol: 27202414.8.0000.5153).

After the first measurements, volunteers underwent an anthropometric analysis to measure height (cm) (Sanny®, Standard, São Bernardo do Campo, Brazil), body mass (kg) (Filizola®, ID-M 150/4, São Paulo, Brazil) and chest, abdomen and thigh skinfolds (mm) (Cescorf®, Top Tec, Porto Alegre, Brazil). The Jackson and Pollock (2004) equation was used for calculating the body density, and the body fat percentage was estimated by Siri (1992) equation. Anthropometric measurements were obtained according to the recommendations of the International Society for the Advancement of Kinanthropometry by a previously instructed anthropometrist (Marfell-Jones, Stewart, & de Ridder, 2012) and data recording and processing were performed in Avaesporte® Software (Sports Systems, Viçosa, Brazil).

Exercise Protocol

The assessed subjects were positioned up against the arm ergometer (Technogym Excite TOP 700®, Cesena, Italy) with their feet laterally spaced shoulder width apart, and the central module of the crankshaft positioned in line with the xiphoid process with a pronated grip (Figure 1). The protocol consisted of a 3-minute warm-up with the upper limbs ergometer speed maintained at 50 to 60 rpm, and a load of 20 watts. After this period, 15 watts was added every 2 minutes until voluntary exhaustion or inability to maintain the frequency of 50-60 rpm. A test was considered valid when the participants reached the 85% of the maximum heart rate (MHR) estimated by the equation of(Tanaka, Monahan, & Seals, 2001). Blood lactate levels were recorded by capillary test (Roche®, Accutrend Plus, Indianapolis, USA) at the end of the exercise, with the second drop of blood used for analysis after cleaning the area with alcohol and drying it with cotton. HR was continuously monitored in order to control effort intensity (Polar FS1®, Kemple, Finland) throughout the experiment, as well as implementing the Borg Rating of Perceived Exertion (RPE) Scale during the test and after its termination on a scale from 6 to 20 points (Borg, 1982).

Thermographic measurement

The protocol for capturing the thermographic images was performed according to the recommendations of the European Association of Thermology (Ring & Ammer, 2012) and Thermographic imaging in sports and exercise medicine (TISEM) Consensus (Moreira et al., 2017). Prior to the evaluation, the participants were instructed to avoid all influencing factors. The evaluation was performed in a room with stable temperature (19.7±1.5°C) and relative humidity (56.9±5%) conditions, as well as there being no wind directed to the image site collection or exercise performance area. Environmental conditions were recorded by a digital anemometer (Instrutherm®, AD-250, Sao Paulo, Brazil). A minimum acclimatization period of 10 minutes standing was respected (Marins, Moreira, et al., 2014; Moreira et al., 2017), which evaluated the subjects dressed only in swimming trunks, heart monitor and sport shoes without crossing their arms, performing any sudden movements or rubbing any part of their body. Six thermograms were recorded for each subject: Before starting the exercise step in rest (REP), immediately after exercise (PEX), and once every 15 minutes during 60 minutes of recovery (R15, R30, R45 and R60). Figure 1 shows the data collection timeline in this study.

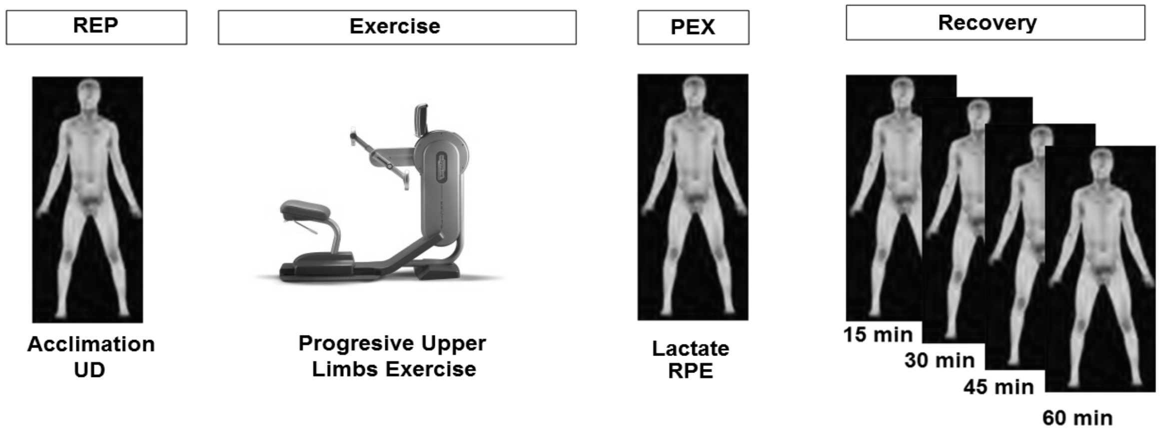

Fig.1. Experimental procedures. REP: rest; PEX: immediately after exercise; UD: urine density; RPE: Rating of Perceived Exertion.

Body Tsk was monitored by way of thermograms obtained with ITR-25 Imager® (Fluke, Everett, USA) at a distance of 3 meters and a total of four sets of images as follows: anterior lower limbs, anterior upper limbs and trunk, posterior lower limbs and posterior upper limbs and trunk. The following anatomical points on the anterior portion of the body and their corresponding points in the posterior portion were adopted (Figure 2), as per the recommendations adopted in previous studies (de Andrade Fernandes et al., 2014; de Andrade Fernandes et al., 2016). The thermographic images were analyzed using Smartview 3.1® software (Fluke, Everett, USA), which allows for measuring a body area temperature manually demarcated by a rectangle. Thus, the ROIs regarding the thighs, legs, arms, forearms, upper back, lower back, chest and abdomen were defined in the anterior and posterior views (Figure 2), and the average body temperature of each ROI was obtained. The Tsk calculation considered the average of the two body segments in the arms, forearms, thighs and legs in their respective views.

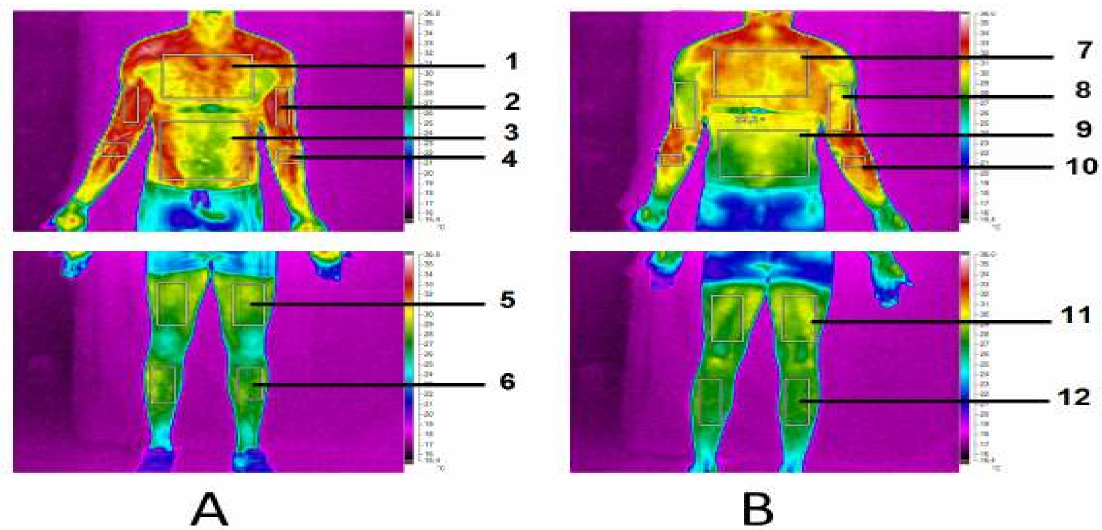

Fig. 2. ROIs analyzed before, immediately after and during the recovery period. A = Anterior View (1: Chest; 2: Forearm; 3: Abdomen; 4: Arm; 5: Thigh and 6: Leg) and B = Posterior View (7: Superior Back; 8: Forearm; 9: Lumbar; 10: Arm; 11: Thigh and 12: Leg).

Statistical Analysis

Exploratory data analysis was performed for identifying and correcting extreme values. Normality and homoscedasticity were tested using the Kolmogorov-Smirnov test and the Bartlett criterion, respectively. We used analysis of variance (ANOVA) for repeated measures to establish the difference among means of the Tsk in each ROI before, immediately after and during recovery from exercise. We used the Mauchly sphericity test for validating repeated measurements, and applied the Greenhouse-Geisser correction when necessary. If we observed a difference in the ANOVA, we used the post hoc Tukey test. The magnitude of treatment effects was calculated using η^2 effect size. The standardized effect size (Cohen's d) analysis was used to interpret the magnitude of differences among measurements. The α level was set at 0.05 for all analyses. We used SPSS (version 20.0; SPSS Inc., Chicago, IL, USA) to analyze the statistics.

Results

The performance measures immediately after exercise corresponding to a fairly intense exercise (RPE = 18.0±2.0; HRmax = 167±17.5 BPM; Blood lactate = 6.8±2.8 mmol/L; total effort time = 12.8±2.4 min; Max Load = 113.0±20.0 watts). Figures 3 to 5 show Tsk behavior of the different ROIs obtained during the experiment for the anterior and posterior view of the upper and lower body.

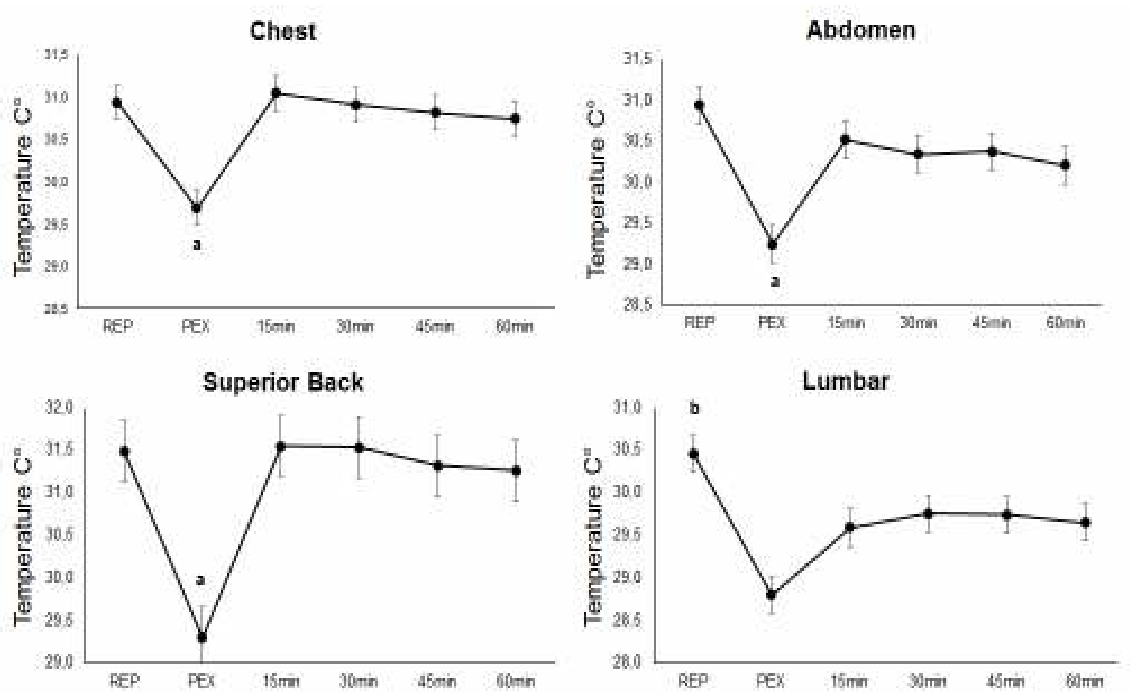

Fig. 3. Tsk behavior in the chest, abdomen, superior back and lumbar ROIs. Statistical differences with: [a] *p*<.001 from PEX vs other measurement moments; [b] P<.001 from REP vs PEX.

There was a significant difference between moments in the pectoral Tsk (F=11,531; *p*<0.001; ES = 0.435). Tsk reduced at PEX (Δ 1.3±0.3°C; 95%CI 0.23–2.27; *p*=0.01; ES=0.14) and returned to the REP after 15min of recovery (*p*=1.0), remaining stable in comparison to the other moments (p=1.0). A similar result was observed for the abdomen, where differences between the moments were observed (F=14,520; *p*<0.001; ES=0.492), where the Tsk reduced at PEX (Δ 1.7±0.2°C; 95%CI 1.03–2.34; *p*<0.001; ES=0.15) and returned to the REP with 15min of recovery (p=1.0), remaining stable in comparison to the other moments (30min p=0.328; 45min p=0.643 and 60min p=0.25). Regarding the anterior arm, there was a significant difference between the moments (F=18,269; *p*<0.001; ES=0.549), where the Tsk did not change at PEX (p=1.0) and increased in comparison to the REP with 15min of recovery (Δ 1.4±0.1°C; 95%CI 0.97–1.88; *p*<0.001; ES=0.16), staying above the resting condition at 30 min (Δ 1.0±0.2°C; 95%CI 0.44–1.55; *p*<0.001; ES=0.14) and 45min (Δ 0.7±0.1°C; 95%CI 0.23–1.14; *p*=0.001; ES=0.13) of recovery. Tsk returned to REP condition after 60 min of recovery (*p*=0.459). For the anterior forearm, there was a significant difference between the moments (F=9,736, *p*<0.001, ES=0.394), where the Tsk did not change at PEX (*p*=1.0) and increased in comparison to the REP with 15min of recovery (Δ 1.2±0.2°C; 95%CI 0.71–1.74; *p*<0.001; ES=0.15), returning to REP after 30min (*p*=0.086), and remaining stable in comparison to the other moments (p=1.0). All results for the arms are shown in Figure 4.

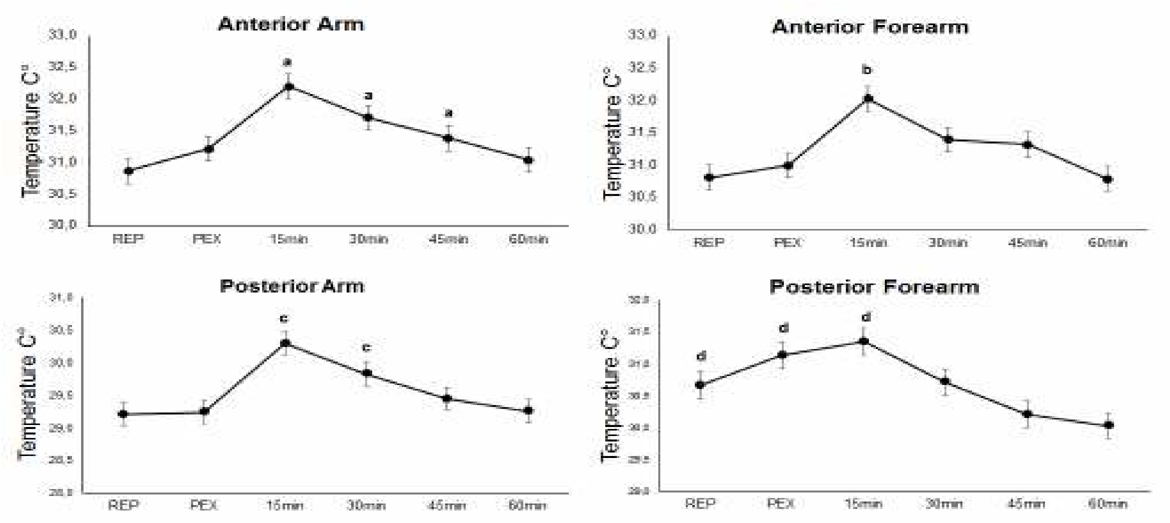

Fig. 4. Tsk behavior in the upper back, lower back, anterior and posterior arm and forearm ROIs. Statistical differences with: [a] *p*<.001 from 15min, 30min and 45min vs other measurement moments; [b] *p*<.001 from 15min vs other measurement moments. [a] *p*<.001 from PEX vs other measurement moments; [c] *p*<.001 from 15min and 30min vs REP and PEX; [d] *p*<.001 from REP, PEX and 15min vs 60min.

Regarding the arm measurements, inferential analyzes indicated that there was a significant difference between the moments in the upper dorsal (F=13,383, *p*<0.001, ES=0.472), where the Tsk reduced at PEX (Δ 1.0±0.2°C; 95%CI 0.21–1.86; *p*=0.008; ES=0.14), returned to REP after 15 minutes of recovery (*p*=1.0), and remained stable in comparison to the other moments (*p*=1.0). There was also a significant difference between the moments in the lumbar spine (F=16,943; *p*<0.001; ES=0.53), where the Tsk reduced at PEX (Δ 1.7±0.3°C; 95%CI 0.69–2.64; *p*<0.001; ES=0.15) and remained below the REP at all times of recovery [15min (Δ 0.9±0.2°C; 95%CI 0.16–1.6; *p*=0.011; ES=0.13); 30min (Δ 0.7±0,2°C; 95%CI 0.14–1.28; *p*=0.009; ES=0.13); 45min (Δ 0.7±0.2°C; 95%CI 0.2–1.2; *p*=0.003; ES=0.13) and 60min (Δ 0.8±0.2°C; 95%CI 0.25–1.27; p=0.002; ES=0.13)]. For the posterior arms, there was a significant difference between the moments (F=6,921; *p*=0.002; ES=0.316), where the Tsk did not change at PEX (p=1.0), increased in relation to the REP with 15min of recovery (Δ 1.1±0.3°C; 95%CI 0.2–1.97; *p*=0.01; ES=0.13) and returned to REP at 30min of recovery (*p*=0.278), remaining stable in comparison to the other moments (*p*=1.0). In the posterior forearm, we observed a significant difference between the moments (F=13,317; *p*<0.001; ES=0.47), where Tsk reduced significantly in comparison to REP at 60min PEX (Δ 1.1±0.2°C; 95%CI 0.28–1.81; *p*=0.004; ES=0.13). No changes were found when the other moments were compared with the REP [post-exercise (*p*=1.0); 15min (*p*=0.119); 30min and 45min (*p*=1.0)]. The results for the thermograms analyzed in the lower limbs are shown in Figure 5.

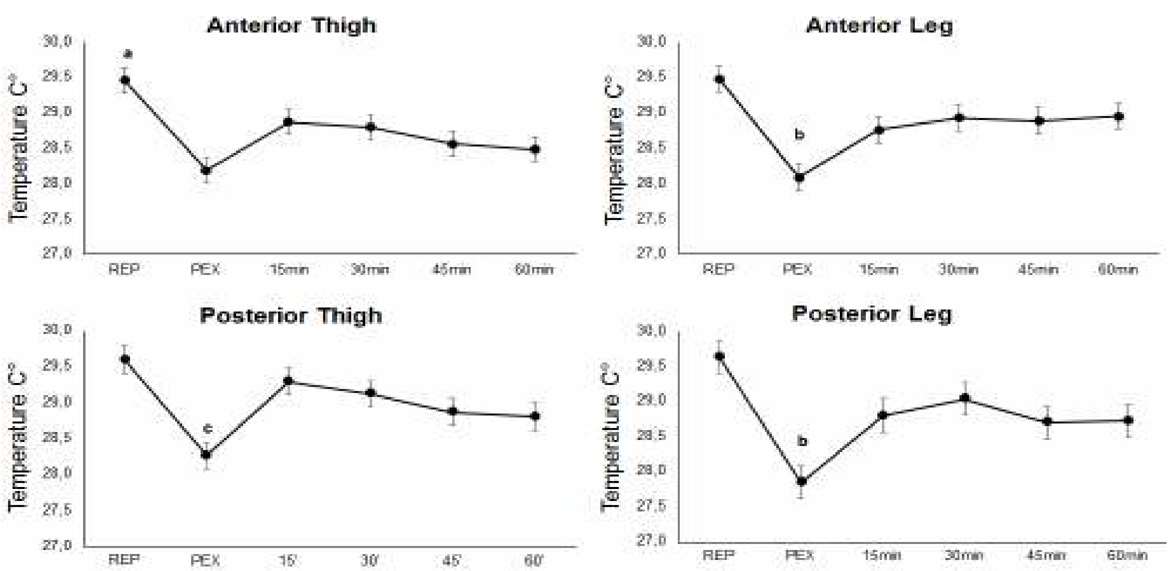

Fig. 5. Tsk behavior in the thigh and leg ROIs (anterior and posterior). Statistical differences with: [a] *p*<0.001 from REP vs PEX, 45min and 60min; [b] *p*<0.001 from PEX vs other measurement moments; [c] *p*=0.008 from PEX vs other measurement moments except 60min.

For the anterior lower limbs, there was a significant difference between the moments in the thigh (F=11,347, *p*<0.001, ES=0.431), where the Tsk reduced at PEX (Δ 1.3±0.2°C; 95%CI 0.61–1.92; *p*<0.001; ES=0.15), returned to the resting condition with 15min (*p*=0.176) and 30min of recovery (*p*=0.114), and reduced again in comparison to the REP at the 45min (Δ 0.9±0.2°C; 95%CI 0.11–1.71; *p*=0.019; ES=0.13) and 60min of recovery (Δ 1.0±0.2°C; 95%CI 0.16–1.79; *p*=0.012; ES=0.14). There was also a significant difference between the moments in the posterior leg (F=14,477; *p*<0.001; ES=0.491), where the Tsk reduced at PEX (Δ 1.4±0.2°C; 95%CI 0.74–2.06; *p*<0.001; ES=0.16), remaining below the REP with 15min (Δ 0.7±0.2°C; 95%CI 0.05–1.37; *p*=0.029; ES=0.13) and 30min of recovery (Δ 0.6±0.2°C; 95%CI 0.003–1.11; *p*=0.048; ES=0.13). No differences were observed at 45min (p=0.072) and 60min after exercise (p=0.18) in comparison to the REP.

Regarding the posterior thigh, there was a significant difference between the moments (F=6,911, *p*=0.008, ES=0.315), when the Tsk reduced PEX (Δ 1.4±0.4°C; 95%CI 0.01–2.77; *p*=0.048; ES=0.14), but did not present significant difference in comparison to REP and during recovery [15min (p=1.0); 30min (p=1.0); 45min (p=0.457) and 60min (p=0.238)]. Finally, there was a significant difference between the moments in the posterior leg (F=20,328; *p*<0.001; ES=0.575), where the Tsk reduced at PEX (Δ 1.6±0.2°C; 95%CI 0.95–2.31; *p*<0.001; ES=0.17), but did not present a significant difference in comparison to REP and during recovery [15min (*p*=0.281); 30min (*p*=0.168); 45min (*p*=0.075) and 60min (*p*=0.055)].

Discussion

This study examined the Tsk response of several ROIs to progressive exercise using an arm ergometer, which implicates muscle involvement of the lower limbs and has very few references in the literature. The main contribution of this study was to quantify these changes in Tsk which occurred after progressive exercise of the lower limbs and its evolution along the acute recovery process. It is well established that during exercise there is a redistribution of blood flow from inactive areas such as visceral fat, skin and muscles not recruited during exercise to the active skeletal muscles through a vasodilation and vasoconstriction control (Laughlin et al., 2012; Mortensen & Saltin, 2014). However, the magnitude of how this occurs is yet unknown. Given that these adjustments interfere with Tsk, infrared thermography has been identified as an important tool for analysing the thermal response of the body surface to exercise, being directly related to the hemodynamic and thermoregulation adjustments produced. The progressive exercise protocol had an average duration of 12±2.4 min and was held until voluntary exhaustion or inability to maintain between 50-60 rpm; thus, it should be considered as a quite intense activity with moderate duration. Additionally, the valid test required that the volunteers reach 85% of MHR as estimated by the Tanaka et al. (2001) equation, and considering that the value of MHR obtained on the progressive test using an arm ergometer is 10-20 bpm lower than the value estimated by equations designed to exercise the lower limbs (Hill, Talbot, & Price, 2014), it is expected that the effort that the volunteers performed was higher than 85% as the Tanaka equation could overestimate the MHR value obtained with an arm ergometer. The degree of local vasodilation during exercise is closely linked to the activity intensity (Terwoord, Hearon, Racine, Luckasen, & Dinenno, 2017), so that it seems that Tsk behavior should be at the maximum for the performed incremental protocol applied to the upper limbs. Regarding the maximum performance measures, the only one that was not reached was lactate, where the mean was below 8mmol/L (Caputo & Denadai, 2004).

The main finding of this study is to observe different thermal behaviors of the considered ROIs after exercise according to implantation of the muscles during the exercise. The results showed a reduction in Tsk immediately after exercise in all the monitored ROIs from the trunk and lower limbs (i.e. inactive areas during exercise). In contrast Tsk in posterior and anterior arm and forearm ROIs, which were the active areas, remained unchanged immediately after exercise compared to the resting values. Active areas receive greater blood flow by vasodilatation mechanism which occurs due to lack of oxygen and the increased concentrations of lactate, adenosine phosphate compounds, adenosine, and carbon dioxide phosphate from muscle activity (Hellsten, Nyberg, Jensen, & Mortensen, 2012). However, the effect of those metabolites only appears after 15min of recovery. During exercise, it is important to keep the temperature of the muscles at the optimal values. Contraction of the muscle fibers and the blood flow supply should increase the internal temperature and subsequently the skin temperature; however, the skin is refrigerated sweating, and additionally the movements of the upper limbs during exercise generates forced ventilation that breaks the skin's natural protective convection layer and probably increase the head loss through the skin of the moving limbs during exercise.

Similar thermal behaviors to the results obtained in our study for arm ergometer exercises have also been reported for exercises performed on a treadmill (Clark et al., 1977; Merla et al., 2010) and cycle ergometer (Akimov & Son'kin, 2010; Hayashi et al., 2012; Levels et al., 2012). Laughlin et al. (2012) reported that there is a trend to lower Tsk on non-active limbs caused by a possible decrease in blood flow, with these cardiovascular adjustments being very important to keep the increased metabolism of the active muscle during exercise. Reductions in Tsk at the beginning and just after performing high-intensity exercise have also been reported (Adamczyk, Boguszewski, & Siewierski, 2014; Arfaoui, Bertucci, Letellier, & Polidori, 2014) mediated by the action of the central nervous system and the release of vasoconstrictor hormones. The study by Fernández-Cuevas et al. (2014) also showed a post-exercise reduction in skin temperature in all the inactive ROIs caused by possible cutaneous vasoconstrictor action to redirect blood flow to the metabolically active regions. According to Adamczyk et al. (2014), there is a strong relationship between the intensity of effort and Tsk descent, with a greater magnitude of Tsk descent being observed after exercises with higher intensities. Muscle density is a factor that may also contribute to these different results, since the active region in an arm exercise comprises relatively smaller muscle mass than exercises carried out on a treadmill where the lower limbs are exercised. Upper limbs have different vasomotor interaction and a lower resistance to fatigue (Hellsten et al., 2012), justifying our RPE values of 18.1 ± 1.2 after exercise (i.e. "very strong").

Maintaining Tsk of the active regions is likely to occur due to increased internal muscle heat inherent to the performed exercise, and the increased blood flow probably caused by increased concentrations of lactate, adenosine phosphate compounds, adenosine, and carbon dioxide coming from the progressive addition of load, stimulating a vasodilation process in the active ROIs (Adamczyk et al., 2014; Hellsten et al., 2012; Laughlin et al., 2012) which is antagonistic to adrenergic cutaneous vasoconstriction occurring in the inactive region, causing the Tsk to drop after exercise and returning back to normal values after 15 minutes of recovery. Additionally, it was observed during the recovery period (15min, 30min, 45min, 60min) that the pectoral and upper back areas returned to baseline and remained stable, while at rest (abdomen, low back, and anterior and posterior thigh and leg) showed a delay in Tsk recovery. This means that even within the recovery period there could exist different vascular adjustments in each ROI (Adamczyk et al., 2014). Hellsten et al. (2012) reported differences in vascular function between the forearm and lower limbs due to the hydrostatic pressure in the lower limbs, their displacement functions and support of the body mass generating differences in the vasodilation response.

It is observed that the fast recovery of Tsk to the resting values of the pectoral and upper back only 15min after exercise indicates an increased blood flow in the upper torso, which is then directed to the regions that were active during exercise in order to optimize the reestablishment of Tsk in those areas. For the lower regions of the trunk and the lower limbs, values below the baselines recorded at rest were obtained even after 60 minutes of recovery post-exercise. This behavior may occur again because of the redirection of post-exercise blood flow to the exercised areas in order to facilitate post-exercise muscle recovery. After 15 min of recovery, there was a decrease of Tsk in the active regions (i.e. arm and forearm), then progressively returning to basal levels probably due to the local muscle recovery, which makes it unnecessary to maintain the same vasodilatation level any longer. A limitation of this study was the lack of blood flow measurement in upper limbs and relating the results to Tsk data. There is a need for further studies to evaluate the behavior of Tsk for upper limb exercises, which could be interesting (for example) to assess competitive wheelchair athletes' performances in order to understand the thermoregulation processes in these kinds of activities, providing interesting data for clothing design and strategies for cooling the skin in hot environments and the conservation of Tsk in cold environments.

Conclusion

It is concluded that progressive exercise performed with upper limbs gradually until exhaustion does not immediately increase Tsk values in the metabolically active areas after exercise, but after 15 minutes of passive recovery. However, Tsk is reduced in the inactive areas immediately after exercise with two different recovery tendencies. Tsk in the upper back and chest returned to baseline at the first 15 minutes of recovery, while Tsk was maintained below baseline in the lower limbs and lower trunk during 60 minutes of passive recovery.

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Conflict of interest

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

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