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Original Article

Thermal responses of the thighs of university handball players after a resistance training session using leg extension exercises

JAIME DELLA CORTE[1], ROGÉRIO ALVES DE SOUZA[2,3], EDUARDO BORBA NEVES[4], JURANDIR BAPTISTA DA SILVA[5,6], FLAVIO DE ANDRADE VIGNOLI[7], JOÃO PEDRO BOMFIM TORRES[2], JULIANA BRANDÃO PINTO DE CASTRO[5,6], LEANDRO DE LIMA E SILVA[5,6]
[1]Postgraduate Program in Human Anatomy and Biomechanics, Castelo Branco University, Rio de Janeiro, BRAZIL
[2]Castelo Branco University, Rio de Janeiro, BRAZIL
[3]Gissoni Application College, Rio de Janeiro, BRAZIL
[4]Brazilian Army Research Institute of Physical Fitness (IPCFEx), Rio de Janeiro, BRAZIL
[5]Postgraduate Program in Exerciseand Sport Sciences, Institute of Physical Education and Sports, Rio de Janeiro State University, Rio de Janeiro, BRAZIL
[6]Laboratory of Exercise and Sport (LABEEs), Institute of Physical Education and Sports, Rio de Janeiro State University, Rio de Janeiro, BRAZIL
[7]Postgraduate Program in Bodybuilding and Resistance Training, Estácio de Sá University, Rio de Janeiro, BRAZIL

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Abstract:
Training with high-performance athletes often takes the musculoskeletal system to physiological limits, which can generate changes in metabolic processes with a direct impact on the production of body heat. Thermography is an important tool for monitoring such processes. **Purpose:** To analyze the skin temperature (T_{SK}) reactions of the anterior part of thighs on Brazilian handball players after a resistance training session. **Material & methods:** Twelve male athletes (age: 20.9 ± 2.4 years; height 1.78 ± 0.05 m; Body Mass Index: 28.74 ± 8.1 kg/m^2) were submitted to tests and retests of one repetition maximum (1RM) for the dominant and non-dominant sides in the leg extension exercise. After 48 hours of this test, the participants underwent a maximum resistance training session. Thermographic images were collected before, immediately after the training session, and after 10 and 15 minutes of rest. Passive recovery between sets was three minutes. **Results**: The significant differences in maximum temperatures between the dominant and non-dominant sides at all times of the study were less than 0.4ºC. There were changes to the average T_{SK} on the dominant side ($F = 5.249$; $p = 0.003$) and non-dominant ($F = 4.158$; $p = 0.011$), both with significant reductions at the time of 15 minutes of rest when compared to the pre- and post-training sessions. There were changes in the minimum T_{SK} on the dominant side ($F = 4.790$; $p = 0.006$) with significant reductions at 10 minutes and 15 minutes of rest when compared to the pre-training session. **Conclusions:** It was evidenced that the volume and intensity of the training have an important participation in the temperature behavior of the physically active areas, indicating great metabolic demand in short duration activities with high dynamic effort.
Keywords: Physical exercise,Muscle strength, Thermography, Skin temperature, Athletes, Sports

Introduction

Handball is a complex and multifactorial team sport.The characteristics of this sport modality require high-intensity and short-term efforts from athletes[1], including dynamic and explosive actions, such as blocking, jumping, throwing, and moving in different directions and speeds, involving frequent body contact. Thus, it is considered at high riskfor the occurrence of injuries[2]. Along with technical and tactical training, to optimize the physical conditioning and specific sports performance of the players, it should be included in the resistance training (RT) sessions of the athletes, exercises that promote greater resistance to intermittent efforts of high intensity and of short duration,as well as increased muscle strength and power[3,4,5].

RT is usually performed using external loads. This training includes exercises with stimuli of maximum or close to maximum intensity, triggering mechanical and metabolic stresses, and activating the satellite cells[6]. As a result, the exercised muscles develop some level of inflammation and tissue damage, which are repaired during the recovery period[7]. Training with high-performance athletes often takes the musculoskeletal system to physiological limits. This can generate changes in metabolic processes with a direct impact on the production of body heat. Hence, infrared thermography is an important tool for monitoring these processes[8].

Corresponding Author: JAIME DELLA CORTE, E-mail: jaimedellacorte@yahoo.it

Thermography is a reliable, safe, and non-invasive device that has applicability in sports as an auxiliary tool for training planning. Thermography allows the analysis of the relationship between loads and local thermal variations in exercised segments[9], helping to understand the physiological mechanisms during physical effort[10,11], monitoring and evaluating muscle recovery immediately after the physical activity and after 24, 48, 72, and 96 hours[12,13,14]. This way, thermography supports injury identification[15] and allows athletes to return to training and/or the games[16]. Moreover, it contributes to the verification of thermal adjustments resulting from physical efforts, which may indicate abnormal behavior of some physiological functions by measuring the temperature of a specific body region of interest or through a broader analysis of the body as a whole[17].

The thermoregulatory functions are activated immediately when starting physical exercise.Thus, to compensate for the increase in internal temperature, adaptive responses occur, such as vasodilation.This increases blood flow to the skin to facilitate heat exchange by convection and by evaporation, creating mechanisms of heat dissipation during exercise in an environment with controlled temperature[18].

The measurement of skin temperature (T_{SK}) using thermographic imaging to detect injuries in professional athletes is generally based on the assessment of thermal symmetry between the sides of the body. The following scale is used for interpretation among the differences in T_{SK} obtainedin the regions of interest: a) Normal: asymmetries ≤ 0.4º C; b) Monitoring: asymmetries ≥ 0.5º C, it is advisable to reassess and verify if there is influence of some external factor; c) Prevention: values between 0.8º C and 1.0º C, it is recommended a reduction of the training, or even its suspension and medical or physiotherapeutic evaluation; d) Alarm: values between 1.1º C and 1.5º C, immediate suspension of training and medical or physiotherapeutic evaluation;e) Severity: asymmetries ≥ 1.6º C, it suggests an asymmetry with a pathological characteristic or an important lesion, with recommendation of medical or physiotherapeutic evaluation[19].

In this context, it is essential to evaluate and monitor thermal variations in the face of physical efforts in an attempt to control the training load and better understand the influence of RT on the thermoregulatory system.Therefore, the present study aimed to analyze the thermal cutaneous responses of the anterior thighs of university handball players before and after anRT session and after 10 and 15 minutes of rest.

Material & methods

Study design

Original field research of the descriptive type, which is based on the premise that problems can be solved and practices can be improved through the description and analysis of objective and direct observations[20].

Participants

The sample consisted of 12 apparently healthy volunteers,age 20.9 ± 2.4 years, height 1.78 ± 0.05m and BMI 28.74 ± 8.1 kg/m^2, male handball athletes from a university team in the West Zone of Rio de Janeiro, Brazil, who met the inclusion criteria: a) right-footed; b) handball athletes for more than 18 months; c) RT practitioners with at least one year of experience and a minimum weekly training frequency of three days. The study adopted the following exclusion criteria: a) those who had bone, muscle or joint injuries or limitations, which made it impossible to perform the scheduled exercises; b) those who used ergogenic substances; c) those who responded positively to the Physical Activity Readiness Questionnaire (PAR-Q)[21].

This research was conducted in accordance with the Declaration of Helsinki[22] and as determined by Resolution no. 466/2012 of the National Health Council[23] on research with human beings. The Human Research Ethics Committee of the local University approved this study under the number 28901414.3.0000.5218. All participants were informed about the protocols and training session and voluntarily signed the consent form.

Procedures

Data collection took place as follows: each volunteer, always at the same time, made three visits with an interval of at least 48 hours between them.On the first visit, the volunteers answered the PAR-Q. Individuals considered fit for the study were elucidated about all data collection procedures and study intervention;they signed the consent form, made the anthropometric measurements, and performed the tests of one maximum repetition (1RM) in the leg extension exercise in a unilateral way for the dominant (right) and non-dominant (left) sides. On the second visit, the athletes performed the 1RM retests. On the third visit, the participants underwent an RT session. Thermographic images were taken before and immediately after the training session and after 10 and 15 minutes of rest. Participants were instructed not to perform physical exercises of any kind and not to ingest stimulating substances in the 24 hours preceding both data collection and the intervention. All tests, retests, and training sessions were performed at times similar to the athletes' training and in a place with controlled ambient temperature.

Anthropometric measurements

To characterize the sample, height was determined using a stadiometer (Cardiomed, model WCS, Brazil), with a maximum capacity of 2.20 m and accuracy of 0.001 m. Measurements for body composition of total body mass (TBM), body mass index (BMI), body fat percentage (%BF), skeletal muscle percentage (%SM), and basal metabolic rate (BMR) were performed using a bioimpedance scale (BIA) (OMRON®, Full Body Sensor, model HBF-514C, USA)[24]with a precision of 100 g, limitation of 150 kg for TBM and age between 18 and 80 years for both sexes. Anthropometric measurements followed specific protocols suggested by the International Standards for Anthropometric Assessment (ISAK)[25].

Regarding the measurements with BIA, all subjects received the following recommendations: 1) not to use diuretic medications in the last seven days; 2) not drinking alcoholic beverages in the last 48 hours; 3) abstain from vigorous physical exercise in the last 24 hours; 4) keep fasting for at least three hours before the measurement; 5) urinate at least 30 minutes before the measurement; 6) not taking a shower or taking a sauna just before performing the measurement; 7) do not step on the scale with wet feet; 8) wear light clothes, bare feet and a body free of metallic adornments.

To avoid failures in measuring with the BIA, the evaluators took the following precautions: 1) position the scale on a flat and consistent surface so that it was stabilized; 2) insert the data, age, height, and sex of the participant in the BIA's memory; 3) instruct the participant to step on the BIA platform, holding the electrode bar in their hands, so that their thumbs were also part of the grip; 4) adjust the participant on the BIA platform so that the heels (hindfoot) were on the two electrodes furthest from the display and the fingers (forefoot) were occupying the electrodes closest to the display; 5) after the TBM value flashes three times on the display, the participant should flex the shoulders, staying at 90º to the trunk. The participant remained with the body erect, knees extended, and looking at a fixed point ahead, above the horizontal line. At the end of the reading, the BIA again showed the TBM and the other data, successively.

One repetition-maximum test (1RM)

To check the training load and exercise prescription criteria, the 1RM test was used, following the recommendations of Brown[26]. Unilateral exercises (dominant and non-dominant) of the lower limbs were performed on the leg extension exercise (Buick Fitness Equipment, model MP-140, Brazil). The additional weights used in the study were previously measured on a precision digital electronic scale (Filizola®, model PL-150, Brazil). The 1RM tests were performed in a single day, adopting the following procedures: 1) start a warm-up series with a load low enough that would allow the performance of five to ten repetitions with ease; 2) one-minute rest; 3) performance another warm-up series with a load that allows three to five repetitions to be completed, which usually implies an increase of about 4.5 to 9 kg or 5 to 10% of the previous load; 4) two-minute rest; 5) calculate another increase of 4.5 to 9 kg or 5 to 10% that would allow completing two to three repetitions; 6) rest for two to four minutes; 7) estimate another increase of 4.5 to 9 kg or 5 to 10% that would allow the performance of only one repetition completely and correctly. Having managed to complete the repetition, the individual proceeded to the next step, otherwise, skip to step 9; 8) Rest for two to four minutes, calculating another moderate increase in load (4.5 to 9 kg or 5 to 10%) and repeat the test; 9) If the individual is unable to complete correctly, rest for two to four minutes, reduce the load by 2.3 to 4.5 kg and repeat. The load continued to be increased or reduced as needed until the actual load for 1RM was determined. If the load was not found within five attempts after completing the warm-up series, a new test day should be scheduled with a 48-hour interval between attempts[26]. The registered load was determined from the maximum obtained to perform 1RM. After a 48-hour rest, following the same procedures as the tests for obtaining the reproducibility of the loads, the volunteers were submitted to retests. The highest load established on both days was considered as 1RM[27], as long as the difference between them was not more than 5%. However, if the stipulated percentage was exceeded, a new test and retest were scheduled. To reduce the margin of error in the tests and retests of 1RM, the following strategies were adopted: a) standardized instructions were provided before the test so that the individual was aware of the whole routine that involved data collection; b) the individual was instructed on the exercise execution technique; c) the evaluators were attentive to the position adopted by the practitioner at the time of the measurement, since small variations in the positioning of the joints involved in the movement could trigger other muscles, leading to erroneous interpretations of the scores obtained; d) verbal stimuli were performed to keep the stimulation level high[28]. For a better description of the movement, it was established that each subject was seated in the machine with the knees in 90º of flexion and the articular axis aligned with the equipment axis, foot support on the anterior face of the distal third of the legs, with all plates (loads) overlapping, this being the initial position. The complete knee extension movement, that is, the ability to lift the determined load until the knee joint reached 0º, was considered the final position. The amplitudes were previously measured by a 360º steel goniometer. The speed of execution of the movement was two seconds for the concentric phase and two seconds for the eccentric phase. The validation took place under the following criteria: a) no interval was allowed between the concentric and eccentric phases; b) repetitions that did not fit the pre-established technical standards were not counted. The tests were interrupted when the individuals were unable to perform the movement correctly and/or completely in the programmed exercise, with voluntary concentric failure occurring[29].

Skin temperature (T_{SK})

The protocol for capturing infrared images was performed according to the recommendations of the Consensus Thermographic Imaging in Sports and Exercise Medicine (TISEM)[30]. The camera used was the

Forward Looking Infra-Red (FLIR) (FLIR One Pro iOS model, Wilsonville, OR, USA)[31]coupled to an Apple© smartphone (iPhone XR model, São Paulo, SP, Brazil). The FLIR One Pro iOS is capable of detecting temperatures with dynamic scene ranges between -20º and 400ºC, with an accuracy of ±3ºC or ±5%, typical differences percentage between ambient and scene temperature. This equipment contains two cameras, one with a Lepton™ thermal sensor, a pixel size of 12 µm and a spectral range of 8 to 14 µm and the other with Video Graphics Array (VGA) with high definition, 160 × 120 pixels. Thus, two images are obtained and merged using Multi Spectral Dynamic Imaging (MSX) technology, which superimposes a thermal image over a photographic image, resulting in a clear thermographic image with a visual resolution of 1440 × 1080 pixels, in which the smallest details can be seen.

For the results to be less influenced by possible external factors, some precautions were taken before obtaining the thermographic images. Thus, all participants were instructed as follows: 1) avoid exposure to the sun or UVA ultraviolet rays between 10 am and 4 pm in the last 24 hours; 2) not performing vigorous physical exercises in the last 24 hours; 3) do not undergo any therapeutic massage treatment in the last 24 hours; 4) do not drink alcohol or coffee in the last 6 hours; 5) do not take a very hot or cold shower minutes before the evaluation; 6) do not apply cream, gel or any other cosmetic products under the skin; and 7) wear appropriate clothing (men: shorts or swim trunks; women: shorts and top, or bikini)[32]. The software used to evaluate the thermographic images of the anterior part of the athletes' thighs was FLIR Tools®, which allows importing, editing, and analyzing images quickly and turning them into professional inspection reports. The application allows adjusting the level and thermal amplitude, changing the color palette, and regulating parameters, such as emissivity and reflective temperature.

Training session

After the specific warm-up[33] with a series of 12 repetitions in the leg extension exercise with a load of 60% of 1RM and two minutes of rest, the participants underwent the study intervention.The intervention consisted of an RT session of maximum strength, performed until the concentric failure in the leg extension exercise with a load of 90% of 1RM[34]. The session consisted of five sets for the lower limb dominant side (right), five sets for the lower limb non-dominant side (left), and five sets with no recovery interval between the dominant and non-dominant sides. During the execution of the sets, the athletes were encouraged to exhale in the concentric phase and inhale in the eccentric phase of the movement, thus avoiding the Valsalva maneuver.

The movement execution speed required was the same as for tests and retests (two seconds for the concentric phase and two seconds for the eccentric phase). The intervals between sets were three minutes of passive recovery. At the end of the training session, the participants indicated the rating of perceived exertion (RPE), according to the OMNI-RES scale[35]. The evaluators captured the thermographic images of the anterior part of the athletes' thighs, the main muscle group involved in the study exercise, from the angle perpendicular to the region of investigation, at a distance between 100 and 150 cm. The images displayed (Fig. 1) were taken before, immediately after the training session, and after 10 and 15 minutes of rest. Participants sat at rest in the laboratory with a controlled temperature between 18 and 22ºC, for at least 15 minutes, before the initial thermographic images of the athletes' thighs were recorded.

To avoid incorrect measurements, external heat sources have been turned off. In addition, to measure and guarantee the temperature and humidity stability of the environment, two Akso digital thermo-hygrometers (model AK27new, Brazil) were placed at the intervention site. The temperature in the laboratory's intervention room was maintained at 20.2 ± 0.6ºC, with a relative humidity reading of 51.7 ± 1.5% RH.

Figure 1 shows thermographic images of the thighs in the pre-, post-training session, 10 and 15 minutes of rest moments.

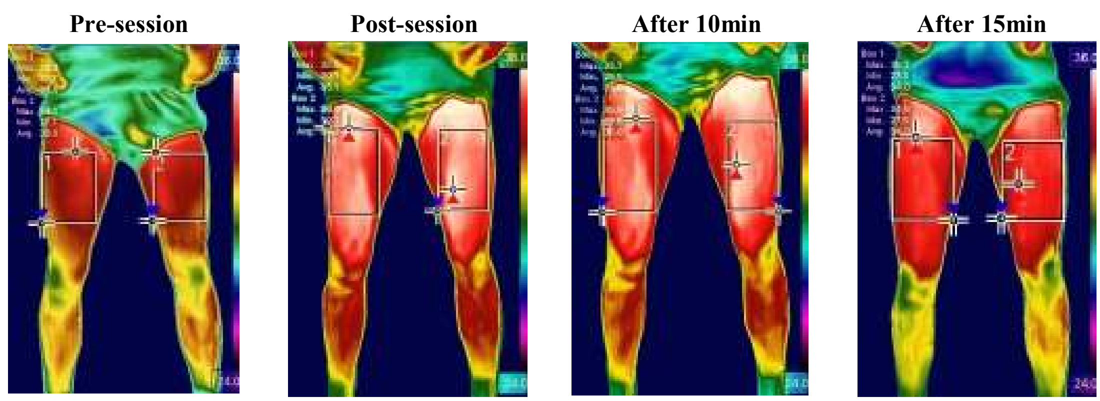


Fig. 1. Illustration of thermographic images analysis where the rectangles indicate the regions of interest

Statistical Analysis

The data were processed using the IBM Statistical Package for Social Sciences (SPSS) software version 22.0 (Chicago, IL, USA) and presented by the descriptive analysis of mean, standard deviation, and minimum and maximum values. The normality and homogeneity of the sample data were verified, respectively, with the Shapiro-Wilk and Levene tests. To compare the skin temperature between the dominant and non-dominant sides at each moment, the paired t-Student test was applied. To check the behavior of skin temperature at different times, one-way ANOVA was applied, followed by Bonferroni's post hoc. The level of significance was set at $p<0.05$.

Results

Table 1 shows the data regarding the participants' body composition.

Table 1. Body composition (n = 12).

	Age (years)	Height (m)	TBM (kg)	%BF	FM (kg)	%SM	SMM (kg)	BMI (kg/m²)	BMR (kcal)
Mean	20.9	1.78	91.3	29.4	29.7	33.0	28.6	28.74	1800.5
Standard deviation	2.4	0.05	26.7	12.5	20.3	6.8	3.4	8.1	292.1
Minimum	18	1.71	64.1	14.5	9.3	23.6	25.6	20.69	1550
Maximum	26	1.85	146.0	48.6	71.0	44.7	34.6	46.60	2403

TBM: total body mass; %BF: body fat percentage; FM: fat mass; %SM: skeletal muscle percentage; SMM: skeletal muscle mass; BMI: body mass index; BMR: basal metabolic rate.

Table 2 presents the data related to the participants' training session.

Table 2. Resistance training session.

	90% of 1RM – DS, (kg)	90% de 1RM – NDS, (kg)	Total RM	TTV (kg)	RPE (0 to 10)
Mean	54.2	50.8	68.2	3591.2	8.9
Standard deviation	12.9	12.2	7.8	1057.3	0.8

90% of 1RM – DS: training load for the dominant side; 90% of 1RM – NDS: training load for the non-dominant side; Total RM: total of repetitions maximum (sets × repetitions); TTV: total training volume (exercises x load x sets x repetitions); RPE: rating of perceived exertion.

Table 3 shows the comparison of skin temperature between the dominant and non-dominant sides of the participants, presented by the mean, standard deviation, and paired t-Student test.

Table 3. Comparison of skin temperature between the dominant and non-dominant sides.

	Pre-Training Session			Post-Training Session		
	Maximum (ºC)	Average (ºC)	Minimum (ºC)	Maximum (ºC)	Average (ºC)	Minimum (ºC)
Dominant	33.12± 3.6	31.23± 3.4	25.01± 3.9	33.80± 1.8	30.67± 2.0	22.81± 3.1
Non-dominant	33.18± 3.6	31.13± 3.5	24.92± 3.4	33.97± 1.8	30.98± 2.0	23.87± 3.0
t (p-value)	*0.599*	*0.321*	*0.739*	*0.359*	*0.007**	*0.0001**
	After 10 minutes of rest			After 15 minutes of rest		
	Maximum (ºC)	Average (ºC)	Minimum (ºC)	Maximum (ºC)	Average (ºC)	Minimum (ºC)
Dominant	31.68± 3.0	28.31± 3.2	20.37± 3.5	30.67± 2.9	26.67± 3.8	20.16± 4.0
Non-dominant	32.02± 2.8	28.73± 3.1	21.35± 3.4	30.97± 2.8	27.28 ± 3.7	21.20± 3.8
t (p-value)	*0.053*	*0.002*[#]	*0.002*[#]	*0.013*[¥]	*0.0001*[¥]	*0.0001*[¥]

*: Significant difference in the moment post-training session; [#]: Significant difference in the moment 10 minutes of rest; [¥]: Significant difference in the moment 15 minutes of rest; *t* (p-value): paired t-Student test.

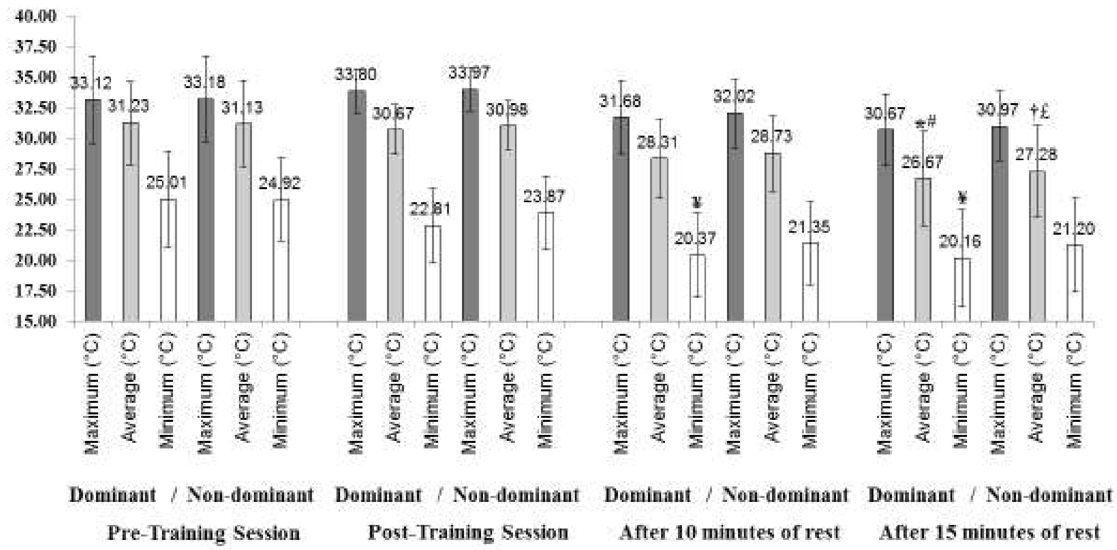
Table 4 exhibits the analysis of skin temperature variations on the dominant and non-dominant sides, presented by one-way ANOVA and the comparison by Bonferroni's post hoc, in cases where significant changes occurred.

Table 4. Changes in skin temperature on the dominant and non-dominant sides in the moments evaluated in the study.

one-way ANOVA			Bonferroni's post hoc				
T_{SK} dominant side	F	Sig.	T_{SK} dominant side				Sig.
Maximum	2.813	0.050	Average	Pre-session	>	15min	0.007*
Average	5.249	0.003		Post-session	>	15min	0.023*
Minimum	4.790	0.006	Minimum	Pre-session	>	10min	0.018*
				Pre-session	>	15min	0.012*
T_{SK} non-dominant side	F	Sig.	T_{SK} non-dominant side				Sig.
Maximum	2.595	0.064	Average	Pre-session	>	15min	0.027*
Average	4.158	0.011		Post-session	>	15min	0.038*
Minimum	3.488	0.023					

T_{SK}:skin temperature; *: The mean difference is significant at the 0.05 level.

Figure 2 shows the thermal responses of the anterior part of the thighs.



*: Significant difference in the average T_{SK} of the dominant side between pre-training and after 15 minutes of rest; #: Significant difference in the average T_{SK} of the dominant side between post-training and after 15 minutes of rest; ¥: Significant difference in the minimum T_{SK} of the dominant side between pre-training and after 10 and 15 minutes of rest; †: Significant difference in the average T_{SK} of the non-dominant side between pre-training and after 15 minutes of rest; £: Significant difference in the average T_{SK} of the non-dominant side between post-training and after 15 minutes of rest.

Discussion

This study aimed to analyze the thermal responses of the anterior part of the thighs caused by stresses of the muscular tissues directly involved in the execution of anRT session with the leg extension exercise in university handball athletes.

Vardasca et al.[36]affirm that thermographic images have been efficient in the early identification of signs of inflammation, which can facilitate the identification of injury determining factors, which can be detected by thermal asymmetries. This statement is in agreement with the results found in the present study (Table 3), because even after comparing the temperatures of the dominant and non-dominant sides and having observed, in the post-training session, that the average T_{SK} values ($t = 3.305$; $p<0.05$) and minimum T_{SK} ($t = 6.436$; $p<0.05$) on the non-dominant side were significantly higher than those on the dominant side; at the moment 10 minutes of rest it was observed that the values of the average T_{SK} ($t = 4.123$; $p<0.05$) and minimum T_{SK} ($t = 4.171$; $p<0.05$) on the non-dominant side were significantly higher than those on the dominant side. Additionally, it was observed at the moment 15 minutes of rest that the values of maximum T_{SK} ($t = 2.978$; $p<0.05$), average T_{SK} ($t = 5.870$; $p<0.05$), and minimum T_{SK} ($t = 5.947$; $p<0.05$) on the non-dominant side were significantly higher than those on the dominant side, the thermal reactions were within normal limits since the maximum temperatures between all moments were below 0.4º C between the two sides.

For Fernandeset al.[37], the behavior of T_{SK} is altered by factors inherent to physical exercise, in terms of duration and intensity, and may continue a downward curve, especially when the exercise is progressive up to maximum levels and short duration. However, T_{SK} increases in active muscle regions in exercises when it is maintained with constant intensity or medium and long duration. According to Neves et al.[38], the T_{SK} on active muscles, when compared to the values observed before exercise, increases during the execution of high-intensity anaerobic exercises, decreasing slowly after its completion and returning to increase in the following days, on the other hand, during the performance of low-intensity aerobic exercises, the T_{SK} on the active muscles decreases, returning to baseline values a few minutes after starting the physical effort, showing a small increase in T_{SK} in the following days. Regarding T_{SK} on non-active muscles, it can be said that it decreases during physical activity, returning to the initial values a few minutes after the end, increasing equally to the active muscles in the days after exercise.

Such information strengthens the evidence of the present study, which consisted of a training session with short and intense series (Table 2), indicating a RPE scale = 8.9 (hard), in which significant differences were found in the results of the average T_{SK} in the dominant side ($F = 5.249$; $p = 0.003$), with significant reductions at the time of 15 minutes of rest when compared to the pre-training session, and when compared to the post-training session. Moreover, changes were observed in the minimum T_{SK} of the dominant side ($F = 4.790$; $p = 0.006$) with significant reductions in the 10 minutes of rest and 15 minutes of rest when compared to the pre-training session. Changes were also observed for the average T_{SK} of the non-dominant side ($F = 4.158$; $p = 0.011$), with significant reductions at the 15-minute rest time compared to the pre-training session; and when compared to the post-training session (Table 4 and Fig. 2).

Similarly, Della Corte et al.[39]analyzed the T_{SK} of the anterior thighs of 10 men (age: 24.0 ± 2.7 years), Physical Education students, and with at least one year of experience in RT.The participants performed five unilateral sets until the concentric failure with the dominant side of the lower limb in the leg extension exercise with a load of 70% of 10RM and an indication of RPE scale = 10.0 (extremely hard). The authors realized, as in the present study, that there were no significant changes in the temperature of the region of interest immediately after the training session, with the possible hypothesis that practitioners experienced in RT could recruit more synergistic muscles to perform the same movement, requiring less of the agonist muscles.

Corroborating these findings, Neves et al.[40] evaluated the influence of body position on the behavior of T_{SK} and heart rate of 31 untrained volunteers, aged between 18 and 30 years, during two training sessions and up to one hour of rest after the conclusion of the training. Fifteen women performed the unilateral biceps curl exercise (biceps group – BG) and 16 performed the back half squat at 90º (quadriceps group – QG), both with four sets of 10 repetitions, with intensity randomized to 70% or 85% of 10RM, and a 30-second recovery interval between them. Regarding the T_{SK}, similarly to this study, it was observed that, after the end of the training sessions, there was a significant reduction in the T_{SK} of the active muscles in both groups (BG and QG), with similar thermal responses for the intensities of 70% and 85% 10 RM until the 15th minute. From 15 minutes (the moment that marks the change from a standing position to a sitting position) to the minute 20–60, there was an abrupt increase in T_{SK}, returning to levels close to those seen before the training sessions. It was concluded that T_{SK} decreases in active muscles during exercise and after the first minutes of the rest period, but returns to baseline values up to one hour of rest and that the change in body posture is capable of causing changes in T_{SK}.

Conversely, Oliveira et al.[41] evaluated 16 men (age: 22.5 ± 2.1 years) using an arm ergometer. The protocol consisted of a 3-minute warm-up with the upper limb ergometric speed maintained between 50 and 60 repetitions per minute (rpm) and a load of 20 watts. After this period, 15 watts were added every 2 minutes until exhaustion or the inability to maintain a speed of 50–60 rpm, all participants reached 85% of the underestimated maximum heart rate. It was observed that the progressive exercise performed with the upper limbs until exhaustion did not immediately increase the T_{SK} values in the metabolically active areas after the exercise, but after 15 minutes of rest. Differently, Della Corte et al.[42]compared the thermal variations of the anterior thighs of male basketball athletes, under-17 category, after two distinct RT sessions, one of muscular power (PTP) with TTV = 5498.9 kg, intensity 60% of 1RM and RPE scale = 5.3 (somewhat easy) and another of maximum muscle strength (STP) with TTV = 1317.4 kg, 90% intensity of 1RM and RPE = 9.5 (hard). The results of this study revealed that the value of the percentage difference of the maximum T_{SK} between pre- and post-training sessions of the PTP (7.6%) was almost twice higher than that of the STP (4.0%).

Probable explanations would be that, when starting the training, depending on its duration and intensity, the temperature of the musculature that participates in the gestural motor tends to be maintained or increased at the end of the physical exercise, because biochemical energy is converted into mechanical and thermal energy during the resynthesis of adenosine triphosphate. This way, blood flow to the physically active region during exercise increases as a reflex response to metabolites from physical activity, such as carbon dioxide volume, lactate, adenosine diphosphate, and adenosine monophosphate[43]. Adrenergic action decreases blood flow to inactive regions of the skin through cutaneous vasoconstriction, redirecting blood to the active musculature, favoring the removal of exercise metabolites, taking nutrients to decrease peripheral fatigue, contributing to the continuity of physical activity[44].

The limitations of the present study are related to only male subjects as participants and the sample size, which can limit the external validation of the results.Therefore, caution is suggested in interpreting the findings of the present study.

Conclusions

The present study revealed thatmaximum strength training session, performed until the concentric failure, prescribed in the leg extension exercise,caused significant decreases in the T_{SK} of the anterior thighs after 10 and 15 minutes of rest in university handball players. This outcome indicated great metabolic demand in short-term activities with high dynamic effort, showing that the training volume and intensity can have significant participation in the temperature behavior of physically active areas.It has also been shown that the infrared-thermal camera is a useful analysis device, which can help in controlling the trainingload and the muscular tissuestress,observe some physiological abnormalities, asymmetries, or disorders of blood circulation before or after a maximum-strength training session.

It is recommended for further investigations to use infrared cameras with a higher visual resolution, with the applicability of verifying thermographic images captured close and/or distant from the participants, to analyze muscle groups from other regions of interest, in addition to those who are directly involved with physical exercise. It is also suggested to conduct training methods that have different volumes and intensities; post-training recovery time increased; a greater number of participants/athletes from the same or other sports; other age groups of both sexes; and different levels of physical conditioning.

Conflicts of interest - The authors have no conflicts of interest to declare.

References

1. Massuca L, Branco B, Miarka B, Fragoso I. Physical fitness attributes of team-handball players are related to playing position and performance level. *Asian J Sports Med*. 2015;6(1):e24712. https://doi.org/10.5812/asjsm.24712
2. Ghobadi H, Rajabi H, Farzad B, Bayati M, Jeffreys I. Anthropometry of world-class elite handball players according to the playing position: Reports from men’s handball World Championship 2013. *J Hum Kinet*. 2013;39(1):213-220. https://doi.org/10.2478/hukin-2013-0084
3. Hermassi S, Chelly MS, Fathloun M, Shephard RJ. The effect of heavy- vs. moderate-load training on the development of strength, power, and throwing ball velocity in male handball players. *J Strength Cond Res*. 2010;24(9):2408-2418. https://doi.org/10.1519/JSC.0b013e3181e58d7c
4. Hermassi S, Chelly MS, Tabka Z, Shephard RJ, Chamari K. Effects of 8-week in-season upper and lower limb heavy resistance training on the peak power, throwing velocity, and sprint performance of elite male handball players. *J Strength Cond Res*. 2011;25(9):2424-2433. https://doi.org/10.1519/JSC.0b013e3182030edb
5. DelloIacono A, Ardigò LP, Meckel Y, Padulo J. Effect of small-sided games and repeated shuffle sprint training on physical performance in elite handball players. *J Strength Cond Res*. 2016;30(3):830-840. https://doi.org/10.1519/JSC.0000000000001139
6. Wolinski PA, Neves EB, Pietrovski EF. Analysis of hemodynamic and vascular repercussions of Kaatsu training. *ConScientiae Saúde*. 2013;12(2):305-312. https://doi.org/10.5585/conssaude.v12n2.4032
7. Bandeira F, Moura MAM, Souza MA, Nohama P, Neves EB. Can thermography aid in the diagnosis of muscle injuries in soccer athletes? *RevBrasMed Esporte*. 2012;18(4):246-251. https://doi.org/10.1590/S1517-86922012000400006
8. Neves EB, Reis VM. Fundamentos da termografia para o acompanhamento do treinamento desportivo. *Revista Uniandrade*. 2014;15(2):79-86. http://dx.doi.org/10.18024/1519-5694/revuniandrade.v15n2p79-86
9. Côrte ACR, Hernandez AJ. Application of medical infrared thermography to sports medicine. *Rev Bras Med Esporte*. 2016;22(40):315-319. https://dx.doi.org/10.1590/1517-869220162204160783
10. Merla A, Mattei PA, Di Donato L, Romani GL. Thermal imaging of cutaneous temperature modifications in runners during graded exercise. *Ann Biomed Eng*. 2010;38(1):158-163. https://doi.org/10.1007/s10439-009-9809-8
11. Fernandes AA, Amorim PRS, Brito CJ, Sillero-Quintana M, Bouzas Marins JC. Regional skin temperature response to moderate aerobic exercise measured by infrared thermography. *Asian J Sports Med*. 2016;7(1):e29243. https://doi.org/10.5812/asjsm.29243
12. Fernandes AA, Amorim PR, Brito CJ, Moura AG, Moreira DG, Costa CM, Sillero-Quintana M, Marins JC. Measuring skin temperature before, during and after exercise: a comparison of thermocouples and infrared thermography. *PhysiolMeas*. 2014;35(2):189-203. https://doi.org/10.1088/0967-3334/35/2/189
13. Neves EB, Moreira TR, Lemos R, Vilaça-Alves J, Rosa C, Reis VM. Using skin temperature and muscle thickness to assess muscle response to strength training. *Rev Bras Med Esporte*. 2015;21(5):350-354. https://dx.doi.org/10.1590/1517-869220152105151293
14. Neves EB, Moreira TR, Lemos RJCA, Vilaça-Alves J, Reis VM. The thermal response of biceps brachii to strength training. *GazzettaMedicaItalianaArchivio per le ScienzeMediche*. 2016;175(10):391-399.
15. Bandeira F, Neves EB, Moura MAM, Nohama P. The thermography in support for diagnosis of muscle injury in sport. *Rev Bras Med Esporte*. 2014;20(1):59-64. https://doi.org/10.1590/S1517-86922014000100012
16. Fernández-Cuevas I, Marins JCB, Lastras JA, Gomez-Carmona PM, Cano SP, García-Concepción MA, et al. Classification of factors influencing the use of infrared thermography in humans: A review. *Infrared Physics & Technology*. 2015;71:28-55. http://dx.doi.org/10.1016/j.infrared.2015.02.007
17. Formenti D, Ludwig N, Gargano M, Gondola M, Dellerma N, Caumo A, Alberti G. Thermal imaging of exercise-associated skin temperature changes in trained and untrained female subjects. *Ann Biomed Eng*. 2013;41(4):863-871. https://doi.org/10.1007/s10439-012-0718-x
18. Johnson JM, Minson CT, Kellogg Jr DL. Cutaneous vasodilator and vasoconstrictor mechanisms in temperature regulation. *Compr Physiol*. 2014;4(1):33-89. https://doi.org/10.1002/cphy.c130015

19. Marins JCB, Fernández-Cuevas I, Arnaiz-Lastras J, Fernandes AA, Sillero-Quintana M.Applications of infrared thermography in sports. A review. *Rev Int Med Cienc Act FísDeporte*. 2015;15(60):805-824.
20. Thomas JR, Nelson JK, Silverman SJ. *Métodos de Pesquisa em Atividade Física*. 6ª ed. Porto Alegre: Artmed; 2012.
21. American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription*. 9th ed. Philadelphia: Wolters Kluwer; Lippincott Williams & Wilkins; 2014.
22. World Medical Association (WMA).Declaration of Helsinki. *Ethical Principles for Medical Research Involving Human Subjects*. Adoptedbythe 64th WMA General Assembly; October 2013.
23. Brasil.Resolução nº 466, de 12 de dezembro de 2012. *Diretrizes e normas regulamentadoras de pesquisa envolvendo seres humanos*. Ministério da Justiça. Conselho Nacional de Saúde. Diário Oficial da União. Brasília: DF. Junho 2013;12:59.
24. Bosy-Westphal A, Later W, Hitze B, Sato T, Kossel E, Gluer CC, Heller M, Muller MJ. Accuracy of bioelectrical impedance consumer devices for measurement of body composition in comparison to whole body magnetic resonance imaging and dual X-ray absorptiometry. *Obes Facts*. 2008;1(6):319-324. https://doi.org/10.1159/000176061
25. Stewart A, Marfell-Jones M, Olds T, Ridder H. *International standards for anthropometric assessment*. New Zealand, ISAK: Lower Hutt; 2011.
26. Brown LE.*Strength Training*. National Strength and Conditioning Association. 2nd ed. Champaign, IL: Human Kinetics; 2017.
27. Paz GA, Maia MF, Lima VP, Oliveira CG, Bezerra E, Simão R, Miranda H. Maximal exercise performance and electromyography responses after antagonist neuromuscular proprioceptive facilitation: A pilot study. *J ExercPhysiol Online*. 2012;15(6):60-67.
28.Miranda H, Simão R, Vigário PS, Salles BF, Pacheco MTT, Willardson JM. Exercise order interacts with rest interval during upper body resistance exercise. *J Strength Cond Res*. 2010;24(6):1573-1577. https://doi.org/10.1519/JSC.0b013e3181d8ea61
29. Della Corte J, Paz GA, Castro JBP, Miranda H. Hypotensive effect induced by strength training using the DeLorme and Oxford methods in trained men. *Pol J Sport Tourism*. 2018;25(1):23-30. https://doi.org/10.2478/pjst-2018-0004
30. Moreira DG, Costello JT, Brito CJ, Adamczyk JG, Ammer K, Bach AJ, et al. Thermographic imaging in sports and exercise medicine: a Delphi study and consensus statement on the measurement of human skin temperature. *J Therm Biol*. 2017;69:155-162. https://doi.org/10.1016/j.jtherbio.2017.07.006
31. Jaspers MEH, Carrière ME, Meij-de Vries A, Klaessens JHGM, van Zuijlen PPM. The FLIR ONE thermal imager for the assessment of burn wounds: Reliability and validity study. *Burns*. 2017;43(7):1516-1523. https://doi.org/10.1016/j.burns.2017.04.006
32. Moreira DG, Costello JT, Brito CJ, Sillero-Quintana M. A checklist for measuring skin temperature with infrared thermography in sports and exercise medicine. *ThermologyInternational*. 2017;27(4):141-143.
33. Souza PA, Teixeira DR, Della Corte J, Batista CAS, Miranda HL, Paz GA. Acute effect of intra-set static stretching on antagonists versus passive interval on the performance of maximum repetitions of agonists in leg extension machine. *Rev Bras CineantropomDesempenho Hum*. 2020;22:e60225. http://dx.doi.org/10.1590/1980-0037.2020v22e60225
34. Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc*. 2004;36(4):674-688. https://doi.org/10.1249/01.MSS.0000121945.36635.61
35. Naclerio F, Rodríguez-Romo G, Barriopedro-Moro MI, Jiménez A, Alvar BA, Triplett NT. Control of resistance training intensity by the OMNI perceived exertion scale. *J Strength Cond Res*. 2011;25(7):1879-1888. https://doi.org/10.1519/JSC.0b013e3181e501e9
36. Vardasca R, Ring F, Plassmann P, Jones C. Thermal symmetry of the upper and lower extremities in healthy subjects. *ThermologyInternational*. 2012;22(1):53-60.
37.Fernandes AA, Amorim PRS, Prímola-Gomes TN, Sillero-Quintana M, Fernández-Cuevas I, Silva RG, Pereira JC, Marins JCB. Evaluation of skin temperature during exercise by infrared thermography: A systematic review. *Rev Andal Med Deporte*. 2012;5(3):113-117. https://doi.org/10.1016/S1888-7546(12)70017-5
38. Neves EB, Vilaca-Alves J, Antunes N, Felisberto IM, Rosa C, Reis VM. Different responses of the skin temperature to physical exercise: Systematic review. *Conf Proc IEEE Eng Med Biol Soc*. 2015;2015:1307-1310. https://doi.org/10.1109/EMBC.2015.7318608
39. Della Corte J, Pinheiro CB, Lima BLP, Vignoli FA, Oliveira JGM, Castro JBP, Lima VP. Thermographic analysis of thighs of trained men during the leg extension exercise. *Journal of Physical Education and Sport*. 2019;19(4):2458-2465. https://doi.org/10.7752/jpes.2019.04373
40. Neves EB, Cunha RM, Rosa C, Antunes NS, Felisberto IMV, Vilaça-Alves J, Reis VM. Correlation between skin temperature and heart rate during exercise and recovery, and the influence of body position in these

variables in untrained women. *Infrared Physics & Technology*. 2016;75:70-76. https://doi.org/10.1016/j.infrared.2015.12.018

41. Oliveira SAF, Marins JCB, Silva AG, Brito CJ, Moreira DG, Sillero-Quintana M. Measuring of skin temperature via infrared thermography after an upper body progressive aerobic exercise. *Journal of Physical Education and Sport*. 2018;18(1):184-192. https://doi.org/10.7752/jpes.2018.01024
42. Della Corte J, Pereira WLM, Corrêa EELS, Oliveira JGM, Lima BLP, Castro JBP, Lima VP. Influence of power and maximal strength training on thermal reaction and vertical jump performance in Brazilian basketball players: a preliminary study. *Biomedical Human Kinetics*. 2020;12(1):91-100. https://doi.org/10.2478/bhk-2020-0012
43. Camargo MG, Furlan MMDP. The body's physiological response to high temperatures: exercise, temperature extremes and thermal diseases. *RevistaSaúde e Pesquisa*. 2011;4(2):278-288.
44. Hodges GJ, Johnson JM. Adrenergic control of the human cutaneous circulation. *ApplPhysiolNutrMetab*. 2009;34(5):829-839. https://doi.org/10.1139/H09-076