Original Article

Thermographic analysis of thighs of trained men during the leg extension exercise

JAIME DELLA CORTE^{1,2}, CLAUDIO DE BIASE PINHEIRO³, BRUNO LUCAS PINHEIRO LIMA^{2,4}, FLAVIO DE ANDRADE VIGNOLI^{2,5}, JOÃO GABRIEL MIRANDA DE OLIVEIRA^{2,3}, JULIANA BRANDÃO PINTO DE CASTRO^{2,4}, VICENTE PINHEIRO LIMA^{1,2,3,4}

¹Postgraduate Program in Human Anatomy and Biomechanics, Castelo Branco University, Rio de Janeiro, RJ, BRAZIL

²Research Group on Performance, Exercise and Health Biodynamics (BIODESA), Castelo Branco University, Rio de Janeiro, RJ, BRAZIL

³Faculty of Physical Education, Castelo Branco University, Rio de Janeiro, RJ, BRAZIL

⁴Postgraduate Program in Exercise and Sport Sciences, Rio de Janeiro State University, Rio de Janeiro, RJ, BRAZIL

⁵Postgraduate Program in Resistance Training, Estácio de Sá University, Rio de Janeiro, RJ, BRAZIL

Published online: December 31, 2019

(Accepted for publication: December 04, 2019)

DOI:10.7752/jpes.2019.04373

Abstract:

The infrared thermography is a non-radioactive and non-invasive detection tool. It allows the analysis of physiological functions associated with skin temperature control. **Purpose:** To analyze the influence of resistance training (RT) on the skin temperature of the thigh in trained individuals. **Methods:** Ten recreationally trained men (age: 24.0 ± 2.7 years; height: 1.74 ± 0.1 m; body mass index: 27.16 ± 3.8 kg/m²) were submitted to anthropometric evaluation and determination of the loads for 10 repetition maximum (RM) on the dominant side, using the leg extension exercise. After 48 hours, the subjects were conducted to the training session, which consisted of five sets with loads equal to 70% of 10 RM. The recovery intervals between the series were three minutes. At the end of the training session, the participants indicated the OMNI perceived exertion scale as very hard. Thermographic images were taken before the training session and immediately after the last RT sets. The mean room temperature was maintained at 20.3 ± 0.4 °C, with a mean relative air humidity of $55.3 \pm 1.0\%$ RH. **Results:** No significant difference was found in the skin anterior thigh temperature of the dominant and non-dominant side of the individuals after the intervention. **Conclusion:** The volume and intensity characteristics prescribed in the present study were not able to alter significantly the skin temperature of the participants' anterior thigh immediately after the training session.

KeyWords: resistance training, thermography, muscle strength, thermal imaging, infrared rays

Introduction

Resistance training (RT) consists of a training modality that uses loads to improve muscular capacities, such as muscle strength, power, hypertrophy and muscular endurance¹. The practice of RT consists of the manipulation of variables, for instance, the number of exercises, sets, and repetitions; interval time between exercises and sets; time under tension; order of exercises, fractionation of training, among others. This training can trigger different physiological responses beneficial to health². The RT has presented effective results for individuals with the most diverse goals and levels of physical fitness and in the improvement of athletic performance³.

RT is associated with physiological adaptations due to inflammatory processes and muscle damage from the stimuli applied during the training sessions^{4,5}. Inflammatory processes result in signs such as heat, pain, and hyperemia. The heat can be measured subjectively by observation through thermographic image capture^{6,7}.

Thermography is a highly sensitive, fast, safe and painless diagnostic imaging test without contrast, contact or ionizing radiation. Through a special camera, it is able to capture long infrared radiation emitted by the human body, thus making it possible to measure the temperature of the skin surface and form an image of the thermal distribution⁸.

The central body temperature of humans is maintained constant through adjustments of physiological mechanisms in order to achieve the balance between the production of internal heat and the heat lost in the environment⁹. These adjustments are considered adaptations that are critical for conserving the internal temperature, estimated at approximately 37 degrees Celsius (°C), which preserves vital metabolic functions. However, the skin temperature may range from 10 to 42°C¹⁰. This is mainly due to exposure to certain

environmental conditions, such as extreme temperatures, air humidity, and solar radiation¹¹, as well as during the practice of physical exercise¹².

Physical exercises performed in RT increase the metabolism, as well as considerably increase the heat production, according to the intensity of the physical effort employed and the environmental conditions¹³. Constantly, athletes are exposed to physical training and competition stresses. Reactions from misaligned loads are frequent. Hence, early diagnosis is important. In addition, the localization of inflammation is a critical step for correct treatment and support for prescriptions of safer physical exercises^{14,15}.

In sports medicine, the use of thermography can help to achieve better results for athletes, as it is an instrument for identifying risks and preventing injuries, as well as being an important tool in the follow-up of RT, based on evaluation and quantification of work loads¹⁶. Therefore, the aim of this study was to analyze the influence of RT on the skin temperature of the dominant and non-dominant sides of the thighs of trained individuals, with the use of infrared thermography as the main evaluation technique.

Material & methods

Study Design

Original laboratory research of the descriptive type, where the study seeks to determine future status, opinions or projections in the answers obtained. It is based on the premise that problems can be solved and practices can be improved by describing and analyzing objective and direct observations¹⁷.

Participants

The sample consisted of ten male volunteers, apparently healthy, with mean age of 24.0 ± 2.7 years, height of 1.74 ± 0.1 m, and body mass index (BMI) of 27.16 ± 3.8 kg/m², all Physical Education students from a University of the West Zone of Rio de Janeiro, Brazil.

Individuals met the following inclusion criteria: a) RT practitioners with at least one year of experience; and b) minimum weekly frequency of three sessions. It was excluded from the study: a) all those with degenerative or metabolic diseases; b) those who had lesions or musculoskeletal limitations that prevented the performance of the scheduled exercises; c) those who used ergogenic substances; d) those who had a cardiac pacemaker or any other implanted medical device; and e) those with positive Physical Activity Readiness Questionnaire (PAR-Q)¹⁸.

Procedures

All participants were informed about the entire training protocol and, as determined by the Brazilian National Health Council, Resolution 466/2012 on research with human beings¹⁹, voluntarily signed the informed consent form. The data were collected as follows: each volunteer performed three non-consecutive visits, which were always at the same hour of the day and at intervals of at least 48 hours. At the first visit, subjects were elucidated on all data collection procedures and study intervention; answered the PAR-Q questionnaire; signed the informed consent form, were submitted to the anthropometric measurements and the tests for 10 repetition maximum (RM). At the second visit, subjects were submitted to 10RM retests. At the third visit, the participants performed the training session, and the images were collected before and after the RT.

The participants were instructed not to perform physical exercises of any nature and did not ingest stimulant substances in the 24 hours prior to both data collection and intervention. All tests, retests and training sessions were performed at times similar to those of the volunteers' training and at controlled ambient temperature. To characterize the sample, height was determined using a stadiometer (Cardiomed, model WCS, Brazil), with a maximum capacity of 2.20 m and an accuracy of 0.001 m. The body composition (total body mass - TBM, body mass index - BMI, body fat percentage - %BF, percentage of skeletal muscle - %SM and basal metabolic rate - BMR) was measured using a bioimpedance (OMRON®, Full Body Sensor, model HBF-514C, USA) with a limit of 150 kg and a precision of 100g for TBM. Anthropometric measurements followed the specific protocols of the International Standards for Anthropometric Assessment (ISAK)²⁰.

Regarding measurements with bioimpedance, all subjects received the following recommendations: 1) no use diuretic medications in the last seven days; 2) fasting for at least three hours; 3) no drinking alcohol in the last 48 hours; 4) abstain from vigorous physical exercises in the last 24 hours; 5) urinate at least 30 minutes before measurement; 6) no bath or sauna just before performing the measurement; 7) do not climb on the scale with wet feet; and 8) wear light suits, bare feet, and body free of metal ornaments. To avoid measurement failures with bioimpedance, the researchers took the following precautions: 1) position the scale on a flat and consistent surface so that it could be stabilized; 2) previously insert the data, age, height and sex of the participant; 3) instruct the participant to climb on the platform of the bioimpedance holding the electrode bar in their hands, so that the thumbs were also part of the grip; 4) adjust the participant on the bioimpedance platform so that the heels were on the two electrodes farthest from the display and the fingers were occupying the electrodes closest to the display; and 5) after the value of the TBM blinked three times on the display, ask the participant to flex the shoulders by being 90° in relation to the trunk. The participant should be with the body erect, knees extended and looking at a fixed point ahead, above the horizontal line. The thermal images were obtained using the Flir²¹ camera (Flir One Pro iOS model, Wilsonville, OR, USA) coupled to an Apple©

smartphone (iPhone model 6, Cupertino, CA, USA). The Flir One Pro iOS is capable of detecting temperatures with dynamic scene ranges between -20° and 400°C , accurate to $\pm 3^{\circ}\text{C}$ or $\pm 5\%$, typical percentage of differences between ambient and scene temperatures. It contains two cameras, one with a LeptonTM thermal sensor, a pixel size of $12\text{ }\mu\text{m}$ and a spectral range of $8\text{ to }14\text{ }\mu\text{m}$ and a video graphics array (VGA) with high definition, 160×120 pixels. Thus, two images are obtained that are merged with multispectral dynamic imaging (MSX) technology, which superimposes a thermal image on a photographic image, enriching the images with perigrams in the areas of interest, resulting in a thermographic image with a visual resolution of 1440×1080 pixels.

To avoid the influence of possible external factors, some precautions were taken prior to obtaining the thermographic images. Therefore, participants were instructed as follows: 1) avoid exposure to the sun or ultraviolet UVA at the hours between 10 am and 4 pm in the last 24 hours; 2) not performing vigorous physical exercises in the last 24 hours; 3) do no therapeutic massage treatment in the last 24 hours; 4) do not take hot or cold bath 6 hours before the evaluation; 5) do not drink alcohol or coffee in the last 6 hours; 6) do not apply cream, gel or any other cosmetic products under the skin; and 7) wear appropriate clothing (i.e.: shorts or swimwear).

Test of 10 Repetition Maximum (10RM)

In order to verify the training overload and exercise prescription criteria, it was applied to the 10 RM test, following Brown's recommendations²². The unilateral leg extension exercise with the dominant lower limb was performed in the Buick Fitness Equipment (model MP-140, Brazil). The additional loads used in the study were previously measured in the Filizola® brand digital precision scale (model PL-150, Brazil).

The 10 RM tests were performed in a single day. Participants initially performed a warm-up with two sets, one with 15 repetitions of 40% and one with 12 repetitions of 50%, respectively, both estimated for 10RM of the usual training load. The interval between the two sets in the warm-up was one minute. The first attempt to perform the 10RM was performed three minutes after the warm-up. The intervals were set at five minutes, with a maximum of three attempts allowed. If the load was not found, a new test day was performed with a 48-hour interval between attempts. The load recorded was determined from the maximum obtained for 10RM. After resting for at least 48 hours, following the same procedures of the 10RM tests, in order to obtain the reproducibility of the loads, the volunteers were submitted to the retests. It was considered as 10RM the highest load established on both days²³, provided that the difference between them was less than 5%. However, if the stipulated percentage was exceeded, a new test and retest were scheduled.

In order to reduce the margin of error in 10RM tests and retests, the following strategies were adopted²⁴: a) standardized instructions were provided before the test, so that the participant was aware of the whole routine that involved the data collection; b) the participant was instructed on the technique of execution of the exercise; c) the evaluators were aware of the position adopted by the practitioner at the time of the measurement, because 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 in order to keep a high stimulation level. For a better description of the movement, it was established that, in the initial position, each subject should be seated in the leg extension equipment with knees flexed at 90° and its articular axis aligned with the axis of the equipment, feet support on the anterior face of the distal third of the legs, and all plates (loads) should be overlapped. The final position was considered the complete unilateral movement (dominant side) of knee extension, that is, until its articulation reached 0° . For standardization purposes, the initial position was defined by the touching of the plates and the final position by the touch of the bar of the equipment on an elastic cord used for reference (Fig. 1). The amplitudes were previously measured by a steel goniometer with a 360° amplitude.

Fig. 1. Leg extension exercise, Left: Initial position; Right: Final position

The velocity of movement was two seconds for the concentric phase and two seconds for the eccentric phase. The validation included the following criteria: a) no interval was allowed between the concentric and eccentric phases; b) the repetitions that did not fit the pre-established technical standards were not counted²⁵. The tests were stopped when the participants were unable to perform the complete movement, with a voluntary concentric failure occurring at 10RM²⁶.

Training Session

Participants were submitted to RT in the dominant lower limb, which consisted of a specific warm-up^{27,28} of one set of 12 repetitions in the leg extension exercise with a load of 50% of the maximum load obtained in the data collection. Two minutes after warm-up, five sets with 70% loads of 10 RM were performed until the concentric failure.

During the repetitions, individuals were encouraged to exhale in the concentric phase and to inspire in the eccentric phase of the movement, avoiding the Valsalva maneuver. The speed execution of the movement was the same as in the tests and retests. The intervals between the sets were three minutes. At the end of the training session, the participants indicated the rating of perceived exertion (RPE) as ten, which, accordingly to the OMNI-RES scale²⁹, means very hard.

The researchers captured the thermal images from the angle perpendicular to the area under investigation, at a distance between 100 and 150 cm. The subjects remained at least 15 minutes sitting at rest before the initial temperatures were recorded. The images of the anterior portion of the thighs were made before the training session and immediately after the last sets of the RT session (Fig. 2). In Fig. 2, the reddest region is the one with the highest body temperature.

To avoid incorrect measurements, external heat sources have been turned off. In addition, in order to measure and ensure the stability of the temperature and humidity of the environment, two thermal digital hygrometers (Akso, AK27new) were placed in the room where the thermal images were obtained. The mean temperature of the room was maintained at $20.3 \pm 0.4^{\circ}\text{C}$, with a mean air humidity reading of $55.3 \pm 1.0\%$ RH.

Pre-Training

Post-Training

Fig. 2. Thermographic images

Statistical Analysis

The data were processed in the software *Statistical Package for Social Sciences* (SPSS 22.0 – Chicago, IL, EUA) and presented with the descriptive analysis of mean, standard deviation and minimum, and maximum values. The normality and homogeneity of the sample data were verified with the Shapiro-Wilk and Levene tests, respectively. Based on the results, the paired Student's t-test was used to analyze the existence or not of significant differences between the pre and post-training thermographic responses. The level of significance was set at $p < 0.05$.

Results

Table 1 shows the characteristics of the sample.

Table 1. Characteristics of the sample (n=10).

	Age (years)	Height (m)	TBM (kg)	SMM (kg)	SM (%)	BF (%)	FFM (kg)	BMI (kg/m ²)	BMR (kcal)
Mean	24.0	1.74	82.5	32.3	39.5	21.6	64.5	27.16	1842.8
SD	2.7	0.1	13.5	4.9	2.5	4.5	10.6	3.8	155.9
Minimum	21	1.59	61.7	26.0	33.2	16.5	49.4	21.71	1603
Maximum	29	1.82	106.6	43.6	42.2	32.5	89.0	32.71	2133
SW (p-value)	0.085	0.283	0.996	0.182	0.111	0.066	0.307	0.577	0.897

TBM: total body mass; SMM: skeletal muscle mass; SM: skeletal muscle; BF: body fat; FFM: fat-free mass; BMI: body mass index; BMR: basal metabolic rate; SD: standard deviation; SW (p-value): Shapiro-Wilk normality test.

Table 2 presents the characteristics of the participants' training session.

Table 2. Training session characteristics.

	70% of 10 RM (kg)	Total RM	Total Volume (sets x kg x RM)
Mean	34.2	56.5	1944.4
SD	4.4	5.2	372.3
Minimum	27.3	48	1474.2
Maximum	44.1	65	2646.0
SW (p-value)	0.202	0.965	0.637

70% of 10 RM: workload; SD: standard deviation; SW (p-value): Shapiro-Wilk normality test.

Table 3 shows the results of the skin temperature of the anterior part of the participants' thighs.

Table 3. Skin temperature.

Pre-training session						
Dominant side				Non-dominant side		
	Maximum (°C)	Average (°C)	Minimum (°C)	Maximum (°C)	Average (°C)	Minimum (°C)
Mean	32.9	31.2	26.9	32.9	30.6	27.0
SD	1.7	1.7	3.3	1.7	2.0	3.0
Post-training session						
Mean	33.5	31.8	27.6	31.7	29.9	24.8
SD	3.0	3.3	3.7	2.7	3.0	3.6
Test t (p-value)	0.441	0.505	0.680	0.080	0.347	0.171

SD: standard deviation; Test t (p-value): paired t-Student test for dependent samples.

In the present study, no significant differences were found between pre and post training temperature values.

Discussion

This study aimed to identify the influence of the resistance training under skin temperature of the dominant and non-dominant side of the anterior portion of the thigh, of trained individuals, through thermographic images. According to the data obtained, it is possible to say that there were no significant differences in the skin temperature of the participants, before and immediately after the training session.

During physical exercise, the metabolic rate increases, consequently, it generates more heat in the body, which triggers the skin's thermoregulatory processes, causing changes in skin temperature³⁰. These changes imply a redistribution of blood circulation, from less active to areas that are more active. With the continuity of

the exercise, the blood flow is redirected to the area under greater stress, having as one of the objectives to change heat with the environment³¹.

The research conducted by Escamilla-Galindo et al.³² sought to analyze the behavior of skin temperature to understand the acute cross-effect after unilateral lower limb training in two different groups, one with young people with high RT experience and one with low experience. The main results showed that, regardless of the limb (exercised versus not exercised), differences were observed in the skin temperature of the regions of interest after the training session. However, the increase in skin temperature was more significant for the group with low experience, suggesting that the effect of skin temperature may depend on the training level of the subjects.

Similar to this study, Bandeira et al.³³ captured, before and after the training sessions, the thermographic image on the right side of the femoral quadriceps of athletes, divided into two distinct groups. The experimental group performed three resistance exercises (squats, rack, and extensor table), in consecutive series, with loads of 80% of 10 RM in each apparatus, with recovery interval of 90 seconds between sets. The control group performed a low-intensity activity, which consisted of a continuous running with monitoring established between 50 and 60% of the heart rate (HR). The results indicated that the athletes in the experimental group had significant increases in the temperature of the muscles analyzed after performing the RT.

In the experiment by Fernández-Cuevas et al.³⁴, the researchers used infrared thermography to compare skin temperature changes related to muscle and joint activity of upper and lower limbs during, immediately and up to eight hours after strength training with four sets of 10 repetitions at 70% of 1RM, with 90 seconds of rest between sets and three minutes between exercises; and aerobic training of 45 minutes on the treadmill with intensity for 60 to 75% of the HR. It was observed that the effects on skin temperature were more relevant after aerobic training, with recovery lasting between one and two hours. Therefore, the use of thermography was able to provide important information about local adaptations in response to the reestablishment of the initial skin temperature after training, indicating whether the athlete has recovered enough to train or compete again.

Sanz-López et al.³⁵ investigated, through thermography, the training effect on the patellar and calcaneus tendons, before, after training and after 10 minutes of a 60-minute running session with the intensity of 80% of HR during three days. As results were found a smaller bilateral increase of the temperature in the patellar tendon soon after the training of the first day of the race. In the calcaneal tendon, similar changes were observed only from the second day of running, such as temperature increase after the run and absence of significant difference between contralateral limbs. As the other studies previously mentioned, the authors reported the importance of the use of thermography as an auxiliary tool for the prevention of injuries.

Some limitations may be mentioned in the present study. The sample size was small, which can limit the external validation of the findings of this research. Another limitation was that no other method was used in addition to the evaluation. Therefore, caution is suggested in interpreting the findings of the present study.

Conclusions

The investigation concluded that the training session, with the volume and intensity characteristics prescribed in the present study, did not induce significant changes in the skin temperature of the thigh, dominant and non-dominant side, of the participants immediately after the training session. According to the studies used that obtained similar results, a probable response may be due to the fact that the individuals analyzed are already experienced in RT and, therefore, they recruit more synergistic muscles to perform the same movement, requiring less effort of the agonist's muscles.

It is suggested that future studies investigate the same muscle groups with different physical exercises, duration, intensity and post-training rest time, in order to observe the responses in the cutaneous temperature of the individuals.

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

References

1. Paz GA, Robbins DW, Oliveira CG, Bottaro M, Miranda H. Volume load and neuromuscular fatigue during an acute bout of agonist-antagonist paired-set vs. traditional-set training. *J Strength Cond Res.* 2017;31(10):2777-2784. <http://dx.doi.org/10.1519/JSC.0000000000001059>
2. Simão R, Fleck SJ, Polito M, Monteiro W, Farinatti P. Effects of resistance training intensity, volume, and session format on the post exercise hypotensive response. *J Strength Cond Res.* 2005;19(4):853-858. <http://dx.doi.org/10.2147/CIA.S79625>
3. Harries SK, Lubans DR, Callister R. Comparison of resistance training progression models on maximal strength in sub-elite adolescent rugby union players. *J Sci Med Sport.* 2016;19(2):163-169. <https://doi.org/10.1016/j.jsams.2015.01.007>
4. Damas F, Phillips SM, Libardi CA, Vechin FC, Lixandrão ME, Jannig PR, et al. Resistance training-induced changes in integrated myofibrillar protein synthesis are related to hypertrophy only after attenuation of muscle damage. *J Physiol.* 2016;594(18):5209-5222. <https://doi.org/10.1113/JP272472>

5. Ide BN, Nunes LAS, Brenzikofer R, Macedo DV. Time course of muscle damage and inflammatory responses to resistance training with eccentric overload in trained individuals. *Mediators Inflamm.* 2013;2013:204942. <https://doi.org/10.1155/2013/204942>
6. Choi E, Lee PB, Nahm FS. Interexaminer reliability of infrared thermography for the diagnosis of complex regional pain syndrome. *Skin Res Technol.* 2013;19(2):189-193.
7. Langemo DK, Spahn JG. A reliability study using a long-wave infrared thermography device to identify relative tissue temperature variations of the body surface and underlying tissue. *AdvSkinWoundCare.* 2017;30(3):109-119. [10.1097/01.ASW.0000511535.31486.bb](https://doi.org/10.1097/01.ASW.0000511535.31486.bb)
8. Carvalho AR, Medeiros DL, Souza FT, Paula GF, Barbosa, PM, Vasconcellos PRO, et al. Temperature variation of the quadriceps femoris muscle exposed to two forms of cryotherapy by means of thermograph. *Rev Bras Med Esporte.* 2012;18(2):109-111. <http://dx.doi.org/10.1590/S1517-86922012000200009>
9. Kenny GP, Journeay WS. Human thermoregulation: separating thermal and nonthermal effects on heat loss. *Front Biosci.* 2010;15(1):259-290.
10. Drinkwater E. Effects of peripheral cooling on characteristics of local muscle. *Med Sport Sci.* 2008;53(1):74-88.
11. Johnson JM. Exercise in a hot environment: the skin circulation. *Scand J Med Sci Sports.* 2010;20(3):29-39.
12. Merla A, Mattei PA, Di Donato L, Romani GL. Thermal imaging of cutaneous temperature modifications in runners during graded exercise. *Ann Biomed Eng.* 2009;38(1):158-163.
13. Kroemer KHE, Grandjean E. *Manual de ergonomia: adaptando o trabalho ao homem.* 5ª ed. São Paulo: Bookman; 2005.
14. Hardaker NJ, Moss AD, Richards J, Jarvis S, McEwan C, Selfe J. The relationship between skin surface temperature measured via non-contact thermal imaging and intra-muscular temperature of the rectus femoris muscle. *Thermol Int.* 2007;17(2):45-50.
15. Ferreira JJ, Mendonça LC, Nunes LA, Andrade Filho AC, Rebelatto JR, Salvini TF. Exercise-associated thermographic changes in young and elderly subjects. *Ann Biomed Eng.* 2008;36(8):1420-1427.
16. Côte ACR, Hernandez AJ. Application of medical infrared thermography to sports medicine. *RevBrasMedEsporte.* 2016;22(4):315-319. <http://dx.doi.org/10.1590/1517-869220162204160783>
17. Thomas JR, Nelson JK, Silverman SJ. *Métodos de pesquisa em atividade física.* 6ª ed. Porto Alegre: Artmed; 2012.
18. American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription.* 9th ed. Philadelphia: WoltersKluwer; Lippincott Williams & Wilkins; 2014.
19. Brasil. Resolução nº 466/12, 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. 12 dez2012, Brasília.
20. Marfell-Jones M, Stewart A, Carter L. *International standards for anthropometric assessment.* South Africa, ISAK: Potchefstroom; 2006.
21. 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.
22. Brown LE. *Strength training.* 2nd ed. Champaign, IL: Human Kinetics; 2017.
23. 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 Exerc Physiol Online.* 2012;15(6):60-67.
24. 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.
25. 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>
26. Loureiro S, Dias I, Sales D, Alessi I, Simão R, Fermino RC. Effect of different phases of the menstrual cycle on the performance of muscular strength in 10RM. *Rev Bras Med Esporte.* 2011;17(1):22-25. <http://dx.doi.org/10.1590/S1517-86922011000100004>
27. Paz GA, Maia MF, Lima VP, Miranda H. Effect of agonist-antagonist method compared to traditional on muscular volume and activation. *RevBrasAtivFis Saúde.* 2014;19(1):54-63. <http://dx.doi.org/10.12820/rbafs.v.18n5p54>
28. Miranda H, Maia MF, Paz GA, Costa PB. Acute effects of antagonist static stretching in the inter-set rest period on repetition performance and muscle activation. *Res Sports Med.* 2015;23(1):37-50.
29. 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.

30. Fernandes AA, Amorim PRDS, Brito CJ, Sillero-Quintana M, BouzasMarins JC. Regional skin temperature response to moderate aerobic exercise measured by infrared thermography. *Asian J Sports Med.* 2016;7:e29243.
31. Charkoudian N. Mechanisms and modifiers of reflex induced cutaneous vasodilation and vasoconstriction in humans. *J Appl Physiol.* 2010;109:1221-8.
32. Escamilla-Galindo VL, Estal-Martínez A, Adamczyk JG, Brito CJ, Arnaiz-Lastras J, Sillero-Quintana M. Skin temperature response to unilateral training measured with infrared thermography. *J ExercRehabil.* 2017;13(5):526-534.<http://dx.doi.org/10.12965/jer.1735046.523>
33. Bandeira F, Moura MAMD, Souza MAD, Nohama P, Neves EB. Can thermography aid in the diagnosis of muscle injuries in soccer athletes? *RevBrasMed Esporte.* 2012;18(4):246-251.<http://dx.doi.org/10.1590/S1517-86922012000400006>
34. Fernández-Cuevas I, Sillero-Quintana M, Garcia-Concepcion MA, Serrano JR, Gomez-Carmona P, Marins JCB. Monitoring skin thermal response to training with infrared thermography. *New Studies in Athletics.* 2014;29(1):57-71.
35. Sanz-López F, Martínez-Amat A, Hita-Contreras F, Valero-Campo C, Berzosa C. Thermographic assessment of eccentric overload training within three days of a running session. *J Strength Cond Res.* 2016;30(2):504-511.