Functional performance and thermal imaging of the lower limb between male and female trained

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Abstract. The purpose of this study was to investigate changes in functional performance such as thermal images of the lower limbs; muscular power and clinical test performed for predict knee mechanics in males and females practitioners of resistance exercise with free-weights. Twenty male and eighteen female practitioners of resistance exercise (RE) with free-weights were recruited for research. All subjects practiced regularly RE 4.8 ± 0.4 days' week^{-1}and total volume of 255.1 ± 9.2 minutes per week. All thermal images were performed in a thermoneutral room with temperature of 21ºC with a relative humidity of 65%. Then, all subjects performed three CMJ trials and one min rest between trials. Finally, males and females performed the SLSD test with subjects stood on an 8-inch wooden box, assumed a single-limb stance. The two-way ANOVA yielded main effects for the group in the single leg step down test (SLSD test) ($F_{1.36}$ = 9.260, p<.004), push-off phase ($F_{1.36}$ = 27.11, p<.0001) and landing phase ($F_{1.36}$ = 16.72, p<.0002) showed significant differences (p<.05) between sex. Thermal images showed significant difference only in the mean skin temperature at the posterior left and right leg between males vs. females (p<.05). Pearson's analysis demonstrated that jump height was significantly correlated with SLSD test in males and females. However, male showed negative correlation between skin temperature at the anterior leg and jump height. These finding shown the efficiency thermal images and SLSD test as possible tools to investigate muscle power in males and females that practice RE with free-weights.
Keywords*: countermovement jump test, thermal images, muscular power, resistance exercise.*

Introduction

Resistance exercises (RE) have been proposed in sports guidelines to improve physical conditioning and health, mainly by the positive effects on functional capacity, increase basal metabolic rate, decreases blood pressure, and improves blood lipid profiles, insulin sensitivity and glucose tolerance (1-3). RE is a combination of dynamic actions and static effort, where specific devices should be used to evaluate muscle strength and involves multiple variables that can be arranged to specifically meet training goals and individual needs, such as: exercise order, rest interval between sets, exercise mode, training frequency, movement velocity, training volume, repetitions per set, number of sets, type of muscle action, and the load intensity (1,3,4). In addition, RE can be done using many different types of equipment such as medicine balls, resistance tubing, theraballs, and body weight supported movements (5). However, RE with free-weights use an isotonic resistance which provides the same amount of resistance throughout the range of motion which allow for movement in multiple planes, require balance and promote significant gains of strength and hypertrophy (6,7).

The benefits of RE can be had by male and female of all ages and can help promote a longer more independent life. Conversely, the magnitude of the response to the RE can also be influenced by the sex factor, once the information available in the literature has indicated that the majority of female present lower values of muscular strength than male both in the upper and in the lower limbs (8,9). Sex differences in strength performance may be the result of other factors that can affect relative load, including variations in movement patterns and muscle activation, including speed of movement and hip, knee and ankles anatomy (10,11). However, these alterations are not yet fully cleared when male and female are submitted to the same type of training program. But, in relation to functional performance and thermal imaging of the lower limbs between male and female number of researches is limited.

Functional performance combined with thermal imaging assessments may provide valuable information [12]. Infrared thermography is a non-invasive method used to visualize human body temperature changes in response to physiological processes or pathological reactions related to the control of the temperature of the skin, without exposing the patient to any type of radiation (12-14). This technique has been used increasingly in medical and sports areas with applications related to the diagnosis of musculoskeletal disorders and in the evaluation of muscle performance and recovery after training (12-14). Thermal symmetry of the human body is similar between the sides of the body which are identical in shape and size, being taken at the same angle (13). On the other hand, injuries or inflammation lead to vasodilatation and increase of inflammatory mediators in the area, which result in an increase of the metabolism and blood flow in the region, consequently, increase local body temperature and disturb this normal symmetric pattern (12,14,15). However, no scientific studies have been identified that used this physiological evaluation of the functional performance between male vs. female.
Resulting from an examination of existing literature and professional interest, the aim of this study was to investigate changes in the thermal imaging profiles, muscular power and functional performance of the lower limbs between male and female practitioners of resistance exercise. It was hypothesized that male and female would show significant functional performance difference and thermal imaging in lower limbs and positive correlation between functional performance and muscular power of the lower limbs.

Material and Method

Study design. This is a randomized comparative study. The sample size was determined by including all participants that complied with the eligibility criteria. All participants (male and female) were practitioners of resistance exercise and underwent three tests to assess thermal imaging, muscular power and functional performance of the lower limbs.
All tests were performed in a single assessment session in the following order: anthropometric measurements; thermal imaging sequences of lower limbs (thighs and legs); muscular power (CMJ test); and functional performance of the lower limbs (Single leg step down test). All assessment were carried out in a temperature-controlled environment (temperature 21° C, 65% relative humidity) by a Hygro-Thermometer with Humidity Alert (Extech Instruments, Massachusetts, EUA). All assessments occurred between 2:00 and 4:00 P.M.
Participants. Twenty male (n=20; 23.5 ± 5.5 years; 176.1 ± 5.8 cm; 82.1 ± 7.1 kg; 25.7 ± 1.9 kg/m^2; 17.1 ± 3.9 % body fat) and eighteen female (n=18; 23.3 ± 4.5 years, 163.8 ± 4.3 cm, 67.1 ± 9.8 kg; 25.1 ± 3.1 kg/m^2; 21.4 ± 6.4 % body fat) practitioners of RE were recruited for research. All participants practiced regularly RE 4.8 ± 0.4 days week^{-1}, low aerobic training of 1.2 ± 0.4 day week^{-1} and total volume of 255.1 ± 9.2 minutes per week. Participants with at least one year of RE experience were included to participate in the current study.
Exclusion criteria included: (1) use of anabolic steroids, drugs or medication with potential impact in physical performance (self-reported); (2) presence of musculoskeletal injury in the past 6 months and (3) previous hip, knee or ankle surgery.
RE group showed a routine of the training to whole body with resistance bands, free-weights and medicine balls. All participants completed the Physical Activity Readiness Questionnaire (PAR-Q).
The study was approved by Ethical Committee for Human Experiments of the Augusto Motta University Center and was performed in accordance with ethical standards in sport and exercise science research (CAAE: 99955018.6.0000.5235). All participants were informed about the experimental procedures and gave written informed consent prior to participation (16). No clinical problems occurred during the study.
Body composition was assessed via bioelectrical impedance analysis using a device with built-in electrodes for the hands and feet (InBody 720). Participants wore their normal indoor clothing and were instructed to stand barefoot in an upright position with both feet on two separate electrodes on the surface of the machine, with arms abducted and hands gripping two electrodes fixed within the surface of two handles.
All analyses were performed after an 8-hour fast. All biometric measures were undertaken in an acclimatized room (21°C). No clinical problems occurred during the study.
Acquisition of the thermographic images. All thermographic images were performed between 8:00 and 9:00 A.M. in a thermoneutral room with temperature of 21ºC with a relative humidity of 65%. The equilibration period to evaluate skin temperature was set in 15 minutes.

Thermal images sequences of lower limbs (thighs and legs) were acquired in an anteroposterior manner (i.e., frontal and dorsal views) by a digital infrared thermo-camera (Flir Systems Inc®, model T-540, USA) with a measurement range of 20°C to 650°C (accuracy of ± 2°C or 2 %; sensitivity of ≤ 0.05°C), an infrared spectral band from 7.5 to 14 microns, a refresh rate of 60Hz and an FPA (Focal Plane Array) of 320 x 240 pixels. The distance between the subject and the camera was standardized at four meters and the index of human skin emissivity was set to 0.98.
Analyze of the body regions of interest (ROI) were selected by a drawing rectangular area by the software (Smartview3.1 - Fluke®, Everett, USA), which provided us with the average and maximum temperatures from each analyzed ROI (12,13). Selection of the ROI utilized 5 cm above the upper border of the patella and groin line for the thigh, and for the leg, 5 cm below the lower border of the patella and 10 cm above the malleolus (12). Figure 1 shows representative anterior and posterior thermal images from thighs and legs. Coffee, tea and alcohol intake were prohibited for four hours before testing. Soccer players do not use physiotherapy before the test (e.g. massage, electrotherapy, ultrasound, heat treatment, cryotherapy, hydrotherapy) and without cosmetics products before the measurements to obtain thermal images most meaningful of skin temperature. All soccer players reported the absence of any type of sports injury according to these criteria.

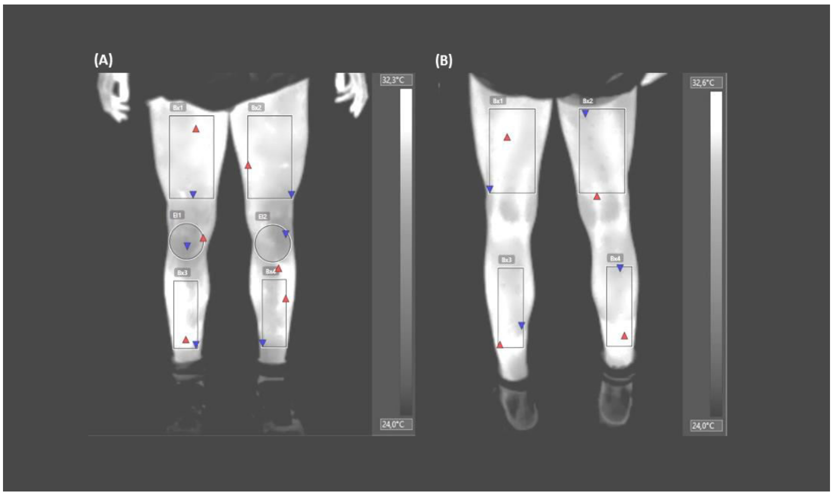

Figure 1. Thermal images anterior (A) and posterior (B) views from thighs and legs

Countermovement jump test (CMJ. After acquisition of the thermographic images all participants did a self-myofascial release with a foam roller (FR) with dimensions of 6.25" x 6.25" x 20.25" (SKLZ, CA, USA) applied over anterior-posterior regions of the thighs and legs in both lower limbs for 4 sets of 20 s in each region of interest with a 20-s rest period between sets. The participants started at the proximal region of the thighs and legs and rolled down toward to the distal region.
All participants were instructed to utilize their body mass over the thighs and legs with the help of the arms to make the movement and speed was controlled by a metronome (2s per pass). Two-minute rest was allowed between warm-up and CMJ.
The CMJ started with the participants at a static standing position with hands on the hip, and the jump was preceded by a countermovement of acceleration below the center of gravity achieved by free knee flexion that was observed and visually controlled by the examiner. During the jump, the trunk was kept as vertical as possible, and the athlete was instructed to jump at the highest possible speed and to the highest vertical point that they could reach.
All participants performed three practices CMJ trials followed by three CMJ trials and one min rest between trials. Standardized verbal stimulus was given during the test to ensure maximal performance. Each subject started the CMJ in the standing position, dropped into the squat position, and then immediately jumped as high as possible. After the maximal countermovement jump, participants landed back onto the force platform in a bilateral stance and returned to the anatomical neutral position. Failed attempts were marked if participants had any vertical displacement when stepping off the platform or did not contact the force platform with both feet during landing. Jump power considered the fact that in skilled jumpers, participants chose the depth that maximized both peak force and peak velocity resulting in maximal power output.

Trials were sampled at 1000Hz using the Ballistic Measurement System and software, consisting of two isolated electrical platforms rigid 60- by 42-cm with an open circuit configuration that is closed when a subject stand on the platform (Globus Ergo Tester; Codognè; Italy).
The platform was connected to a computer, which computed and stored the push-off phase, landing phase and flight time with a temporal resolution of 1ms. Peak force during the push-off phase was identified as the peak vertical ground reaction forces prior to take off. However, peak force of the landing phase was identified as the absolute peak vertical ground reaction forces after the initial ground contact from the maximal countermovement jump. The displacement of center of gravity (jump height - h) during flight was estimated by means of flight time through a standardized kinematic equation $h=t^2 \cdot g/8$, where g is the gravity acceleration (9.81 m/s^2). Data were collected immediately after zeroing until jump completion.
Single leg step down test (SLSD test). Functional performance of the lower limbs was measured using SLSD test. SLSD test started with participants stood on an 8-inch wooden box, assumed a single-limb stance and performed a squat which required the heel of the free leg to make contact with a scale on the floor to confirm a successful trial.
Participants were required to make contact with the scale but not exceed 10% of body weight to prevent weight transfer off of the test limb. Upon contacting the scale, participants returned to the start position. Participants were asked to complete as many step-downs as possible in 60 s. Step-downs were not counted if the subject did not make contact with the scale, transferred >10% of body weight onto their free limb when contacting the scale, or did not fully return to the starting position (17). Five-minute rest was allowed between CMJ and SLSD tests.
Statistical analysis. All data are presented as mean ± SD. Statistical analysis was initially performed using the Shapiro-Wilk normality test and the homoscedasticity test (Bartlett criterion). Two-way analysis of variance (ANOVA) was used to test for main and interaction effects of the group (Levels: male vs. female) and timing of measurement (levels: acquisition of the thermographic images, CMJ, SLSD test) for each outcome variable independently. When a significant *F*-value was found *Bonferroni* post hoc pair wise comparisons of means were examined. Correlations between variables were assessed using Pearson correlation coefficients and their corresponding 95% confidence intervals. The significance level was set at 0.05 and the software used for statistics was GraphPad® (Prism 6.0, San Diego, CA, USA).

Results

All analyzed data presented normal distribution. The two-way ANOVA yielded main effects for the group in the SLSD test ($F_{1.36}$ = 9.260, $p<.004$), push-off phase ($F_{1.36}$ = 27.11, $p<.0001$) and landing phase ($F_{1.36}$ = 16.72, $p<.0002$) such that *Bonferroni* post- hoc showed significant differences ($p<.05$) between male vs. female (Table I). In addition, a significantly ($p<.0001$) improved jump height was evident in male in relation to female.
Summary statistics for the effects of male and female groups by timing of the skin temperature measurements are shown in Tables II and III.

Table I. Physical performance and lower limb functionality between male vs. female practitioners RE with free-weights

		Males	**Females**	***p<***	**95% CI difference**
Single Leg Step Down Test (repetitions)	left	45.9 ± 10.5	37 ± 8.5	.05	8.9 (-16.09; -1.70)
	right	47.5 ± 10.6	37.8 ± 8.5	.01	9.6 (-16.86; -2.46)
Countermovement jump Push-off phase (kg)	left	97.9 ± 16.4	71.9 ± 12,4	.001	25.9 (-37.03; -14.93)
	right	97.3 ± 15.6	74.7 ± 14.4	.001	22.6 (-33.66; - 11.56)
Landing phase (kg)	left	181.7 ± 45.2	136.1 ± 21.4	.001	45.6 (-73.71; -17.48)
	right	189.6 ± 48.9	140.4 ± 25.2	.001	49.1 (-77.28; -21.06)
Jump height (cm)		31 ± 3.7	23 ± 4	.0001	8.5 (5.74; 11.36)

Phase push-off = concentric phase during the jump.

Table II. Maximal values of skin temperature (°C) of thigh, leg and knee between male and female practitioners RE with free-weights

Body regions of interest		Males	Females	Main and Interaction effects
Anterior thigh				Interaction: $F_{1,36}$ = 0,429, p = 0,51
	left	32.8 ± 1.2	32.6 ± 1.5	Group: $F_{1,36}$ = 24,88, p = 0,47
	right	32.7 ± 1.1	32.4 ± 1.4	Timing: $F_{1,36}$ = 2,77, p= 0,10
Posterior thigh				Interaction: $F_{1,36}$ = 0,027, p = 0,86
	left	32.5 ± 0.9	32.2 ± 1.3	Group: $F_{1,36}$ = 0,606, p = 0,44
	right	32.5 ± 0.9	32.2 ± 1.2	Timing: $F_{1,36}$ = 0,001, p = 0,96
Anterior leg				Interaction: $F_{1,36}$ = 0,703, p = 0,40
	left	32.6 ± 0.9	32.5 ± 1.2	Group: $F_{1,36}$ = 0,000, p = 0,97
	right	32.5 ± 1.0	32.6 ± 1.1	Timing: $F_{1,36}$ = 0,428, p = 0,51
Posterior leg				Interaction: $F_{1,36}$ = 0,928, p = 0,34
	left	32.5 ± 0.7	31.8 ± 1.4	**Group: $F_{1,36}$ = 4,114, p< 0,05**
	right	32.5 ± 0.7	31.9 ± 1.2	Timing: $F_{1,36}$ = 0,675, p = 0,41
Anterior knee				**Interaction:$F_{1,36}$ = 4,325, p < 0,04**
	left	31.6 ± 1.2	31.9 ± 1.6	Group: $F_{1,36}$ = 0,085, p = 0,77
	right	31.7 ± 1.0	31.6 ± 1.5	Timing: $F_{1,36}$ = 1,697, p = 0,20

Post-hoc Bonferroni: *p* >.05 male vs. female.

Table III. Mean values of skin temperature (°C) of thigh, leg and knee between male and female practitioners RE with free-weights

Body regions of interest		Males	Females	Main and Interaction effects
Anterior thigh				Interaction: $F_{1,36}$ = 0.335, p = 0.56
	left	31.5 ± 1.1	31.0 ± 1.7	Group: $F_{1,36}$ = 0.919, p = 0.34
	right	31.4 ± 1.1	31.0 ± 1.7	Timing: $F_{1,36}$ = 0.485, p= 0.49
Posterior thigh				Interaction: $F_{1,36}$ = 1.950, p = 0.17
	left	31.5 ± 0.9	30.9 ± 1.5	Group: $F_{1,36}$ = 1.631, p = 0.20
	right	31.4 ± 1.0	30.9 ± 1.5	Timing: $F_{1,36}$ = 0.977, p = 0.32
Anterior leg				Interaction: $F_{1,36}$ = 0.000, p = 0.98
	left	31.5 ± 1.0	31.2 ± 1.2	Group: $F_{1,36}$ = 0.776, p = 0.38
	right	31.5 ± 0.9	31.2 ± 1.2	Timing: $F_{1,36}$ = 0.075, p = 0.78
Posterior leg				Interaction: $F_{1,36}$ = 0.018, p = 0.89
	left	31.5 ± 0.8	30.4 ± 1.4*	**Group: $F_{1,36}$ = 8.120, p< 0.00**
	right	31.5 ± 0.8	30.5 ± 1.4*	Timing: $F_{1,36}$ = 0.712, p = 0.40
Anterior knee				**Interaction: $F_{1,36}$ = 6.024, p < 0.01**
	left	30.1 ± 1.3	30.3 ± 1.7	Group: $F_{1,36}$ = 0.012, p = 0.91
	right	30.3 ± 1.2	30.2 ± 1.4	Timing: $F_{1,36}$ = 0.032, p = 0.85

Post-hoc Bonferroni: * *p* <.05 compared to male.

From the two-way ANOVA it was observed interaction effect between group*timing for the maximum (F1.36 = 4.325, p <.04) and mean (F1.36= 6.024, p <.01) knee skin temperature measured at the anterior thigh (Tables II and III, respectively). In the absence of statistical evidence for interaction effects in relation to the other regions of interest, significant main effects for group were observed for the maximum(F1.36 =

4.144, p <.05) and mean (F1.36 = 8.120, p <.000) skin temperature measured at the posterior leg (Tables II and III). However, post-hoc Bonferroni did not find significant difference in the maximum skin temperature of male and female (p>.05). Conversely, significant main effects (p <.05) for timing of measurement were observed only for the mean skin temperature at the posterior left and right leg between male vs. female (Table III). Pearson's correlation analysis showed that jump height between the male and female was significantly associated with the number of repetitions for left (*r*= 0.41, *p*< .008) and right leg (*r*= 0.40, *p*< .01) obtained during SLSD test (Figure 2).

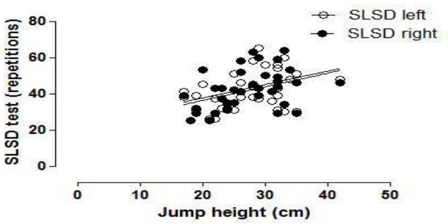

Figure 2. Scatter Plots displaying the correlation analysis (Pearson's coefficient) between Jump height and SLSD test in practitioners of RE with free-weights male and female

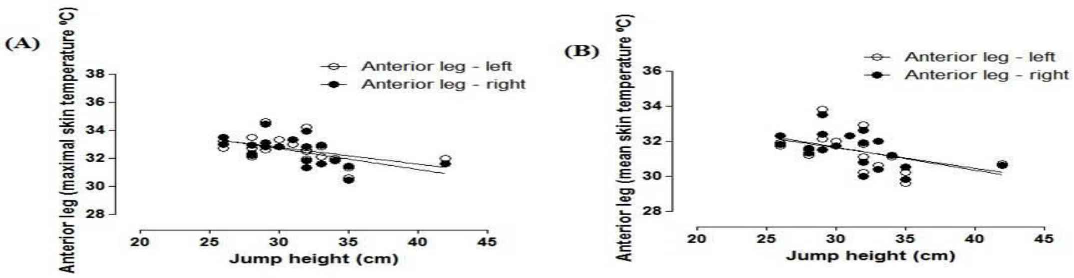

Figure 3 (A, B). Scatter Plots displaying the correlation analysis (Pearson's coefficient) between Jump height and maximal and mean values of skin temperature at the anterior leg in practitioners of RE with free-weights male.

Discussion

This study compared changes in the thermal imaging, muscular power and functional performance of the lower limbs between male vs. female practitioners of RE. Our findings support the original hypothesis that male and female would difference between functional performances and muscular power in lower limbs (SLSD test, different phases of the CMJ test and jump height). On the other hand, notable results evidenced in the present study that male and female shown positive correlation between SLSD test and jump height. In addition, the major finding herein was that maximal and mean values of skin temperature at the anterior leg showed negative correlation with jump height in male.

CMJ is commonly used for monitoring neuromuscular status (i.e. fatigue, supercompensation on performance, strength and power muscle) from the analysis of bilateral mechanics and the ability to generate and absorb ground reaction forces by the lower extremity (18). Conversely, power output it is a variable that is strongly linked to the mechanical variables responsible for the force production in the concentric and eccentric phases, and in turn, significantly associate to elastic elements and nervous system properties, but it seems to be a heterogeneous and neutral component between sexes (8,19). This affirmation can be related greater proportion of intramuscular non-contractile tissue in muscle biopsy samples obtained from muscles of the lower body in women when comparing strength and muscle characteristics to men (20,21). Thus, men show greater strength when normalized to fast free mass and were 1.3 times as strong when compared to the women participants (8). Our results showed that male produce 25% more in absolute power output when compared to female. Consequently, current data seem to suggest that the greater power observed in men during CMJ test may be primarily the result of larger muscle mass and strength. Conversely, there are many possible causes for this strength and power difference between male vs. female, they can be summarized as: (1) differences in motivation and the ability to sustain central drive; (2) differences in blood supply to the working muscles; (3) differences in the fuel metabolism and energy supply; (4) intrinsic differences in the composition and fatigue characteristics of the fibers making up the muscle; (5) changes in the excitation-contraction coupling mechanisms; and (6) differences in the cross-bridge formation and myofilament sliding of muscle cells (20,22,23).

SLSD test evaluates of neuromuscular control, functionality and endurance of the lower limb for involving repetitive eccentric and concentric contractions of the quadriceps. In the present study we report sex-related differences of 19.3% in left limb and 20.4% in right limb between male vs. female during performance in SLSD test. This result may suffer influence of the differences between male vs. female that fibers expressing the different myosin heavy chain (MYHC) isoform, i.e. the proportion of MHC IIa fibers in male is 29.8% higher than that of MHC I fibers (24). Conversely, MHC IIa fibers is 30.2% less in female than MHC I fibers (24). Hence, low muscle strength and quality in female may be associated with low proportion of MHC IIa fibers (20,23,24). Thus, sex-related difference in skeletal muscle fatigue resistance is not explicable by differences in motivation, muscle size; oxidative capacity and/or blood flow between sexes, but might be related to differences in fiber type composition (22). However, SLSD test may be an excellent method for evaluating muscular power for presenting a positive correlation with jump height in both sexes.

Considering the low muscle strength and quality in female through CMJ and SLSD test, applying of the more one method for muscle assessment show better reliability. Thus, the use of thermal images combined with assessment of lower limbs functional performance can provide rapid feedback about muscle asymmetry, risk of muscle injury and lower limbs performance. In this way, elevated skin temperatures are possibly the result of higher blood flows in muscle due to inflammation, tissue damage repair or morphological changes in muscle tissue by modifying the cross-sectional area of the muscle (12,25). Conversely, trained participants have a higher cutaneous blood flow than others by several physiological changes (e.g., increased muscle metabolism, anaerobic energy reserve, density of capillaries, nerve conduction rate and morphological changes in muscle tissue by modifying the cross-sectional area of the muscle) (12,13,26,27). In the present study, evaluated male and female practitioners of RE with free-weights that showed contralateral thermal symmetry and all the ROI were not greater than 0.3°C. However, mean skin temperature values at the posterior left and right leg were greater (> 0.7ºC) in the male when compared to the female. This response could be related with several physiological changes, such as: (1) increased muscle metabolism; (2) anaerobic energy reserve; (3) nerve conduction rate; (4) increase capillary density and morphological changes in muscle tissue by modifying the cross-sectional area of the muscle (27,28).

Major finding in the present study was negative correlation between skin temperature at the anterior leg muscle and muscular power. During jump, the early activation of anterior leg muscle is considered as the anticipatory postural adjustments, because anticipatory action of anterior leg muscle serves to move the body weight from the heel to toe so that the heel would be able to lift from the ground and the toes could be used as the fulcrum for propelling the body upward (29,30). A possible explanation for the negative correlation between skin temperature at the anterior leg muscle and jump height is related to decrease in muscle blood volume in tibials anterior muscle by muscle compression during muscle extension in the take off phase (29-31). Hence, muscle thickness greater in the male contributes to increased intramuscular pressure (32).

As limitations of the study, were indicated: (i) the absence of measures of physiological parameters of physical exertion, that would be interesting, but do not limit the answer to the aim of the study; and (ii) a surface electromyography analysis to further explain the mechanisms underpinning alterations in muscle recruitment. Thus, it is suggested that future studies evaluate the physiological and electromyography response before, during and post-effort between sexes.

In conclusion, this study found a negative correlation between skin temperature at the anterior leg muscle and muscle power in the male. On the other hand, the results of this investigation support that male and female shown contralateral thermal symmetry in the lower limbs (ROI < 0.3°C). In addition, SLSD test showed positive correlation with muscle power in the male and female. This finding shows the efficiency thermal images and SLSD test as possible tools to investigate muscle power in the male and female that practice RE.

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