

Original Article (short paper)

## Superficial thermal response to CrossFit® workout

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**Abstract - Aims:** Recently, high-intensity training methods have become popular, integrating the cardiovascular and neuromuscular training in a single training session, among these methods is CrossFit®. The objective of this study was to analyze the superficial thermal response to CrossFit® exercise in men and women, in order to use this knowledge to prevent overuse injuries. **Methods:** Nineteen volunteers involved in CrossFit® exercise for more than 6-month (12 males and 7 females) were recruited. The acquisition of the thermal images was performed in a climatized room in two moments, at rest (before exercise), and after one CrossFit® training session. The training session lasted 45min, comprising warm-up (10-min), accessory work (15-20min), and workout of the day (15-20-min). Before the first image acquisition, volunteers were acclimated for 15 min. The Wilcoxon signed-rank test was used to compare the skin temperature between pre- and post-exercise. **Results:** Temperatures rose significantly pre- to post-exercise in the forearm and anterior thigh regions, while it decreased in the anterior thorax and dorsal lower back regions. These results were found both, in the overall sample, and the male volunteers, but not when the female results were isolated. **Conclusion:** It can be concluded that superficial thermal response to one CrossFit® training session was characterized and was different for men and women. The superficial thermal responses were aligned with the physiological alterations promoted by other modalities, such as resistance training, cycling, and running.

**Keywords:** thermal imaging; Crossfit®; exercise; skin temperature; resistance training

### Introduction

The interest in research with athletes and others engaged in physical activity is not new, however, the study of the superficial thermal response (skin temperature) started a few decades ago<sup>1</sup>. Studies with thermal images with team sports such as football<sup>2</sup> and rugby<sup>3</sup> have been developed in order to assess the recovery of athletes and the incidence of muscle overuse resulting from training.

Santos Bunn et al.<sup>4</sup> developed a meta-analysis and reported the good diagnostic value of thermal imaging for musculoskeletal injuries. The same authors propose the utilization of thermal imaging as a first-line and radiation-free tool for monitoring the occurrence of musculoskeletal injuries. In thermal imaging, the asymmetries are the main suggestive sign of injury<sup>5,6</sup>. This signal is used in the field of sports medicine and other areas of medicine, such as endocrinology<sup>7</sup> and neurology<sup>8</sup>.

Skin plays an important role in thermoregulation during muscular exercise. When we are exercising, the body transforms chemical energy into kinetic and thermal energy, generating an increase in heat production and body temperature, especially in the active muscles. So, muscular exercise causes excessive metabolic production of heat during continued

physical activity and the body has to remove to avoid an excessive increase of internal temperature. To do this, blood flow is drained from core sites to the skin through the activation of vasoconstriction and vasodilatation mechanisms contributing to body temperature control<sup>9-12</sup>.

Moreover, in the field of sports medicine, authors have studied the thermal response to physical exercise by type of training. This characterization of the types of training has divided the studies into<sup>13</sup>: studies of the thermal response to resistance training<sup>14</sup> and studies of the thermal response to aerobic training<sup>15</sup>.

Recently, high-intensity training methods have become popular, integrating the two cardiovascular and neuromuscular stimulus in a single training session, among these methods is CrossFit®<sup>16</sup>. CrossFit® training uses aerobic activities (e.g. running, air bike, or rowing) and bodyweight exercises (e.g. bar muscle-up, handstand and pull up), as well as Olympic weightlifting (e.g. snatch, clean and jerk), among others. CrossFit® training routines involve exercises using large groups of muscles, a high number of repetitions, short recovery periods, and fast execution speed<sup>17</sup>.

The knowledge about new training methods is very important to understand possible injury mechanisms. Studies indicate that the shoulder, lower back, spine, and knee are

the most commonly injured areas in CrossFit®<sup>18,19</sup>. Injury rates reach 3.3/1000 training hours. Athletes that training CrossFit for longer than one year have shown an 82.2% probability of injury<sup>18,19</sup>. Commonly, injuries get an inflammation process at the beginning. An injury is often related to variations in blood flow and these, in turn, can affect the skin temperature<sup>4</sup>. So, infrared thermography could be an interesting instrument to detect earlier tissue alterations.

To the best of our knowledge, there are no studies in the literature on the surface thermal response (Skin temperature) to CrossFit® exercise. The skin temperature may be a potential way to detect different responses to effort and identify earlier differences of temperature between ipsilateral and contralateral areas make prevent an injury at a beginning process<sup>4</sup>. In this sense, the objective of this study was to analyze the superficial thermal response to one CrossFit® training session in men and women, in order to use this knowledge to prevent overuse injuries.

## Methods

### Participants

The sample was composed of 19 volunteers involved in Crossfit® training (12 males and 7 females) with a 6-month minimum experience. The procedures described have been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. The research protocol was approved under number 95/2018 by the Ethical Committee of the Institution where the study took part. Volunteers were informed about the research objectives and procedures and signed a free written informed consent to participate in the study.

The volunteers were selected in 2 CrossFit® training communities. The inclusion criteria were: having more than 6 months of continuous experience in CrossFit® training, having no previous injuries in the last 6 months, agreeing to remain 72 hours without vigorous physical activities before the day of data collection. The exclusion criteria were: presenting injuries on the day of data collection or in the last 6 months, reporting not having complied with the preparation guidelines for data collection, and not being able to finish the experimental exercise session within the expected time.

### Procedures

The subjects received in writing, with at least 7 days prior to the data collection day, the following preparation recommendations: not having a heavy meal, not smoking, and not having consumed alcohol or caffeine twelve hours before the exam; refrain from exercise or physiotherapy during 72 hours before the data collection day, avoiding cosmetics or oil ointments on the skin on the data collection day.

### Protocol and Data Collection Day

The data collection protocol (Figure 1) started with the assessment of anthropometric data: body mass, height, waist circumference, and hip circumference. The acquisition of the thermal images was performed in a climatized room in two moments, at rest (before exercise), and after one CrossFit® training session (after exercise), as presented in Figure 1.

Once Crossfit® classes are never repeated, even in the same affiliate (Box), the 19 individuals herein performed different combinations of exercises. In common, every class started with a 10-min warm-up followed by 15-20min of accessory work. The exercises require strength and technique, involving several kinds of overloads as a barbell or weigh (when lifts were performed), or the body weight (when gymnastics exercises hanging from the bar were performed). The workout of the day (WOD) comprised between 15 and 20min and it was a combination of 3 to 5 exercises performed in rounds and to complete as many repetitions as possible within the time limit that was established. This session organization enables a high-intensity session with a considerable volume (above 300 reps).

The training session was composed of 10 minutes warm-up (exercises to articular mobilization) followed by 20 minutes of exercises divided into 2 stages. The first stage was composed of 3 sets of dynamic and static exercises. The second stage was worked out by 3 sets of 2 exercises each when the subjects should perform as many repetitions as possible during 5 minutes by set (Figure 1). This session organization enables a high-intensity session with a considerable volume (above 300 reps). Although this kind of session planning can result in different amounts of repetition for each subject, the proportional effort tends to be the same because people should exercise with the maximum possible intensity during the prescribed time.

Before image acquisition, volunteers were acclimated for 15 min in a standing position, wearing swim-suits, and avoiding any type of movement, crossing their arms or legs, or scratching throughout the procedure<sup>20-23</sup>. There were collected half-body view images, from a distance of 2m<sup>24</sup>.

### Instruments

For the assessment of anthropometric measures, the following were used: digital balance Filizola®, Personal line, with 150kg maximum load and 0.05kg increments; a stadiometer, Sanny®; and an anthropometry Sanny® medical tape with 2m, model SN 4010.

The infrared images were collected using a T430sc® infrared camera (FLIR, USA), with an image resolution of 320 x 240 pixels, uncooled microbolometer, which has sensors that allow measuring the temperatures ranging from - 20 ° C to + 120 ° C, with thermal sensitivity of 0.05 ° C and accuracy of ± 2 ° C of absolute temperature. The images were performed in a controlled room with temperature set at 20±2 ° C, relative humidity less than 60% and skin emissivity has been set at 0.98. A digital thermo-hygrometer (Minipa® model MT241) for room temperature and humidity monitoring was used.

*Thermal images processing method*

The body was divided into 12 anterior ROI (6 to each body side) and 14 posterior ROI (7 each body side). The regions used were: Anterior Forearm Right (AFR); Dorsal Forearm Right (DFR); Anterior Forearm Left (AFL); Dorsal Forearm Left (DFL); Anterior Arm Right (AAR); Dorsal Arm Right (DAR); Anterior Arm Left (AAL); Dorsal Arm Left (DAL); Anterior Thorax Right (ATXR); Dorsal Upper Back Right (DUBR); Anterior Thorax Left (ATXL); Dorsal Upper Back Left (DUBL); Anterior Abdomen Right (AABR); Dorsal Middle Back Right (DMBR); Anterior Abdo-men Left (AABL); Dorsal Middle Back Left (DMBL); Dorsal Lower Back Right (DLBR); Dorsal Lower Back Left (DLBL); Anterior Thigh Right (ATR); Dorsal Thigh Right(DTR); Anterior Thigh Left(ATL); Dorsal Thigh Left (DTL); Anterior Leg Right (ALR); Dorsal Leg Right

(DLR); Anterior Leg Left (ALL); and Dorsal Leg Left (DLL). Each region of interest (ROIs)<sup>24</sup> was analyzed in terms of mean temperature. Symmetry was analyzed between ipsilateral and its contralateral mean ROI temperature.

*Statistical analysis*

Shapiro-Wilk test was used to analyze data distribution. Mean temperatures (TMe) were obtained of all ROIs studied and it was used in the analysis. Percentiles were used to characterize the sample and due to normal distribution violation, the Wilcoxon test was used to compare the skin temperature between pre- to post-exercise. The level of statistical significance was set at 95%. The Statistical analyses were performed using Statistical Package for Social Sciences (SPSS, version 25.0).

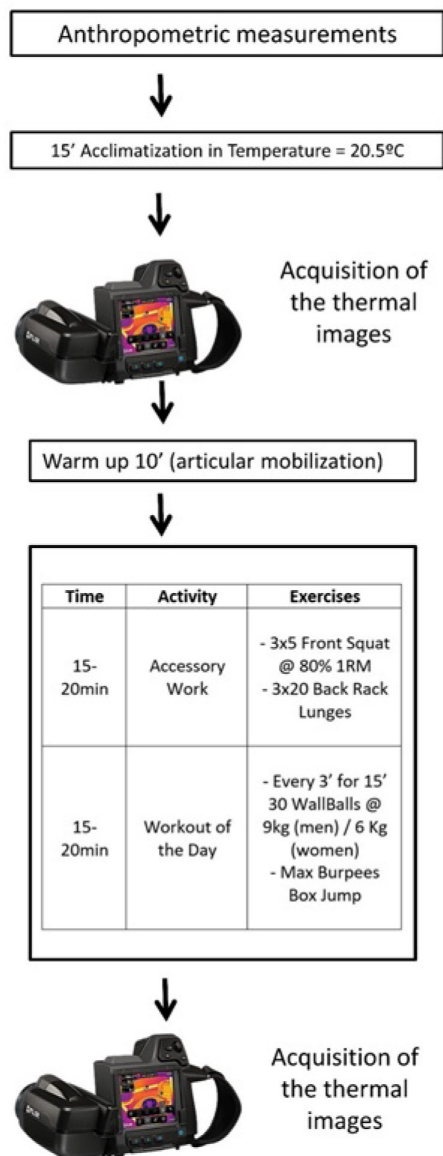
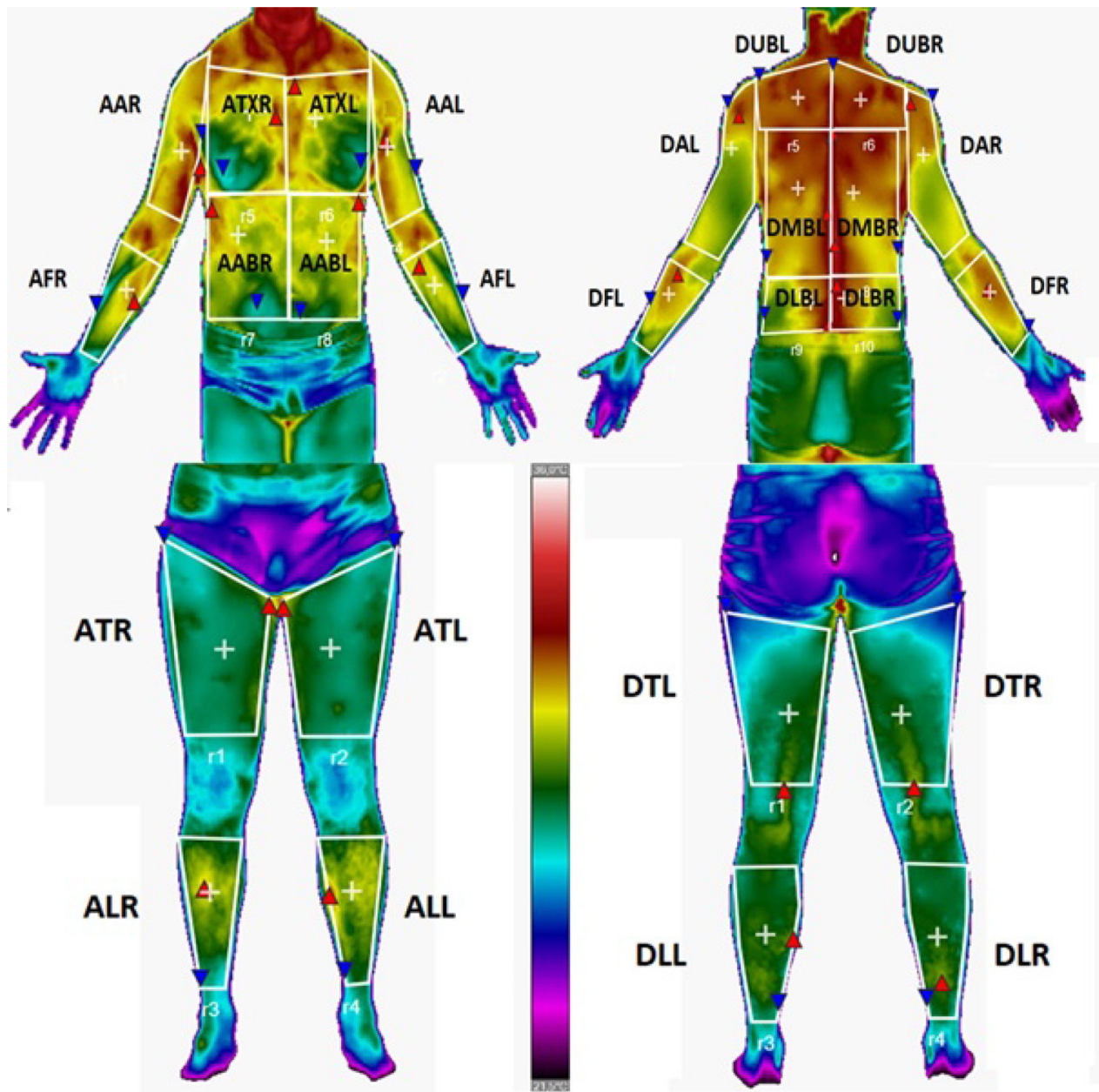


Figure 1 - Data collection protocol.



**Figure 2** - Illustration of the Regions of interest in men, evaluated with infrared thermography.

Legend: Anterior Forearm Right (AFR); Dorsal Forearm Right (DFR); Anterior Forearm Left (AFL); Dorsal Forearm Left (DFL); Anterior Arm Right (AAR); Dorsal Arm Right (DAR); Anterior Arm Left (AAL); Dorsal Arm Left (DAL); Anterior Thorax Right (ATXR); Dorsal Upper Back Right (DUBR); Anterior Thorax Left (ATXL); Dorsal Upper Back Left (DUBL); Anterior Abdomen Right (AABR); Dorsal Middle Back Right (DMBR); Anterior Abdomen Left (AABL); Dorsal Middle Back Left (DMBL); Dorsal Lower Back Right (DLBR); Dorsal Lower Back Left (DLBL); Anterior Thigh Right (ATR); Dorsal Thigh Right (DTR); Anterior Thigh Left (ATL); Dorsal Thigh Left (DTL); Anterior Leg Right (ALR); Dorsal Leg Right (DLR); Anterior Leg Left (ALL); and Dorsal Leg Left (DLL).

## Results

The sample was  $74.80 \pm 13.08$  kg weight,  $1.71 \pm 0.10$  m height,  $25.41 \pm 2.74$  kg·m<sup>-2</sup> body mass index (BMI),  $81.64 \pm 9.54$  cm waist circumference (WC),  $99.31 \pm 3.88$  cm hip circumference (HC), and  $0.82 \pm 0.08$  waist-to-hip ratio (WHR). Only BMI and HC show no differences between sex (Table 1).

Considering the mean ROIs temperature before and after a

CrossFit® session training, data have shown significant thermal asymmetries in both sides of Anterior Forearm, Anterior Thigh, and Dorsal Lower Back and in left Dorsal Forearm, left Anterior Abdomen, and right Anterior Torax (Table 2). These differences were found in the same regions to men's analyses (Table 3).

Moreover, it was observed a different response for women. Women's data showed asymmetries only in the Dorsal Lower Back and in Anterior Leg (Table 4).

**Table 1** - Anthropometric measures of volunteers (12 males and 7 females), Vila Real, Portugal, 2019.

	All (N=19)			Men (N=12)			Women (7)		
	Percentile			Percentile			Percentile		
	25°	50°	75°	25°	50°	75°	25°	50°	75°
Body mass (Kg)*	63.35	76.10	88.40	76.33	84.13	89.35	55.20	59.70	66.60
Height (m)*	1.64	1.71	1.79	1.72	1.76	1.80	1.55	1.60	1.65
BMI	23.38	26.17	27.53	24.68	26.70	28.01	21.15	21.78	26.92
WC (cm)*	72.75	81.00	91.50	81.25	86.48	92.96	68.00	71.00	76.15
HC (cm)	95.50	99.90	103.00	96.01	100.45	102.60	94.40	97.10	103.45
WHR*	0.73	0.83	0.90	0.83	0.88	0.92	0.72	0.73	0.73

\* p < 0.001 – Wilcoxon test

Legend: WC = Waist Circumference, HC = Hip Circumference, WHR = Waist-to-Hip Ratio

**Table 2** - Skin temperature and thermal asymmetries measures of 19 volunteers (12 males and 7 females), before and after a session of CrossFit® training, Vila Real, Portugal, 2019.

	Before			After			Wilcoxon test		
	Percentiles			Percentiles			Z	p value	
	25°	50°	75°	25°	50°	75°			
Anterior forearm R	29.21	30.02	30.76	30.50	31.10	31.89	-2.958 <sup>b</sup>	<b>0.003</b>	↑
Anterior forearm L	29.14	30.15	30.68	30.47	30.81	31.73	-2.656 <sup>b</sup>	<b>0.008</b>	↑
As Ant Forearm	0.09	0.24	0.29	0.03	0.13	0.36	-0.584 <sup>c</sup>	0.559	
Anterior Arm R	30.99	31.45	31.79	30.86	31.75	31.97	-0.121 <sup>b</sup>	0.904	
Anterior Arm L	30.96	31.18	31.55	30.70	31.56	31.86	-0.503 <sup>b</sup>	0.615	
As Ant Arm	0.05	0.16	0.41	0.11	0.16	0.28	-0.684 <sup>c</sup>	0.494	
Anterior Torax R	30.54	30.90	31.16	29.57	30.48	31.02	-2.069 <sup>c</sup>	<b>0.039</b>	↓
Anterior Torax L	30.41	30.87	31.15	29.54	30.46	31.16	-1.851 <sup>c</sup>	0.064	
As Ant Torax	0.06	0.13	0.27	0.05	0.11	0.21	-0.221 <sup>b</sup>	0.825	
Anterior Abdomen R	30.07	30.51	31.06	28.64	30.61	31.07	-1.811 <sup>c</sup>	0.070	
Anterior Abdomen L	30.23	30.67	31.03	28.60	30.34	30.99	-2.073 <sup>c</sup>	<b>0.038</b>	↓
As Ant Abd	0.06	0.13	0.17	0.06	0.12	0.20	-0.161 <sup>b</sup>	0.872	
Anterior Thigh R	27.35	28.28	29.36	28.28	29.20	30.14	-3.321 <sup>b</sup>	<b>0.001</b>	↑
Anterior Thigh L	27.55	28.26	29.56	28.16	29.12	30.10	-3.300 <sup>b</sup>	<b>0.001</b>	↑
AS Ant Thigh	0.07	0.15	0.37	0.08	0.12	0.17	-1.372 <sup>c</sup>	0.170	
Anterior Leg R	27.83	28.78	29.68	28.62	28.80	29.54	-0.926 <sup>b</sup>	0.354	
Anterior Leg L	27.60	28.62	29.48	28.74	28.91	29.39	-1.368 <sup>b</sup>	0.171	
As Ant Leg	0.15	0.21	0.30	0.07	0.21	0.32	-0.523 <sup>c</sup>	0.601	
Dorsal forearm R	29.49	29.76	30.32	29.89	30.16	30.72	-1.811 <sup>b</sup>	0.070	
Dorsal forearm L	29.03	29.69	30.26	29.66	30.22	30.87	-2.696 <sup>b</sup>	<b>0.007</b>	↑
As Dor Forearm	0.11	0.25	0.57	0.12	0.21	0.33	-1.127 <sup>c</sup>	0.260	
Dorsal Arm R	28.79	29.38	29.96	28.28	29.38	30.42	-0.443 <sup>c</sup>	0.658	
Dorsal Arm L	29.07	29.29	29.97	28.66	29.62	30.50	-0.501 <sup>b</sup>	0.616	
As Dor Arm	0.12	0.29	0.50	0.03	0.15	0.24	-1.650 <sup>c</sup>	0.099	
Dorsal Upper Back R	30.84	31.14	31.59	30.16	31.17	31.60	-0.503 <sup>c</sup>	0.615	
Dorsal Upper Back L	30.85	31.17	31.57	30.65	31.14	31.48	-0.523 <sup>c</sup>	0.601	
As Dor Up Back	0.06	0.09	0.19	0.01	0.09	0.20	-0.322 <sup>b</sup>	0.747	

Dorsal Middle Back R	30.07	30.58	31.16	29.16	30.32	31.05	-1.894 <sup>c</sup>	0.058	
Dorsal Middle Back L	30.17	30.56	31.03	29.57	30.36	30.88	-1.891 <sup>c</sup>	0.059	
As Dor Mid Back	0.06	0.10	0.15	0.05	0.10	0.24	-1.007 <sup>b</sup>	0.314	
Dorsal Lower Back R	28.91	29.89	30.40	27.65	29.08	29.68	-2.978 <sup>c</sup>	<b>0.003</b>	↓
Dorsal Lower Back L	28.96	29.97	30.28	27.77	28.86	29.56	-3.070 <sup>c</sup>	<b>0.002</b>	↓
As Dor Low Back	0.11	0.18	0.34	0.09	0.12	0.28	-0.725 <sup>c</sup>	0.469	
Dorsal Thigh R	27.57	28.27	29.23	27.60	29.42	29.94	-1.791 <sup>b</sup>	0.073	
Dorsal Thigh L	27.63	28.32	29.54	27.51	29.55	30.10	-1.650 <sup>b</sup>	0.099	
As Dor Thigh	0.05	0.11	0.25	0.08	0.10	0.24	-0.423 <sup>c</sup>	0.672	
Dorsal Leg R	26.57	28.72	29.70	27.92	28.58	29.84	-1.368 <sup>b</sup>	0.171	
Dorsal Leg L	26.60	28.41	29.58	27.76	28.57	29.53	-1.368 <sup>b</sup>	0.171	
As Dor Leg	0.05	0.17	0.31	0.06	0.18	0.30	-0.262 <sup>c</sup>	0.794	

Legend: Ant = Anterior, Dor = Dorsal, As = Asymmetry, R = right, L = Left, b. Based on negative rank. c. Based on positive rank

**Table 3** - Skin temperature and thermal asymmetries measures of 12 male volunteers, before and after a session of CrossFit® training, Vila Real, Portugal, 2019.

	Before			After			Wilcoxon test		
	Percentiles			Percentiles			Z	p value	
	25°	50°	75°	25°	50°	75°			
Anterior forearm R	29.24	30.02	30.76	30.50	31.10	31.89	-2.958 <sup>b</sup>	<b>0.003</b>	↑
Anterior forearm L	29.24	30.15	30.68	30.47	30.81	31.73	-2.656 <sup>b</sup>	<b>0.008</b>	↑
As Ant Forearm	0.10	0.24	0.29	0.03	0.13	0.36	-0.584 <sup>c</sup>	0.559	
Anterior Arm R	31.03	31.45	31.79	30.86	31.75	31.97	-0.121 <sup>b</sup>	0.904	
Anterior Arm L	30.94	31.18	31.55	30.70	31.56	31.86	-0.503 <sup>b</sup>	0.615	
As Ant Arm	0.05	0.16	0.41	0.11	0.16	0.28	-0.684 <sup>c</sup>	0.494	
Anterior Torax R	30.45	30.90	31.16	29.57	30.48	31.02	-2.069 <sup>c</sup>	<b>0.039</b>	↓
Anterior Torax L	30.38	30.87	31.15	29.54	30.46	31.16	-1.851 <sup>c</sup>	0.064	
As Ant Torax	0.09	0.13	0.27	0.05	0.11	0.21	-0.221 <sup>b</sup>	0.825	
Anterior Abdomen R	29.96	30.51	31.06	28.64	30.61	31.07	-1.811 <sup>c</sup>	0.070	
Anterior Abdomen L	30.10	30.67	31.03	28.60	30.34	30.99	-2.073 <sup>c</sup>	<b>0.038</b>	↓
As Ant Abd	0.06	0.13	0.17	0.06	0.12	0.20	-0.161 <sup>b</sup>	0.872	
Anterior Thigh R	28.35	28.28	29.36	28.28	29.20	30.14	-3.321 <sup>b</sup>	<b>0.001</b>	↑
Anterior Thigh L	28.35	28.26	29.56	28.16	29.12	30.10	-3.300 <sup>b</sup>	<b>0.001</b>	↑
AS Ant Thigh	0.05	0.15	0.37	0.08	0.12	0.17	-1.372 <sup>c</sup>	0.170	
Anterior Leg R	28.82	28.78	29.68	28.62	28.80	29.54	-0.926 <sup>b</sup>	0.354	
Anterior Leg L	28.64	28.62	29.48	28.74	28.91	29.39	-1.368 <sup>b</sup>	0.171	
As Ant Leg	0.17	0.21	0.30	0.07	0.21	0.32	-0.523 <sup>c</sup>	0.601	
Dorsal forearm R	29.54	29.76	30.32	29.89	30.16	30.72	-1.811 <sup>b</sup>	0.070	
Dorsal forearm L	29.11	29.69	30.26	29.66	30.22	30.87	-2.696 <sup>b</sup>	<b>0.007</b>	↑
As Dor Forearm	0.12	0.25	0.57	0.12	0.21	0.33	-1.127 <sup>c</sup>	0.260	
Dorsal Arm R	29.35	29.38	29.96	28.28	29.38	30.42	-0.443 <sup>c</sup>	0.658	
Dorsal Arm L	29.32	29.29	29.97	28.66	29.62	30.50	-0.501 <sup>b</sup>	0.616	
As Dor Arm	0.14	0.29	0.50	0.03	0.15	0.24	-1.650 <sup>c</sup>	0.099	

Dorsal Upper Back R	30.85	31.14	31.59	30.16	31.17	31.60	-0.503 <sup>c</sup>	0.615	
Dorsal Upper Back L	30.84	31.17	31.57	30.65	31.14	31.48	-0.523 <sup>c</sup>	0.601	
As Dor Up Back	0.06	0.09	0.19	0.01	0.09	0.20	-0.322 <sup>b</sup>	0.747	
Dorsal Middle Back R	30.00	30.58	31.16	29.16	30.32	31.05	-1.894 <sup>c</sup>	0.058	
Dorsal Middle Back L	30.04	30.56	31.03	29.57	30.36	30.88	-1.891 <sup>c</sup>	0.059	
As Dor Mid Back	0.03	0.10	0.15	0.05	0.10	0.24	-1.007 <sup>b</sup>	0.314	
Dorsal Lower Back R	28.91	29.89	30.40	27.65	29.08	29.68	-2.978 <sup>c</sup>	<b>0.003</b>	↓
Dorsal Lower Back L	28.89	29.97	30.28	27.77	28.86	29.56	-3.070 <sup>c</sup>	<b>0.002</b>	↓
As Dor Low Back	0.08	0.18	0.34	0.09	0.12	0.28	-0.725 <sup>c</sup>	0.469	
Dorsal Thigh R	28.02	28.27	29.23	27.60	29.42	29.94	-1.791 <sup>b</sup>	0.073	
Dorsal Thigh L	28.40	28.32	29.54	27.51	29.55	30.10	-1.650 <sup>b</sup>	0.099	
As Dor Thigh	0.11	0.11	0.25	0.08	0.10	0.24	-0.423 <sup>c</sup>	0.672	
Dorsal Leg R	28.78	28.72	29.70	27.92	28.58	29.84	-1.368 <sup>b</sup>	0.171	
Dorsal Leg L	28.53	28.41	29.58	27.76	28.57	29.53	-1.368 <sup>b</sup>	0.171	
As Dor Leg	0.07	0.17	0.31	0.06	0.18	0.30	-0.262 <sup>c</sup>	0.794	

Legend: Ant = Anterior, Dor = Dorsal, As = Asymmetry, R = right, L = Left, b. Based on negative rank. c. Based on positive rank.

**Table 4** - Skin temperature and thermal asymmetries measures of 7 female volunteers, before and after a session of CrossFit® training, Vila Real, Portugal, 2019.

	Before			After			Wilcoxon test	
	Percentiles			Percentiles			Z	p value
	25°	50°	75°	25°	50°	75°		
Anterior forearm R	29.20	30.04	31.10	29.35	30.78	31.63	-1.014 <sup>c</sup>	0.310
Anterior forearm L	28.80	30.30	31.05	28.87	30.77	31.41	-0.845 <sup>c</sup>	0.398
As Ant Forearm	0.09	0.26	0.55	0.03	0.20	0.40	-1.355 <sup>d</sup>	0.176
Anterior Arm R	30.74	31.30	31.79	30.05	30.81	31.94	-1.014 <sup>d</sup>	0.310
Anterior Arm L	30.96	31.18	31.55	30.16	30.62	31.82	-1.352 <sup>d</sup>	0.176
As Ant Arm	0.10	0.24	0.41	0.05	0.13	0.27	-0.847 <sup>d</sup>	0.397
Anterior Torax R	30.87	31.02	31.15	29.86	30.48	31.39	-1.690 <sup>d</sup>	0.091
Anterior Torax L	30.73	30.90	31.15	29.37	30.69	31.27	-1.521 <sup>d</sup>	0.128
As Ant Torax	0.01	0.07	0.15	0.05	0.12	0.21	-1.352 <sup>c</sup>	0.176
Anterior Abdomen R	30.08	30.41	30.62	28.29	30.61	31.07	-0.845 <sup>d</sup>	0.398
Anterior Abdomen L	30.23	30.67	30.79	28.51	30.48	30.99	-1.352 <sup>d</sup>	0.176
As Ant Abd	0.06	0.13	0.17	0.10	0.13	0.20	-0.170 <sup>d</sup>	0.865
Anterior Thigh R	26.24	26.68	27.92	26.96	27.91	28.37	-1.859 <sup>c</sup>	0.063
Anterior Thigh L	25.89	26.76	27.78	26.73	28.06	28.29	-1.859 <sup>c</sup>	0.063
AS Ant Thigh	0.07	0.27	0.37	0.11	0.12	0.23	-1.153 <sup>d</sup>	0.249
Anterior Leg R	26.78	27.83	28.64	27.21	28.62	28.80	-0.845 <sup>c</sup>	0.398
Anterior Leg L	26.86	27.60	28.49	27.42	28.75	28.82	-2.028 <sup>c</sup>	<b>0.043</b>
As Ant Leg	0.08	0.19	0.20	0.02	0.21	0.32	-0.512 <sup>c</sup>	0.609
Dorsal forearm R	28.67	29.57	30.17	28.85	29.83	30.52	-0.676 <sup>c</sup>	0.499
Dorsal forearm L	28.98	29.33	30.26	29.51	29.62	30.57	-1.183 <sup>c</sup>	0.237
As Dor Forearm	0.09	0.25	0.31	0.05	0.21	0.66	-0.169 <sup>d</sup>	0.866

Dorsal Arm R	27.72	28.79	29.58	26.22	28.28	29.09	-1.521 <sup>d</sup>	0.128	
Dorsal Arm L	28.02	28.83	29.11	26.13	28.43	29.29	-0.734 <sup>d</sup>	0.463	
As Dor Arm	0.07	0.29	0.59	0.03	0.10	0.20	-1.185 <sup>d</sup>	0.236	
Dorsal Upper Back R	30.76	31.14	31.36	30.09	31.17	31.39	-0.338 <sup>c</sup>	0.735	
Dorsal Upper Back L	30.85	31.17	31.30	30.10	31.11	31.40	-0.254 <sup>c</sup>	0.799	
As Dor Up Back	0.03	0.09	0.12	0.01	0.01	0.20	-0.507 <sup>d</sup>	0.612	
Dorsal Middle Back R	30.07	30.78	30.92	29.06	30.09	31.12	-1.153 <sup>d</sup>	0.249	
Dorsal Middle Back L	30.17	30.80	30.90	29.20	30.17	30.88	-1.352 <sup>d</sup>	0.176	
As Dor Mid Back	0.07	0.12	0.14	0.06	0.14	0.17	-0.339 <sup>c</sup>	0.734	
Dorsal Lower Back R	28.91	29.89	30.12	27.38	29.47	29.81	-2.028 <sup>d</sup>	<b>0.043</b>	↓
Dorsal Lower Back L	29.18	30.04	30.33	27.80	29.31	29.73	-2.197 <sup>d</sup>	<b>0.028</b>	↓
As Dor Low Back	0.11	0.19	0.34	0.09	0.12	0.33	-0.931 <sup>d</sup>	0.352	
Dorsal Thigh R	25.63	26.80	28.05	24.70	27.51	28.07	-0.169 <sup>c</sup>	0.866	
Dorsal Thigh L	25.58	26.88	28.09	24.69	27.40	27.97	0.000 <sup>c</sup>	1.000	
As Dor Thigh	0.04	0.05	0.06	0.02	0.10	0.11	-1.532 <sup>c</sup>	0.125	
Dorsal Leg R	26.30	26.57	27.61	26.04	27.48	27.94	-1.352 <sup>c</sup>	0.176	
Dorsal Leg L	26.15	26.60	27.36	25.77	27.54	27.76	-1.183 <sup>c</sup>	0.237	
As Dor Leg	0.03	0.17	0.33	0.06	0.18	0.30	-0.169 <sup>c</sup>	0.866	

Legend: Ant = Anterior, Dor = Dorsal, As = Asymmetry, R = right, L = Left, c. Based on a negative rank. d. Based on a positive rank. e. The sum of negative rank is equal to the sum of positive rank.

## Discussion

In the present study, the temperature rose significantly pre- to post-exercise the forearm and anterior thigh regions, while it decreased in the anterior thorax and dorsal lower back regions. These results were found both in the overall sample and in the male volunteers but not when the female results were isolated. The analysis of the data in the present study by sex is justified because these groups have a difference in thermal distribution at rest and after physical exercise. In general, men have greater muscle mass and a lower percentage of body fat compared with women<sup>23, 25</sup>. The anthropometric measures of the studies demonstrated that the BMI was within the normal range, being favorable for better heat dissipation<sup>26</sup>. Unfortunately, the use of BMI does not allow to identify differences in body composition, although differences in the body fat distribution areas between genders can be assumed. Bandeira et al.<sup>15</sup> found a significant correlation between thigh skin temperature and thigh skinfold thickness over the rectus femoris muscle.

The differences found from pre- to post-exercise (table 2 and table 3) are expected to reflect the exercises that were performed. The exercises may have been able to produce microlesions, considering the intensity of the training, which may justify the significant variation in temperature in several ROI due to a possible inflammatory process. Muscle inflammation is believed to result from strength training, as it reflects muscle damage from mechanical stress by high loads<sup>15, 27, 28</sup>.

The main temperature differences found on both sides of the body after training compared to the pre-workout temperatures

explain adequately the effort made by the sample. The air squad exercise is composed of all of the 3 WOD sets. This exercise promotes great and intense stimulus to rectus femoris, vastus medialis, and vastus intermedius<sup>29, 30</sup>. In addition, the wall sit, an isometric exercise, also requires this musculature, serving to warm-up and to promote pre-exhaustion exercise, increasing the proportional effort.

Although Palmaris Longus, Flexor Digitorum Profundus, Flexor Digitorum Superficialis, Flexor carpi ulnaris, and deep finger flexors are not directly worked, they are used to wield the bar during pull-ups and hold the load during the unbroken farmer carry<sup>29</sup>. Likewise, the increase in DFL temperature may have happened due to the isometric requirement of the Brachial Radial and the Flexor Carpi Ulnaris<sup>29</sup>. Interestingly, this difference was found only on the left side of the body. The difference for the right side was not significant but could be considered a borderline value ( $p = 0.07$ ). In any way, this value can be considered a possible imbalance between the muscles of the dorsal forearm area between the right and left sides body sides. A longitudinal study would be necessary to understand this result more fully.

The decrease in skin temperature found in the lower back region may be happened due to a greater demand in the anterior musculature because a lot of planks, sit-ups, pull-ups, and push-ups were performed<sup>29, 31</sup>. These exercises work muscles localized in the low back region like an agonist or synergistic muscle<sup>29, 32</sup>. Also, pull-ups demand more upper back muscles<sup>29</sup>. These exercises may justify a greater blood flow to the required muscles, decreasing the temperature in those that are not in



greater demand<sup>13,31,33</sup>. However, Data was showed a unilateral decrease in the left anterior abdominal region and the left thoracic region temperatures, without any plausible justification for this. To correctly understand these results, it would be necessary to follow the sample for a longer time, with a greater number of training sessions, in order to verify whether these asymmetries would continue to happen or not.

The surface skin temperature varies according to the type of exercise, intensity, duration, muscle mass, and subcutaneous fat layer<sup>34,35</sup>. Hillen et al.<sup>36</sup> suggested that the magnitude of the body adjustments is mainly dependent on the intensity, duration, and type of exercise in combination with individual prerequisites. Neves et al.<sup>33</sup> suggested that skin temperature increases in people that performed either high volume or high-intensity anaerobic training. In the training session herein, we may find both high -intensity and high volume. So, this combination of exercises seems to have been responsible for the increase in temperature found in the aforementioned ROI. Our data is aligned with that in previous studies<sup>37-40</sup>, however, it is in disagreement with others<sup>41,42</sup>.

The temperature variations in the current study seem to be physiological. Over 30 years ago, Feldman and Nickoloff<sup>43</sup> suggested that the differences between ipsilateral and contralateral parts are considered normal if less than 0.6 °C. More recently, Formenti et al.<sup>39</sup> and Al-Nakhli et al.<sup>44</sup> found changes in contralateral temperatures after exercising above 1° C, evaluating legs and hips. So, the small differences found in this study between the right and left side of the various ROIs, suggest that the exercise session did not promote injuries or important asymmetries, being consistent with an expected physiological response.

Table 2 showed an increase in skin temperature in several ROI. This found is aligned with Neves et al.<sup>45</sup> and Flores et al.<sup>46</sup> that observed an increase in surface temperature immediately after exercise. The same had been found in hard exercises, which involve smaller muscles on a smaller body region, like ROI over the Anterior Forearm region<sup>36,47</sup>.

Tansey and Johnson<sup>48</sup> pointed out that exercise of itself will increase body temperature, in part, due to initial cutaneous vasoconstriction, along with vasoconstriction in other nonactive muscle vascular beds. The result of these alterations is a bigger cardiac output being available to active skeletal muscle. Training or repeated bouts of exercise have been shown to improve exercise performance through various physiological adaptations and one of the most important of these is to promote increased peripheral blood flow while maintaining arterial blood pressure<sup>49</sup>.

Regarding the ROIs in the trunk region (Table 2, 3, and 4), which present a decrease in skin temperature after the exercise, Neves et al.<sup>28</sup> reported that there is a blood flow redistribution to the active muscles, reducing, by vasoconstriction, the blood flow to the skin, as seen in the present study. Savastano et al.<sup>50</sup> and Chudecka, Lubkowska & Kempnińska-Podhorodecka<sup>51</sup> also suggested that regions of the body of greater adiposity reduce the dissipation of central heat and the peripheral areas such as upper limbs can exercise greater heat dissipation because fat skin is supposed to reduce the effectiveness of this mechanism<sup>52</sup>. Neves et al.<sup>53</sup> concluded that the muscle mass can influence the skin temperature and suggested their results may be generalizable to other regions of the trunk.

The limitations of this study refer to sample size and the lack of a control group. Also, the inner characteristic of the CrossFit® (non-standardized exercise protocol), as well as, in female volunteers, the menstrual cycle, and the use of contraceptives was not controlled.

## Conclusion

It can be concluded that superficial thermal response to one CrossFit® training session was characterized and was different for men and women. The superficial thermal responses were aligned with the physiological alterations promoted by other modalities of exercise studied previously, such as resistance training, cycling, and running. Temperatures rose significantly pre- to post-exercise in the forearm and anterior thigh regions, while it decreased in the anterior thorax and dorsal lower back regions. These results were found both, in the overall sample and the male volunteers, but not when the female results were isolated.

Although the CrossFit® has a high probability of injury, the evaluated subjects presented a thermal response without evidence of injury. As stated earlier, an injury is usually related to variations in blood flow and these can affect the skin's temperature. Therefore, infrared thermography can be an interesting instrument to detect previous changes in tissue such as those that occur in overuse injuries. Moreover, the surface thermal images showed an interesting, comfortable, and reliable instrument to analyze and track training results. This way of measurement has shown a series of advantages, like short response time with high accuracy, sensitivity, and reproducibility, the capability of monitoring specific body region of interest (ROI), or on the entire body (global analysis), enabling the subjects a free movement during exercises.

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## Erratum

In the article “*Superficial thermal response to CrossFit® workout*”, published in volume 26, number 4, 2020: DOI: <http://dx.doi.org/10.1590/S1980-65742020000400157> and identification e10200157.

In the *Figure 1*:

**Where it reads:** Data collection protocol.

**Should be:** Data collection protocol (with an example of workout).

In the *Conclusion*:

**Where it reads:** Although the CrossFit® has a high probability of injury

**Should be:** Although the CrossFit® has some probability of injury