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Body Composition and Temperature Analysis Depending on Level of Physical Activity in People Training CrossFit

Marta Kuczkowska[1]

[1]Faculty of Physiotherapy, University School of Physical Education in Wroclaw, Poland

Correspondence to: Marta Kuczkowska, email: marta.kuczkowska94@gmail.com

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Abstract

Aims: The study aimed to analyze body composition and body surface temperature in people training CrossFit. Relationships between the analyzed parameters and the level of CrossFit advancement and sex of the subjects were also studied.

Material and methods: The study was carried out at CrossFit Eternia club in Wroclaw, Poland, on a group of 40 volunteers who were divided according to their level of advancement in the CrossFit program. Body composition was tested using the bioelectrical impedance assessment (BIA) method and body surface temperature was examined with the FLIR T335 thermal imaging camera. In groups with a high level of physical activity, a lower level of body fat (FAT) content was shown (%).

Results: Surface temperature most often and strongly correlated with total body water TBW [%] in the group of advanced men. Gender and level of advancement differentiated individual body composition parameters and body surface temperatures in people training CrossFit. In the group of people with an advanced level, a greater content of lean body mass was shown, and at the same time, a lower content of adipose tissue. Also, higher body temperatures were found in men than in women, and higher temperatures were found in people with higher levels of advancement than in groups with lower levels.

Conclusions: Gender has a significant influence on the average temperature of the measured body areas. Advanced groups showed higher mean body temperatures than intermediate groups.

Key words

physical activity,
thermal imaging,
bioelectrical impedance assessment (BIA),
body composition,
CrossFit

Introduction

With the increasing availability of a variety of training programs, people can more easily maintain a high level of physical fitness. The positive impact of physical exercise on a person's well-being and mental health cannot be overlooked [1]. Recently, increasing attention has been paid to high-intensity group workout programs [2]. Traditional programs have been replaced by the rapidly growing popularity of high-intensity interval training (HIIT), which has been described as an effective, time-saving program that can reduce the effects of diabetes and hypertension [1]. CrossFit is an expanded form of HIIT training that originated in 2000 and continues to develop rapidly [3].

CrossFit training methodology consists of combining intense resistance training with multi-joint movements performed in several planes simultaneously. This training weaves together strength training, gymnastics, and aerobic exercises [1]. It is important to note that people training CrossFit can expect excessive muscle soreness and delayed onset muscle soreness (DOMS) following exercise more often than people training other sport disciplines. Therefore, CrossFit trainees should properly moderate their workouts and plan their rest cycles to avoid overtraining and prevent injuries [4].

Aims

This study aimed to analyze body composition and body surface temperature in CrossFit athletes. In addition, relationships of the analyzed parameters to the level of advancement and gender of the subjects (athletes) were studied.

Material and methods

The study group consisted of 40 people, including 20 women and 20 men. The study was carried out between November 2019 and February 2020, at CrossFit Eternia club in Wroclaw, Poland, an affiliated sports club with properly trained coaches and equipment for CrossFit training. Subjects were active members of the CrossFit club and residents of Wroclaw city or surrounding areas in the Lower Silesian voivodship. Participants gave their voluntary consent to participate in the study and to have their personal data processed, including name, surname, telephone number, height, body weight, body mass index (BMI), parameters measured by bioelectrical impedance assessment (BIA), and medical history of any diseases or injuries. Study participants were informed about the purpose and method of the study and gave their written consent.

Participants were divided by gender into either intermediate or advanced groups, for a total of four groups. Everyone qualifying for the intermediate group met the following inclusion criteria: CrossFit training experience of at least one-year, regular workouts of at least two per week, duration of a single workout unit of at least 60 minutes, no current injuries or diseases excluding them from training. Everyone qualifying for the advanced group met the following inclusion criteria: training experience of at least three years, systematic training of at least three training sessions per week, duration of a single training unit of at least 90 minutes, no current injuries or illnesses excluding them from training. Exclusion criteria included current injuries precluding training and comorbidities precluding participation in the study. Contraindications to BIA were pregnancy, epilepsy, and an implanted pacemaker or other metal implants. Contraindications to thermal imaging were fever, warm drinks or meals one hour before the test, or use of stimulants just before the study.

Through the division of the subjects by gender and level of advancement, the whole group was divided into four subgroups: intermediate males (M1), advanced males (M2), intermediate females (F1), and advanced females (F2). Each participant underwent the same research protocol before a training unit, which included completing a personal questionnaire, an examination of body composition using the BIA, and measurements of thermal imaging of the entire body in the forward and backward standing positions. The tests were performed in the order listed above. An original questionnaire was designed for this study that included questions about participants' training experience, the number of training units undertaken per week and the time of a single training unit, past injuries and surgeries, and existing comorbidities. The questionnaire also contained personal and contact information. In addition, a printout of the BIA test with body composition was attached to the questionnaire, and the results of successive thermograms were entered into results after the thermal images were taken.

Body composition was analyzed by bioelectrical impedance analysis (BIA). A non-invasive body composition analyzer TANITA BC-418 MA (Tanita Poland, Poznan, Poland) was used to easily determine the amount of water in the body. With this method, body composition is calculated by analyzing the resultant electrical resistance exhibited by a body as a result of passing a low-intensity, high-frequency current through it [5]. A single measurement of body composition was carried out before the workout unit, but after eliminating possible contraindications and after the subject had completed a personal questionnaire.

The following parameters were assessed after the insertion of sex, age, and body height (cm) of the subject: body weight (kg), body mass index (BMI; kg/m2), percentage of body fat (FAT; %), fat mass (total fat mass of the body; FM; kg), fat-free body mass (mass of muscles and internal organs of the body; FFM; kg), total body water (total amount of water retained in the body; TBW; kg and %), and impedance (Ω).

A FLIR T335 thermal imaging camera was used to measure the surface temperature of the body. Thermal imaging allows for the detection of infrared radiation with a wavelength of 9–14 μm, which is emitted by various objects with temperatures higher than absolute zero, including human tissues [6]. Thermal imaging itself is defined as an imaging process in the mid-infrared spectrum [7]. The measurement of body surface temperature is entirely non-invasive, painless, and safe for both the subject and the investigator. Thermal dispersion invisible to the eye is presented in thermographic images, called thermograms [7].

Before the thermal imaging tests, the subject first had to undergo a period of body adaptation to the prevailing environmental temperature conditions. Adaptation was made by having subjects undress to underwear and leaving the subject's body surface exposed for 10 minutes. During this time, the subject completed the questionnaire with instructional assistance from the investigator. The next step was to take a single body composition measurement using a Tanita device. After the habituation period, four thermograms were taken in the correct order. Each thermographic image of the patient was taken in a standing position, front and back. The subject assumed a posture corresponding to the standard anatomical position.

Thermal imaging was performed following the standards of the European Thermographic Society. Thermal images were taken in the same room at a distance of 2 meters from the subject, at a constant room temperature of 20–23°C and a constant relative humidity of 50%. The thermograms were interpreted using FLIR Thermal Studio software. A total of 12 measuring areas from A1 to A12 were identified on the thermograms (**Fig. 1**).

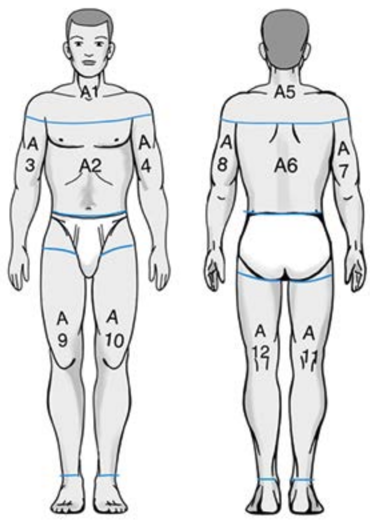

Figure 1. Schematic distribution of measurement areas in thermographic analysis.

Source: The figure is based on an article Dębiec-Bąk et al. [8].

For each of the 12 measuring areas, minimum temperature (Tmin), maximum temperature (Tmax), and mean temperature (Tmean) were determined. Measuring areas A1-A4 and A9-A10 indicated temperature areas on the front of the body, while zones A5-A8 and A11-A12 indicated areas on the back of the body (**Fig. 2**). The measurement areas were divided into front or back before being used in the statistical analysis.

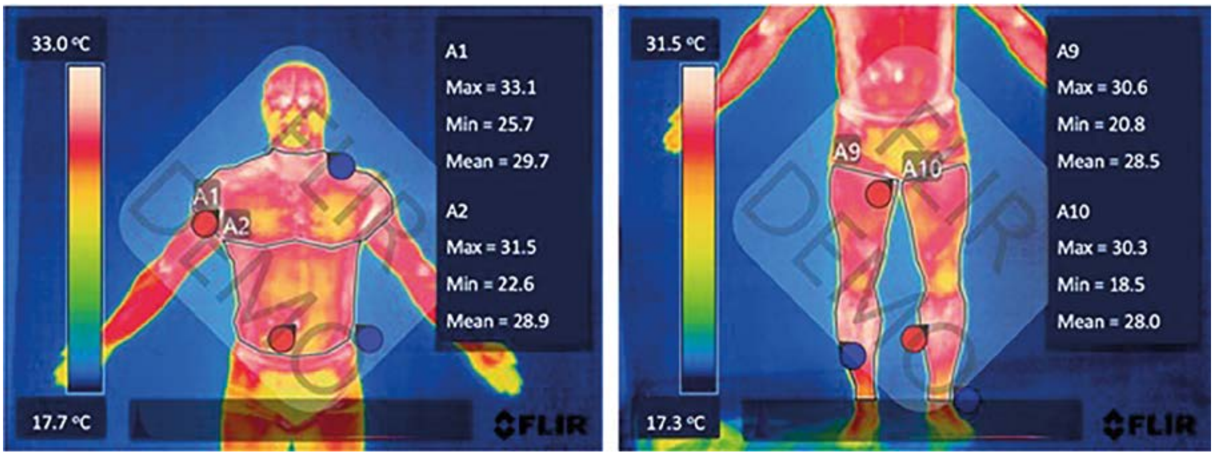

Figure 2. Example measurement areas of the upper body (A1 and A2; figure left) and the lower body (A9 and A10, figure right). *Source:* Own research material from FLIR Thermal Studio software.

Statistical analysis was performed using Statistica PL version 13, licensed for the Academy of Physical Education in Wroclaw, Poland. Basic descriptive statistics, normality of Shapiro-Wilk distribution tests, Student's t-tests for independent samples, and Chi-square statistics to determine the relationship between qualitative variables were analyzed. Multivariate analysis of variance for temperature variables considered the areas of measurements performed. Pearson correlations were also used to identify associations between surface temperature and body composition analysis parameters by gender and level of advancement of the study groups. All tests were verified at $p < 0.05$ significance level. Analyses of relationships were based on: $r_{xy} = 0$ (no correlation); $0 < r_{xy} < 0.1$ (very weak correlation); $0.1 < r_{xy} < 0.3$ (weak correlation); $0.3 < r_{xy} < 0.5$ (medium correlation); $0.5 < r_{xy} < 0.7$ (high correlation); $0.7 < r_{xy} < 0.9$ (very high correlation); $0.9 < r_{xy} < 1$ (almost full correlation); and $r_{xy} = 1$ (full correlation, functional relationship).

Results

In order to undertake a preliminary comparison of the study group according to the gender of the subjects, the Student's t-test was used for the means in the independent groups, taking into account the parameters presented in **Table 1**. The analysis of body composition between the different study groups divided by gender showed statistically significant differences for parameters including BMI, FAT, FFM, and TBW. Age and training experience did not differ significantly by gender (**Table 1**).

Table 1. Analysis of the variability of the basic parameters between men and women.

Variable	M (mean)	F (mean)	t	p*
Age [years]	34.20	32.05	0.911	0.37
Body weight [kg]	87.73	62.66	8.02	**0.00**
Body height [cm]	181.50	168.50	7.01	**0.00**
BMI [kg/m2]	26.66	22.18	4.79	**0.00**
FAT [%]	18.45	25.61	-3.387	**0.00**
FM [kg]	16.63	16.58	0.03	0.98
FFM [kg]	71.11	46.09	15.69	**0.00**
TBW [kg]	49.79	32.48	13.94	**0.00**
TBW [%]	56.94	52.30	3.40	**0.00**
Training experience [years]	3.05	2.80	0.51	0.61

Notes: Bold values indicate statistically significant correlations with p<0.05 (*Student's t-test).
Abbreviations: M – male; F – female; BMI – body mass index; FAT – body fat; FM – fat mass; FFM – fat-free body mass; TBW – total body water.

The BMI analysis highlighted the differences between the gender groups. The male group had a mean BMI of 26.7 kg/m^2, which suggests being overweight according to BMI normal weight ranges. Considering that these were advanced or intermediate CrossFit trainees, however, it can be concluded that they had more muscle mass, which is not necessarily reflected in the BMI norm ranges.
Bivariate analysis of variance was performed on factors such as gender versus level of training experience, and results showed statistically significant differences between the male and female groups. However, the FAT (%) parameter analysis in the groups divided by level of experience rather than gender. In the F2 group the FAT (%) was lower than in the F1 group, and the same distribution occurred in the male groups; that is, the percentage of body fat in group M2 was lower than that in group M1 (**Figure 3**).

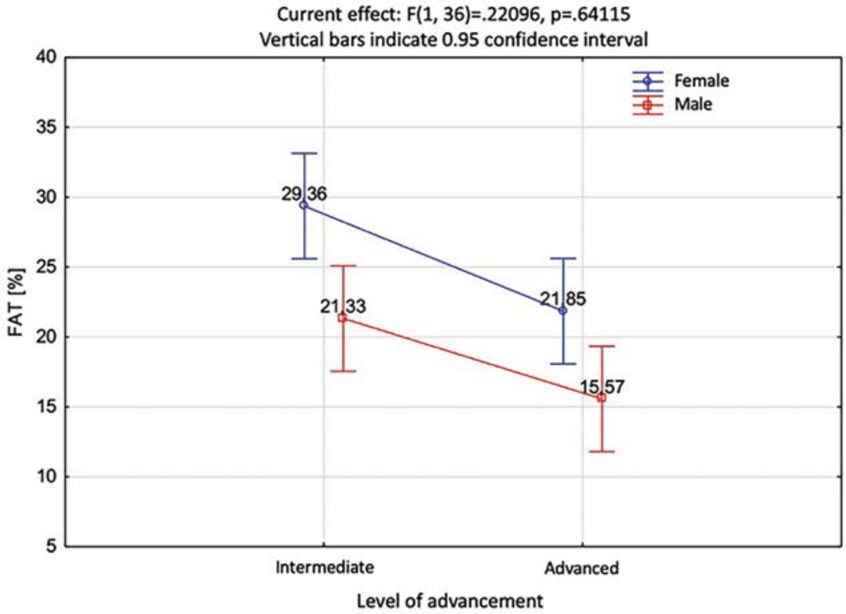

Figure 3. Results of FAT [%] according to gender groups and level of advancement.

The analysis of the FFM (kg) parameter also clearly showed differences between the gender groups. In the male group, FFM (kg) values were significantly higher than in the female group. Additionally, the values were higher in the advanced F2 and M2 groups than in the intermediate F1 and M1 groups (**Figure 4**).

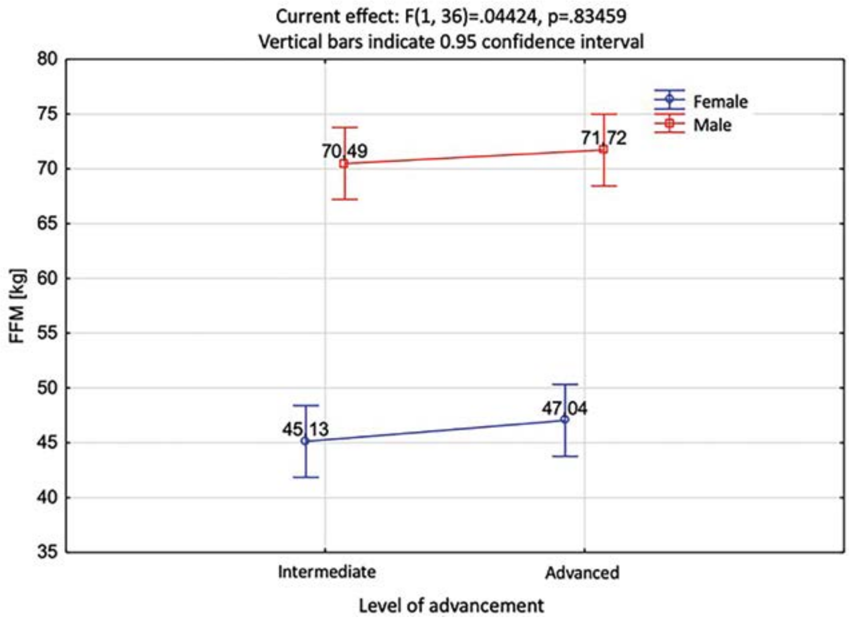

Figure 4. Results of FFM [kg] according to gender groups and level of advancement.

Similarly, the TBW (%) parameter was considered and also showed clear differences by gender group. In the male group, TBW (%) values were significantly higher than in the female group. Additionally, in the advanced F2 and M2 groups, the values were higher than in the intermediate F1 and M1 groups.

An analysis of variance was used to examine how body surface temperature among study participants varied according to their level of advancement and gender. Gender was one of the main factors differentiating the study groups, as this factor significantly affected the average temperatures of the measured areas (**Table 2**). Thus, the well-known fact that males have, on average, higher body temperatures than females was confirmed. However, statistical significance in the effect of gender on the mean temperatures of specific measurement areas was not proven.

Table 2. A substantial part of variance analysis for 12 measurement areas for mean temperatures in thermal imaging.

Effect	p
Gender	**0.010359**
Level of advancement	0.082530
Gender * Level of advancement	0.535610

Notes: Bold values indicate statistically significant correlations with p<0.05.

Analysis of the body surface temperature of the study groups according to participants' level of advancement (excluding gender) showed statistically significantly higher average temperatures in the upper body than in the lower body in the advanced groups (**Figure 5**). It was also shown that the advanced groups showed higher average body temperatures than the intermediate groups.

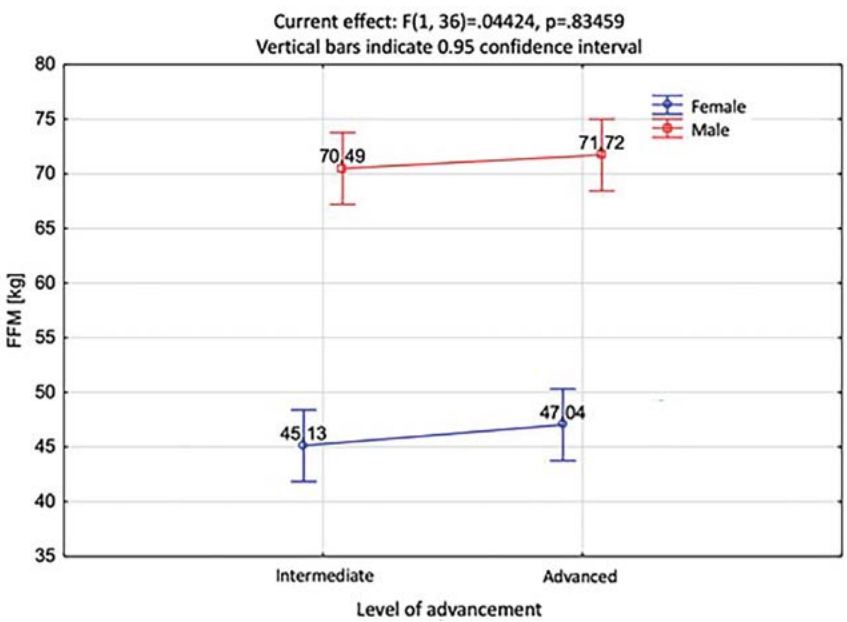

Figure 5. Mean temperatures in the analyzed body areas according to the level of advancement and excluding sex division.

The correlations found were used to determine the relationship between body surface temperature and body composition parameters in four groups divided by gender and level of advancement in CrossFit. In the group of intermediate men (M1), the associations between the studied areas of average body temperature and BMI, FAT (%), FAT (kg), FFM (kg), and TBW (kg) were negative. This relationship indicates that as these parameters increased, the average temperature of all measured areas decreased (**Table 3**). Statistically significant correlations were recorded for the back (posterior) upper limb areas between the parameters BMI, FAT (%), and FAT (kg). For this region, there were strong or very strong correlations between BMI and the temperatures of measured areas. The correlations between most of the measured areas and FAT (%) and FAT (kg) were strong. Correlations between the measured body areas and TBW (%) were positive and, in most cases, also strong. This relationship indicates that as this parameter increased, average temperature increased. Statistically significant correlations were also noted between TBW (%) and the front (anterior) upper and lower limb areas.

Table 3. Correlations of the average surface temperature with body composition parameters in intermediate males (M1) group.

Variable	M1 group (intermediate)											
	A1 Tmean [°C]	A2 Tmean [°C]	A3 Tmean [°C]	A4 Tmean [°C]	A5 Tmean [°C]	A6 Tmean [°C]	A7 Tmean [°C]	A8 Tmean [°C]	A9 Tmean [°C]	A10 Tmean [°C]	A11 Tmean [°C]	A12 Tmean [°C]
BMI [kg/m²]	-0.54	-0.52	-0.55	-0.54	-0.58	-0.55	**-0.69**	**-0.72**	-0.59	-0.61	-0.62	-0.62
FAT [%]	-0.34	-0.27	-0.62	-0.56	-0.41	-0.31	**-0.70**	**-0.73**	-0.57	-0.54	-0.55	-0.56
FAT [kg]	-0.35	-0.27	-0.59	-0.56	-0.40	-0.32	**-0.70**	**-0.72**	-0.57	-0.54	-0.58	-0.58
FFM [kg]	-0.47	-0.34	-0.26	-0.37	-0.42	-0.36	-0.38	-0.39	-0.31	-0.30	-0.41	-0.43
TBW [kg]	-0.21	-0.21	-0.18	-0.23	-0.18	-0.21	-0.48	-0.49	-0.18	-0.20	-0.27	-0.31
TBW [%]	0.55	0.36	**0.67**	**0.67**	0.59	0.42	0.56	0.58	**0.69**	0.62	**0.67**	**0.65**

Notes: Bold values indicate statistically significant correlations with $p<0.05$.

Abbreviations: M – male; BMI – body mass index; FAT – body fat; FM – fat mass; FFM – fat-free body mass; TBW – total body water.

In the group of advanced training males (M2), correlations between most of the measured areas of mean body temperature and BMI, FAT (%), and FAT (kg) were negative. This relationship indicates that as these parameters increased, mean temperature of the measured areas decreased (**Table 4**). The correlations between BMI and the measured areas mainly were weak or average, while a strong and statistically significant correlation appeared with the frontal lower limb area. In contrast, the correlations between FFM (kg), TBW (kg), and TBW (%) with most of the average temperature areas measured were positive, which indicates that as these parameters increased, the average temperature of the body areas studied also increased. Correlations between the TBW parameter (%) and the vast majority of the measured areas of average body temperature were high or very high, and additionally were statistically significant between the areas of lower limbs, the thoracic region, and the trunk up to the level of the iliac spine at the front and back of the body. With the FFM (kg) parameter, the areas of average body temperature mostly correlated weakly.

Table 4. Correlations of the average surface temperature with body composition parameters in advanced males (M2) group.

Variable	M2 group (advanced)											
	A1 T mean [°C]	A2 Tmean [°C]	A3 Tmean [°C]	A4 Tmean [°C]	A5 Tmean [°C]	A6 Tmean [°C]	A7 Tmean [°C]	A8 Tmean [°C]	A9 Tmean [°C]	A10 Tmean [°C]	A11 Tmean [°C]	A12 Tmean [°C]
BMI [kg/m²]	0.21	-0.34	-0.21	-0.39	-0.22	-0.16	-0.24	-0.33	-0.59	**-0.63**	-0.41	-0.44
FAT [%]	0.03	-0.41	-0.43	-0.62	-0.32	-0.22	-0.61	**-0.63**	-0.43	-0.56	-0.45	-0.45
FAT [kg]	0.18	-0.35	-0.31	-0.51	-0.24	-0.14	-0.41	-0.46	-0.49	-0.60	-0.41	-0.42
FFM [kg]	0.60	0.11	0.25	0.25	0.19	0.20	0.58	0.51	-0.19	-0.20	0.10	0.11
TBW [kg]	**0.74**	0.36	0.39	0.31	0.46	0.45	0.57	0.51	0.03	0.06	0.32	0.31
TBW [%]	0.39	**0.75**	0.60	0.60	**0.74**	**0.66**	0.59	0.60	**0.64**	**0.79**	**0.76**	**0.71**

Notes: Bold values indicate statistically significant correlations with $p<0.05$.

Abbreviations: M – male; BMI – body mass index; FAT – body fat; FM – fat mass; FFM – fat-free body mass; TBW – total body water.

When analyzing the correlations more globally without dividing by advancement level, strong and statistically significant correlations of the BMI, FAT (%), FAT (kg), and TBW (%) parameters were noted in the male group concerning almost all measured areas of mean temperatures. These correlations were negative; that is, as these parameters increased, the average temperature of the measured areas decreased. Correlations of FFM (kg) and TBW (kg) were weak in relation to the temperatures of measured body areas; however, correlations of TBW (%) with all measured areas of average temperature were strong and statistically significant. These were also positive correlations, indicating that the average body temperature increased with an increase in this parameter. In contrast, in the groups of women, the correlations of the examined areas of average surface temperature with all studied parameters of body composition were mainly weak.

In the group of intermediate women (W1), the correlations between the body composition parameters studied and the areas of average temperature were mostly weak or very weak (**Table 5**). The associations between BMI, FAT (%), FM (kg), and the measured areas of average body temperature were mainly positive. This relationship indicates that these parameters increased, the average temperature of most of the measured body areas increased. The opposite situation was true between the TBW (%) parameter and the measured areas of average temperature, where the correlations were mostly negative. This relationship indicates that as TBW (%) increased, the temperature of most examined body areas decreased. In none of the analyzed areas were the relationships statistically significant.

Table 5. Correlations of the average surface temperature with body composition parameters in an intermediate females (F1) group.

Variable	M2 group (advanced)											
	A1 T mean [°C]	A2 Tmean [°C]	A3 Tmean [°C]	A4 Tmean [°C]	A5 Tmean [°C]	A6 Tmean [°C]	A7 Tmean [°C]	A8 Tmean [°C]	A9 Tmean [°C]	A10 Tmean [°C]	A11 Tmean [°C]	A12 Tmean [°C]
BMI [kg/m²]	0.13	0.23	0.14	0.15	0.12	0.19	-0.01	-0.05	0.25	0.27	0.21	0.09
FAT [%]	0.22	0.34	0.10	0.06	0.22	0.30	-0.13	-0.20	0.24	0.25	0.16	0.06
FAT [kg]	0.17	0.27	0.04	0.04	0.20	0.25	-0.14	-0.18	0.16	0.19	0.14	0.05
FFM [kg]	-0.11	-0.07	-0.11	0.02	0.07	-0.05	0.04	0.08	-0.19	-0.10	-0.02	0.02
TBW [kg]	-0.11	-0.07	-0.01	0.13	0.01	-0.06	0.10	0.14	-0.07	0.01	0.05	0.03
TBW [%]	-0.35	-0.49	-0.01	0.11	-0.37	-0.44	0.30	0.39	-0.21	-0.20	-0.11	-0.06

Notes: Bold values indicate statistically significant correlations with p<0.05
Abbreviations: F – female; BMI – body mass index; FAT – body fat; FM – fat mass; FFM – fat-free body mass; TBW – total body water.

In the group of advanced women (W2), the correlations between all measured areas of average body temperature and the BMI, FAT (%), FAT (kg), FFM (kg), and TBW (kg) parameters were negative. This relationship means that as the studied parameters increased, the average temperature of the body areas decreased (**Table 6**). Between BMI and most of the areas measured, correlations were weak or average, but in association with the lower extremity areas correlations were strong or very strong, and correlations for the posterior lower extremity area were also statistically significant. Similar results were found between the measured areas of average temperature and the FAT (%), FAT (kg), and TBW (kg) parameters. However, correlations between TBW (%) and the measured areas of average body temperature were, for the most part, weak or average, but positive. This relationship indicates that with an increase in this parameter, average body temperatures of the measured areas also increased. The correlation between TBW (%) and posterior lower limb area was strong and statistically significant.

Table 6. Correlations of the average surface temperature with body composition parameters in an advanced females (F2) group.

Variable	F2 group (advanced)											
	A1 T mean [°C]	A2 Tmean [°C]	A3 Tmean [°C]	A4 Tmean [°C]	A5 Tmean [°C]	A6 Tmean [°C]	A7 Tmean [°C]	A8 Tmean [°C]	A9 Tmean [°C]	A10 Tmean [°C]	A11 Tmean [°C]	A12 Tmean [°C]
BMI [kg/m²]	-0.23	-0.34	-0.16	-0.26	-0.58	-0.40	-0.20	-0.28	-0.58	-0.52	-0.62	**-0.79**
FAT [%]	-0.16	-0.21	-0.08	-0.11	-0.53	-0.43	-0.17	-0.30	-0.42	-0.39	-0.58	**-0.71**
FAT [kg]	-0.18	-0.23	-0.10	-0.17	-0.53	-0.40	-0.18	-0.31	-0.48	-0.44	-0.61	**-0.76**
FFM [kg]	-0.05	-0.02	-0.03	-0.11	-0.07	0.02	-0.05	-0.06	-0.48	-0.39	-0.56	-0.58
TBW [kg]	-0.02	-0.11	-0.02	-0.10	-0.18	-0.10	-0.07	-0.12	-0.55	-0.46	**-0.72**	**-0.74**
TBW [%]	0.23	0.18	0.11	0.17	0.50	0.39	0.18	0.29	0.45	0.41	0.52	**0.67**

Notes: Bold values indicate statistically significant correlations with $p<0.05$

Abbreviations: F – female; BMI – body mass index; FAT – body fat; FM – fat mass; FFM – fat-free body mass; TBW – total body water.

Discussion

Because the popularity of training with CrossFit is still growing, it is worth paying attention to an analysis of body composition and body surface temperature of people training CrossFit [1]. Most of the studies that have used the BIA method to analyze body composition in athletes have compared groups of athletes or monitored the changes between them. Coaches of various sports can easily use body composition parameters to create and optimize training programs properly. One of the most widely used portable methods for these purposes is BIA. However, while it is relatively inexpensive, convenient, and easy to use, measurement errors are also considerable [9].

In the 1970s, it was shown from a group of football players that body composition varies from athlete to athlete, suggesting that body composition even in the same sport can be highly variable. In the 1960s, it was proven that an increase in body fat decreases performance [9]. In the 1990s, professional football players were compared to bodybuilders in terms of body composition, but showed an increase in FFM compared to bodybuilders. In 2001, Grund et al. found that strength and endurance-trained men had a lower FM and a higher percentage of TBW than untrained men [9,10]. It has also been proven that strength-trained men had a higher FFM content than typically endurance-trained and untrained men [9,10]. An increase in TBW and extracellular fluid was also observed in young athletes who trained more than 9 hours per week compared to athletes who trained less than 9 hours per week [9,10]. Our results conclude that men with high levels of physical activity have significantly higher TBW levels. Based on available studies, it appears that this is related to a higher content of muscle tissue.

BMI is the most popular index used to detect obesity and overweight, which researchers justify because it is strongly correlated with human body fat [11]. However, an efficiency of ability to estimate fat tissue content is incorrectly attributed to this indicator [11]. It should be mentioned that the essential use of BMI is the comparative assessment of larger social groups and populations [11].

In our study, BIA was used to analyze body composition. This is a technology that allows for easy determination of basic parameters through electrical resistance and low-intensity, high-frequency currents [5]. When analyzing BMI values, differences in gender groups were clearly seen. The average age in the group of the examined men was 34 years, while in women it was 32 years. In the group of men, this parameter averaged 26.7 years, while in women, it averaged 22.2 years. According to widely available WHO standards, ideal BMI for ages 25–34 is 20–25, while desirable body weight is within the range of 18.5–24.99 kg/m2. This would suggest that there were incidences of being overweight in the group of men surveyed. However, one has to wonder if this is the case. Given that these were advanced or intermediate CrossFit trainees, participants in fact had more muscle mass than the average person, which does not necessarily translate into normal BMI ranges. In our study, among the advanced groups without gender division, BMI correlated weakly with the measured areas of average body temperature. However, analyzed more precisely, in the advanced groups of both women and men, BMI correlated negatively, which indicates that the average temperature of most of the measured body areas decreased with an increase in BMI. In addition, in both advanced groups, selected areas on the lower limbs correlated significantly with BMI.

Our study showed that people with higher levels of physical activity have lower percentages of body fat. The study also indicated a higher body fat percentage in women than in men. Currently, there are no universal and approved body fat percentage norms, although a proposed normal body fat percentage for ages 6–20 was suggested in 2009, which was later supplemented with adult norms in the form of percentile grids [11]. Analyzing the results of our study, we can see that the group with a higher level of physical activity, and especially the advanced male group, had a higher content of FFM, which is largely muscle tissue.

Thermography is an entirely safe, side effect-free, non-invasive method of recording body temperature changes [12]. Publications dealing with thermal imaging analysis among athletes have included basketball players, water polo players, volleyball and handball players, and football players [14–18]. The human body maintains a constant temperature of approximately 37°C, independent of environmental factors [12]. The average temperature inside the body is 37°C and 33°C on the surface, though these numbers depend on individual characteristics [16]. The variance between the external and internal body temperatures results from the temperature of the internal organs and the thermal properties of the tissues separating the organs from the body surface [16]. These changes are affected by adipose and muscle tissue content, the volume of blood flow and its temperature, skin humidity, and the amount of energy produced by metabolic processes [16].

In professional, semi-professional, and amateur sport, researchers are constantly looking for non-invasive research and diagnostic methods that can help to achieve an increasingly better training performance and contribute to success. As early as 1985, it was shown that physical performance and adaptation to exercise depend largely on effective thermoregulation of the body, which can be assessed by internal body temperature and surface temperatures [16]. Thus, thermal imaging can be an excellent tool for coaches of various sport disciplines to assess the dynamics of their athletes' body surface temperatures, which involves accurate monitoring of the efficiency of their thermoregulatory processes [16].

Our study analyzed body surface temperature in CrossFit trainees, divided by level of CrossFit advancement. It has been proven that people with a high level of physical activity show higher mean body temperatures, regardless of gender. Therefore, it can be concluded that endogenous heat removal systems work more effectively and efficiently in more highly trained people than in people with a lower level of training. Advanced individuals may have accelerated responses related to sweat dynamics.

Women's responses to sweating during heat load are generally lower than those of men. It should also be noted that the changing rate of release of sex hormones during the menstrual cycle modifies thermoregulatory processes in women; because of this, there are differences in body temperatures at rest and thermal responses to positive or negative heat loads that depend on the phase of the menstrual cycle [19]. In our study, the oldest participant was aged 46 while the youngest was 22, so the subjects in the group of women studied were unlikely to have undergone menopause. Therefore, the thermoregulatory processes of the group of women would have been influenced by the release rate of sex hormones.

In the group of advanced men (M2), the parameter TBW (%) strongly and significantly correlated mainly with the measured areas of the mean temperature of the lower limbs and the posterior part of the trunk. This relationship correlated positively, indicating that mean body temperature increased when TBW (%) increased. In the intermediate male group (M1), the situation was similar, but statistical significance was marked in the correlation of TBW (%) with areas of mean temperature in the lower limbs and posterior parts of the upper limbs. In the group of intermediate women (W1), the association of the mean temperature of the body areas studied with TBW (%) was mostly weak and statistically insignificant. On the other hand, in the group of advanced women (W2), TBW (%) correlations with the mean temperatures of body areas were similar to the results for the men, but strong and significant correlations of this parameter were shown only with the posterior lower limb area. Therefore, it can be concluded that in the male groups, the high correlation of TBW (%) with the mean temperature of the lower limb areas was affected by higher FFM (kg) levels. A higher FFM (kg) level in men indicates a higher percentage of tissue hydration and higher blood flow, suggesting an increase in temperature in these body regions.

By continuing this research in the future, it would be possible to investigate the effects of the entire training cycle on changes in surface body temperature and body composition in CrossFit trainees. It would therefore be possible to increase awareness in the coaching community that thermal imaging is a suitable tool for the diagnosis of overload and inflammatory conditions. Moreover, it is possible to make coaches aware that using BIA measurements of body composition is an easy and convenient way to create and optimize training programs.

Conclusions

This study showed that gender and level of advancement differentiate individual body composition parameters and body surface temperatures in CrossFit trainees. The groups with a higher level of advancement showed higher fat-free mass and lower body fat compositions. In addition, the results showed higher body temperatures in males than in females and higher temperatures in subjects with a higher level of advancement. Surface temperature correlated most significantly with total body water composition in the group of advanced males who train CrossFit.

Abbreviations

BIA – bioelectrical impedance assessment;
BMI – body mass index;
DOMS – delayed onset muscle soreness;
F1 – group of intermediate females;
F2 – group of advanced females;
FAT (%) – percentage of body fat;
FFM (kg) – fat-free body mass;
FM (kg) – fat mass; M1 – group of intermediate males;
M2 – group of advanced males;
TBW (%) – percentage total body water;
TBW (kg) – total body water mass.

References

1. Cieślik B, Kuligowski T, Rutkowski T. The Effect of 8-week CrossFit®-based Training on Body Composition inHealthy Adults. Prace Naukowe Akademii im. Jana Długosza w Częstochowie, Kult Fiz. 2016; 15 (4): 169-179.
2. Meyer J, Morrison J, Zuniga J. The benefits and risks of CrossFit. A systematic review. Workplace Health Saf. 2017; 65 (12): 612-618.
3. Kosendiak J, Lipska A, Borkowski J, Grobelna J. Reakcje organizmu zawodników Cross-Fit na wykonanie workoutu „Fran". J Educ Health Sport 2017; 7 (6): 1197-1214.
4. Drum SN, Bellovary B, Jensen R, Moore M, Donath L. Perceived demands and post-exercise physical dysfunction in CrossFit® compared to an ACSM based training session. J Sport Med Phys Fit. 2017; 57 (5): 604-609.
5. Lewitt A, Mądro E, Krupienicz A. Theoretical foundations and practical applications of bioelectrical impedance analysis (BIA). Endokrynol Otył Zab Przem Mat. 2007; 2 (4): 79-84.
6. Modrzejewska A, Parafiniuk M. The application of thermography in medicine – literature review. Pomeranian J Life Sci. 2018; 64 (3): 29-32.
7. Prasał M, Sawicka KM, Wysokiński A, Wolski T. Thermography in Medical Diagnostics. Przegl Lek. 2010; 67 (2): 127-130.
8. Dębiec-Bąk A, Gruszka A, Sobiech KA, Skrzek A. Age dependence of thermal imaging analysis of body surface temperature in women after cryostimulation. Hum Mov. 2013; 14(4), 299-304.
9. Moon JR. Body composition in athletes and sports nutrition: an examination of the bioimpedance analysis technique. Eur J Clin Nutr 2013; 67: 54-59.
10. Quiterio AL, Carnero EA, Silva AM, Baptista F, Sardinha LB. Weekly training hours are associated with molecular and cellular body composition levels in adolescent athletes. J Sports Med Phys Fitness 2009; 49: 54-63.
11. Stupnicki R, Tomaszewski P. Wskaźnik masy ciała a zawartość tkanki tłuszczowej u dorosłych. Hyg Publ Health 2016; 51 (4): 335-338.
12. Dębiec-Bąk A, Skrzek A. Porównanie rozkładu temperatury powierzchniowej ciała kobiet i mężczyzn za pomocą termowizji. Acta Bio-Opt Infor Med. 2012; 18 (1): 25-30.
13. Stępień A, Pawlus J, Nowak E, Kulka J, Giełżecki J, Kraft O, Puto T, Klauz G. Comparison of the radioisotopic and thermograpic techniques in imaging of bone-joint system Diseases. Acta Bio-Opt Infor Med, Inż Biomed. 2006; 12 (2), 77-80.
14. Chudecka M, Lubkowska A. Temperature changes of selected body's surfaces of handball players in the course of training estimated by thermovision, and the study of the impact of physiolgical and morphological factors on the skin temperature. J Ther Biol. 2010, 35 (8): 379-385.
15. Chudecka M, Lubkowska A. Evaluation of the body surface temperature changes in the basketball players' after training. Acta Bio-Opt Infor Med, Inż Biomed. 2011; 17 (4), 271-274.
16. Chudecka M. Use of thermal imaging in the evaluation of body surface temperature in various physiological states in patients with different body compositions and varying levels of physical activity. Centr Europ J Sport Sci Med. 2013; 2 (2), 15-20.
17. Chudecka M, Lubkowska A. The use of thermal imaging to evaluate body temperature changes of athletes during training and a study on the impact of physiological and morphological factors on skin temperature. Hum Mov. 2012; 13 (1): 3-39.
18. Dębiec-Bąk A, Pawik Ł, Skrzek A. Thermoregulation of football players after cryotherapy in thermography. J Therm Anal Calorim. 2016; 126, 1633-1644.
19. Kaciuba-Uscilko H, Grucza R. Gender differences in thermoregulation. Curr Opin Clin Nutr Metab Care. 2001; 4 (6): 533-536.