Intra- and inter-session reliability and repeatability of an infrared thermography device designed for materials to measure skin temperature of the triceps surae muscle tissue of athletes

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Background: Infrared thermography devices have been commonly applied to measure superficial temperature in structural composites and walls, being cheaper than other thermographic devices used to measure superficial human muscle tissue temperature, which could be of interest in the triceps surae of athletes according to prior studies. *Objective:* The purpose was to determine intra- and inter-session reliability and repeatability of the Manual Infrared Camera PCE-TC 30 thermography device designed initially to measure superficial temperature of materials in the triceps surae muscle tissue of athletes. *Methods:* A total of 34 triceps surae muscles were bilaterally assessed from 17 healthy athletes by the Manual Infrared Camera PCE-TC 30 thermography device in order to determine intra- and inter-session reliability and repeatability of the skin temperature of the soleus, medial and lateral gastrocnemius muscles. Intraclass correlation coefficient (ICC), standard error of measurement (SEM), minimum detectable change (MCD), systematic error of measurement, correlation (*r*) and Bland-Altman plots completed with linear regression models (R^2) were analyzed. *Results:* Intra- and inter-session measurements of the infrared thermography device designed for materials in the triceps surae muscle tissue of athletes showed excellent reliability ($ICC_{(1,2)}$=0.968–0.977), measurement errors (SEM=0.186–0.232ºC; MDC=0.515–0.643 ºC), correlations (*r*=0.885–0.953) and did not present significant systematic error of measurements (*P*>.05). Adequate agreement between each pair of measurement moments was presented by the Bland-Altman plots according to the limits of agreement and non-significant linear regression models (R^2=0.000–0.019; P>.05). *Conclusions:* The proposed Manual Infrared Camera PCE-TC 30 thermography device designed initially to measure superficial temperature of materials presented excellent intra- and inter-session reliability and repeatability in the triceps surae muscle tissue of athletes. Future studies should consider the measurement errors of this tool to measure skin temperature of soleus, medial and lateral gastrocnemius muscles in order to promote triceps surae muscle prevention and recovery in athletes.

Article

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Abstract

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Objective: The purpose was to determine intra- and inter-session reliability and repeatability of the Manual Infrared Camera PCE-TC 30 thermography device designed initially to measure superficial temperature of materials in the triceps surae muscle tissue of athletes.

Methods: A total of 34 triceps surae muscles were bilaterally assessed from 17 healthy athletes by the Manual Infrared Camera PCE-TC 30 thermography device in order to determine intra- and inter-session reliability and repeatability of the skin temperature of the soleus, medial and lateral gastrocnemius muscles. Intraclass correlation coefficient (ICC), standard error of measurement (SEM), minimum detectable change (MCD), systematic error of measurement, correlation (r) and Bland-Altman plots completed with linear regression models (R^2) were analyzed.

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Conclusions: The proposed Manual Infrared Camera PCE-TC 30 thermography device designed initially to measure superficial temperature of materials presented excellent intra- and inter-session reliability and repeatability in the triceps surae muscle tissue of athletes. Future studies should consider the measurement errors of this tool to measure skin temperature of soleus, medial and lateral gastrocnemius muscles in order to promote triceps surae muscle prevention and recovery in athletes.

***Kewords*:** Athletes; Lower Extremity; Repeatability; Reproducibility of Results; Thermography.

***Highlights*:**

- Prior high quality thermography devices were reliable to measure skin temperature
- The proposed device was initially designed for materials superficial temperature

- This device is reliable and repeatable to measure triceps surae skin temperature
- This cheap tool could promote triceps surae prevention and recovery in athletes

1. Introduction

Infrared thermography was proposed as one of the most relevant non-ionizing radiation tools in order to assess skin temperature related to muscle tissue conditions, such as compartmental syndrome, but there is a lack of scientific evidence for other musculoskeletal conditions (Sanchis-Sánchez et al., 2014). Among different application fields, inflammation and perfusion-based conditions may be benefited by thermographic imaging use in the sport medicine field (Ramirez-GarciaLuna et al., 2022). This device was used as a main outcome measurement to determine superficial temperature in the human muscle tissue of athletes' lower limbs for injury prevention (Côrte et al., 2019), muscle activity (Rodriguez-Sanz et al., 2019), evaluation before and after treatments (Rodriguez et al., 2018; Benito-de-Pedro et al., 2019) as well as assessments before and after running, being the triceps surae from athletes considered as a main focus linked to musculoskeletal conditions (Rodríguez-Sanz et al., 2017; Rodriguez-Sanz et al., 2018; Rodriguez et al., 2018; Benito-de-Pedro et al., 2019).

Thermography assessment was used to measure cutaneous temperature of triceps surae muscles in soccer players with equinus condition after running (Rodriguez-Sanz et al., 2018), as well as at rest (Rodríguez-Sanz et al., 2017). In addition, this tool was applied to determine the treatment effects after different physical therapy interventions in triathletes (Benito-de-Pedro et al., 2019). In addition, infrared thermography was utilize to measure skin temperature changes after compressive stockings use in athletes (Rodriguez et al., 2018).

The FLIR/SC3000/QWIP Thermacan infrared thermal device presented a 8–9 µm spectral range, a temperature sensitivity of 0.02 K, a display of 320 x 240 pixels with 20º lens and a spatial resolution of 1.1 mrad, being frequently used to evaluate superficial temperature in the human tissue with an adequate reliability and repeatability (Rodríguez-Sanz et al., 2017; Rodriguez-Sanz et al., 2018; Rodriguez et al., 2018; Benito-de-Pedro et al., 2019), by both manual and automatic thermographic software package measurement methods with an adequate agreement and excellent intraclass correlation coefficient (ICC > 0.80) (Requena-Bueno et al., 2020). Prior statistical procedures, such as ICC and Bland-Altman plots including limits of agreement (LoA), were used to compare infrared thermographic values in the lower limbs showing that both manual and automatic definition devices presented an excellent ICC from 0.92 to 0.99 with an adequate agreement by visual distribution and similar LoA by the ThermoHuman® devices (Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020), excellent inter-session reproducibility with an ICC of 0.88 using the digital infrared camera IRTIS-2000® (Zaproudina et al., 2008), and almost perfect agreement in replication with an ICC from 0.94 to 0.97 by the Thermofocus® thermal imaging device (Petrova et al., 2018). Nevertheless, these devices showed a higher cost compared with an infrared thermography device to evaluate superficial temperature on materials, such as the Manual Infrared Camera PCE-TC 30, which displayed a sensor resolution of 80x80, a measurement range from 0 to 250ºC, a display of 320 x 240 pixels, a thermal sensitivity of 80 mK and 8 mm lens (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014). Despite this thermal imaging system presented very low parameters concerning geometrical resolution (80 x 80 pixels) and thermal sensitivity of 80 mK, while other thermal imaging systems displayed high definition resolution (1280 x 960 pixels) and higher thermal sensitivity of 20 mK (Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020), the Manual Infrared Camera PCE-TC 30 geometrical resolution and thermal sensitivity features could present adequate reliability to measure triceps surae muscle tissue temperature variations

(Rodríguez-Sanz et al., 2017; Rodriguez-Sanz et al., 2018; Rodriguez et al., 2018; Benito-de-Pedro et al., 2019).

This cheaper infrared thermography device was applied to measure superficial temperature in structural composites and walls according to quality inspections such as reproducibility, stability, reliability and operating temperature (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014), but it has not been applied to measure superficial human muscle tissue temperature, which could be of interest in the triceps surae of athletes according to our prior studies (Rodríguez-Sanz et al., 2017; Rodriguez-Sanz et al., 2018; Rodriguez et al., 2018; Benito-de-Pedro et al., 2019; Requena-Bueno et al., 2020). We hypothesized that this device developed initially for non-vivo structures could provide an adequate reliability and repeatability to determine skin temperature in the triceps surae muscle human tissue of athletes, being cheaper with respect to the infrared thermography device used in human studies. Thus, the purpose of the present study was to determine the intra- and inter-session reliability and repeatability of the Manual Infrared Camera PCE-TC 30 thermography device designed initially to measure superficial temperature of materials in the triceps surae muscle tissue of athletes.

2. Materials and Methods

2.1. Study design

The present study was carried out from January 2020 to May 2021 according to The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) criteria (Vandenbroucke et al., 2014). Furthermore, Helsinki Declarations as well as specific human experimentation ethical rules were taken into account.(Holt, 2014) The ethic committee for clinical interventions of the Hospital Clínico San Carlos, Madrid (Spain) approved this study with internal code number 20/021-E on January 20, 2020 on January 20, 2020. All study subjects signed the document of the informed consent form prior to beginning this reliability study. In addition, the present study study was supported by a Contract 83 between the between the Complutense University and PCE Ibérica S.L. (Reference number: 6-2020), providing specific grant for this research project.

2.2. Sample size

The determination for sample size determination was calculated by bi-variate correlations statistical procedures through G*Power 3.1.9.2 programme (G*Power©, from Dusseldorf University, in Germany), considering a 0.4 correlation coefficient to achieve a moderate correlation(Lobo et al., 2016) between infrared thermography measurements, applying a 1-tailed hypothesis, a .05 α error and a 0.80 power. Lastly, the considered sample size was 34 triceps surae muscles in order to achieve the required thermography measurements for a 0.801 actual power.

2.3. Participants

Thirty-four triceps surae muscles were bilaterally analyzed from 17 healthy athletes considering a consecutive sampling recruitment procedure. First, inclusion criteria comprised specifically healthy athletes who aged 18-65 years providing previously the consent inform document, carrying out sport activities and training for at least two hours as well as one day per week, with moderate (level-II) or vigorous (level-III) intensities for physical activity with metabolic equivalent indexes greater than 600 METs/min/week, measured by the International Questionnaire for Physical Activity (IPAQ) (Roman-Viñas et al., 2010). Second, exclusion criteria included soreness, congenital dysfunctions, neuromuscular conditions, rheumatic alterations, body mass index (BMI) greater than 31 kg/m^2, previous neurological conditions, prior surgeries, skin pathologies, and some alterations in the lower limbs region (i.e. chronic ankle instability presence, prior sprains or previous fractures) according to the thermographic influence of compartmental, stress, inflammation and perfusion-based conditions (Sanchis-Sánchez et al., 2014; Ramirez-GarciaLuna et al., 2022) and, lastly, difficulties or inability in order to carry out the actions to complete the study course.

2.4. Procedure

Intra- and inter-session reliability and repeatability of the skin temperature of the triceps surae muscles were bilaterally assessed by the Manual Infrared Camera PCE-TC 30 at the same day separated by 1 hour (considered as intra-day measurements) and alternate days separated by 48 hours (considered as inter-day measurements), respectively (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014). Indeed, participants were asked for continue within their daily life and physical exercise routine (avoiding unusual efforts or activity changes) between measurements and no taking drugs at the prior week nor vasomotor substances (i.e., caffeine) at the same measurement day, as well as heavy metals were not allowed. All measurements were assessed with patients standing up in relaxed position in the same room within a 24.1 ± 1 C° temperature and a 45 ± 10% humidity, without direct ventilation flow towards examiners or participants (Rodríguez-Sanz et al., 2017).

2.5. Descriptive data

Descriptive data including sex (categorized as male or female), age (measured in years), height (measured in cm), weight (measured in kg), BMI (expressed as kg/cm^2 following the Quetelet´s index) (Garrow, 1986). main sport category (divided into fitness considered as bodybuilding exercise or soccer), side (categorized as right or left), and dominance (expressed as yes or no) and smoker (expressed as yes or no) were detailed (Calvo-Lobo et al., 2019). As a tool with adequate psychometric properties, metabolic equivalent index per minute per week (METs/min/week) were evaluated by the IPAQ in order to determine physical activity and its categorization as moderate (600 – 1500 METs/min/week) and vigorous (≥ 1500 METs/min/week) physical activity (Gauthier, Lariviere & Young, 2009).

2.6. Infrared thermography

Firstly, the Manual Infrared Camera PCE-TC 30 (PCE Instruments UK Ltd; Southampton, United Kingdom), which displayed a sensor resolution of 80x80, a measurement range from 0 to 250ºC, a display of 230 x 240 pixels, a thermal sensitivity of 80 mK and 8 mm lens (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014). The infrared thermography imaging process was performed with the participant placed at 1 m of distance from the camera and standing up in a relaxed position. Bilaterally, the triceps surae complex, including lateral (Figure 1A and 1B) and medial (Figure 1C and 1D) gastrocnemius as well as soleus (Figure 1E and 1F) muscles, was measured by a region of interest (ROI) through 5 infrared thermography images for each muscle. Removing the highest and lowest values, the mean of the 3 measurements were used for data analysis. Infrared images and data were analyzed by a blinded and experienced evaluator using the Guide™ Report Express (PCE Instruments UK Ltd; Southampton, United Kingdom) (Rodríguez-Sanz et al., 2017). This software provided the mean thermal value (ºC) of the selected ROI of 1 cm^2 coinciding with the center of a landmark for each muscle (Figure 1). These landmarks were used to determine superficial skin temperature and placed superior to the Achilles tendon for the soleus muscle and in the thickest part of the medial and lateral gastrocnemius muscles according to prior similar studies (Benito-de-Pedro et al., 2019; Rojas-Valverde et al., 2021).

Please, include Figure 1 here or hereabouts

Figure 1. Infrared thermography images of the triceps surae complex, including left (A) and right (B) lateral gastrocnemius, left (C) and right (D) medial gastrocnemius, and left (E) and right (F) soleus muscles, including the thermal values of the region of interest (ROI) of 1 cm^2.

2.7. Statistical Analyses

The 24.0 Statistical Package programme for Social Science (named SPSS; from IBM-Corp, in Armonk, NY) was considered as the package for data analyses. The α error as set at .05 and thus a *P*-value lower than .05 was considered as statistical significance. Kolmogorov-Smirnov statistical test and visual inspection of histograms were considered to detail the distribution of normality. Data adjusted to normal distribution were detailed through means ± standard deviations (SD) in conjunction with the upper and lower limits of 95% confidence interval (CI). Data adjusted to non-normal distribution were detailed through medians ± interquartile ranges (IR). Infrared thermography measurements for intra- as well as inter-session evaluations were compared through paired-samples Student *t* tests considering parametric tests as well as Wilcoxon tests regarding non-parametric tests. The reliability and repeatability between each pair of measurements were analyzed by ICC for bidirectional absolute agreement as well as Pearson (*r*) or Spearman (*ρ*) correlations coefficients as parametric or non-parametric tests, respectively. Furthermore, $ICC_{(2,1)}$ values were specifically interpreted as poor for < 0.40 $ICC_{(2,1)}$, weak for 0.40-0.59 $ICC_{(2,1)}$, good for 0.60-0.74 $ICC_{(2,1)}$, as well as excellent for 0.75-1.00 $ICC_{(2,1)}$ (Calvo-Lobo et al., 2019). Next, correlation coefficients were specifically interpreted as week for 0.00-0.40 *r* or *ρ*, moderate for 0.41-0.69 *r* or *ρ*, as well as strong for 0.70-1.00 *r* or *ρ* (Lobo et al., 2016). Standard errors for measurements (SEM) values were detailed through SD × $\sqrt{(1 - ICC)}$. After, minimum detectable changes (MDC) values were detailed through $\sqrt{2}$

$\times 1.96 \times SEM$ for 95% CI. Both MDC and SEM were detailed through Bland and Altman recommendations (Calvo-Lobo et al., 2019). Limits for agreement (LoA) for each pair of measurements were detailed through differences means $\pm$ $1.96 \times SD$ for 95% CI in line with Bland and Altman.(Bland & Altman, 2010; Calvo-Lobo et al., 2019) In addition, Bland-Altman plots were shown to detail visual agreements for each pair of measurements showing systematic measurement errors of the differences means distributions for each pair of measurements located at Y axis with regards to the means for each pair of measurements located at X axis. These Bland-Altman plots were shown in conjunction with linear regression models. R^2 coefficients were calculated to detail the adjustment quality. The means values for each pair of measurements were considered as independent variables. Lastly, the differences for each pair of measurements were considered as dependent variables (Bland & Altman, 2010).

3. Results

3.1. Descriptive data

The final sample comprised 34 triceps surae muscles bilaterally from 17 healthy athletes, 9 (52.9%) males and 8 (47.1%) females, with mean ± SD (95% CI) age of 41.76 ± 14.42 (36.73 – 46.79) years, weight of 68.57 ± 14.57 (63.40 – 73.64) kg, height of 1.69 ±0.09 (1.66 – 1.73) m, and BMI of 23.45 ± 3.47 (22.24 – 24.66) kg/cm^2. Regarding the main sport category, these athletes performed fitness (n = 14; 82.40%) and soccer (n = 3; 17.6%). All athletes presented right dominant side (n = 17; 100%) and most of them were non-smokers (n = 12; 70.60%). Considering the IPAQ, mean ± SD (95% CI) of metabolic equivalents index per minute per week was 3276.08 ± 1876.49 (2621.34 – 3930.82) METs/min/week, including 8 (47.10%) athletes who performed vigorous physical activity and 9 (52.90%) athlete who performed moderate physical activity. Table 1 showed the normality statistics and significance according to Kolmogorov-Smirnov test.

Please, include Table 1 here or hereabouts

Table 1. Descriptive data and normality statistics and significance according to Kolmogorov-Smirnov test.

3.2. Intra-session reliability and repeatability

According to Table 2, intra-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue of athletes showed excellent reliability ($ICC_{(1,2)}$ = 0.969 – 0.977), measurement errors (SEM = 0.186 – 0.212 ºC; MDC = 0.515 – 0.587 ºC) and did not present any statistically significant systematic error of measurements ($P > .05$).

Please, include Table 2 here or hereabouts

Table 2. Intra-session reliability and repeatability of an infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue of athletes.

Regarding intra-session measurements, bivariate correlations were excellent for the soleus (r = 0.953; $P < .001$), medial gastrocnemius (ρ = 0.885; $P < .001$) and lateral gastrocnemius (r = 0.939; $P < .001$).

In addition, Bland-Altman plots presented an adequate agreement for intra-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the soleus (Figure 2), medial gastrocnemius (Figure 3) and lateral gastrocnemius (Figure 4) muscles of athletes, due to visual distributions of the difference means for each pair of measurements at Y axis with respect to the mean for each pair of measurements at X axis did not present any systematic measurement error and most thermographic measurements were between the upper and lower LoA. In addition to Bland-Altman plots, linear regression models did not show any statistical significance for soleus (R^2 = 0.000; β = 0.003; $F_{1,32}$ = 0.003; P = 0.954), medial gastrocnemius (R^2 = 0.002; β = -0.017; $F_{1,32}$ = 0.065; P =0.800) and lateral gastrocnemius (R^2 = 0.019; β = -0.050; $F_{1,32}$ = 0.626; P =0.435) intra-session measurements.

Please, include Figure 2 here or hereabouts

Figure 2. Bland-Altman plots agreement for intra-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the soleus muscle tissue of athletes, completed with the upper and lower limits of agreement (LoA).

Please, include Figure 3 here or hereabouts

Figure 3. Bland-Altman plots agreement for intra-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the medial gastrocnemius muscle tissue of athletes, completed with the upper and lower limits of agreement (LoA).

Please, include Figure 4 here or hereabouts

Figure 4. Bland-Altman plots agreement for intra-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the lateral gastrocnemius muscle tissue of athletes, completed with the upper and lower limits of agreement (LoA).

3.3. Inter-session reliability and repeatability

According to Table 3, inter-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue of athletes presented excellent reliability ($ICC_{(1,2)}$ = 0.956 – 0.974), measurement errors (SEM =

0.187 – 0.232 ºC; MDC = 0.518 – 0.643 ºC) and did not present any statistically significant systematic error of measurements ($P > .05$).

Please, include Table 3 here or hereabouts

Table 3. Inter-session reliability and repeatability of an infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue of athletes

Considering inter-session measurements, bivariate correlations were also excellent for the soleus ($r = 0.949$; $P < .001$), medial gastrocnemius ($r = 0.914$; $P < .001$) and lateral gastrocnemius ($r = 0.938$; $P < .001$).

Lastly, Bland-Altman plots showed an adequate agreement for inter-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the soleus (Figure 4), medial gastrocnemius (Figure 5) and lateral gastrocnemius (Figure 6) muscles of athletes, since visual distributions of the difference means for each pair of measurements at Y axis with respect to the mean for each pair of measurements at X axis did not present any systematic measurement error and most thermographic measurements were between the upper and lower LoA. In conjunction with Bland-Altman plots, linear regression models did not show any statistical significance for soleus ($R^2 = 0.014$; $\beta = 0.039$; $F_{1,32} = 0.463$; $P = 0.501$), medial gastrocnemius ($R^2 = 0.000$; $\beta = -0.009$; $F_{1,32} = 0.014$; $P = 0.907$) and lateral gastrocnemius ($R^2 = 0.019$; $\beta = -0.050$; $F_{1,32} = 0.621$; $P = 0.436$) inter-session measurements.

Please, include Figure 5 here or hereabouts

Figure 5. Bland-Altman plots agreement for inter-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the soleus muscle tissue of athletes, completed with the upper and lower limits of agreement (LoA).

Please, include Figure 6 here or hereabouts

Figure 6. Bland-Altman plots agreement for inter-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the medial gastrocnemius muscle tissue of athletes, completed with the upper and lower limits of agreement (LoA).

Please, include Figure 7 here or hereabouts

Figure 7. Bland-Altman plots agreement for inter-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the lateral gastrocnemius muscle tissue of athletes, completed with the upper and lower limits of agreement (LoA).

4. Discussion

The Manual Infrared Camera PCE-TC 30 thermography device, which was initially designed to assess superficial temperature of materials (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014), presented excellent intra- and inter-session reliability and repeatability with an adequate agreement avoiding systematic errors of measurement to measure skin temperature of soleus, medial and lateral gastrocnemius muscles, which may be a cheap tool to promote triceps surae muscle prevention and recovery in athletes (Rodríguez-Sanz et al., 2017; Rodriguez-Sanz et al., 2018; Rodriguez et al., 2018; Benito-de-Pedro et al., 2019).

This tool showed similar excellent reliability (ICC > 0.8) compared to the infrared ThermoHuman® device (Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020), the digital infrared camera IRTIS-2000®(Zaproudina et al., 2008) and Thermofocus® thermal imaging device (Petrova et al., 2018), which were specifically designed for human tissue temperature measurements in lower limbs. Indeed, different ThermoHuman® devices showed an excellent intra-session (ICC = 0.99; LoA = 0.0±0.4 – 0.1±0.4 ºC) and inter-session (ICC = 0.92; LoA = 0.1±0.4 – 0.1±0.5ºC) reliability before and after running, respectively, detailing small differences effect sizes (Cohen´s d < 0.4) for foot skin temperature (Requena-Bueno et al., 2020). Specifically, the digital infrared camera IRTIS-2000® applied in the calf region showed adequate intra-session (ICC = 0.84) and inter-session (ICC = 0.66) reliability with similar temperature mean ± SD values for anterior (31.2 ± 0.6 ºC), posterior (30.8 ± 0.6 ºC) and lateral (31.3 ± 0.6 ºC) calf regions (Zaproudina et al., 2008). Finally, the Thermofocus® thermal imaging device presented almost perfect intra-session agreement in different foot regions (ICC = 0.94 – 0.97) showing non-significant replication interactions (P-values = 0.23 – 0.84) (Petrova et al., 2018). Despite the use of such modern thermal imaging systems with better definition resolutions could provide more reliable measurements and improve the quality of the thermograms obtained, the reliability and measurement errors provided by the Manual Infrared Camera PCE-TC 30 thermography may be enough to detect temperature differences linked to clinical musculoskeletal changes (Côrte et al., 2019).

A prior thermographic study carried out by our research group showed that skin thermal evaluation of the triceps surae muscles showed that skin temperature after running was deeply linked to electromyography, which may indirectly reflect triceps surae muscle activity. Despite the Manual Infrared Camera PCE-TC 30 thermography device have not been yet correlated with electromyography values, thermal values could be related with muscle activity in the triceps surae muscles of athletes using this tool according to a similar study using the FLIR/SC3000/QWIP Thermacan-infrared thermal devi.ce (Rodriguez-Sanz et al., 2019)

Athletes may be exposed to physical stress under training loads and competitions with overload reactions which could cause blood flow changes affecting skin temperature (Merla et al., 2010). Infrared thermography may not display anatomical abnormalities, although functional changes may be shown and linked to skin temperature control (Merla et al., 2010; Ring &

Ammer, 2012). Infrared thermography use was proposed as a complementary tool to apply preventive measures, such as cryotherapy, physiotherapy, training load reduction, and massage or recovery boot use, to avoid muscle conditions in professional soccer players. The asymmetry reference values range from 0.5 ºC to 1 ºC between both right and left lower limbs was proposed to initiate this preventive protocol, which reduced up to 63% muscle injuries in a professional soccer season by thermographic monitoring (Côrte et al., 2019). Thus, the Manual Infrared Camera PCE-TC 30 thermography device could be used to determine these cut-off values due to the MDC values varied from 0.5ºC to 0.6 ºC.

4.1. Future studies

Further studies should be designed as randomized clinical trials in order to determine if these asymmetry reference cut-off values could prevent triceps surae muscle injuries.(Côrte et al., 2019) According to prior studies (Hiemstra et al., 2007; Chung et al., 2015), the uninvolved normal side after injury may often be not normal, i.e. presenting temperature values different from healthy subjects, and cut-off values should be also detailed in future muscle recovery studies. In addition, thermographic measurement of the triceps surae with this device should be correlated with the other high-end infrared devices as possible gold standards such as ThermoHuman® (Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020), IRTIS-2000®(Zaproudina et al., 2008) and Thermofocus®(Petrova et al., 2018) tools, as well as correlations with electromyography measurements of the triceps surae muscle activity should be carried out (Rodriguez-Sanz et al., 2019). Lastly, intramuscular temperature should also be correlated with this device in order to determine concurrent validity with respect to a gold standard (Burnham, McKinley & Vincent, 2006).

4.2. Limitations

Various limitations should be considered for the use of this thermographic device. First, the MDC was superior to the lower limbs asymmetry reference range from 0.3 ºC to 0.4ºC proposed as a cut-off for following-up before a preventive protocol (Côrte et al., 2019) and therefore this device should not be used for values lower than 0.5 ºC – 0.6 ºC. Second, concurrent validity of this device has not been performed for human tissue temperature and this validity should be assessed in the next future (Burnham, McKinley & Vincent, 2006). Third, our sample only comprised healthy athletes and further studies should analyze skin temperature with this tool over injured muscle tissue (Alburquerque Santana et al., 2022). Lastly, our sample size calculation was accurately detailed to determine a bivariate moderate correlation between measurements, but our sample size was low to achieve the actual power in order to perform comparisons classifying groups depending on sport category, BMI, and other valued characteristics. In addition, despite statistical analyses were carried out according to our prior sample size calculation model in order to detail bivariate comparisons for intra- and inter-session measurements, future nested type studies should be designed as nested statistical models such as analyses of variance (ANOVA) to determine more accurate temperature comparisons.

5. Conclusion

The proposed Manual Infrared Camera PCE-TC 30 thermography device designed initially to measure superficial temperature of materials presented excellent intra- and inter-session reliability and repeatability to measure skin temperature in the triceps surae muscle tissue of athletes. Future studies should consider the measurement errors of this tool to measure skin temperature of soleus, medial and lateral gastrocnemius muscles in order to promote triceps surae muscle prevention and recovery in athletes.

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Conflicts of Interest: César Calvo-Lobo, David Rodríguez-Sanz and Ricardo Becerro-de-Bengoa-Vallejo declare conflict of interest due to the Contract 83 between the Complutense University and PCE Ibérica S.L. (Reference number: 6-2020) was specifically carried out to study the reliability of the Manual Infrared camera PCE-TC 30 thermography device.

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Table 1(on next page)

Descriptive data and normality statistics and significance according to Kolmogorov-Smirnov test.

Abbreviations: BMI, body mass index; CI, confidence interval; IPAQ, International Physical Activity Questionnaire; K-S, Kolmogorov-Smirnov test; MET/min/week, metabolic equivalent index per minute per week. *P < .05 was considered as statistically significant for a 95% CI.

‡Mean ± standard deviation and the upper and lower limits of 95% CI were used. †Median ± interquartile range and the upper and lower limits of 95% CI were used.

Table 1. Descriptive data and normality statistics and significance according to Kolmogorov-Smirnov test.

Variables	Descriptive data	K-S Statistic	K-S *P*-value
Age (years)	41.76 ± 14.42 (36.73 – 46.79)‡	0.126	.189
Weight (kg)	68.57 ± 14.57 (63.40 – 73.64)‡	0.098	.200
Height (m)	1.69 ±0.09 (1.66 – 1.73)‡	0.142	.078
BMI (kg/m^2)	23.45 ± 3.47 (22.24 – 24.66)‡	0.095	.200
IPAQ (METs/min/week)	3276.08 ± 1876.49 (2621.34 – 3930.82)‡	0.110	.200
Soleus at baseline (ºC)	31.31 ± 1.41 (30.82 – 31.81)‡	0.119	.200
Soleus after 1 hour (ºC)	31.47 ± 1.80 (31.34 – 32.13)‡	0.090	.200
Soleus after 48 hours (ºC)	31.55 ± 1.03 (31.18 – 31.91)‡	0.096	.200
Medial gastrocnemius at baseline (ºC)	31.33 ± 1.40 (30.84 – 31.82)‡	0.138	.098
Medial gastrocnemius after 1 hour (ºC)	31.66 ± 1.81 (31.42 –32.22)†	0.155	.039*
Medial gastrocnemius after 48 hours (ºC)	31.55 ± 1.08 (31.17 – 31.93)‡	0.097	.200
Lateral gastrocnemius at baseline (ºC)	31.24 ± 1.36 (30.76 – 31.71)‡	0.086	.200
Lateral gastrocnemius after 1 hour (ºC)	31.77 ± 1.11 (31.38 –32.16)‡	0.146	.065
Lateral gastrocnemius after 48 hours (ºC)	31.52 ± 1.08 (31.14 – 31.90)‡	0.117	.200

Abbreviations: BMI, body mass index; CI, confidence interval; IPAQ, International Physical Activity Questionnaire; K-S, Kolmogorov-Smirnov test; MET/min/week, metabolic equivalent index per minute per week. *P < .05 was considered as statistically significant for a 95% CI. ‡Mean ± standard deviation and the upper and lower limits of 95% CI were used. †Median ± interquartile range and the upper and lower limits of 95% CI were used.

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Table 2(on next page)

Intra-session reliability and repeatability of an infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue of athletes.

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimum detectable change; SEM, standard error of measurement. *P < .05 was considered as statistically significant for a 95% CI. ‡Mean ± standard deviation and Student t test for paired samples were used. †Median ± interquartile range and Wilcoxon test for paired samples were used.

Table 2. Intra-session reliability and repeatability of an infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue of athletes.

Infrared thermography (ºC)	Baseline measurements (95% CI)	After 1 hour measurements (95% CI)	$ICC_{(1,2)}$ (95% CI)	SEM	MDC	*P*-value
Soleus	31.31 ± 1.41 (30.82 – 31.81)	31.33 ± 1.40 (30.84 – 31.82)	0.977 (0.954 – 0.988)	0.212	0.587	.822‡
Medial gastrocnemius	31.47 ± 1.80 (31.34 – 32.13)	31.66 ± 1.81 (31.42 –32.22)	0.966 (0.931 – 0.983)	0.208	0.576	.467†
Lateral gastrocnemius	31.55 ± 1.03 (31.18 – 31.91)	31.55 ± 1.08 (31.17 – 31.93)	0.969 (0.938 – 0.984)	0.186	0.515	.982‡

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimum detectable change; SEM, standard error of measurement. *P < .05 was considered as statistically significant for a 95% CI. ‡Mean ± standard deviation and Student t test for paired samples were used. †Median ± interquartile range and Wilcoxon test for paired samples were used.

Table 3(on next page)

Table 3. Inter-session reliability and repeatability of an infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue of athletes.

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimum detectable change; SEM, standard error of measurement. *$P < .05$ was considered as statistically significant for a 95% CI. ‡Mean ± standard deviation and Student *t* test for paired samples were used.

Table 3. Inter-session reliability and repeatability of an infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue of athletes.

Infrared thermography (ºC)	**Baseline measurements (95% CI)**	**After 48 hours measurements (95% CI)**	**$ICC_{(1,2)}$ (95% CI)**	**SEM**	**MDC**	***P*-value**
Soleus	31.31 ± 1.41 (30.82 – 31.81)	31.24 ± 1.36 (30.76 – 31.71)	0.974 (0.948 – 0.987)	0.222	0.615	.338‡
Medial gastrocnemius	31.74 ± 1.12 (31.34 – 32.13)	31.77 ± 1.11 (31.38 –32.16)	0.956 (0.913 – 0.978)	0.232	0.643	.682‡
Lateral gastrocnemius	31.55 ± 1.03 (31.18 – 31.91)	31.52 ± 1.08 (31.14 – 31.90)	0.968 (0.937 – 0.984)	0.187	0.518	.719‡

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimum detectable change; SEM, standard error of measurement. *$P < .05$ was considered as statistically significant for a 95% CI. ‡Mean ± standard deviation and Student *t* test for paired samples were used.

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Figure 1

Infrared thermography images of the triceps surae complex, including left (A) and right (B) lateral gastrocnemius, left (C) and right (D) medial gastrocnemius, and left (E) and right (F) soleus muscles, including the thermal values of the region

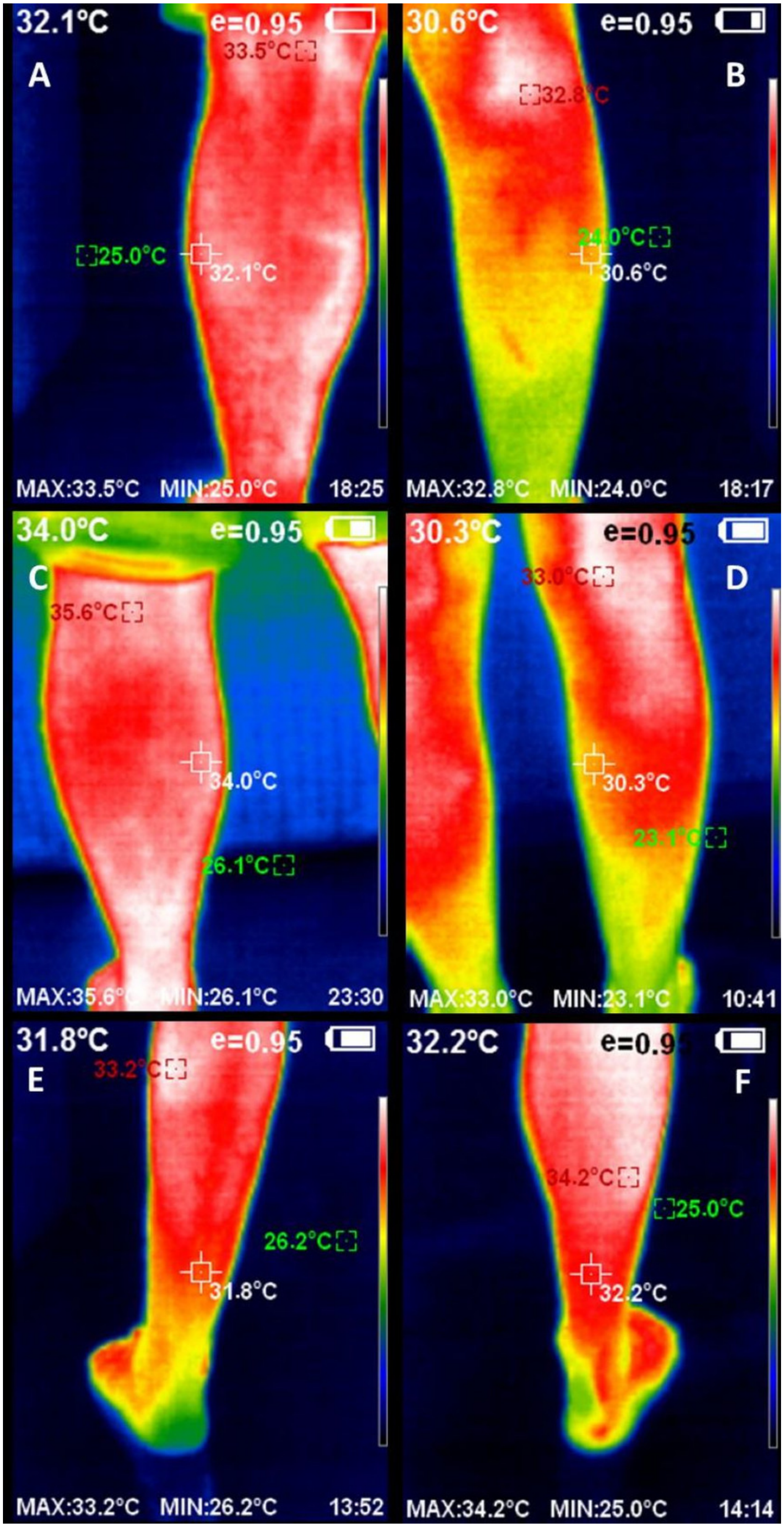
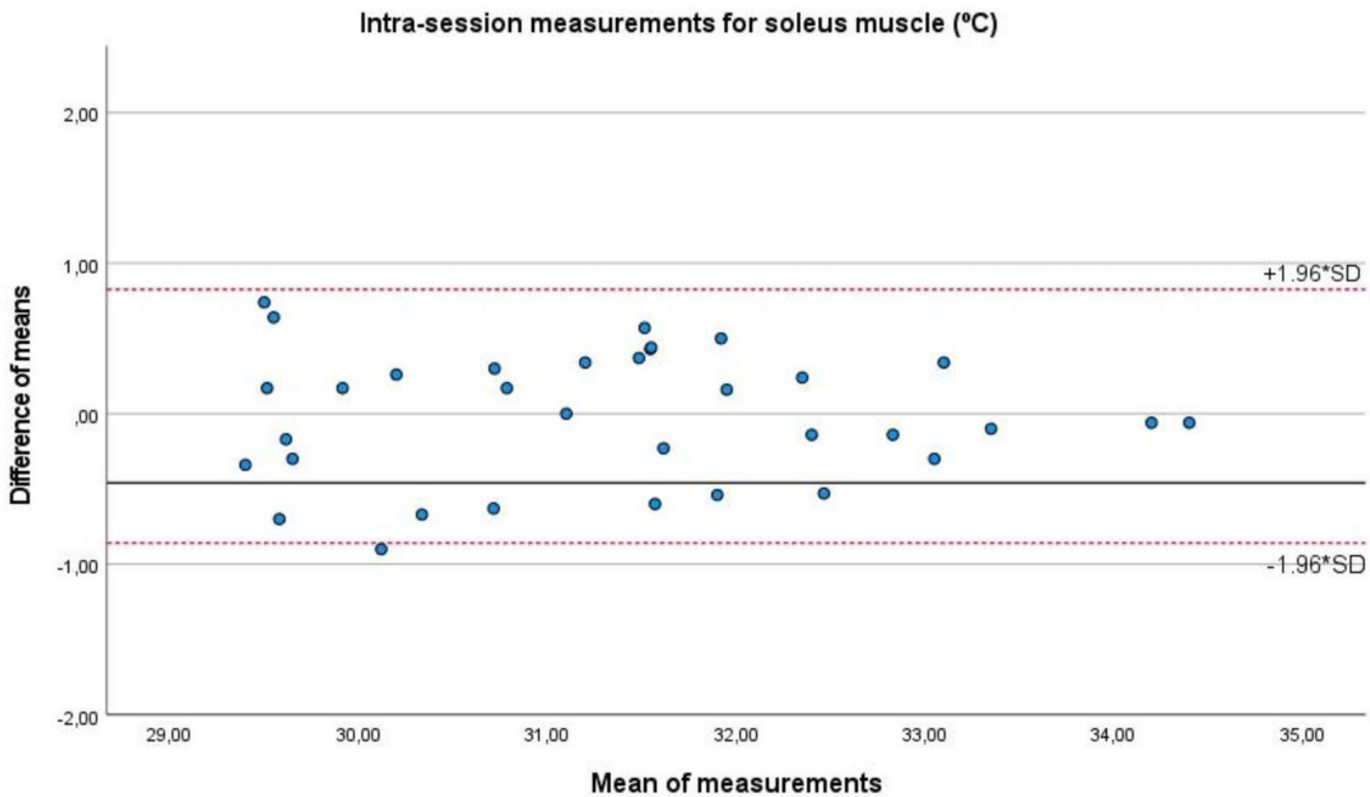

32.1°C
e=0.95
A
33.5°C
25.0°C
32.1°C
MAX:33.5°C MIN:25.0°C 18:25
30.6°C
e=0.95
B
32.8°C
24.0°C
30.6°C
MAX:32.8°C MIN:24.0°C 18:17
34.0°C
e=0.95
C
35.6°C
34.0°C
26.1°C
MAX:35.6°C MIN:26.1°C 23:30
30.3°C
e=0.95
D
33.0°C
30.3°C
23.1°C
MAX:33.0°C MIN:23.1°C 10:41
31.8°C
e=0.95
E
33.2°C
26.2°C
31.8°C
MAX:33.2°C MIN:26.2°C 13:52
32.2°C
F
34.2°C
25.0°C
32.2°C
MAX:34.2°C MIN:25.0°C 14:14

Figure 2

Bland-Altman plots agreement for intra-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the soleus muscle tissue of athletes, completed with the upper and lower limits of agreement (LoA)

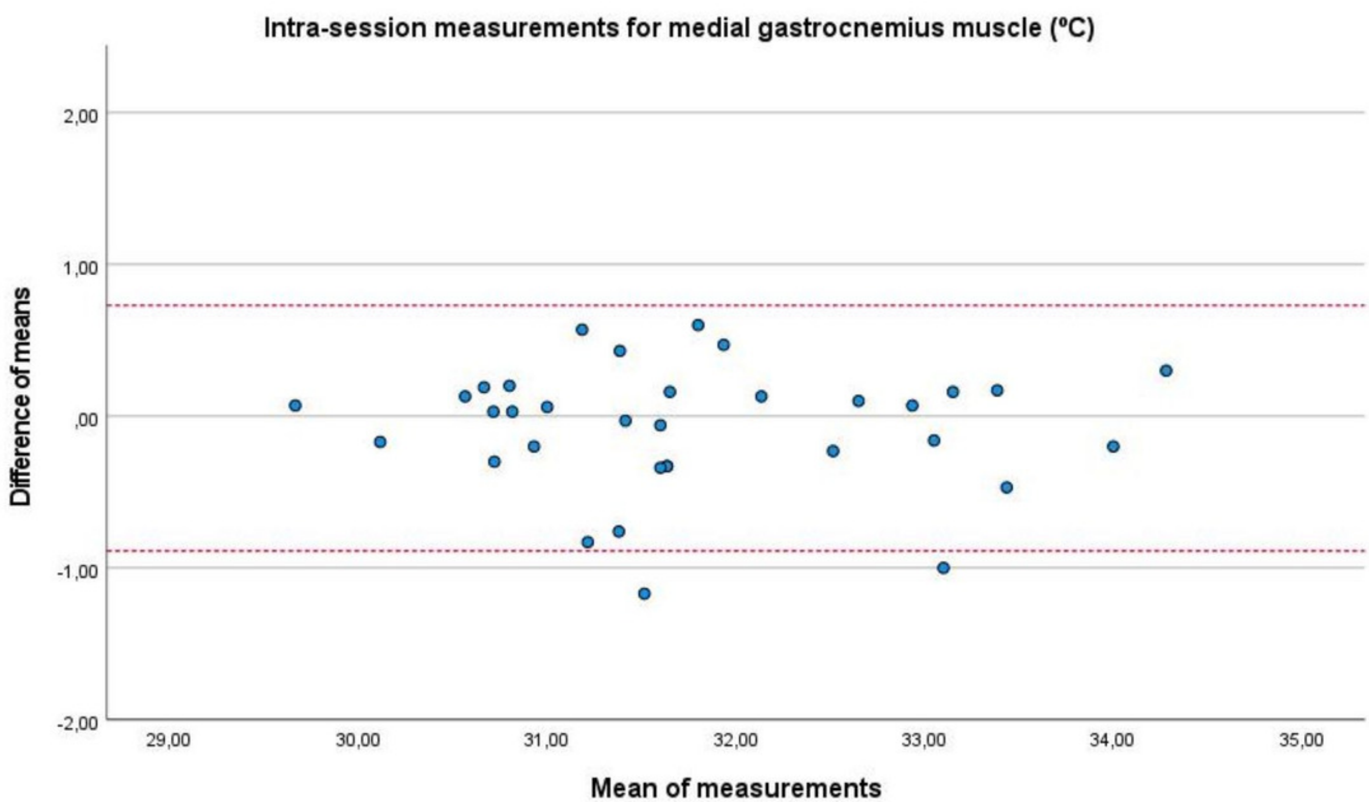


[redacted]

Figure 3

Bland-Altman plots agreement for intra-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the medial gastrocnemius muscle tissue of athletes.

Completed with the upper and lower limits of agreement (LoA).



[redacted]

Figure 4

Bland-Altman plots agreement for intra-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the lateral gastrocnemius muscle tissue of athletes.

Completed with the upper and lower limits of agreement (LoA).

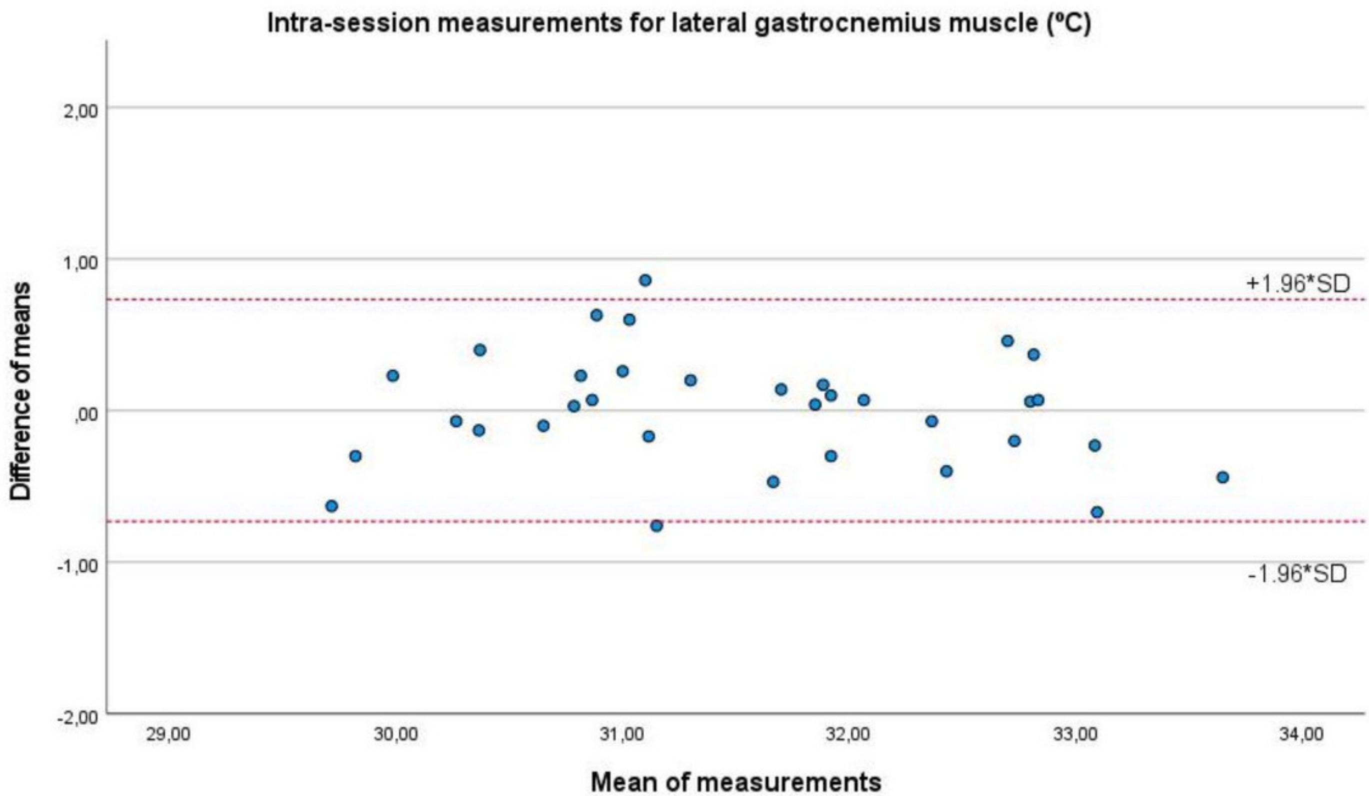
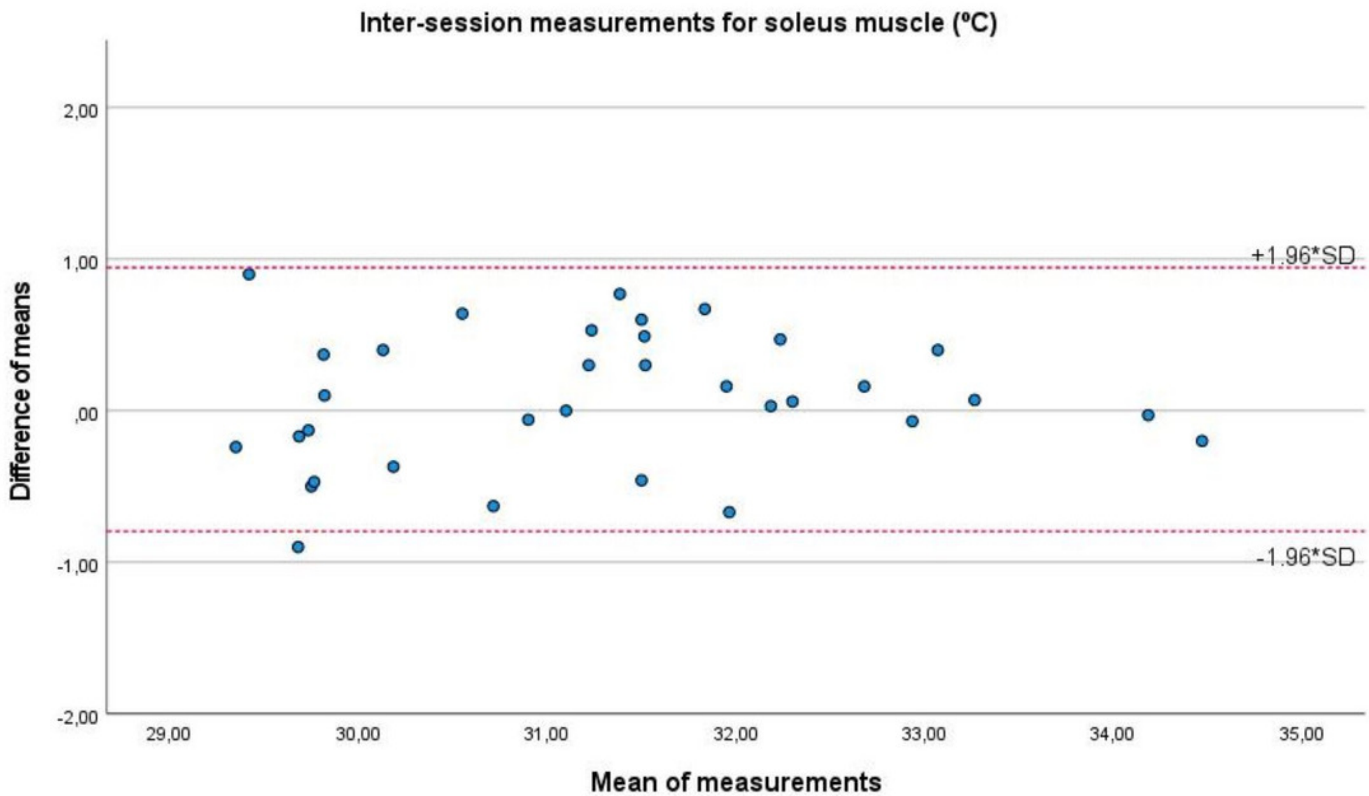


Figure 5

Bland-Altman plots agreement for inter-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the soleus muscle tissue of athletes.

Completed with the upper and lower limits of agreement (LoA).

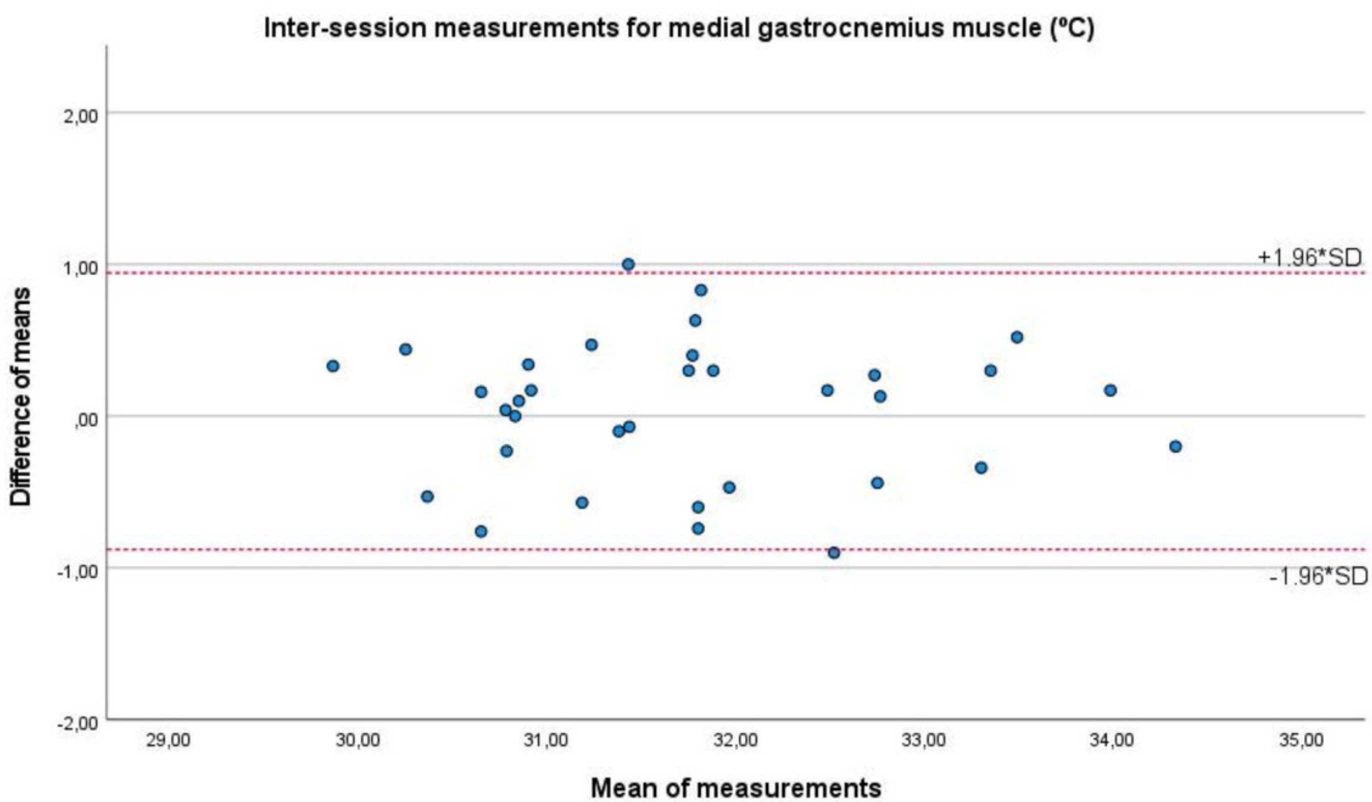


[redacted]

Figure 6

Bland-Altman plots agreement for inter-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the medial gastrocnemius muscle tissue of athletes.

Completed with the upper and lower limits of agreement (LoA).

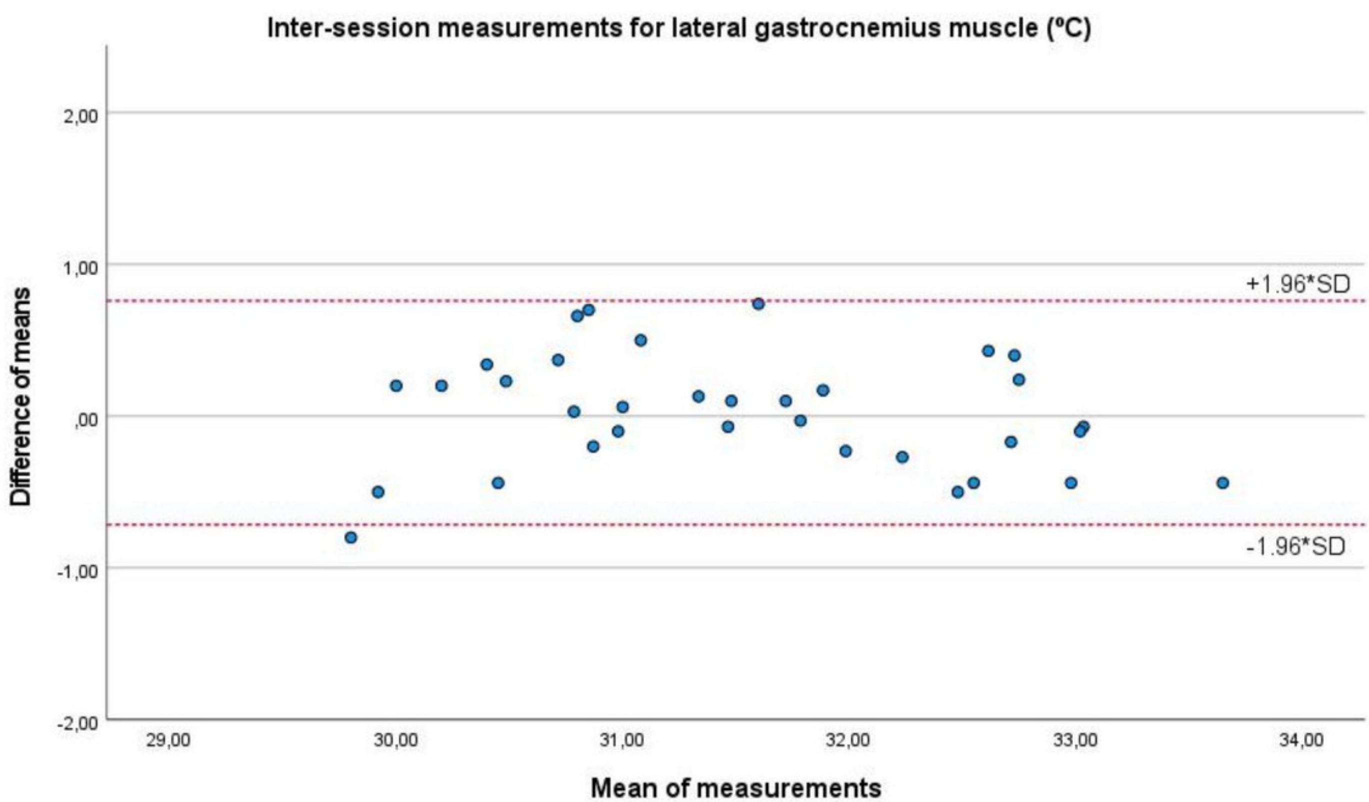


[redacted]

Figure 7

Bland-Altman plots agreement for inter-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the lateral gastrocnemius muscle tissue of athletes.

Completed with the upper and lower limits of agreement (LoA).



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