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. These tools were cheaper than other thermographic devices used to measure superficial human muscle tissue temperature. In addition, infrared thermography has been previously used to assess skin temperature related to muscle tissue conditions in the triceps surae of athletes. Nevertheless, the reliability and repeatability of an infrared thermography device designed for materials, such as the Manual Infrared Camera PCE-TC 30, have yet to be determined to measure skin temperature of the triceps surae muscle tissue of athletes. *Objective:* The purpose was to determine the procedure's intra- and inter-session reliability and repeatability to determine skin temperature within the Manual Infrared Camera PCE-TC 30 thermography device in the triceps surae muscle tissue of athletes, which was initially designed to measure the superficial temperature of materials. *Methods:* A total of 34 triceps surae muscles were bilaterally assessed from 17 healthy athletes using the Manual Infrared Camera PCE-TC 30 thermography device to determine intra- (at the same day separated by 1 hour) and inter-session (at alternate days separated by 48 hours) reliability and repeatability of the skin temperature of the soleus, medial and lateral gastrocnemius muscles. The triceps surae complex weas measured by a region of interest of 1 cm^2 through five infrared thermography images for each muscle. Statistical analyses comprised 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). *Results:* Intra- and inter-session measurements of the proposed infrared thermography procedure 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 procedure to determine skin temperature within the Manual Infrared Camera PCE-TC 30 thermography device presented excellent intra- and inter-session reliability and repeatability in athletes' triceps surae muscle tissue. Future studies should consider the SEM and MDC of this procedure to measure the skin temperature of soleus, medial, and lateral gastrocnemius muscles to promote triceps surae muscle prevention and recovery in athletes.

1 *Article title*

2 **Intra- and Inter-session Reliability and Repeatability of an Infrared**

3 **Thermography Device Designed for Materials to Measure Skin**

4 **Temperature of the Triceps Surae Muscle Tissue of Athletes**

5 *Runing title*
6 Reliability and Repeatability of Infrared Thermography

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28 "Fiabilidad sobre el dispositivo de termografía Manual Infrared camera PCE-TC 30 en humanos" (Reference number: 6-2020).

29 **Institutional Review Board Statement:** This study was approved by the clinical intervention ethics committee of the Hospital
30 Clínico San Carlos, Madrid (Spain), with internal code number 20/021-E on January 20, 2020.

31 **Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

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37 PCE Ibérica S.L. (Reference number: 6-2020) was specifically carried out to study the reliability of the Manual Infrared camera
38 PCE-TC 30 thermography device.

40 *Article*

41 **Intra- and Inter-session Reliability and Repeatability of an**

42 **Infrared Thermography Device Designed for Materials to**

43 **Measure Skin Temperature of the Triceps Surae Muscle**

44 **Tissue of Athletes**

45 **Abstract**

46 *Background:* Infrared thermography devices have been commonly applied to measure superficial

47 temperature in structural composites and walls. These tools were cheaper than other

48 thermographic devices used to measure superficial human muscle tissue temperature. In addition,

49 infrared thermography has been previously used to assess skin temperature related to muscle

50 tissue conditions in the triceps surae of athletes. Nevertheless, the reliability and repeatability of

51 an infrared thermography device designed for materials, such as the Manual Infrared Camera

52 PCE-TC 30, have yet to be determined to measure skin temperature of the triceps surae muscle

53 tissue of athletes.

54 *Objective:* The purpose was to determine the procedure's intra- and inter-session reliability and

55 repeatability to determine skin temperature within the Manual Infrared Camera PCE-TC 30

56 thermography device in the triceps surae muscle tissue of athletes, which was initially designed

57 to measure the superficial temperature of materials.

58   *Methods:* A total of 34 triceps surae muscles were bilaterally assessed from 17 healthy athletes

59   using the Manual Infrared Camera PCE-TC 30 thermography device to determine intra- (at the

60   same day separated by 1 hour) and inter-session (at alternate days separated by 48 hours)

61   reliability and repeatability of the skin temperature of the soleus, medial and lateral

62   gastrocnemius muscles. The triceps surae complex weas measured by a region of interest of 1

63   cm^2 through five infrared thermography images for each muscle. Statistical analyses comprised

64   intraclass correlation coefficient (ICC), standard error of measurement (SEM), minimum

65   detectable change (MCD), systematic error of measurement, correlation (r), and Bland-Altman

66   plots completed with linear regression models (R^2).

67   *Results:* Intra- and inter-session measurements of the proposed infrared thermography procedure

68   showed excellent reliability ($ICC_{(1,2)} = 0.968 - 0.977$), measurement errors (SEM = 0.186 –

69   0.232ºC; MDC = 0.515 – 0.643 ºC), correlations (r = 0.885 – 0.953), and did not present

70   significant systematic error of measurements ($P > .05$). Adequate agreement between each pair

71   of measurement moments was presented by the Bland-Altman plots according to the limits of

72   agreement and non-significant linear regression models ($R^2 = 0.000 - 0.019$; $P > .05$).

73   *Conclusions:* The proposed procedure to determine skin temperature within the Manual Infrared

74   Camera PCE-TC 30 thermography device presented excellent intra- and inter-session reliability

75   and repeatability in athletes' triceps surae muscle tissue. Future studies should consider the SEM

76   and MDC of this procedure to measure the skin temperature of soleus, medial, and lateral

77   gastrocnemius muscles to promote triceps surae muscle prevention and recovery in athletes.

78   **Keywords:** Data Management; Lower Extremity; Reproducibility of Results; Sports;

79   Thermosensing.

80 *Highlights*:

81 • Prior high-quality thermography devices were reliable in measuring skin temperature

82 • The proposed device was initially designed for materials with superficial temperature

83 • This device is reliable and repeatable for measuring triceps surae skin temperature

84 • This cheap tool could promote triceps surae prevention and recovery in athletes

1. Introduction

86   Infrared thermography was proposed as one of the most relevant non-ionizing radiation tools

87 to assess skin temperature related to muscle tissue conditions, such as compartmental syndrome.

88 Nevertheless, there is a lack of scientific evidence for other musculoskeletal conditions (Sanchis-

89 Sánchez et al., 2014). Among different application fields, the use of inflammation and perfusion-

90 based conditions may be evaluated by thermographic imaging in sports medicine (Ramirez-

91 Garcia Luna et al., 2022). This device has been used to determine the superficial temperature of

92 muscle tissue of lower limbs from athletes for injury prevention (Côrte et al., 2019), muscle

93 activity assessment (Rodriguez-Sanz et al., 2019), and evaluations before and after treatments

94 (Rodriguez et al., 2018; Benito-de-Pedro et al., 2019). In addition, assessments before and after

95 running were performed in the triceps surae from athletes as a main focus linked to

96 musculoskeletal conditions (Rodríguez-Sanz et al., 2017; Rodriguez-Sanz et al., 2018; Rodriguez

97 et al., 2018; Benito-de-Pedro et al., 2019).

98   Different thermography methods to determine skin temperature in the calves' muscular

99 region showed good correlations among them ($R^2 = 0.885 - 0.924$) and between both sides ($R^2 =$

100 $0.754 - 0.881$; $r = 0.868 - 0.939$) within adequate agreement by Bland-Altman plots (Ludwig et

101   al., 2014). Thermography assessment was used to measure the cutaneous temperature of triceps

102   surae muscles in soccer players with equinus condition versus non-equinus condition after

103   running (Rodriguez-Sanz et al., 2018), as well as at rest (Rodríguez-Sanz et al., 2017). In

104   addition, this tool was applied to determine the treatment effects after different physical therapy

105   interventions, such as dry needling and ischemic compression, in triathletes (Benito-de-Pedro et

106   al., 2019). In addition, infrared thermography was utilized to measure skin temperature changes

107   after compressive versus standard stockings use in athletes (Rodriguez et al., 2018). All these

108   evaluations were carried out by the FLIR/SC3000/QWIP Thermacan thermographic tool to

109   measure the skin temperature of the triceps surae muscle tissue.

110   The FLIR/SC3000/QWIP Thermacan infrared thermal device presented an 8–9 μm spectral

111   range, a temperature sensitivity of 0.02 K, a display of 320 × 240 pixels with 20º lens and a

112   spatial resolution of 1.1 mrad, being frequently used to evaluate the superficial temperature in the

113   human tissue with adequate reliability and repeatability (Rodríguez-Sanz et al., 2017; Rodriguez-

114   Sanz et al., 2018; Rodriguez et al., 2018; Benito-de-Pedro et al., 2019), by both manual and

115   automatic thermographic software package measurement methods with an adequate agreement

116   and excellent intraclass correlation coefficient (ICC > 0.80) (Requena-Bueno et al., 2020). Prior

117   statistical procedures, such as ICC and Bland-Altman plots, including limits of agreement (LoA),

118   were used to compare infrared thermographic values in the lower limbs showing that both

119   manual and automatic definition devices presented an excellent ICC from 0.92 to 0.99 with an

120   adequate agreement by visual distribution and similar LoA by the ThermoHuman® devices

121   (Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020), excellent inter-session

122   reproducibility with an ICC of 0.88 using the digital infrared camera IRTIS-2000® (Zaproudina

123   et al., 2008), and almost perfect agreement in replication with an ICC from 0.94 to 0.97 by the

124   Thermofocus® thermal imaging device (Petrova et al., 2018).

125   Nevertheless, these devices were more expensive than an infrared thermography device

126   designed to evaluate superficial temperature on materials. One of these thermographic devices

127   was the Manual Infrared Camera PCE-TC 30. This tool displayed a sensor resolution of 80x80, a

128   measurement range from 0 to 250ºC, a display of 320 × 240 pixels, a thermal sensitivity of 80

129   mK, and an 8 mm lens (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014). Despite this, the

130   thermal imaging system presented very low parameters concerning geometrical resolution (80 ×

131   80 pixels) and thermal sensitivity of 80 mK, while other thermal imaging systems displayed high

132   definition resolution (1280 × 960 pixels) and higher thermal sensitivity of 20 mK (Fernandez-

133   Cuevas et al., 2017; Requena-Bueno et al., 2020), the Manual Infrared Camera PCE-TC 30

134   geometrical resolution and thermal sensitivity features could present adequate reliability to

135   measure triceps surae muscle tissue temperature variations (Rodríguez-Sanz et al., 2017;

136   Rodriguez-Sanz et al., 2018; Rodriguez et al., 2018; Benito-de-Pedro et al., 2019). Indeed, the

137   PCE-TC 30 thermal camera has already been employed to assess the thermal behavior of fencing

138   uniforms in athletes (Lamberti et al., 2020), but the reliability and repeatability of this tool

139   directly on the skin of the human muscle have yet to be determined.

140   This infrared thermography device was used to measure superficial temperature in structural

141   composites and walls according to quality inspections, such as reproducibility, stability,

142   reliability, and operating temperature (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014).

143   Although this tool is used to assess thermal temperature in the fencing uniforms of athletes

144   (Lamberti et al., 2020), it has not been applied directly to measure superficial human muscle

145   tissue temperature, which could be of interest in the triceps surae of athletes (Rodríguez-Sanz et

146 al., 2017; Rodriguez-Sanz et al., 2018; Rodriguez et al., 2018; Benito-de-Pedro et al., 2019;

147 Requena-Bueno et al., 2020).

148   We hypothesized that this device – developed initially for non-Vivo structures – could

149 provide adequate reliability and repeatability to determine skin temperature in the triceps surae

150 muscle human tissue of athletes, being less expensive than the infrared thermography device

151 used in human studies. Thus, the purpose of the present study was to determine the intra- and

152 inter-session reliability and repeatability of the procedure to assess skin temperature within the

153 Manual Infrared Camera PCE-TC 30 thermography device in the triceps surae muscle tissue of

154 athletes, which was designed initially to measure the superficial temperature of materials.

155

156 **2. Materials and Methods**

157 *2.1. Study design*

158   The present study was carried out from January 2020 to May 2021 according to The

159 Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) criteria

160 (Appendix 1). The Helsinki Declarations, as well as specific human experimentation ethical

161 rules, were taken into account. The ethics committee for clinical interventions of the Hospital

162 Clínico San Carlos, Madrid (Spain) approved this study with internal code number 20/021-E on

163 January 20, 2020. Before the study began, all participants signed the informed consent form. In

164 addition, the present study was supported by Contract 83 between Complutense University and

165 PCE Ibérica S.L. (Reference number: 6-2020), providing a specific grant for this research

166 project.

167 *2.2. Sample size*

168   The sample size determination was calculated by bi-variate correlations statistical

169   procedures through G*Power 3.1.9.2 program (G*Power$^{©}$, from Dusseldorf University, in

170   Germany), considering a 0.4 correlation coefficient to achieve a moderate correlation (Lobo et

171   al., 2016) between infrared thermography measurements, applying a 1-tailed hypothesis, a 0.05 α

172   error and a 0.80 power. Lastly, the sample size was 34 triceps surae muscles to achieve the

173   required thermography measurements for a 0.801 actual power.

174   *2.3. Participants*

175   Thirty-four triceps surae muscles were bilaterally analyzed from 17 healthy athletes

176   considering a consecutive sampling recruitment procedure. Inclusion criteria comprised

177   specifically healthy athletes aged 18–65 years providing the consent information document

178   previously, carrying out sports activities and training for at least 2 h as well as one day per week,

179   with moderate (level-II) or vigorous (level-III) intensities for physical activity with metabolic

180   equivalent indexes greater than 600 METs/min/week, measured by the International

181   Questionnaire for Physical Activity (IPAQ) (Roman-Viñas et al., 2010).

182   Exclusion criteria included muscle soreness, congenital dysfunctions, neuromuscular

183   conditions, rheumatic alterations, body mass index (BMI) greater than 31 kg/m^2, previous

184   neurological conditions, prior surgeries and skin pathologies. Some alterations in the lower limbs

185   region (i.e., chronic ankle instability presence, prior sprains or previous fractures) were also

186   excluded according to the thermographic influence of compartmental, stress, inflammation, and

187   perfusion-based conditions (Sanchis-Sánchez et al., 2014; Ramirez-GarciaLuna et al., 2022).

188   Lastly, difficulties or inability to carry out the procedure to complete the study course, explained

189   below, were considered as exclusion criteria.

190 *2.4. Procedure*

191   Intra- and inter-session reliability and repeatability of the skin temperature of the triceps

192 surae muscles were bilaterally assessed by the Manual Infrared Camera PCE-TC 30 to determine

193 measurement agreement and concordance at the same day separated by 1 hour (considered as

194 intra-day measurements) and alternate days separated by 48 hours (considered as inter-day

195 measurements), respectively. Indeed, participants were asked to continue with their daily life and

196 physical exercise routine (avoiding unusual efforts or activity changes) between measurements

197 and not taking prescribed medications at the prior week nor vasomotor substances (i.e., caffeine)

198 on the same measurement day, as well as heavy metals were not allowed. A period of 5 minutes

199 of acclimatization of the subjects to the room was applied (Figure 1). All measurements were

200 assessed with patients standing up in a relaxed position in the same room within a 24.1 ± 1 C°

201 temperature and a 45 ± 10% humidity, without direct ventilation flow toward examiners or

202 participants (Rodríguez-Sanz et al., 2017).

203

204   *Please, include Figure 1 here or hereabouts*

205   **Figure 1.** Infographics for evaluating and analyzing the infrared thermography images of the triceps surae complex.

206

207

208 *2.5. Descriptive data*

209   Descriptive data including sex (categorized as male or female), age (measured in years),

210 height (measured in cm), weight (measured in kg), and BMI (expressed as kg/cm^2 following the

211 Quetelet's index) (Garrow, 1986), main sports category (divided into fitness considered as

212 bodybuilding exercise or soccer), side (categorized as right or left), and dominance (expressed as

213 yes or no), and smoker (expressed as yes or no) were detailed (Calvo-Lobo et al. 2019). As a tool

214 with adequate psychometric properties, metabolic equivalent index per minute per week

215 (METs/min/week) was evaluated by the IPAQ to determine physical activity and its

216 categorization as moderate (600–1500 METs/min/week) and vigorous ($\geq$ 1500 METs/min/week)

217 physical activity (Gauthier, Lariviere & Young, 2009).

218 *2.6. Infrared thermography*

219   We used a Manual Infrared Camera PCE-TC 30 (PCE Instruments UK Ltd; Southampton,

220 United Kingdom), which displayed a sensor resolution of 80 × 80, a measurement range from 0

221 to 250ºC, a display of 230 × 240 pixels, a thermal sensitivity of 80 mK and an 8-mm lens (De

222 Villoria et al., 2011; Pérez-Urrestarazu et al., 2014). The infrared thermography imaging process

223 was performed with the participant standing up in a relaxed position 1 m from the camera.

224 Bilaterally, the triceps surae complex, including lateral (Figure 1A and 1B) and medial (Figure

225 1C and 1D) gastrocnemius, as well as soleus (Figure 1E and 1F) muscles, was measured by a

226 region of interest (ROI) through five infrared thermography images for each muscle. Removing

227 the highest and lowest values, the mean of the three measurements was used for data analysis.

228   Infrared images and data were analyzed by a blinded and experienced evaluator using the

229 Guide^{TM} Report Express (PCE Instruments UK Ltd; Southampton, United Kingdom)

230 (Rodríguez-Sanz et al., 2017). This software provided the mean thermal value (ºC) of the

231 selected ROI of 1 cm^2 coinciding with the center of a landmark for each muscle (Figure 2).

232 These landmarks were used to determine superficial skin temperature and placed superior to the

233 Achilles tendon for the soleus muscle and in the thickest part of the medial and lateral

234 gastrocnemius muscles according to prior similar studies (Benito-de-Pedro et al., 2019; Rojas-

235 Valverde et al., 2021).

236

237	*Please, include Figure 2 here or hereabouts*

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

241

242 *2.7. Statistical Analyses*

243 The 24.0 Statistical Package Program for Social Science (named SPSS; from IBM-Corp, in

244 Armonk, NY) was used for data analyses. The α error was set at 0.05, and thus a *P*-value lower

245 than 0.05 was considered statistical significance. The Kolmogorov-Smirnov statistical test and

246 visual inspection of histograms were considered to detail normality distribution. Data adjusted to

247 normal distribution were detailed through means ± standard deviations (SD) in conjunction with

248 the upper and lower limits of 95% confidence interval (CI). Data adjusted to non-normal

249 distribution were detailed through medians ± interquartile ranges (IR). Infrared thermography

250 measurements for intra- and inter-session evaluations were compared through paired-sample

251 Student t-tests considering parametric tests and Wilcoxon tests regarding non-parametric tests.

252 ICC analyzed the reliability and repeatability between each pair of measurements for

253 bidirectional absolute agreement and Pearson (*r*) or Spearman (*ρ*) correlation coefficients as

254 parametric or non-parametric tests, respectively. Furthermore, ICC $_{(2,1)}$ values were specifically

255 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

256 $_{(2,1)}$, and excellent for 0.75 − 1.00 ICC$_{(2,1)}$ (Calvo-Lobo et al., 2019).

257 Next, correlation coefficients were specifically interpreted as weak for 0.00 − 0.40 *r* or *ρ*,

258 moderate for 0.41 − 0.69 *r* or *ρ*, and strong for 0.70 − 1.00 *r* or *ρ* (Lobo et al., 2016). Standard

259 errors for measurements (SEM) values were detailed through SD $\times \sqrt{(1 - ICC)}$. After,

260 minimum detectable changes (MDC) values were detailed through $\sqrt{2} \times 1.96 \times SEM$ for 95%

261 CI. Both MDC and SEM were detailed through Bland and Altman recommendations (Calvo-

262   Lobo et al., 2019). Limits for agreement (LoA) for each pair of measurements were detailed

263   through differences means $\pm\ 1.96 \times SD$ for 95% CI in line with Bland and Altman (Bland &

264   Altman, 2010; Calvo-Lobo et al., 2019).

265   In addition, Bland-Altman plots were shown to detail visual agreements for each pair of

266   measurements showing systematic measurement errors of the differences in means distributions

267   for each pair of measurements located at the Y-axis with regards to the means for each pair of

268   measurements located at the X-axis. These Bland-Altman plots were shown in conjunction with

269   linear regression models. R^2 coefficients were calculated to detail the adjustment quality. The

270   mean values for each pair of measurements were considered independent variables. Lastly, the

271   differences for each pair of measurements were considered dependent variables (Bland &

272   Altman, 2010).

273

3. Results

275   *3.1. Descriptive data*

276   The final sample comprised 34 triceps surae muscles bilaterally from 17 healthy athletes,

277   nine (52.9%) males and eight (47.1%) females, with mean ± SD (95% CI) age of 41.76 ± 14.42

278   (36.73–46.79) years, the weight of 68.57 ± 14.57 (63.40–73.64) kg, the height of 1.69 ± 0.09

279   (1.66–1.73) m, and BMI of 23.45 ± 3.47 (22.24–24.66) kg/m². Regarding the main sports

280   category, these athletes performed in fitness (n = 14; 82.40%) and soccer (n = 3; 17.6%). All

281   athletes presented the dominant right side (n = 17; 100%); most were non-smokers (n = 12;

282   70.60%). Considering the IPAQ, the mean ± SD (95% CI) of metabolic equivalents index per

283   minute per week was 3276.08 ± 1876.49 (2621.34 − 3930.82) METs/min/week, including eight

284   (47.10%) athletes who performed vigorous physical activity and nine (52.90%) athletes who

285   performed moderate physical activity. Table 1 shows the normality statistics and significance

286   according to the Kolmogorov-Smirnov test.

287

288   *Please, include Table 1 here or hereabouts*

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

290

291   *3.2. Intra-session reliability and repeatability*

292   According to Table 2, intra-session measurements of the infrared thermography device

293   designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue

294   of athletes showed excellent reliability ($ICC_{(1,2)}$ = 0.969 – 0.977), measurement errors (SEM =

295   0.186–0.212ºC; MDC = 0.515–0.587ºC) and did not present any statistically significant

296   systematic error of measurements ($P > 0.05$).

297

298   *Please, include Table 2 here or hereabouts*

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

301

302   Regarding intra-session measurements, bivariate correlations were excellent for the soleus (r

303   = 0.953; $P < 0.001$), medial gastrocnemius (ρ = 0.885; $P < 0.001$), and lateral gastrocnemius (r =

304   0.939; $P < 0.001$).

305   In addition, Bland-Altman plots presented an adequate agreement for intra-session

306   measurements of the infrared thermography device designed for materials (Manual Infrared

307   Camera PCE-TC 30) in the soleus (Figure 3), medial gastrocnemius (Figure 4) and lateral

308   gastrocnemius (Figure 5) muscles of athletes, due to visual distributions of the difference means

309   for each pair of measurements at Y axis concerning the mean for each pair of measurements at

310   X-axis did not present any systematic measurement error and most thermographic measurements

311   were between the upper and lower LoA. In addition to Bland-Altman plots, linear regression

312   models did not show any statistical significance for soleus ($R^2 = 0.000$; $\beta = 0.003$; $F_{1,32} = 0.003$;

313    $P = 0.954$), medial gastrocnemius ($R^2 = 0.002$; $\beta = -0.017$; $F_{1,32} = 0.065$; $P = 0.800$), and lateral

314   gastrocnemius ($R^2 = 0.019$; $\beta = -0.050$; $F_{1,32} = 0.626$; $P = 0.435$) intra-session measurements.

315

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316   *Please, include Figure 3 here or hereabouts*

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

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322   *Please, include Figure 4 here or hereabouts*

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

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327   *Please, include Figure 5 here or hereabouts*

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328   **Figure 5.** Bland-Altman plots agreement for intra-session measurements of the infrared thermography device designed for
329   materials (Manual Infrared Camera PCE-TC 30) in athletes' lateral gastrocnemius muscle tissue, completed with the upper and
330   lower limits of agreement (LoA).

331

332   *3.3. Inter-session reliability and repeatability*

333   According to Table 3, inter-session measurements of the infrared thermography device

334   designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle tissue

335   of athletes presented excellent reliability ($ICC_{(1,2)} = 0.956–0.974$), measurement errors (SEM =

336   0.187–0.232 ºC; MDC = 0.518–0.643 ºC), and did not present any statistically significant

337   systematic error of measurements ($P > 0.05$).

338

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

342
343

344   Considering inter-session measurements, bivariate correlations were also excellent for the

345   soleus ($r = 0.949$; $P < 0.001$), medial gastrocnemius ($r = 0.914$; $P < 0.001$), and lateral

346   gastrocnemius ($r = 0.938$; $P < 0.001$).

347   Lastly, Bland-Altman plots showed an adequate agreement for inter-session measurements

348   of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC

349   30) in the soleus (Figure 6), medial gastrocnemius (Figure 7), and lateral gastrocnemius (Figure

350   8) muscles of athletes, since visual distributions of the difference means for each pair of

351   measurements at the Y axis concerning the mean for each pair of measurements at the X axis did

352   not present any systematic measurement error, and most thermographic measurements were

353   between the upper and lower LoA. In conjunction with the Bland-Altman plots, linear regression

354   models did not show any statistical significance for soleus ($R^2 = 0.014$; $\beta = 0.039$; $F_{1,32} = 0.463$;

355     $P = 0.501$), medial gastrocnemius ($R^2 = 0.000$; $\beta = -0.009$; $F_{1,32} = 0.014$; $P = 0.907$), and lateral

356   gastrocnemius ($R^2 = 0.019$; $\beta = -0.050$; $F_{1,32} = 0.621$; $P = 0.436$) inter-session measurements.

357

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

362

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

367

Please, include Figure 8 here or hereabouts

Figure 8. Bland-Altman plots agreement for inter-session measurements of the infrared thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in athletes' lateral gastrocnemius muscle tissue, completed with the upper and lower limits of agreement (LoA).

372

4. Discussion

The proposed procedure within the Manual Infrared Camera PCE-TC 30 thermography device 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. Although this tool was initially designed to assess the superficial temperature of materials (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014), it could be a less expensive device 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). In addition, the PCE-TC 30 thermal camera may be employed to assess the thermal behavior of fencing uniforms in athletes (Lamberti et al., 2020). Our study supports that this device may be directly used to determine superficial human muscle tissue temperature in the triceps surae of athletes with adequate reliability and repeatability (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).

The PCE-TC 30 thermography device 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®

392   devices showed an excellent intra-session (ICC = 0.99; LoA = 0.0 ± 0.4–0.1 ± 0.4 ºC) and inter-

393   session (ICC = 0.92; LoA = 0.1 ± 0.4–0.1 ± 0.5ºC) reliability before and after running,

394   respectively, detailing small differences effect sizes (Cohen's $d < 0.4$) for foot skin temperature

395   (Requena-Bueno et al., 2020).

396   Specifically, the digital infrared camera IRTIS-2000® applied in the calf region showed

397   adequate intra-session (ICC = 0.84) and inter-session (ICC = 0.66) reliability with similar

398   temperature mean ± SD values for anterior (31.2 ± 0.6 ºC), posterior (30.8 ± 0.6ºC), and lateral

399   (31.3 ± 0.6ºC) calf regions (Zaproudina et al., 2008). Finally, the Thermofocus® thermal

400   imaging device presented almost perfect intra-session agreement in different foot regions (ICC =

401   0.94–0.97), showing non-significant replication interactions (P-values = 0.23–0.84) (Petrova et

402   al., 2018). Despite the use of such modern thermal imaging systems with better definition

403   resolutions could provide more reliable measurements and improve the quality of the

404   thermograms obtained, the reliability and measurement errors provided by the Manual Infrared

405   Camera PCE-TC 30 thermography may be enough to detect temperature differences linked to

406   clinical musculoskeletal changes (Côrte et al., 2019).

407   Athletes may be exposed to physical stress under training loads and competitions with

408   overload reactions which could cause blood flow changes affecting skin temperature (Merla et

409   al., 2010). Infrared thermography may not display anatomical abnormalities, although functional

410   changes may be shown and linked to skin temperature control (Merla et al., 2010; Ring &

411   Ammer, 2012). Infrared thermography use was proposed as a complementary tool to apply

412   preventive measures, such as cryotherapy, physiotherapy, training load reduction, and massage

413   or recovery boot use, to avoid muscle conditions in professional soccer players. The asymmetry

414   reference values range from 0.5ºC to 1ºC between both right and left lower limbs was proposed

415   to initiate this preventive protocol, which reduced up to 63% muscle injuries in a professional

416   soccer season by thermographic monitoring (Côrte et al., 2019). Thus, the Manual Infrared

417   Camera PCE-TC 30 thermography device could be used to determine these cut-off values due to

418   the MDC values varied from 0.515 to 0.587 ºC and from 0.518 to 0.643ºC for intra- and inter-

419   session evaluations, respectively.

420   Our research group carried out a prior thermographic study addressing the thermal skin

421   evaluation of the triceps surae muscles. This study showed that skin temperature after running

422   was deeply linked to electromyography, which may indirectly reflect triceps surae muscle

423   activity. Although the Manual Infrared Camera PCE-TC 30 thermography device has not yet

424   been correlated with electromyography values, thermal values could be related to muscle activity

425   in the triceps surae muscles of athletes using this tool according to a similar study using the

426   FLIR/SC3000/QWIP Thermacan-infrared thermal device (Rodriguez-Sanz et al., 2019).

427   Although some less expensive commercially-available thermal cameras could be suitable for

428   skin temperature assessment, employing the PCE-TC 30 camera to assess triceps surae muscle

429   temperature provided reliable and repeatable measures with MDC cut-off values useful to

430   determine preventive protocols for muscle injuries (Côrte et al., 2019).

431   *4.1. Future studies*

432   Further studies should be designed as randomized clinical trials to determine if these

433   asymmetries reference cut-off values could prevent triceps surae muscle injuries (Côrte et al.,

434   2019). According to prior studies (Hiemstra et al., 2007; Chung et al., 2015), the uninvolved

435   normal side after injury may often be not normal, i.e., presenting temperature values different

436   from healthy subjects, and cut-off values should also be detailed in the future muscle recovery

437   studies. In addition, thermographic measurement of the triceps surae with this device should be

438 analyzed by intra- and inter-rater reliability determining SEM and MDC values and correlated

439 with the other high-end infrared devices as possible gold standards such as ThermoHuman®

440 (Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020), IRTIS-2000®(Zaproudina et al.,

441 2008) and Thermofocus® (Petrova et al., 2018) tools. Furthermore, correlations with

442 electromyography measurements of the triceps surae muscle activity should be carried out

443 (Rodriguez-Sanz et al., 2019). Lastly, the intramuscular temperature should also be correlated

444 with this device to determine concurrent validity concerning a gold standard (Burnham,

445 McKinley & Vincent, 2006).

446 *4.2. Limitations*

447   Various limitations should be considered for the use of this thermographic device. First, the

448 MDC was superior to the lower limbs asymmetry reference range from 0.3ºC to 0.4ºC proposed

449 as a cut-off for following-up before a preventive protocol (Côrte et al., 2019) and therefore, this

450 device should not be used for values lower than 0.5ºC–0.6 ºC.

451   Second, the concurrent validity of this device has not been performed for human tissue

452 temperature, and this validity should be assessed in the future (Burnham, McKinley & Vincent,

453 2006).

454   Third, our sample only comprised healthy athletes, and further studies should analyze skin

455 temperature with this tool over injured muscle tissue (Alburquerque Santana et al., 2022).

456   Fourth, our sample size calculation was accurately detailed to determine a moderate

457 bivariate correlation between measurements, but our sample size was low to achieve the actual

458 power to perform comparisons classifying groups depending on sport category, BMI, and other

459 valued characteristics. In addition, despite statistical analyses were carried out according to our

460 prior sample size calculation model to detail bivariate comparisons for intra- and inter-session

461   measurements, future nested type studies should be designed as nested statistical models such as

462   analyses of variance (ANOVA) to determine more accurate temperature comparisons.

463   Finally, in spite of the device was calibrated according to the manufacturer, the fact that the

464   PCE-TC 30 thermography device was not designed for skin temperature assessment could affect

465   the repeatability of the measurement to a lesser extent than its accuracy. Nevertheless, a

466   comparison between the temperature assessed by a validated thermal camera and the PCE-TC 30

467   was not reported. Future studies should evaluate its accuracy due to a possible wrong estimation

468   of the absolute skin temperature. Procedures for thermographic assessment in sports and exercise

469   sciences have been reviewed by Moreira et al. (Moreira et al., 2017) in a consensus statement of

470   the experts in the field. However, our reliability study aimed to standardize the proposed

471   procedure and contributed to improving the methods behind measures.

472

473   **5. Conclusion**

474   The proposed procedure within the Manual Infrared Camera PCE-TC 30 thermography device

475   designed initially to measure the superficial temperature of materials presented excellent intra-

476   and inter-session reliability and repeatability to measure skin temperature in the triceps surae

477   muscle tissue of athletes. Future studies should consider the measurement errors of this

478   procedure to measure the skin temperature of soleus, medial, and lateral gastrocnemius muscles

479   to promote triceps surae muscle prevention and recovery in athletes.

480

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493

494 **References**

495

496 Alburquerque Santana PV, Alvarez PD, Felipe da Costa Sena A, Serpa TK, Assis MG de,

497   Pimenta EM, Costa HA, Sevilio de Oliveira Junior MN, Torres Cabido CE, Veneroso CE.

498   2022. Relationship between infrared thermography and muscle damage markers in

499   physically active men after plyometric exercise. *Journal of Thermal Biology* 104:103187.

500   DOI: 10.1016/J.JTHERBIO.2022.103187.

501 Benito-de-Pedro M, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, Rodríguez-Sanz D,

502   López-López D, Cosín-Matamoros J, Martínez-Jiménez EM, Calvo-Lobo C. 2019.

503   Effectiveness between dry needling and ischemic compression in the triceps surae latent

504   myofascial trigger points of triathletes on pressure pain threshold and thermography: a

505   single blinded randomized clinical trial. *Journal of Clinical Medicine* 8:1632. DOI:

506   10.3390/jcm8101632.

507 Bland JM, Altman DG. 2010. Statistical methods for assessing agreement between two methods

508   of clinical measurement. *International Journal of Nursing Studies* 47:931–936. DOI:

509   10.1016/J.IJNURSTU.2009.10.001.

510 Burnham RS, McKinley RS, Vincent DD. 2006. Three types of skin-surface thermometers: a

511   comparison of reliability, validity, and responsiveness. *American Journal of Physical*

512   *Medicine & Rehabilitation* 85:553–558. DOI: 10.1097/01.PHM.0000223232.32653.7F.

513   Calvo-Lobo C, Almazán-Polo J, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, Palomo-

514   López P, Rodríguez-Sanz D, López-López D. 2019. Ultrasonography comparison of

515   diaphragm thickness and excursion between athletes with and without lumbopelvic pain.

516   *Physical Therapy in Sport* 37:128–137. DOI: 10.1016/j.ptsp.2019.03.015.

517   Chung KS, Ha JK, Yeom CH, Ra HJ, Lim JW, Kwon MS, Kim JG. 2015. Are muscle strength

518   and function of the uninjured lower limb weakened after anterior cruciate ligament injury?

519   Two-year follow-up after reconstruction. *The American Journal of Sports Medicine*

520   43:3013–3021. DOI: 10.1177/0363546515606126.

521   Côrte AC, Pedrinelli A, Marttos A, Souza IFG, Grava J, José Hernandez A. 2019. Infrared

522   thermography study as a complementary method of screening and prevention of muscle

523   injuries: pilot study. *BMJ Open Sport & Exercise Medicine* 5:e000431. DOI:

524   10.1136/BMJSEM-2018-000431.

525   Fernandez-Cuevas I, Marins JC, Lastras JA, Carmona PG, Quintana MS. 2017. Validity,

526   Reliability, And Reproducibility Of Skin Temperature In Healthy Subjects Using Infrared

527   Thermography. *Agache's Measuring the Skin: Non-invasive Investigations, Physiology,*

528   *Normal Constants: Second Edition*:1311–1318. DOI: 10.1007/978-3-319-32383-1_74.

529   Garrow JS. 1986. Quetelet index as indicator of obesity. *Lancet (London, England)* 1:1219.

530   Gauthier AP, Lariviere M, Young N. 2009. Psychometric properties of the IPAQ: a validation

531   study in a sample of northern Franco-Ontarians. *Journal of Physical Activity & Health* 6

532   Suppl 1:S54-60.

533   Hiemstra LA, Webber S, MacDonald PB, Kriellaars DJ. 2007. Contralateral limb strength

534   deficits after anterior cruciate ligament reconstruction using a hamstring tendon graft.

535   *Clinical   Biomechanics   (Bristol,   Avon)   22:543–550.   DOI:*

536   10.1016/J.CLINBIOMECH.2007.01.009.

537   Lamberti G, Leccese F, Salvadori G, Fantozzi F. 2020. Effect of exercise on athletes performing

538   in fencing uniforms: methodology and preliminary results of the use of infrared

539   thermography to detect the thermal behaviour of fencers. *Applied Sciences* 10:3296. DOI:

540   10.3390/APP10093296.

541   Lobo CC, Morales CR, Sanz DR, Corbalan IS, Marin AG, Lopez DL. 2016. Ultrasonography

542   comparison of peroneus muscle cross-sectional area in subjects with or without lateral ankle

543   sprains. *Journal of Manipulative and Physiological Therapeutics* 39:635–644. DOI:

544   10.1016/j.jmpt.2016.09.001.

545   Ludwig N, Formenti D, Gargano M, Alberti G. 2014. Skin temperature evaluation by infrared

546   thermography: Comparison of image analysis methods. *Infrared Physics & Technology*

547   62:1–6. DOI: 10.1016/J.INFRARED.2013.09.011.

548   Merla A, Mattei PA, Di Donato L, Romani GL. 2010. Thermal imaging of cutaneous

549   temperature modifications in runners during graded exercise. *Annals of Biomedical*

550   *Engineering* 38:158–163. DOI: 10.1007/S10439-009-9809-8.

551   Moreira DG, Costello JT, Brito CJ, Adamczyk JG, Ammer K, Bach AJE, Costa CMA, Eglin C,

552   Fernandes AA, Fernández-Cuevas I, Ferreira JJA, Formenti D, Fournet D, Havenith G,

553   Howell K, Jung A, Kenny GP, Kolosovas-Machuca ES, Maley MJ, Merla A, Pascoe DD,

554   Priego Quesada JI, Schwartz RG, Seixas ARD, Selfe J, Vainer BG, Sillero-Quintana M.

555   2017. Thermographic imaging in sports and exercise medicine: A Delphi study and

556   consensus statement on the measurement of human skin temperature. *Journal of Thermal*

557   *Biology* 69:155–162. DOI: 10.1016/J.JTHERBIO.2017.07.006.

558   Pérez-Urrestarazu L, Egea G, Franco-Salas A, Fernández-Cañero R. 2014. Irrigation systems

559   evaluation for living walls. *Journal of Irrigation and Drainage Engineering* 140:04013024.

560   DOI: 10.1061/(asce)ir.1943-4774.0000702.

561   Petrova NL, Whittam A, MacDonald A, Ainarkar S, Donaldson AN, Bevans J, Allen J,

562   Plassmann P, Kluwe B, Ring F, Rogers L, Simpson R, Machin G, Edmonds ME. 2018.

563   Reliability of a novel thermal imaging system for temperature assessment of healthy feet.

564   *Journal of Foot and Ankle Research* 11:22. DOI: 10.1186/S13047-018-0266-1.

565   Ramirez-GarciaLuna JL, Bartlett R, Arriaga-Caballero JE, Fraser RDJ, Saiko G. 2022. Infrared

566   thermography in wound care, surgery, and sports medicine: a review. *Frontiers in*

567   *physiology* 13:838528. DOI: 10.3389/FPHYS.2022.838528.

568   Requena-Bueno L, Priego-Quesada JI, Jimenez-Perez I, Gil-Calvo M, Pérez-Soriano P. 2020.

569   Validation of ThermoHuman automatic thermographic software for assessing foot

570   temperature before and after running. *Journal of Thermal Biology* 92:102639. DOI:

571   10.1016/j.jtherbio.2020.102639.

572   Ring EFJ, Ammer K. 2012. Infrared thermal imaging in medicine. *Physiological Measurement*

573   33:R33-46. DOI: 10.1088/0967-3334/33/3/R33.

574   Rodriguez-Sanz D, Losa-Iglesias ME, Becerro-de-Bengoa-Vallejo R, Dorgham HAA, Benito-de-

575   Pedro M, San-Antolín M, Mazoteras-Pardo V, Calvo-Lobo C. 2019. Thermography related

576   to electromyography in runners with functional equinus condition after running. *Physical

577   Therapy in Sport* 40:193-196. DOI: 10.1016/j.ptsp.2019.09.007.

578   Rodriguez-Sanz D, Losa-Iglesias ME, Becerro de Bengoa-Vallejo R, Palomo-Lopez P, Beltran-

579   Alacreu H, Calvo-Lobo C, Navarro-Flores E, Lopez-Lopez D. 2018. Skin temperature in

580   youth soccer players with functional equinus and non-equinus condition after running.

581   *Journal of the European Academy of Dermatology and Venereology* 32(11):2020-2024.

582   DOI: 10.1111/jdv.14966.

583   Rodríguez-Sanz D, Losa-Iglesias ME, López-López D, Calvo-Lobo C, Palomo-López P,

584   Becerro-de-Bengoa-Vallejo R. 2017. Infrared thermography applied to lower limb muscles

585   in elite soccer players with functional ankle equinus and non-equinus condition. *PeerJ*

586   5:e3388. DOI: 10.7717/peerj.3388.

587   Rodriguez D, Becerro-de-Bengoa-Vallejo R, Iglesias MEL, JIMENEZ EVAMM, Muñoz-García

588   D, Boal EP, lobo CC, López-López D. 2018. Effects of compressive stockings and standard

589   stockings in skin temperature and pressure pain threshold in runners with functional ankle

590   equinus condition. *Journal of Clinical Medicine* 7:454. DOI: 10.3390/jcm7110454.

591   Rojas-Valverde D, Gutiérrez-Vargas R, Sánchez-Ureña B, Gutiérrez-Vargas JC, Priego-Quesada

592   JI. 2021. Relationship between skin temperature variation and muscle damage markers after

593   a marathon performed in a hot environmental condition. *Life (Basel, Switzerland)* 11:725.

594   DOI: 10.3390/LIFE11080725.

595   Roman-Viñas B, Serra-Majem L, Hagströmer M, Ribas-Barba L, Sjöström M, Segura-Cardona

596   R. 2010. International physical activity questionnaire: reliability and validity in a Spanish

597   population. *European Journal of Sport Science* 10:297–304. DOI:

598   10.1080/17461390903426667.

599 Sanchis-Sánchez E, Vergara-Hernández C, Cibrián RM, Salvador R, Sanchis E, Codoñer-Franch

600   P. 2014. Infrared thermal imaging in the diagnosis of musculoskeletal injuries: A systematic

601   review and meta-analysis. *American Journal of Roentgenology* 203:875–882. DOI:

602   10.2214/AJR.13.11716.

603 De Villoria RG, Yamamoto N, Miravete A, Wardle BL. 2011. Multi-physics damage sensing in

604   nano-engineered structural composites. *Nanotechnology* 22:185502. DOI: 10.1088/0957-

605   4484/22/18/185502.

606 Zaproudina N, Varmavuo V, Airaksinen O, Närhi M. 2008. Reproducibility of infrared

607   thermography measurements in healthy individuals. *Physiological measurement* 29:515–

608   524. DOI: 10.1088/0967-3334/29/4/007.

609

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/m²)	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.

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

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. 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.

Figure 1

Infographics for evaluating and analyzing the infrared thermography images of the triceps surae complex

Acclimatisation of the subject to the room
(5 minutes)

Temperature= 24.1+/-1ºC
Humidity= 45+/-10%
No direct ventilation flow

Evaluation room

EVALUATION

Subject in a relaxed standing position

Subject-------1m-------Camera

Focus on each muscle (ROI)

5 images/muscle

1 hour

1st Evaluation

2nd Evaluation

Intra-day
measurements

48 hours

3rd Evaluation

Inter-day
measurements

Blinded evaluator
Calculate the mean of the 3
measurements (delete highest and
lowest values)
Guide™ Report Express

Analysis
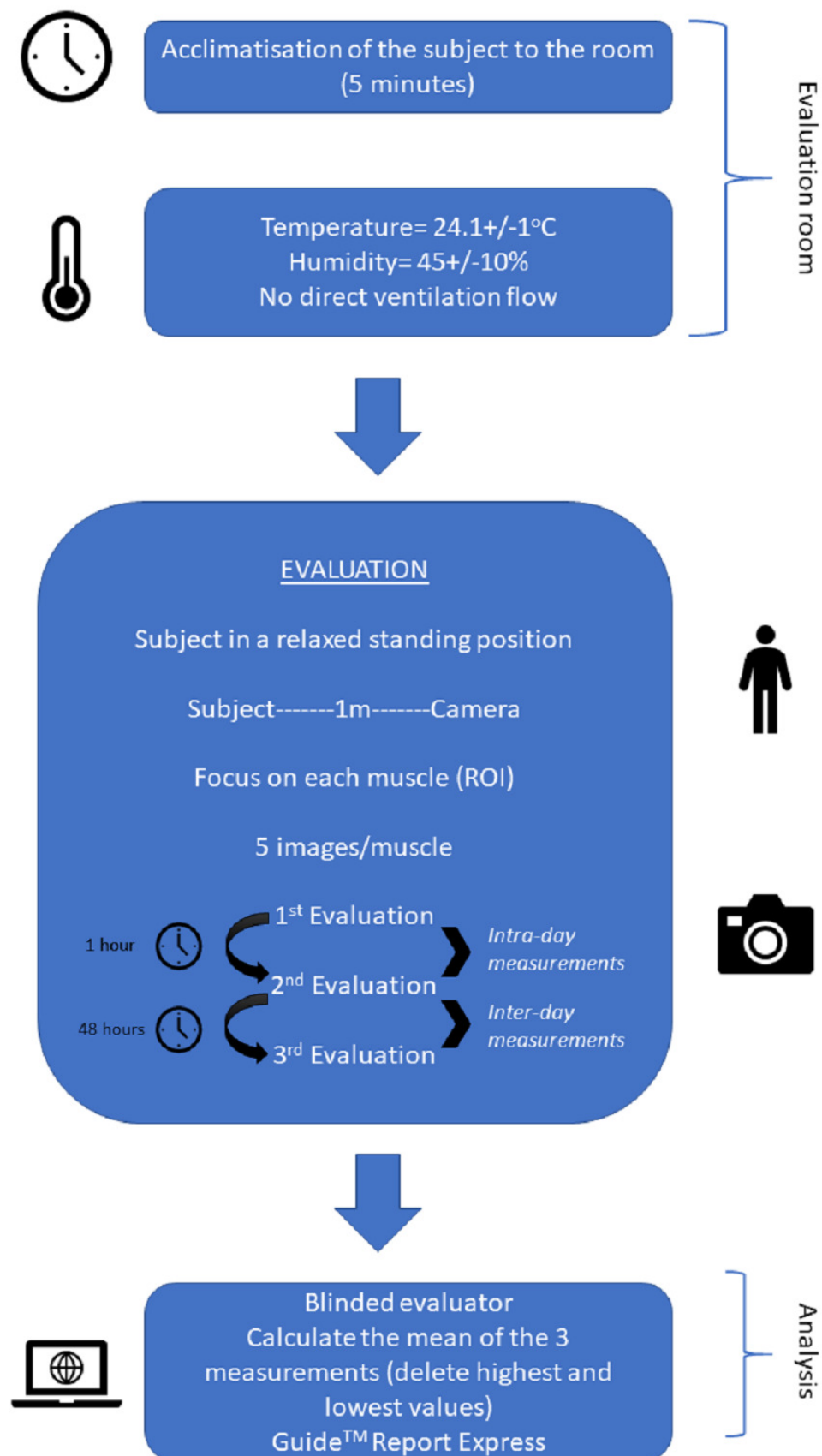
Figure 2

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 intere
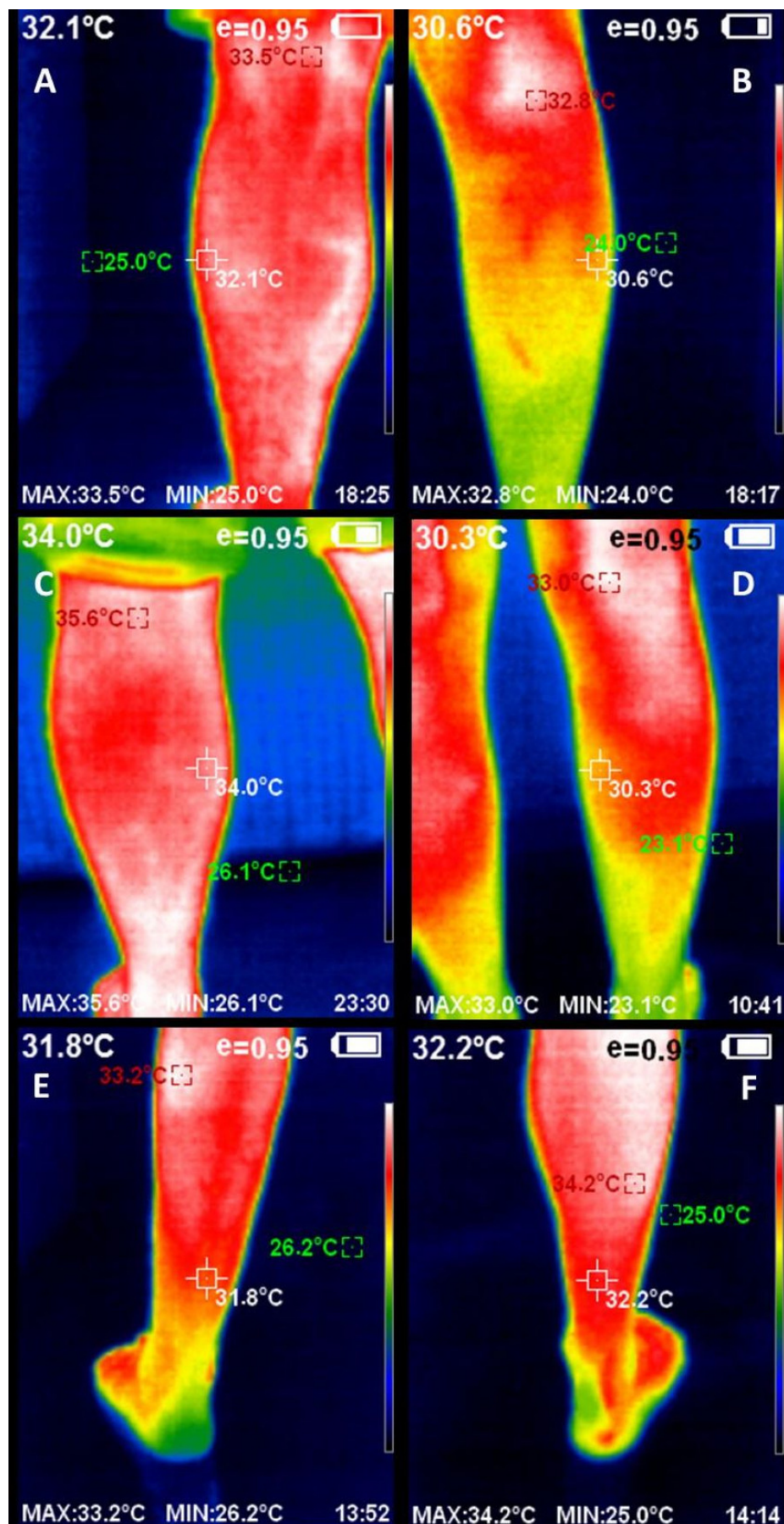
Figure 3

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

Completed with the upper and lower limits of agreement (LoA).
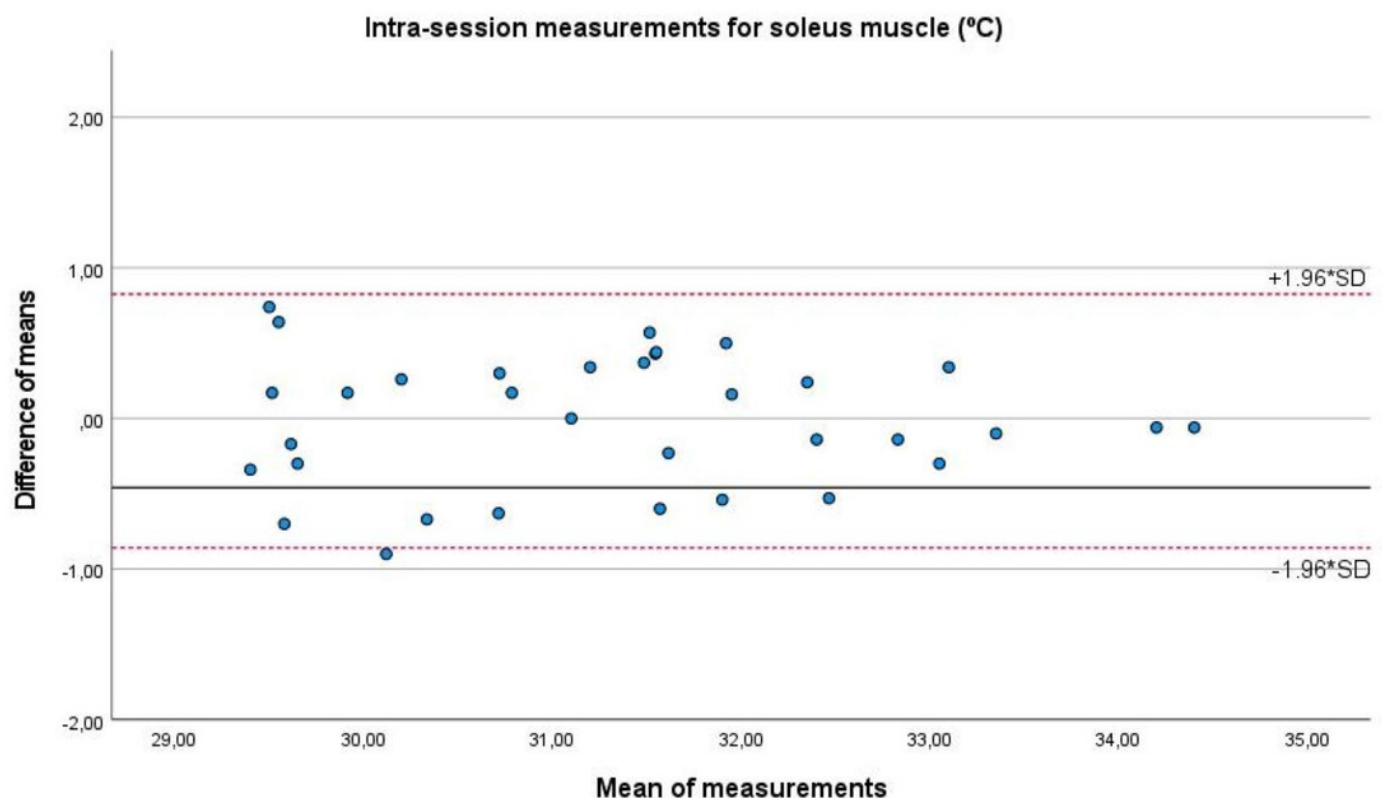
Figure 4

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

Completed with the upper and lower limits of agreement (LoA).
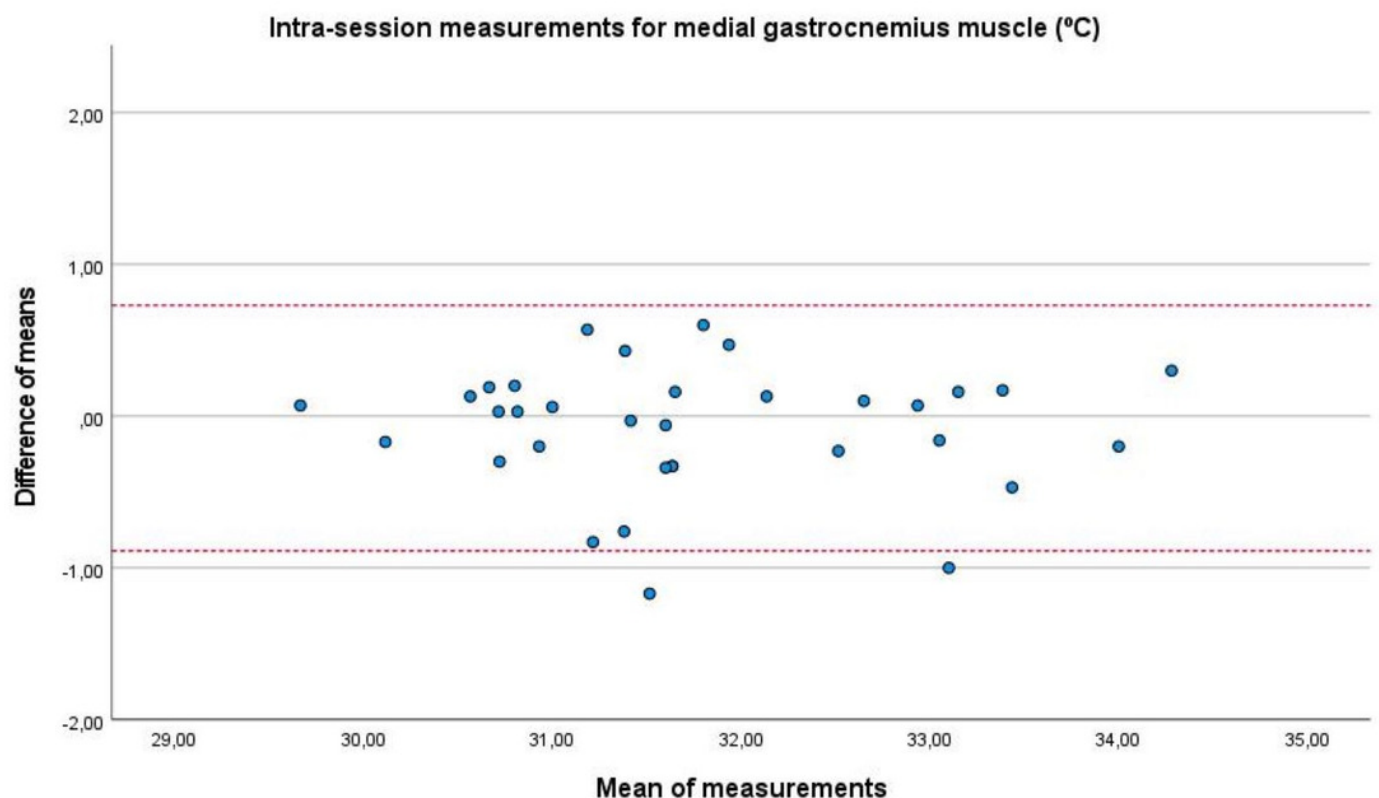
Figure 5

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

Completed with the upper and lower limits of agreement (LoA).
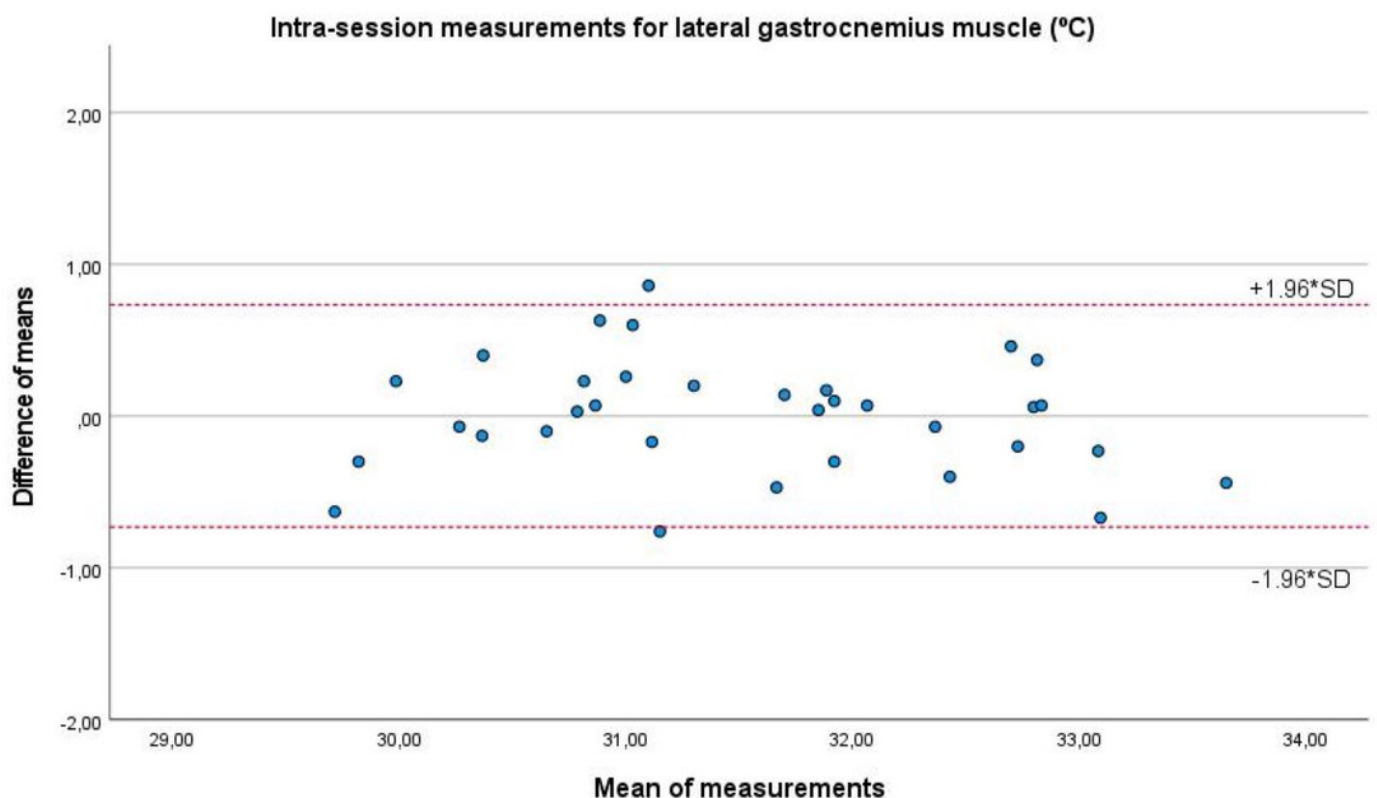
Figure 6

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

Completed with the upper and lower limits of agreement (LoA).
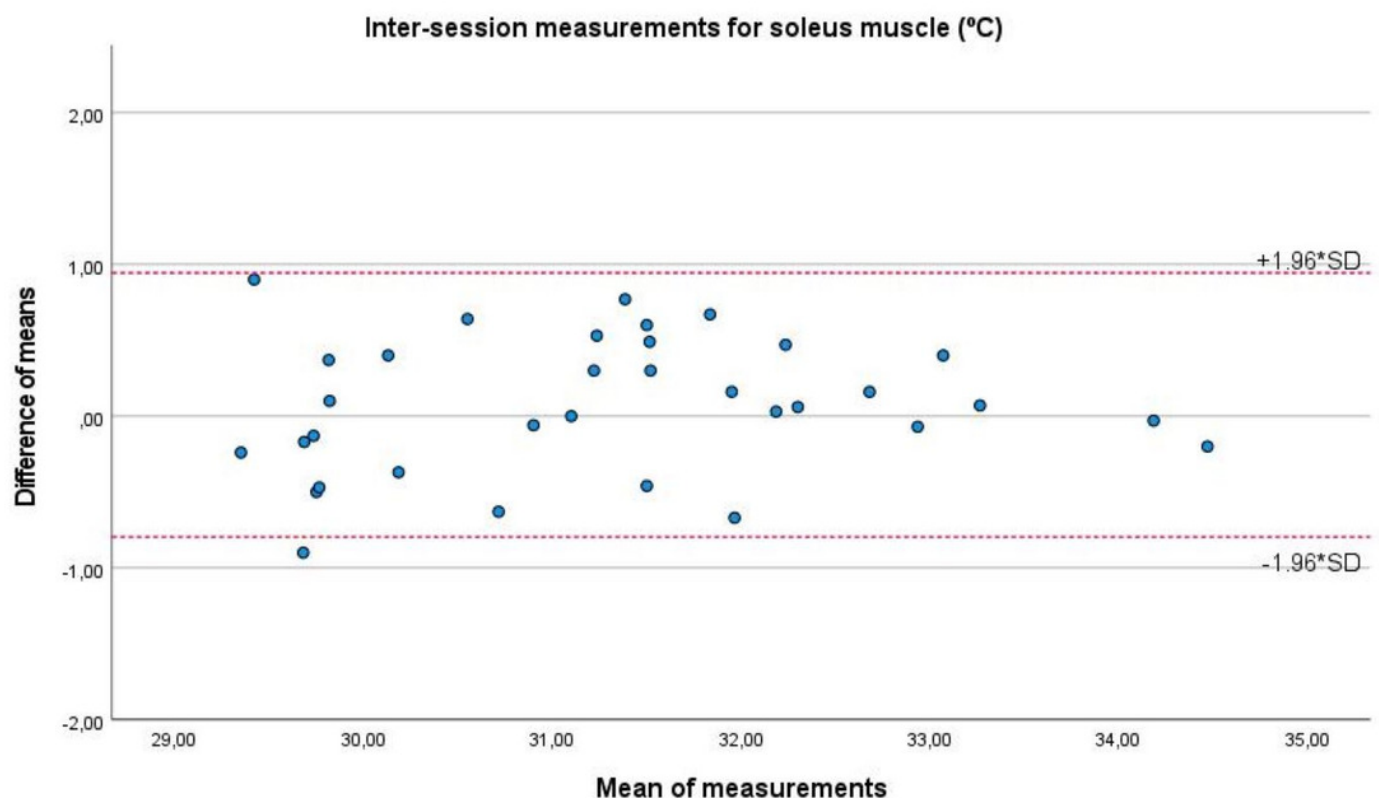
Figure 7

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

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

Figure 8

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

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