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*Article title*

**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**

*Running title*

**Reliability and Repeatability of Infrared Thermography**

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29 | **Funding:** This work has been supported by a Contract 83 between the Complutense University and PCE Ibérica S.L. entitle  
30 | “Fiabilidad sobre el dispositivo de termografía Manual Infrared camera PCE-TC 30 en humanos” (Reference number: 6-  
31 | 2020).

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

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

35 | **Data Availability Statement:** Raw data are available in supplementary file 1.

36 | **Acknowledgments:** Authors acknowledge the support from the Contract 83 between the Complutense University and PCE  
37 | Ibérica S.L. entitle “Fiabilidad sobre el dispositivo de termografía Manual Infrared camera PCE-TC 30 en humanos”  
38 | (Reference number: 6-2020), providing specific grant for the present research.

39 | **Conflicts of Interest:** The authors declare conflict of interest due to the Contract 83 between the Complutense University  
40 | and PCE Ibérica S.L. (Reference number: 6-2020) was specifically carried out to study the reliability of the Manual Infrared  
41 | camera PCE-TC 30 thermography device.

42

43 | *Article*

44 **Intra- and Inter-session Reliability and Repeatability of an**  
45 **Infrared Thermography Device Designed for Materials to**  
46 **Measure Skin Temperature of the Triceps Surae Muscle**  
47 **Tissue of Athletes**

48 **Abstract**

49 *Background:* Infrared thermography devices have been commonly applied to measure  
50 superficial temperature in structural composites and walls. These tools were cheaper than  
51 other thermographic devices used to measure superficial human muscle tissue temperature,  
52 which could be of interest to athletes' triceps surae,  according to prior studies. ~~Infrared~~  
53 ~~thermography devices have been commonly applied to measure superficial temperature in~~  
54 ~~structural composites and walls, being cheaper than other thermographic devices used to~~  
55 ~~measure superficial human muscle tissue temperature, which could be of interest in the triceps~~  
56 ~~surae of athletes according to prior studies.~~

57 *Objective:* The purpose was to determine the procedure's intra- and inter-session reliability  
58 and repeatability to determine skin temperature within the Manual Infrared Camera PCE-TC  
59 30 thermography device in the triceps surae muscle tissue of athletes, which was initially  
60 designed to measure the superficial temperature of materials. ~~The purpose was to determine~~  
61 ~~intra- and inter-session reliability and repeatability of the Manual Infrared Camera PCE-TC~~

62 | ~~30 thermography device designed initially to measure superficial temperature of materials in~~  
63 | ~~the triceps surae muscle tissue of athletes.~~

64 | ~~Methods: A total of 34 triceps surae muscles were bilaterally assessed from 17 healthy~~  
65 | ~~athletes using the Manual Infrared Camera PCE-TC 30 thermography device to determine~~  
66 | ~~intra- and inter-session reliability and repeatability of the skin temperature of the soleus,~~  
67 | ~~medial and lateral gastrocnemius muscles. Statistical analyses comprised intraclass correlation~~  
68 | ~~coefficient (ICC), standard error of measurement (SEM), minimum detectable change~~  
69 | ~~(MCD), systematic error of measurement, correlation ( $r$ ), and Bland-Altman plots completed~~  
70 | ~~with linear regression models ( $R^2$ ).~~ A total of 34 triceps surae muscles were bilaterally  
71 | assessed from 17 healthy athletes by the Manual Infrared Camera PCE-TC 30 thermography  
72 | device in order to determine intra- and inter-session reliability and repeatability of the skin  
73 | temperature of the soleus, medial and lateral gastrocnemius muscles. Intraclass correlation  
74 | coefficient (ICC), standard error of measurement (SEM), minimum detectable change  
75 | (MCD), systematic error of measurement, correlation ( $r$ ) and Bland-Altman plots completed  
76 | with linear regression models ( $R^2$ ) were analyzed.

77 | ~~Results: Intra- and inter-session measurements of the proposed infrared thermography~~  
78 | ~~procedure showed excellent reliability ( $ICC_{(1,2)}=0.968-0.977$ ), measurement errors~~  
79 | ~~( $SEM=0.186-0.232^\circ C$ ;  $MDC=0.515-0.643^\circ C$ ), correlations ( $r=0.885-0.953$ ), and did not~~  
80 | ~~present significant systematic error of measurements ( $P>.05$ ).~~ Intra- and inter-session  
81 | measurements of the infrared thermography device designed for materials in the triceps surae  
82 | muscle tissue of athletes showed excellent reliability ( $ICC_{(1,2)}=0.968-0.977$ ), measurement  
83 | errors ( $SEM=0.186-0.232^\circ C$ ;  $MDC=0.515-0.643^\circ C$ ), correlations ( $r=0.885-0.953$ ) and did  
84 | not present significant systematic error of measurements ( $P>.05$ ). Adequate agreement

85 between each pair of measurement moments was presented by the Bland-Altman plots  
86 according to the limits of agreement and non-significant linear regression models ( $R^2=0.000$ –  
87  $0.019$ ;  $P>.05$ ).

88 **Conclusions:** The proposed procedure to determine skin temperature within the Manual  
89 Infrared Camera PCE-TC 30 thermography device presented excellent intra- and inter-session  
90 reliability and repeatability in athletes' triceps surae muscle tissue. Future studies should  
91 consider the SEM and MDC of this procedure to measure the skin temperature of soleus,  
92 medial, and lateral gastrocnemius muscles to promote triceps surae muscle prevention and  
93 recovery in athletes. ~~The proposed Manual Infrared Camera PCE-TC 30 thermography device~~  
94 ~~designed initially to measure superficial temperature of materials presented excellent intra-~~  
95 ~~and inter-session reliability and repeatability in the triceps surae muscle tissue of athletes.~~  
96 ~~Future studies should consider the measurement errors of this tool to measure skin~~  
97 ~~temperature of soleus, medial and lateral gastrocnemius muscles in order to promote triceps~~  
98 ~~surae muscle prevention and recovery in athletes.~~

99 **Keywords:** ~~Keywords:~~ Athletes, Lower Extremity; Repeatability, Reproducibility of Results;  
100 Thermography

101

### 102 **Highlights:**

- 103 • Prior high quality thermography devices were reliable in measuring ~~to measure~~ skin  
104 temperature
- 105 • The proposed device was initially designed for materials superficial temperature

- 106 • This device is reliable and repeatable for measuring ~~to measure~~ triceps surae skin  
107 temperature
- 108 • This cheap tool could promote triceps surae prevention and recovery in athletes

## 109 1. Introduction

110 Infrared thermography was proposed as one of the most relevant non-ionizing radiation  
111 tools to assess skin temperature related to muscle tissue conditions, such as compartmental  
112 syndrome. Nevertheless, there is a lack of scientific evidence for other musculoskeletal  
113 conditions (Sanchis-Sánchez et al., 2014). Among different application fields, the use of  
114 inflammation and perfusion-based conditions may be evaluated by thermographic imaging in  
115 sports medicine (Ramirez-Garcia Luna et al., 2022). This device ~~was~~ has been used to  
116 determine the superficial temperature of muscle tissue of lower limbs from athletes for injury  
117 prevention (Côte et al., 2019), muscle activity assessment (Rodríguez-Sanz et al., 2019), and  
118 evaluations before and after treatments (Rodríguez et al., 2018; Benito-de-Pedro et al., 2019).  
119 In addition, assessments before and after running were performed in the triceps surae from  
120 athletes as a main focus linked to musculoskeletal conditions (Rodríguez-Sanz et al., 2017;  
121 Rodríguez-Sanz et al., 2018; Rodríguez et al., 2018; Benito-de-Pedro et al., 2019). ~~Infrared~~  
122 ~~thermography was proposed as one of the most relevant non-ionizing radiation tools in order~~  
123 ~~to assess skin temperature related to muscle tissue conditions, such as compartmental~~  
124 ~~syndrome, but there is a lack of scientific evidence for other musculoskeletal conditions~~  
125 ~~(Sanchis-Sánchez et al., 2014). Among different application fields, inflammation and~~  
126 ~~perfusion-based conditions may be benefited by thermographic imaging use in the sport~~  
127 ~~medicine field (Ramirez-Garcia Luna et al., 2022). This device was used as a main outcome~~  
128 ~~measurement to determine superficial temperature in the human muscle tissue of athletes'~~

129 lower limbs for injury prevention (Côte et al., 2019), muscle activity (Rodríguez-Sanz et al.,  
130 2019), evaluation before and after treatments (Rodríguez et al., 2018; Benito-de-Pedro et al.,  
131 2019) as well as assessments before and after running, being the triceps surae from athletes  
132 considered as a main focus linked to musculoskeletal conditions (Rodríguez-Sanz et al., 2017;  
133 Rodríguez-Sanz et al., 2018; Rodríguez et al., 2018; Benito-de-Pedro et al., 2019).

134 Different thermography methods to determine skin temperature in the calves' muscular  
135 region showed good correlations among them ( $R^2 = 0.885 - 0.924$ ) and between both sides ( $R^2$   
136 = 0.754 - 0.881;  $r = 0.868 - 0.939$ ) within adequate agreement by Bland-Altman plots  
137 (Ludwig et al., 2014). Thermography assessment was used to measure the cutaneous  
138 temperature of triceps surae muscles in soccer players with equinus condition versus non-  
139 equinus condition after running (Rodríguez-Sanz et al., 2018), as well as at rest (Rodríguez-  
140 Sanz et al., 2017). In addition, this tool was applied to determine the treatment effects after  
141 different physical therapy interventions, such as dry needling and ischemic compression, in  
142 triathletes (Benito-de-Pedro et al., 2019). In addition, infrared thermography was utilized to  
143 measure skin temperature changes after compressive versus standard stockings use in athletes  
144 (Rodríguez et al., 2018). All these evaluations were carried out by the FLIR/SC3000/QWIP  
145 Thermacon thermographic tool to measure the skin temperature of the triceps surae muscle  
146 tissue. Thermography assessment was used to measure cutaneous temperature of triceps surae  
147 muscles in soccer players with equinus condition after running (Rodríguez-Sanz et al., 2018),  
148 as well as at rest (Rodríguez-Sanz et al., 2017). In addition, this tool was applied to determine  
149 the treatment effects after different physical therapy interventions in triathletes (Benito-de-  
150 Pedro et al., 2019). In addition, infrared thermography was utilize to measure skin  
151 temperature changes after compressive stockings use in athletes (Rodríguez et al., 2018).

152 The FLIR/SC3000/QWIP Therman infrared thermal device presented an 8–9 μm  
153 spectral range, a temperature sensitivity of 0.02 K, a display of 320 × 240 pixels with 20° lens  
154 and a spatial resolution of 1.1 mrad, being frequently used to evaluate the superficial  
155 temperature in the human tissue with adequate reliability and repeatability. The  
156 ~~FLIR/SC3000/QWIP Therman infrared thermal device presented a 8–9 μm spectral range, a~~  
157 ~~temperature sensitivity of 0.02 K, a display of 320 × 240 pixels with 20° lens and a spatial~~  
158 ~~resolution of 1.1 mrad, being frequently used to evaluate superficial temperature in the human~~  
159 ~~tissue with an adequate reliability and repeatability~~ (Rodríguez-Sanz et al., 2017; Rodríguez-  
160 Sanz et al., 2018; Rodríguez et al., 2018; Benito-de-Pedro et al., 2019), by both manual and  
161 automatic thermographic software package measurement methods with an adequate  
162 agreement and excellent intraclass correlation coefficient (ICC > 0.80) (Requena-Bueno et al.,  
163 2020). Prior statistical procedures, such as ICC and Bland-Altman plots, including limits of  
164 agreement (LoA). ~~Prior statistical procedures, such as ICC and Bland-Altman plots including~~  
165 ~~limits of agreement (LoA),~~ were used to compare infrared thermographic values in the lower  
166 limbs showing that both manual and automatic definition devices presented an excellent ICC  
167 from 0.92 to 0.99 with an adequate agreement by visual distribution and similar LoA by the  
168 ThermoHuman® devices (Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020),  
169 excellent inter-session reproducibility with an ICC of 0.88 using the digital infrared camera  
170 IRTIS-2000® (Zaproudina et al., 2008), and almost perfect agreement in replication with an  
171 ICC from 0.94 to 0.97 by the Thermofocus® thermal imaging device (Petrova et al., 2018).:-

172 Nevertheless, these devices showed a higher cost than an infrared thermography device  
173 designed to evaluate superficial temperature on materials. One of these thermographic devices  
174 was the Manual Infrared Camera PCE-TC 30. This tool displayed a sensor resolution of  
175 80x80, a measurement range from 0 to 250°C, a display of 320 × 240 pixels, a thermal

176 sensitivity of 80 mK, and an 8 mm lens (De Villoria et al., 2011; Pérez-Urrestarazu et al.,  
177 2014). Despite this, the thermal imaging system presented very low parameters concerning  
178 geometrical resolution (80 × 80 pixels) and thermal sensitivity of 80 mK, while other thermal  
179 imaging systems displayed high definition resolution (1280 × 960 pixels) and higher thermal  
180 sensitivity of 20 mK. ~~Nevertheless, these devices showed a higher cost compared with an~~  
181 ~~infrared thermography device to evaluate superficial temperature on materials, such as the~~  
182 ~~Manual Infrared Camera PCE-TC 30, which displayed a sensor resolution of 80x80, a~~  
183 ~~measurement range from 0 to 250°C, a display of 320 x 240 pixels, a thermal sensitivity of 80~~  
184 ~~mK and 8 mm lens (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014).~~ Despite this  
185 ~~thermal imaging system presented very low parameters concerning geometrical resolution (80~~  
186 ~~x 80 pixels) and thermal sensitivity of 80 mK, while other thermal imaging systems displayed~~  
187 ~~high definition resolution (1280 x 960 pixels) and higher thermal sensitivity of 20 mK~~  
188 ~~(Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020), the Manual Infrared Camera~~  
189 ~~PCE-TC 30 geometrical resolution and thermal sensitivity features could present adequate~~  
190 ~~reliability to measure triceps surae muscle tissue temperature variations (Rodríguez-Sanz et~~  
191 ~~al., 2017; Rodriguez-Sanz et al., 2018; Rodriguez et al., 2018; Benito-de-Pedro et al., 2019).~~  
192 Indeed, the PCE-TC 30 thermal camera has already been employed to assess the thermal  
193 behavior of fencing uniforms in athletes (Lamberti et al., 2020), but the reliability and  
194 repeatability of this tool directly on the skin of the human muscle need to behas yet to be  
195 determined.

196 This infrared thermography device was used to measure superficial temperature in  
197 structural composites and walls according to quality inspections, such as reproducibility,  
198 stability, reliability, and operating temperature (De Villoria et al., 2011; Pérez-Urrestarazu et  
199 al., 2014). Although this tool is used to assess thermal temperature in the fencing uniforms of

200 athletes (Lamberti et al., 2020), it has not been applied directly to measure superficial human  
201 muscle tissue temperature, which could be of interest in the triceps surae of athletes  
202 (Rodríguez-Sanz et al., 2017; Rodríguez-Sanz et al., 2018; Rodríguez et al., 2018; Benito-de-  
203 Pedro et al., 2019; Requena-Bueno et al., 2020). This cheaper infrared thermography device  
204 was applied to measure superficial temperature in structural composites and walls according  
205 to quality inspections such as reproducibility, stability, reliability and operating temperature  
206 (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014), but it has not been applied to  
207 measure superficial human muscle tissue temperature, which could be of interest in the triceps  
208 surae of athletes according to our prior studies (Rodríguez-Sanz et al., 2017; Rodríguez-Sanz  
209 et al., 2018; Rodríguez et al., 2018; Benito-de-Pedro et al., 2019; Requena-Bueno et al.,  
210 2020).

211 We hypothesized that this device — developed initially for non-Vivo structures — could  
212 provide adequate reliability and repeatability to determine skin temperature in the triceps  
213 surae muscle human tissue of athletes, being cheaperless expensive than the infrared  
214 thermography device used in human studies. Thus, the purpose of the present study was to  
215 determine the intra- and inter-session reliability and repeatability of the procedure to assess  
216 skin temperature within the Manual Infrared Camera PCE-TC 30 thermography device in the  
217 triceps surae muscle tissue of athletes, which was designed initially to measure the superficial  
218 temperature of materials. We hypothesized that this device developed initially for non-vivo  
219 structures could provide an adequate reliability and repeatability to determine skin  
220 temperature in the triceps surae muscle human tissue of athletes, being cheaper with respect to  
221 the infrared thermography device used in human studies. Thus, the purpose of the present  
222 study was to determine the intra- and inter-session reliability and repeatability of the Manual

223 ~~Infrared Camera PCE-TC 30 thermography device designed initially to measure superficial~~  
224 ~~temperature of materials in the triceps surae muscle tissue of athletes.~~

## 225 2. Materials and Methods

### 226 2.1. Study design

227 ~~The present study was carried out from January 2020 to May 2021 according to The~~  
228 ~~Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) criteria~~  
229 ~~(Appendix 1). The Helsinki Declarations, as well as specific human experimentation ethical~~  
230 ~~rules, were taken into account. The ethics committee for clinical interventions of the Hospital~~  
231 ~~Clínico San Carlos, Madrid (Spain) approved this study with internal code number 20/021-E~~  
232 ~~on January 20, 2020. Before the study began, all participants signed the informed consent~~  
233 ~~form. In addition, the present study was supported by Contract 83 between Complutense~~  
234 ~~University and PCE Ibérica S.L. (Reference number: 6-2020), providing a specific grant for~~  
235 ~~this research project. The present study was carried out from January 2020 to May 2021~~  
236 ~~according to The Strengthening the Reporting of Observational Studies in Epidemiology~~  
237 ~~(STROBE) criteria (Vandenbroucke et al., 2014). Furthermore, Helsinki Declarations as well~~  
238 ~~as specific human experimentation ethical rules were taken into account. (Holt, 2014) The~~  
239 ~~ethic committee for clinical interventions of the Hospital Clínico San Carlos, Madrid (Spain)~~  
240 ~~approved this study with internal code number 20/021-E on January 20, 2020 on January 20,~~  
241 ~~2020. All study subjects signed the document of the informed consent form prior to beginning~~  
242 ~~this reliability study. In addition, the present study study was supported by a Contract 83~~  
243 ~~between the between the Complutense University and PCE Ibérica S.L. (Reference number:~~  
244 ~~6-2020), providing specific grant for this research project.~~

### 245 2.2. Sample size

246 The sample size determination was calculated by bi-variate correlations statistical  
247 procedures through G\*Power 3.1.9.2 program (G\*Power<sup>®</sup>, from Dusseldorf University, in  
248 Germany), considering a 0.4 correlation coefficient to achieve a moderate correlation (Lobo et  
249 al., 2016) between infrared thermography measurements, applying a 1-tailed hypothesis, a  
250 0.05  $\alpha$  error and a 0.80 power. Lastly, the sample size was 34 triceps surae muscles to achieve  
251 the required thermography measurements for a 0.801 actual power.

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254 University, in Germany), considering a 0.4 correlation coefficient to achieve a moderate  
255 correlation (Lobo et al., 2016) between infrared thermography measurements, applying a 1-  
256 tailed hypothesis, a .05  $\alpha$  error and a 0.80 power. Lastly, the considered sample size was 34  
257 triceps surae muscles in order to achieve the required thermography measurements for a 0.801  
258 actual power.

### 259 2.3. Participants

260 Thirty-four triceps surae muscles were bilaterally analyzed from 17 healthy athletes  
261 considering a consecutive sampling recruitment procedure. Inclusion criteria comprised  
262 specifically healthy athletes aged 18–65 years providing the consent information document  
263 previously, carrying out sports activities and training for at least 2 h as well as one day per  
264 week, with moderate (level-II) or vigorous (level-III) intensities for physical activity with  
265 metabolic equivalent indexes greater than 600 METs/min/week, measured by the International  
266 Questionnaire for Physical Activity (IPAQ) (Roman-Viñas et al., 2010).

267 Thirty-four triceps surae muscles were bilaterally analyzed from 17 healthy athletes  
268 considering a consecutive sampling recruitment procedure. First, inclusion criteria comprised  
269 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). Exclusion criteria included muscle soreness, congenital dysfunctions, neuromuscular conditions, rheumatic alterations, body mass index (BMI) greater than 31 kg/m<sup>2</sup>, 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 to carry out the procedure to complete the study course.  Second, exclusion criteria included soreness, congenital dysfunctions, neuromuscular conditions, rheumatic alterations, body mass index (BMI) greater than 31 kg/m<sup>2</sup>, 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 to determine measurement agreement and concordance 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. Indeed, participants were asked to continue with

294 their daily life and physical exercise routine (avoiding unusual efforts or activity changes)  
295 between measurements and not taking drugs  the prior week nor vasomotor substances  
296 (i.e., caffeine) on the same measurement day, as well as heavy metals were not allowed. A  
297 period of 5 minutes of acclimatization of the subjects to the room was applied (Figure 1). All  
298 measurements were assessed with patients standing up in a relaxed position in the same room  
299 within a  $24.1 \pm 1$  C° temperature and a  $45 \pm 10\%$  humidity, without direct ventilation flow  
300 toward examiners or participants (Rodríguez-Sanz et al., 2017). Intra- and inter-session  
301 reliability and repeatability of the skin temperature of the triceps surae muscles were  
302 bilaterally assessed by the Manual Infrared Camera PCE-TC 30 at the same day separated by  
303 1 hour (considered as intra-day measurements) and alternate days separated by 48 hours  
304 (considered as inter-day measurements), respectively (De Villoria et al., 2011; Pérez-  
305 Urrestarazu et al., 2014). Indeed, participants were asked for continue within their daily life  
306 and physical exercise routine (avoiding unusual efforts or activity changes) between  
307 measurements and no taking drugs at the prior week nor vasomotor substances (i.e., caffeine)  
308 at the same measurement day, as well as heavy metals were not allowed. All measurements  
309 were assessed with patients standing up in relaxed position in the same room within a  $24.1 \pm 1$   
310 C° temperature and a  $45 \pm 10\%$  humidity, without direct ventilation flow towards examiners  
311 or participants (Rodríguez-Sanz et al., 2017).

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*Please, include Figure 1 here or hereabouts*

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

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## 319 2.5. Descriptive data

320 Descriptive data including sex (categorized as male or female), age (measured in years),  
321 height (measured in cm), weight (measured in kg), and BMI (expressed as  $\text{kg}/\text{cm}^2$  following  
322 the Quetelet's index) (Garrow, 1986), main sports category (divided into fitness considered as  
323 bodybuilding exercise or soccer), side (categorized as right or left), and dominance (expressed  
324 as yes or no), and smoker (expressed as yes or no) were detailed (Calvo-Lobo et al., 2019). As  
325 a tool with adequate psychometric properties, metabolic equivalent index per minute per week  
326 (METs/min/week) was evaluated by the IPAQ to determine physical activity and its  
327 categorization as moderate (600–1500 METs/min/week) and vigorous ( $\geq 1500$   
328 METs/min/week) physical activity (Gauthier, Lariviere & Young, 2009).  
329 ~~Descriptive data including sex (categorized as male or female), age (measured in years), height (measured in  
330 cm), weight (measured in kg), BMI (expressed as  $\text{kg}/\text{cm}^2$  following the Quetelet's index)  
331 (Garrow, 1986), main sport category (divided into fitness considered as bodybuilding exercise  
332 or soccer), side (categorized as right or left), and dominance (expressed as yes or no) and  
333 smoker (expressed as yes or no) were detailed (Calvo-Lobo et al., 2019). As a tool with  
334 adequate psychometric properties, metabolic equivalent index per minute per week  
335 (METs/min/week) were evaluated by the IPAQ in order to determine physical activity and its  
336 categorization as moderate (600–1500 METs/min/week) and vigorous ( $\geq 1500$   
337 METs/min/week) physical activity (Gauthier, Lariviere & Young, 2009).~~

## 338 2.6. Infrared thermography

339 We used a Manual Infrared Camera PCE-TC 30 (PCE Instruments UK Ltd;  
340 Southampton, United Kingdom), which displayed a sensor resolution of 80 × 80, a  
341 measurement range from 0 to 250°C, a display of 230 × 240 pixels, a thermal sensitivity of 80

342 mK and an 8 mm lens (De Villoria et al., 2011; Pérez-Urrestarazu et al., 2014). The infrared  
343 thermography imaging process was performed with the participant standing up in a relaxed  
344 position 1 m from the camera. Bilaterally, the triceps surae complex, including lateral (Figure  
345 1A and 1B) and medial (Figure 1C and 1D) gastrocnemius, as well as soleus (Figure 1E and  
346 1F) muscles, was measured by a region of interest (ROI) through five infrared thermography  
347 images for each muscle. Removing the highest and lowest values, the mean of the three  
348 measurements was used for data analysis. Firstly, the Manual Infrared Camera PCE-TC 30  
349 (PCE Instruments UK Ltd; Southampton, United Kingdom), which displayed a sensor  
350 resolution of 80x80, a measurement range from 0 to 250°C, a display of 230 x 240 pixels, a  
351 thermal sensitivity of 80 mK and 8 mm lens (De Villoria et al., 2011; Pérez-Urrestarazu et al.,  
352 2014). The infrared thermography imaging process was performed with the participant placed  
353 at 1 m of distance from the camera and standing up in a relaxed position. Bilaterally, the  
354 triceps surae complex, including lateral (Figure 1A and 1B) and medial (Figure 1C and 1D)  
355 gastrocnemius as well as soleus (Figure 1E and 1F) muscles, was measured by a region of  
356 interest (ROI) through 5 infrared thermography images for each muscle. Removing the  
357 highest and lowest values, the mean of the 3 measurements were used for data analysis.

358 Infrared images and data were analyzed by a blinded and experienced evaluator using the  
359 Guide™ Report Express (PCE Instruments UK Ltd; Southampton, United Kingdom)  
360 (Rodríguez-Sanz et al., 2017). This software provided the mean thermal value (°C) of the  
361 selected ROI of 1 cm<sup>2</sup> coinciding with the center of a landmark for each muscle (Figure 2).  
362 ~~Infrared images and data were analyzed by a blinded and experienced evaluator using the~~  
363 ~~Guide™ Report Express (PCE Instruments UK Ltd; Southampton, United Kingdom)~~  
364 ~~(Rodríguez-Sanz et al., 2017). This software provided the mean thermal value (°C) of the~~  
365 ~~selected ROI of 1 cm<sup>2</sup> coinciding with the center of a landmark for each muscle (Figure 1).~~

366 These landmarks were used to determine superficial skin temperature and placed superior to  
367 the Achilles tendon for the soleus muscle and in the thickest part of the medial and lateral  
368 gastrocnemius muscles according to prior similar studies (Benito-de-Pedro et al., 2019; Rojas-  
369 Valverde et al., 2021).

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371 *Please, include **Figure 2** here or hereabouts*

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

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377 *Please, include **Figure 1** here or hereabouts*

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

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381

## 382 2.7. Statistical Analyses

383 The 24.0 Statistical Package **Program** for Social Science (~~named SPSS~~; from IBM-Corp,  
384 in Armonk, NY) **was used** for data analyses. **The  $\alpha$  error was** set at 0.05, and thus a *P*-value  
385 **lower than 0.05 was considered statistical** significance. The Kolmogorov-Smirnov statistical  
386 **test and visual inspection of** histograms were considered **to detail normality distribution.** ~~The~~  
387 ~~24.0 Statistical Package programme for Social Science (named SPSS; from IBM-Corp, in~~  
388 ~~Armonk, NY) was considered as the package for data analyses. The  $\alpha$  error as set at .05 and~~  
389 ~~thus a *P*-value lower than .05 was considered as statistical significance. Kolmogorov-Smirnov~~  
390 ~~statistical test and visual inspection of histograms were considered to detail the distribution of~~  
391 ~~normality.~~ Data adjusted to normal distribution were detailed through means  $\pm$  standard  
392 deviations (SD) in conjunction with the upper and lower limits of 95% confidence interval  
393 (CI). Data adjusted to non-normal distribution were detailed through medians  $\pm$  interquartile  
394 ranges (IR). **Infrared thermography measurements for intra- and inter-session evaluations**

395 were compared through paired-sample Student t-tests considering parametric tests and  
396 Wilcoxon tests regarding non-parametric tests. ICC analyzed the reliability and repeatability  
397 between each pair of measurements for bidirectional absolute agreement and Pearson ( $r$ ) or  
398 Spearman ( $\rho$ ) correlation coefficients as parametric or non-parametric tests, respectively.  
399 Furthermore, ICC<sub>(2,1)</sub> values were specifically interpreted as poor for < 0.40 ICC<sub>(2,1)</sub>, weak for  
400 0.40–0.59 ICC<sub>(2,1)</sub>, good for 0.60–0.74 ICC<sub>(2,1)</sub>, and excellent for 0.75–1.00 ICC<sub>(2,1)</sub> (Calvo-  
401 Lobo et al., 2019). Infrared thermography measurements for intra- as well as inter-session  
402 evaluations were compared through paired-samples Student  $t$  tests considering parametric  
403 tests as well as Wilcoxon tests regarding non-parametric tests. The reliability and repeatability  
404 between each pair of measurements were analyzed by ICC for bidirectional absolute  
405 agreement as well as Pearson ( $r$ ) or Spearman ( $\rho$ ) correlations coefficients as parametric or  
406 non-parametric tests, respectively. Furthermore, ICC<sub>(2,1)</sub> values were specifically interpreted  
407 as poor for < 0.40 ICC<sub>(2,1)</sub>, weak for 0.40–0.59 ICC<sub>(2,1)</sub>, good for 0.60–0.74 ICC<sub>(2,1)</sub>, as well as  
408 excellent for 0.75–1.00 ICC<sub>(2,1)</sub> (Calvo-Lobo et al., 2019).

409 Next, correlation coefficients were specifically interpreted as weak for 0.00–0.40  $r$  or  $\rho$ ,  
410 moderate for 0.41–0.69  $r$  or  $\rho$ , and strong for 0.70–1.00  $r$  or  $\rho$  (Lobo et al., 2016). Standard  
411 errors for measurements (SEM) values were detailed through  $SD \times \sqrt{\frac{1}{n}}$ . Next, correlation  
412 coefficients were specifically interpreted as weak for 0.00–0.40  $r$  or  $\rho$ , moderate for 0.41–0.69  
413  $r$  or  $\rho$ , as well as strong for 0.70–1.00  $r$  or  $\rho$  (Lobo et al., 2016). Standard errors for  
414 measurements (SEM) values were detailed through  $SD \times \sqrt{\frac{1}{n}}$ . After, minimum detectable  
415 changes (MDC) values were detailed through  $\sqrt{2} \times 1.96 \times SEM$  for 95% CI. Both MDC and  
416 SEM were detailed through Bland and Altman recommendations (Calvo-Lobo et al., 2019).  
417 Limits for agreement (LoA) for each pair of measurements were detailed through differences

418 means  $\pm 1.96 \times SD$  for 95% CI in line with Bland and [Altman \(Bland & Altman, 2010; Calvo-](#)  
419 [Lobo et al., 2019\)](#).

420 ~~Altman (Bland & Altman, 2010; Calvo-Lobo et al., 2019)~~

421 ~~In addition, Bland-Altman plots were shown to detail visual agreements for each pair of~~  
422 ~~measurements showing systematic measurement errors of the differences in means~~  
423 ~~distributions for each pair of measurements located at the Y-axis with regards to the means~~  
424 ~~for each pair of measurements located at the X-axis. These Bland-Altman plots were shown in~~  
425 ~~conjunction with linear regression models.  $R^2$  coefficients were calculated to detail the~~  
426 ~~adjustment quality. The mean values for each pair of measurements were considered~~  
427 ~~independent variables. Lastly, the differences for each pair of measurements were considered~~  
428 ~~dependent variables (Bland & Altman, 2010).~~~~In addition, Bland-Altman plots were shown to~~  
429 ~~detail visual agreements for each pair of measurements showing systematic measurement~~  
430 ~~errors of the differences means distributions for each pair of measurements located at Y axis~~  
431 ~~with regards to the means for each pair of measurements located at X axis. These Bland-~~  
432 ~~Altman plots were shown in conjunction with linear regression models.  $R^2$  coefficients were~~  
433 ~~calculated to detail the adjustment quality. The means values for each pair of measurements~~  
434 ~~were considered as independent variables. Lastly, the differences for each pair of~~  
435 ~~measurements were considered as dependent variables (Bland & Altman, 2010).~~

436

### 437 3. Results

#### 438 3.1. Descriptive data

439 The final sample comprised 34 triceps surae muscles bilaterally from 17 healthy athletes,  
440 [nine](#) (52.9%) males and [eight](#) (47.1%) females, with mean  $\pm$  SD (95% CI) age of  $41.76 \pm$

441 14.42 (36.73–46.79) years, the weight of  $68.57 \pm 14.57$  (63.40–73.64) kg, the height of  $1.69 \pm$   
442  $0.09$  (1.66–1.73) m, and BMI of  $23.45 \pm 3.47$  (22.24–24.66) kg/cm<sup>2</sup>. Regarding the main  
443 sports category, these athletes performed in fitness (n = 14; 82.40%) and soccer (n = 3;  
444 17.6%). All athletes presented the dominant right side (n = 17; 100%); most were non-  
445 smokers (n = 12; 70.60%). Considering the IPAQ, the mean  $\pm$  SD (95% CI) of metabolic  
446 equivalents index per minute per week was  $3276.08 \pm 1876.49$  (2621.34–3930.82)  
447 METs/min/week, including eight (47.10%) athletes who performed vigorous physical activity  
448 and nine (52.90%) athletes who performed moderate physical activity. Table 1 shows the  
449 normality statistics and significance according to the Kolmogorov-Smirnov test. The final  
450 sample comprised 34 triceps surae muscles bilaterally from 17 healthy athletes, 9 (52.9%)  
451 males and 8 (47.1%) females, with mean  $\pm$  SD (95% CI) age of  $41.76 \pm 14.42$  (36.73–46.79)  
452 years, weight of  $68.57 \pm 14.57$  (63.40–73.64) kg, height of  $1.69 \pm 0.09$  (1.66–1.73) m, and  
453 BMI of  $23.45 \pm 3.47$  (22.24–24.66) kg/cm<sup>2</sup>. Regarding the main sport category, these  
454 athletes performed fitness (n = 14; 82.40%) and soccer (n = 3; 17.6%). All athletes presented  
455 right dominant side (n = 17; 100%) and most of them were non-smokers (n = 12; 70.60%).  
456 Considering the IPAQ, mean  $\pm$  SD (95% CI) of metabolic equivalents index per minute per  
457 week was  $3276.08 \pm 1876.49$  (2621.34–3930.82) METs/min/week, including 8 (47.10%)  
458 athletes who performed vigorous physical activity and 9 (52.90%) athlete who performed  
459 moderate physical activity. Table 1 showed the normality statistics and significance according  
460 to Kolmogorov-Smirnov test.

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Please, include Table 1 here or hereabouts

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

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### 3.2. Intra-session reliability and repeatability

466 According to Table 2, intra-session measurements of the infrared thermography device  
 467 designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle  
 468 tissue of athletes showed excellent reliability ( $ICC_{(1,2)} = 0.969 - 0.977$ ), measurement errors  
 469 ( $SEM = 0.186-0.212^{\circ}C$ ;  $MDC = 0.515-0.587^{\circ}C$ ) and did not present any statistically  
 470 significant systematic error of measurements ( $P > 0.05$ ).According to Table 2, intra-session  
 471 measurements of the infrared thermography device designed for materials (Manual Infrared  
 472 Camera PCE-TC 30) in the triceps surae muscle tissue of athletes showed excellent reliability  
 473 ( $ICC_{(1,2)} = 0.969 - 0.977$ ), measurement errors ( $SEM = 0.186 - 0.212^{\circ}C$ ;  $MDC = 0.515 -$   
 474  $0.587^{\circ}C$ ) and did not present any statistically significant systematic error of measurements ( $P$   
 475  $> .05$ ).

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477 *Please, include Table 2 here or hereabouts*

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

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481 *Please, include Table 2 here or hereabouts*

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

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485 Regarding intra-session measurements, bivariate correlations were excellent for the  
 486 soleus ( $r = 0.953$ ;  $P < 0.001$ ), medial gastrocnemius ( $\rho = 0.885$ ;  $P < 0.001$ ) and lateral  
 487 gastrocnemius ( $r = 0.939$ ;  $P < 0.001$ ).Regarding intra-session measurements, bivariate  
 488 correlations were excellent for the soleus ( $r = 0.953$ ;  $P < .001$ ), medial gastrocnemius ( $\rho =$   
 489  $0.885$ ;  $P < .001$ ) and lateral gastrocnemius ( $r = 0.939$ ;  $P < .001$ ).

490 In addition, Bland-Altman plots presented an adequate agreement for intra-session  
 491 measurements of the infrared thermography device designed for materials (Manual Infrared  
 492 Camera PCE-TC 30) in the soleus (Figure 3), medial gastrocnemius (Figure 4) and lateral

493 gastrocnemius (Figure 5) muscles of athletes, due to visual distributions of the difference  
494 means for each pair of measurements at Y axis concerning the mean for each pair of  
495 measurements at X-axis did not present any systematic measurement error and most  
496 thermographic measurements were between the upper and lower LoA. In addition, Bland-  
497 Altman plots presented an adequate agreement for intra-session measurements of the infrared  
498 thermography device designed for materials (Manual Infrared Camera PCE-TC 30) in the  
499 soleus (Figure 2), medial gastrocnemius (Figure 3) and lateral gastrocnemius (Figure 4)  
500 muscles of athletes, due to visual distributions of the difference means for each pair of  
501 measurements at Y axis with respect to the mean for each pair of measurements at X axis did  
502 not present any systematic measurement error and most thermographic measurements were  
503 between the upper and lower LoA. In addition to Bland-Altman plots, linear regression  
504 models did not show any statistical significance for soleus ( $R^2 = 0.000$ ;  $\beta = 0.003$ ;  $F_{1,32} =$   
505  $0.003$ ;  $P = 0.954$ ), medial gastrocnemius ( $R^2 = 0.002$ ;  $\beta = -0.017$ ;  $F_{1,32} = 0.065$ ;  $P = 0.800$ )  
506 and lateral gastrocnemius ( $R^2 = 0.019$ ;  $\beta = -0.050$ ;  $F_{1,32} = 0.626$ ;  $P = 0.435$ ) intra-session  
507 measurements.

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509 *Please, include Figure 3 here or hereabouts*

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

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514 *Please, include Figure 2 here or hereabouts*

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

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520 *Please, include Figure 4 here or hereabouts*

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

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526 | *Please, include Figure 3 here or hereabouts*

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

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531 | *Please, include Figure 5 here or hereabouts*

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

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537 | *Please, include Figure 4 here or hereabouts*

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

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### 542 | 3.3. Inter-session reliability and repeatability

543 | According to Table 3, inter-session measurements of the infrared thermography device  
544 | designed for materials (Manual Infrared Camera PCE-TC 30) in the triceps surae muscle  
545 | tissue of athletes presented excellent reliability ( $ICC_{(1,2)} = 0.956$ – $0.974$ ), measurement errors  
546 | ( $SEM = 0.187$ – $0.232$  °C;  $MDC = 0.518$ – $0.643$  °C), and did not present any statistically  
547 | significant systematic error of measurements ( $P > 0.05$ ).

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

551 | ( $SEM = 0.187 - 0.232$  °C;  $MDC = 0.518 - 0.643$  °C) and did not present any statistically  
552 | significant systematic error of measurements ( $P > .05$ ).

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*Please, include Table 3 here or hereabouts*

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**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

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Considering inter-session measurements, bivariate correlations were also excellent for the soleus ( $r = 0.949$ ;  $P < 0.001$ ), medial gastrocnemius ( $r = 0.914$ ;  $P < 0.001$ ), and lateral gastrocnemius ( $r = 0.938$ ;  $P < 0.001$ ). 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 ( $r = 0.938$ ;  $P < .001$ ).

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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 6), medial gastrocnemius (Figure 7), and lateral gastrocnemius (Figure 8) muscles of athletes, since visual distributions of the difference means for each pair of measurements at the Y axis concerning the mean for each pair of measurements at the X axis did not present any systematic measurement error, and most thermographic measurements were between the upper and lower LoA. In conjunction with the 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.

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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

578 gastrocnemius (Figure 6) muscles of athletes, since visual distributions of the difference  
579 means for each pair of measurements at Y axis with respect to the mean for each pair of  
580 measurements at X axis did not present any systematic measurement error and most  
581 thermographic measurements were between the upper and lower LoA. In conjunction with  
582 Bland-Altman plots, linear regression models did not show any statistical significance for  
583 soleus ( $R^2 = 0.014$ ;  $\beta = 0.039$ ;  $F_{1,32} = 0.463$ ;  $P = 0.501$ ), medial gastrocnemius ( $R^2 = 0.000$ ;  $\beta =$   
584  $-0.009$ ;  $F_{1,32} = 0.014$ ;  $P = 0.907$ ) and lateral gastrocnemius ( $R^2 = 0.019$ ;  $\beta = -0.050$ ;  $F_{1,32} =$   
585  $0.621$ ;  $P = 0.436$ ) inter-session measurements.

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587 *Please, include **Figure 6** here or hereabouts*

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

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593 *Please, include **Figure 5** here or hereabouts*

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

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598 *Please, include **Figure 7** here or hereabouts*

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

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604 *Please, include **Figure 6** here or hereabouts*

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

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610 | *Please, include [Figure 8](#) here or hereabouts*

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

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616 | *Please, include [Figure 7](#) here or hereabouts*

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

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#### 621 | 4. Discussion

622 | [The proposed procedure within the Manual Infrared Camera PCE-TC 30 thermography](#)  
623 | [device presented excellent intra- and inter-session reliability and repeatability with an](#)  
624 | [adequate agreement avoiding systematic errors of measurement to measure skin temperature](#)  
625 | [of soleus, medial and lateral gastrocnemius muscles. Although this tool was initially designed](#)  
626 | [to assess the superficial temperature of materials \(De Villoria et al., 2011; Pérez-Urrestarazu](#)  
627 | [et al., 2014\), it could be a cheap toolless expensive device to promote triceps surae muscle](#)  
628 | [prevention and recovery in athletes \(Rodríguez-Sanz et al., 2017; Rodriguez-Sanz et al., 2018;](#)  
629 | [Rodriguez et al., 2018; Benito-de-Pedro et al., 2019\).](#) [In addition, the PCE-TC 30 thermal](#)  
630 | [camera may be employed to assess the thermal behavior of fencing uniforms in athletes](#)  
631 | [\(Lamberti et al., 2020\). Our study supports that this device may be directly used to determine](#)  
632 | [superficial human muscle tissue temperature in the triceps surae of athletes with adequate](#)  
633 | [reliability and repeatability \(Rodríguez-Sanz et al., 2017; Rodriguez-Sanz et al., 2018;](#)  
634 | [Rodriguez et al., 2018; Benito-de-Pedro et al., 2019; Requena-Bueno et al., 2020\).](#)[The](#)  
635 | [Manual Infrared Camera PCE-TC 30 thermography device, which was initially designed to](#)

636 assess superficial temperature of materials (De Villoria et al., 2011; Pérez-Urrestarazu et al.,  
637 2014), presented excellent intra- and inter-session reliability and repeatability with an  
638 adequate agreement avoiding systematic errors of measurement to measure skin temperature  
639 of soleus, medial and lateral gastrocnemius muscles, which may be a cheap tool to promote  
640 triceps surae muscle prevention and recovery in athletes (Rodríguez-Sanz et al., 2017;  
641 Rodríguez-Sanz et al., 2018; Rodríguez et al., 2018; Benito-de-Pedro et al., 2019).

642 The PCE-TC 30 thermography device showed similar excellent reliability ( $ICC > 0.8$ )  
643 compared to the infrared ThermoHuman® device (Fernandez-Cuevas et al., 2017; Requena-  
644 Bueno et al., 2020), the digital infrared camera IRTIS-2000® (Zaproudina et al., 2008), and  
645 Thermofocus® thermal imaging device (Petrova et al., 2018), which were specifically  
646 designed for human tissue temperature measurements in lower limbs. Indeed, different  
647 ThermoHuman® devices showed an excellent intra-session ( $ICC = 0.99$ ;  $LoA = 0.0 \pm 0.4-0.1$   
648  $\pm 0.4$  °C) and inter-session ( $ICC = 0.92$ ;  $LoA = 0.1 \pm 0.4-0.1 \pm 0.5$ °C) reliability before and  
649 after running, respectively, detailing small differences effect sizes (Cohen's  $d < 0.4$ ) for foot  
650 skin temperature (Requena-Bueno et al., 2020).

651 This tool showed similar excellent reliability ( $ICC > 0.8$ ) compared to the infrared  
652 ThermoHuman® device (Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020), the  
653 digital infrared camera IRTIS-2000® (Zaproudina et al., 2008) and Thermofocus® thermal  
654 imaging device (Petrova et al., 2018), which were specifically designed for human tissue  
655 temperature measurements in lower limbs. Indeed, different ThermoHuman® devices showed  
656 an excellent intra-session ( $ICC = 0.99$ ;  $LoA = 0.0 \pm 0.4-0.1 \pm 0.4$  °C) and inter-session ( $ICC =$   
657  $0.92$ ;  $LoA = 0.1 \pm 0.4-0.1 \pm 0.5$ °C) reliability before and after running, respectively, detailing  
658 small differences effect sizes (Cohen's  $d < 0.4$ ) for foot skin temperature (Requena-Bueno et  
659 al., 2020).

660 Specifically, the digital infrared camera IRTIS-2000® applied in the calf region  
661 showed adequate intra-session (ICC = 0.84) and inter-session (ICC = 0.66) reliability  
662 with similar temperature mean  $\pm$  SD values for anterior ( $31.2 \pm 0.6$  °C), posterior ( $30.8 \pm$   
663  $0.6$ °C), and lateral ( $31.3 \pm 0.6$ °C) calf regions (Zaproudina et al., 2008). Finally, the  
664 Thermofocus® thermal imaging device presented almost perfect intra-session agreement in  
665 different foot regions (ICC =  $0.94 - 0.97$ ), showing non-significant replication interactions ( $P$ -  
666 values =  $0.23 - 0.84$ ) posterior ( $30.8 \pm 0.6$  °C) and lateral ( $31.3 \pm 0.6$  °C) calf regions  
667 (Zaproudina et al., 2008). Finally, the Thermofocus® thermal imaging device presented  
668 almost perfect intra-session agreement in different foot regions (ICC =  $0.94 - 0.97$ ) showing  
669 non-significant replication interactions ( $P$ -values =  $0.23 - 0.84$ ) (Petrova et al., 2018). Despite  
670 the use of such modern thermal imaging systems with better definition resolutions could  
671 provide more reliable measurements and improve the quality of the thermograms obtained,  
672 the reliability and measurement errors provided by the Manual Infrared Camera PCE-TC 30  
673 thermography may be enough to detect temperature differences linked to clinical  
674 musculoskeletal changes (Côte et al., 2019).

675 Athletes may be exposed to physical stress under training loads and competitions with  
676 overload reactions which could cause blood flow changes affecting skin temperature (Merla et  
677 al., 2010). Infrared thermography may not display anatomical abnormalities, although  
678 functional changes may be shown and linked to skin temperature control (Merla et al., 2010;  
679 Ring & Ammer, 2012). Infrared thermography use was proposed as a complementary tool to  
680 apply preventive measures, such as cryotherapy, physiotherapy, training load reduction, and  
681 massage or recovery boot use, to avoid muscle conditions in professional soccer players. The  
682 asymmetry reference values range from  $0.5$ °C to  $1$ °C between both right and left lower limbs  
683 was proposed to initiate this preventive protocol, which reduced up to 63% muscle injuries in

684 a professional soccer season by thermographic monitoring (Côte et al., 2019). Thus, the  
685 Manual Infrared Camera PCE-TC 30 thermography device could be used to determine these  
686 cut-off values due to the MDC values varied from 0.515 to 0.587 °C and from 0.518 to  
687 0.643°C for intra- and inter-session evaluations, respectively.

688 Our research group carried out a prior thermographic study addressing the thermal skin  
689 evaluation of the triceps surae muscles. This study showed that skin temperature after running  
690 was deeply linked to electromyography, which may indirectly reflect triceps surae muscle  
691 activity. Although the Manual Infrared Camera PCE-TC 30 thermography device has not yet  
692 been correlated with electromyography values, thermal values could be related to muscle  
693 activity in the triceps surae muscles of athletes using this tool according to a similar study  
694 using the FLIR/SC3000/QWIP Thermancan-infrared thermal device. A prior thermographic  
695 study carried out by our research group showed that skin thermal evaluation of the triceps  
696 surae muscles showed that skin temperature after running was deeply linked to  
697 electromyography, which may indirectly reflect triceps surae muscle activity. Despite the  
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699 electromyography values, thermal values could be related with muscle activity in the triceps  
700 surae muscles of athletes using this tool according to a similar study using the  
701 FLIR/SC3000/QWIP Thermancan-infrared thermal device (Rodriguez-Sanz et al., 2019)

702 Athletes may be exposed to physical stress under training loads and competitions with  
703 overload reactions which could cause blood flow changes affecting skin temperature (Merla et  
704 al., 2010). Infrared thermography may not display anatomical abnormalities, although  
705 functional changes may be shown and linked to skin temperature control (Merla et al., 2010;  
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707 apply preventive measures, such as cryotherapy, physiotherapy, training load reduction, and

708 massage or recovery boot use, to avoid muscle conditions in professional soccer players. The  
709 asymmetry reference values range from 0.5 °C to 1 °C between both right and left lower limbs  
710 was proposed to initiate this preventive protocol, which reduced up to 63% muscle injuries in  
711 a professional soccer season by thermographic monitoring (Côte et al., 2019). Thus, the  
712 Manual Infrared Camera PCE-TC 30 thermography device could be used to determine these  
713 cut-off values due to the MDC values varied from 0.5°C to 0.6 °C.

714 Although some less expensive commercially-available thermal cameras could be suitable  
715 for skin temperature assessment, employing the PCE-TC 30 camera to assess triceps surae  
716 muscle temperature providesd reliable and repeatable measures with MDC cut-off values  
717 useful to determine preventive protocols for muscle injuries (Côte et al., 2019).

#### 718 4.1. Future studies

719 Further studies should be designed as randomized clinical trials to determine if these  
720 asymmetries reference cut-off values could prevent triceps surae muscle injuries (Côte et al.,  
721 2019). According to prior studies (Hiemstra et al., 2007; Chung et al., 2015), the uninvolved  
722 normal side after injury may often be not normal, i.e., presenting temperature values different  
723 from healthy subjects, and cut-off values should also be detailed in the future muscle recovery  
724 studies. In addition, thermographic measurement of the triceps surae with this device should  
725 be analyzed by intra- and inter-rater reliability determining SEM and MDC values and  
726 correlated with the other high-end infrared devices as possible gold standards such as  
727 ThermoHuman® (Fernandez-Cuevas et al., 2017; Requena-Bueno et al., 2020), IRTIS-  
728 2000®(Zaproudina et al., 2008) and Thermofocus® (Petrova et al., 2018) tools. Furthermore,  
729 correlations with electromyography measurements of the triceps surae muscle activity should  
730 be carried out (Rodriguez-Sanz et al., 2019). Lastly, the intramuscular temperature should

731 also be correlated with this device to determine concurrent validity concerning a gold  
732 standard (Burnham, McKinley & Vincent, 2006).

733 Further studies should be designed as randomized clinical trials in order to determine if  
734 these asymmetry reference cut-off values could prevent triceps surae muscle injuries. (Côte et  
735 al., 2019) According to prior studies (Hiemstra et al., 2007; Chung et al., 2015), the  
736 uninvolved normal side after injury may often be not normal, i.e. presenting temperature  
737 values different from healthy subjects, and cut-off values should be also detailed in future  
738 muscle recovery studies. In addition, thermographic measurement of the triceps surae with  
739 this device should be correlated with the other high-end infrared devices as possible gold  
740 standards such as ThermoHuman® (Fernandez-Cuevas et al., 2017; Requena-Bueno et al.,  
741 2020), IRTIS-2000® (Zaproudina et al., 2008) and Thermofocus® (Petrova et al., 2018) tools,  
742 as well as correlations with electromyography measurements of the triceps surae muscle  
743 activity should be carried out (Rodríguez-Sanz et al., 2019). Lastly, intramuscular temperature  
744 should also be correlated with this device in order to determine concurrent validity with  
745 respect to a gold standard (Burnham, McKinley & Vincent, 2006).

#### 746 4.2. Limitations

747 Various limitations should be considered for the use of this thermographic device. First,  
748 the MDC was superior to the lower limbs asymmetry reference range from 0.3°C to 0.4°C  
749 proposed as a cut-off for following-up before a preventive protocol (Côte et al., 2019) and  
750 therefore, this device should not be used for values lower than 0.5°C–0.6 °C.

751 Second, the concurrent validity of this device has not been performed for human tissue  
752 temperature, and this validity should be assessed in the future (Burnham, McKinley &  
753 Vincent, 2006).

754 Third, our sample only comprised healthy athletes, and further studies should analyze  
755 skin temperature with this tool over injured muscle tissue (Albuquerque Santana et al., 2022).

756 Fourth, our sample size calculation was accurately detailed to determine a moderate  
757 bivariate correlation between measurements, but our sample size was low to achieve the  
758 actual power to perform comparisons classifying groups depending on sport category, BMI,  
759 and other valued characteristics. In addition, despite statistical analyses were carried out  
760 according to our prior sample size calculation model to detail bivariate comparisons for intra-  
761 and inter-session measurements, future nested type studies should be designed as nested  
762 statistical models such as analyses of variance (ANOVA) to determine more accurate  
763 temperature comparisons.

764 Finally, the fact that the PCE-TC 30 thermography device was not calibrated for skin  
765 temperature assessment could affect the repeatability of the measurement to a lesser extent  
766 than its accuracy. Nevertheless, a comparison between the temperature assessed by a  
767 validated thermal camera and the PCE-TC 30 was not reported. Future studies should evaluate  
768 its accuracy due to a possible wrong estimation of the absolute skin temperature. Procedures  
769 for thermographic assessment in sports and exercise sciences have been reviewed by Moreira  
770 et al. (Moreira et al., 2017) in a consensus statement of the experts in the field. However, our  
771 reliability study aimed to standardize the proposed procedure and contributed to improving  
772 the methods behind measures. ~~Various limitations should be considered for the use of this~~  
773 ~~thermographic device. First, the MDC was superior to the lower limbs asymmetry reference~~  
774 ~~range from 0.3 °C to 0.4°C proposed as a cut-off for following-up before a preventive protocol~~  
775 ~~(Côte et al., 2019) and therefore this device should not be used for values lower than 0.5 °C –~~  
776 ~~0.6 °C. Second, concurrent validity of this device has not been performed for human tissue~~  
777 ~~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 (Albuquerque 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.—~~

788

## 789 5. Conclusion

The proposed procedure within the Manual Infrared Camera PCE-TC 30 thermography device designed initially to measure the 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 procedure to measure the skin temperature of soleus, medial, and lateral gastrocnemius muscles to promote triceps surae muscle prevention and recovery in athletes.

~~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.~~

802

803 **Funding:** César Calvo-Lobo, David Rodríguez-Sanz and Ricardo Becerro-de-Bengoa-Vallejo  
804 declared that this work has been supported by a Contract 83 between the Complutense  
805 University and PCE Ibérica S.L. entitle “Fiabilidad sobre el dispositivo de termografía  
806 Manual Infrared camera PCE-TC 30 en humanos” (Reference number: 6-2020).

807 **Acknowledgments:** Authors acknowledge the support from the Contract 83 between the  
808 Complutense University and PCE Ibérica S.L. entitle “Fiabilidad sobre el dispositivo de  
809 termografía Manual Infrared camera PCE-TC 30 en humanos” (Reference number: 6-2020),  
810 providing specific grant for the present research.

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

815

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