Infrared thermography applied to lower limb muscles in elite soccer players with functional ankle equinus and non-equinus condition

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Gastrocnemius-soleus equinus (GSE) is a foot-ankle complaint in which the extensibility of the gastrocnemius (G) and soleus muscles (triceps surae) and ankle are limited to a dorsiflexion beyond a neutral ankle position. The asymmetric forces of leg muscles and the associated asymmetric loading forces might promote major activation of the triceps surae, tibialis anterior, transverses abdominal and multifidus muscles. Here, we made infrared recordings of 21 sportsmen (elite professional soccer players) before activity and after 30 min of running. These recordings were used to assess temperature modifications on the gastrocnemius, tibialis anterior, and Achilles tendon in GSE and non-GSE participants. We identified significant temperature modifications among GSE and non-GSE participants for the tibialis anterior muscle (mean, minimum, and maximum temperature values). The cutaneous temperature increased as a direct consequence of muscle activity in GSE participants. IR imaging capture was reliable to muscle pattern activation for lower limb. Based on our findings, we propose that non-invasive IR evaluation is suitable for clinical evaluation of the status of these muscles.

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2 ankle equinus and non-equinus condition.

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ABSTRACT

37 Gastrocnemius-soleus equinus (GSE) is a foot-ankle complaint in which the extensibility of the
38 gastrocnemius (G) and soleus muscles (triceps surae) and ankle are limited dorsiflexion beyond
39 a neutral ankle position [1,2]. The asymmetric forces of leg muscles and the associated
40 asymmetric loading forces might promote major activation of the triceps surae, tibialis anterior,
41 transversus abdominus and multifidus muscles hence modify temperature . Here, we made
42 infrared recordings of 21 sportsmen (elite professional soccer players) before activity and after
43 30 min of running. These recordings were used to assess temperature modifications on the
44 gastrocnemius, tibialis anterior, and Achilles tendon in GSE and non-GSE participants. We
45 identified significant temperature modifications among GSE and non-GSE participants for the
46 tibialis anterior muscle (mean, minimum, and maximum temperature values). The cutaneous
47 temperature mean GSE increased more than non-GSE . IR imaging reliably captured
48 temperature associated with muscle pattern activation for lower limb. Based on our findings, we
49 propose that non-invasive IR evaluation is suitable for clinical evaluation of the status of these
50 muscles.

51

1. INTRODUCTION

53 Gastrocnemius-soleus equinus (GSE) is a functional limitation of the ankle. GSE is defined as
54 the inability of the ankle to dorsiflex beyond a neutral position with the knee extended (it remains
55 <0°) or with the knee flexed (it remains <0°) (after excluding osseus restriction) [1,2]. Although
56 GSE is clinically asymptomatic, it may cause an alteration in the triceps surae muscles, tibialis
57 anterior muscle (TA), and Achilles tendon (AT). GSE is closely related to asymmetric loading
58 patterns and muscular alteration for contraction [3-6].

59

60 Asymmetric body loading is associated with GSE and may cause a higher activation of low-back
61 and pelvic muscles (e.g., the quadratus lumborum) and lower limb muscles (e.g., the TA). GSE
62 has been much studied using the mean of force pressure platform, Romberg-test analysis, and
63 sway-area development approaches [7,8,9,10]. The relationships between muscle contraction
64 condition and posture have been investigated by electromyography[11,12,13]. GSE condition shows
65 a relationship with gait and posture [9,10] . Also, several studies have investigated whether
66 activation of skeletal muscles promotes heat transfer and thus increases cutaneous temperature
67 [14,15,16,17].

68 Orthostatic posture is typically assessed by the complex activation of anti-gravitational muscles
69 (e.g., the triceps surae muscles). Modifications in cutaneous temperature are associated with
70 gait and posture alterations, asymmetric loading forces, and an altered range of ankle or knee
71 movement. High thermal infrared (IR) imaging can non-invasively identify cutaneous
72 temperature variations [14].

73 Here we aimed to assess whether high-resolution thermal IR can detect cutaneous temperature
74 variations in GSE and Non-GSE individuals and thus detect association between the
75 extensibility to triceps-surae (with GSE and Non-GSE) and the role of TA in professional
76 sportsmen. The aim of the study was to check thermal differences between GSE and Non
77 GSE-group before running and after running exercise.

78

2. METHODS

80 In this case-control study, 21 healthy male participants (professional soccer players) (age 23 ±
81 2.9 years, body mass index (applying Quetelet´s equation follow BMI = weight (kg) / height(m)^2
82) 20.2 ± 1.2) were included. A consecutive sampling method was used to select participants.
83 Eighteen subjects were right-footed, and three were left-footed, as defined by the self-report on
84 the lower limb predominant used in sports activities. All participants successfully completed the
85 study. The exclusion criteria were the presence of musculoskeletal injuries, low back and pelvic
86 pain, sprains, tendon injuries in lower limbs, use of drugs in the week preceding the test, and
87 scoliosis.

88

89 The principal study variable was temperature. An IR ThermaCam was used to register the
90 maximum, minimum and mean temperature values of the TA, AT, and G regions.

91 ***Ethical considerations*** – The Research and Ethics Committee of the University of A Coruña (A
92 Coruña, Spain; record number: CE 06/2014) approved the study. All subjects provided informed
93 consent before the beginning of the study. The ethical standards for human experimentation of
94 the Declaration of Helsinki were respected. The Strengthening the Reporting of Observational
95 Studies in Epidemiology (STROBE) guidelines were applied. The study size was derived as a
96 convenience sample method.

97

98 ***IR imaging*** – The subjects were given a series of standardization rules before attending the
99 experimental measurements [14]. Specifically, during the week prior to the trial, the participants
100 were asked not to use drugs. Also, on the test day, vasomotor substances (e.g., caffeine) and
101 heavy meals were not allowed.

102 Paper signals were attached to the lower limb with anatomical references (TA, G, and AT). All
103 measurements were acquired in a laboratory with a temperature of 24.1 ± 1 Cº, humidity of 45%
104 ± 10% and no direct ventilation-flow towards participants or raters.

105 ***Clinical exploration and capture of IR-imaging –*** First, participants lay in a supine position
106 on a gurney, and their GSE status was assessed with the knee extended and flexed. The range
107 of ankle dorsiflexion movement was checked using a goniometer to evaluate the angle between
108 the plantar line of the foot and the tibia axis. The rater maintained the subtalar joint in a neutral
109 position and the angle in a dorsiflexion position [rather than midfoot-dorsiflexion (rocker bottom)

110 or midfoot-equinus (pseudoequinus)]. The Silverskiold-test was used to check GSE from other
111 types of equines [3,4]. A 20° movement with the knee flexed and 10° movement with the knee
112 extended was considered a normal range of ankle dorsiflexion [3,5,6]. Equinus analysis was
113 carried out by the same Podiatry Doctor (R.B.B.V) to ensure the reliability of measurements.

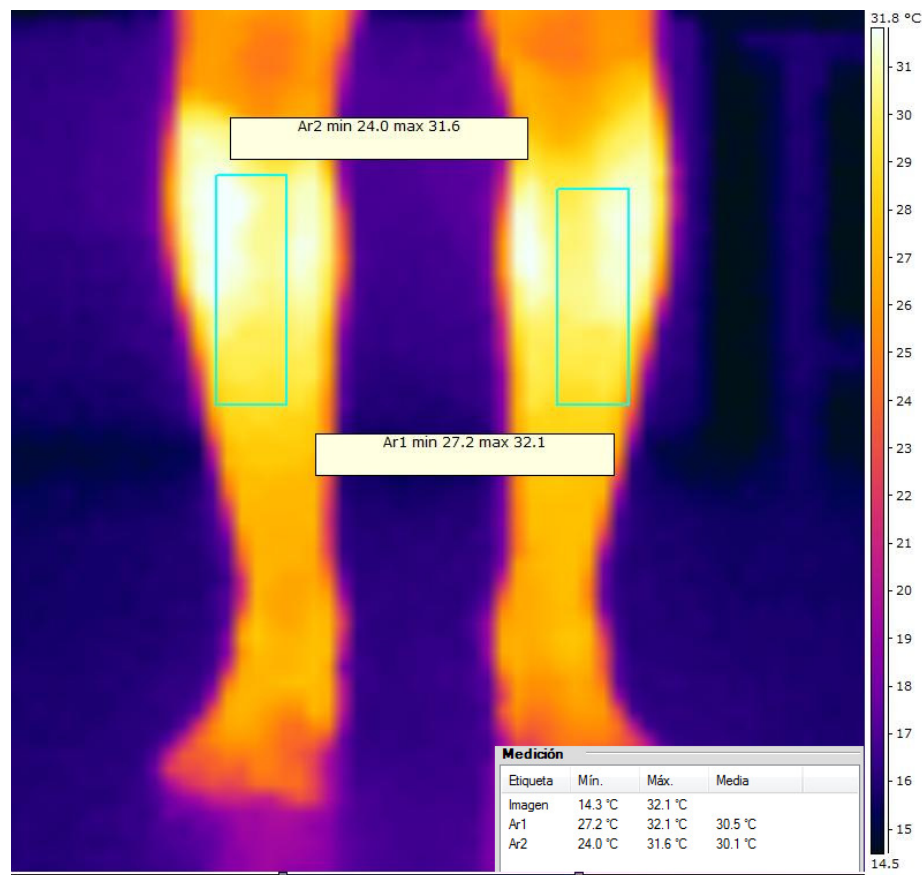
114 The IR-imaging process (high resolutions thermograms) started with the participant standing up
115 in a relaxed position. We captured the TA, G, and AT regions in that order. Five IR-images
116 were taken for every muscle. Participants then ran for 30 min on a treadmill at a speed of 9
117 km/h and the IR-imaging repeated.

118 IR-imaging was performed using an FLIR/SC3000/QWIP Thermacan infrared thermal device
119 with a 8–9 µm spectral range and 0.02-K temperature sensitivity (NETD at 30◦C). The 320
120 ×240/FPA device presents a 20◦-lens. The images were captured with a 1.1 mrad spatial-
121 resolution. IR-imaging acquisition was carried out by the same clinician (DRS) using a tripod.

122 **DATA ANALYSIS**

123 IR-images and data were analyzed using rater (DRS) with the FLIR® software Termocan
124 Researcher Professional V.2.9.This software provides to rater the minimum, maximum and
125 mean thermal values for the selected muscles. This body selections-regions were bilaterally
126 selected with landmark position and selected by the blinded clinical operator who ignored
127 hypothesis of study and the experimental conditions. An IR-Imaging example is shown in Figure
128 1.

129

130

STATISTICAL ANALYSIS

132 Statistical analyses were performed with SPSS (version 22.0 for Windows, IBM SPSS Statistics
133 for Windows, Armonk, NY, IBM Corp) with an α error of 0.05 (95% confidence interval [CI]), with
134 the desired power of 80% (β error of 0.2).

135 Shapiro-Wilks test was used to assess data normality. All data were normally distributed, and
136 parametric statistical tests were selected. The mean and standard deviation of the temperature
137 data were obtained for the selected lower limb muscles (AT, TA,G).

138 Unpaired sample student's t test were performed to test for statistically significant differences in
139 height, weight, body mass index, and age between the two groups. A Paired Student's t-tests
140 were performed to determine differences between the groups (equinus vs. non-equinus), as well
141 as between imaging sessions (before vs. after running).

142

RESULTS

144 We found no statistically significant differences between the equinus vs. non-equinus groups for
145 participant height, weight, age or body mass index (Table 1).

Table 1. Participant characteristics (n = 10 non-equinus and 11 equinus participants)

	Equinus Group	Non- Equinus Group
Age (years)*	23.56 ± 2.61 (21–28)	20 ± 2.16 (19–27)
Height (cm)*	175.5 ± 7.9	173.1 ± 5.2
Weight (kg)*	75.2 ± 3.9	74.5 ± 3.1
Body mass index*	20.2 ± 1.3	20.1 ± 1.5

* No statistically significant difference between groups ($p \geq 0.05$).

146

147 We found no significant differences in TA, G or AT temperatures between the GSE and non-
148 GSE participants before running (Table 2).

Table 2. Temperature values (Degrees Celsius) for tibialis anterior, gastrocnemius-soleus and Achilles tendon for gastrosoleus equinus (GSE) and non-gastrosoleus equinus (Non-GSE) participants before exercise.

Variable	Mean	SD	P value
Tibialis right anterior minimum temperature before exercise			
GSE	31.01	± 1.3	,342*
Non GSE	30.86	± 0.56	,331*
Tibialis anterior right maximum temperature before exercise			
GSE	30.85	± 1.32	,397*
Non GSE	31.07	± 0,81	,401*
Tibialis anterior right mean temperature before exercise			
GSE	31.3	± 1.3	,430*
Non GSE	31.09	± 0.56	,435*
Tibialis anterior left minimum temperature before exercise			
GSE	28.82	± 2.47	1,14*
Non GSE	29.74	± 0.82	1,15*
Tibialis anterior left maximum temperature before exercise			

GSE	31.87	± 1.35	,486*
Non GSE	31.65	± 0,53	,504*

Tibialis anterior left mean temperature before exercise

GSE	31.01	± 1.3	,354*
Non GSE	31.86	± 0.56	,366*

Gastrocnemius left minimum temperature before exercise

GSE	28.41	± 1.57	,449*
Non GSE	28.71	± 1.39	,441*

Gastrocnemius left maximum temperature before exercise

GSE	30.85	± 1.32	,442*
Non GSE	31.07	± 0,81	,452*

Gastrocnemius left mean temperature before exercise

GSE	29.92	± 1.34	,687*
Non GSE	30.12	± 0.84	,681*

Gastrocnemius right minimum temperature before exercise

GSE	28.35	± 2.0	1,065*
Non GSE	29.1	± 0.94	1,1*

Gastrocnemius right maximum temperature before exercise

GSE	31.1	± 1.14	,357*
Non GSE	31.91	± 0,86	,362*

Gastrocnemius right mean temperature before exercise

GSE	29.89	± 1.14	,608*
Non GSE	30.17	± 0.93	,614*

Achilles tendon left minimum temperature before exercise

GSE	22.52	± 3.59	,581*

Non GSE	23.22	± 1.16	,605*
Achilles tendon Left maximum temperature before exercise			
GSE	29.52	± 1.58	,819*
Non GSE	28.93	± 1.75	,815*
Achilles tendon left mean temperature before exercise			
GSE	26.57	± 1.92	,393*
Non GSE	26.87	± 1.47	,399*
Achilles tendon right minimum temperature before exercise			
GSE	22.74	± 2.34	,364*
Non GSE	23.05	± 1.26	,367*
Achilles tendon right maximum temperature before exercise			
GSE	29.57	± 1.88	,062*
Non GSE	29.51	± 1.13	,064*
Achilles tendon right mean temperature before exercise			
GSE	26.29	± 1.68	1,48*
Non GSE	27.46	± 1.93	1,47*

149 * No statistically significant difference between groups ($p \geq 0.05$). † Statistically significant
150 difference between groups (P<0.05). N = 10 non-equinus and N = 11 equinus participants

151

152 However, after running, the TA temperature (minimum, maximum, and mean) was significantly
153 warmer in the GSE than the Non GSE participants (P <.05). Also, the minimum G temperatures
154 (both right and left) and left AT mean temperature were significantly warmer in the GSE than the
155 Non-GSE participants (Table 3).

Table 3. Temperature values (Degrees Celsius) for tibialis anterior, gastrocnemius-soleus and Achilles tendon for gastrosoleus equinus (GSE) and non-gastrosoleus equinus (Non-GSE) participants after exercise.

Variable	Mean	SD	P value
Tibialis anterior right minimum temperature after exercise			

Non GSE	27.1	± 1.9	,007†
GSE	29.04	± 0.76	,008†

Tibialis anterior right maximum temperature after exercise

Non GSE	30.28	± 1.53	,006†
GSE	31.95	± 0,8	,006†

Tibialis anterior right mean temperature after exercise

Non GSE	29.14	± 1.88	,035†
GSE	30.63	± 0.89	,034†

Tibialis anterior left minimum temperature after exercise

Non GSE	27.12	± 1.63	,001†
GSE	29.42	± 0.65	,001†

Tibialis anterior left maximum temperature after exercise

Non GSE	30.52	± 1.19	,038†
GSE	31.72	± 1.25	,038†

Tibialis anterior left mean temperature after exercise

Non GSE	29.36	± 1.62	,029†
GSE	30.77	± 1.04	,027†

Gastrocnemius left minimum temperature after exercise

Non GSE	27.92	± 1.65	,033†
GSE	29.38	± 1.16	,031†

Gastrocnemius left maximum temperature after exercise

Non GSE	30.31	± 1.39	,036†
GSE	31.32	± 1.22	,035†

Gastrocnemius left mean temperature after exercise

Non GSE	29.27	± 1.53	,063*

GSE	30.44	± 1.12	,06*
Gastrocnemius right minimum temperature after exercise			
Non GSE	27.81	± 1.67	,025†
GSE	29.29	± 0.97	,024†
Gastrocnemius right maximum temperature after exercise			
Non GSE	30.5	± 1.32	,140*
GSE	31.3	± 0,98	,135*
Gastrocnemius right mean temperature after exercise			
Non GSE	29.20	± 1.48	,025†
GSE	30.55	± 0.93	,023†
Achilles tendon left minimum temperature after exercise			
Non GSE	24.04	± 3.34	,146*
GSE	25.75	± 1.24	,139*
Achilles tendon Left maximum temperature after exercise			
Non GSE	30.44	± 2.02	,278*
GSE	31.23	± 0.93	,267*
Achilles tendon left mean temperature after exercise			
Non GSE	27.88	± 2.13	,020†
GSE	29.87	± 1.3	,019†
Achilles tendon right minimum temperature after exercise			
Non GSE	24.41	± 3.15	,216*
GSE	25.85	± 1.65	,207*
Achilles tendon right maximum temperature after exercise			
Non GSE	30.27	± 1.79	,073*
GSE	31.5	± 1.02	,07*

Achilles tendon right mean temperature after exercise			
Non GSE	27.91	± 1.67	,006*
GSE	29.85	± 1.2	,005*

* No statistically significant difference between groups ($p \geq 0.05$). † Statistically significant difference between groups (P<0.05). N = 10 non-equinus and N = 11 equinus participants

156

DISCUSSION

157

158 Here, we identified an increase in TA temperature after running in professional soccer
159 professionals with GSE condition compared to those without GSE. The minimum G
160 temperatures (right and left lower limb) and mean AT (left lower limb) temperature were also
161 higher in GSE than non-GSE participants.

162 Ankle torque was higher in GSE participants than non-GSE participants[22]. The TA requires
163 stronger contraction in GSE condition and, therefore, might be affected early by fatigue, thus
164 explaining our observed increase in TA temperature in GSE participants compared to non-GSE
165 participants. While participants remain without running activity, we didn´t found differences. The
166 running exercise may serve a stimulus to increase temperature in muscles and consequently
167 differences between groups.

168 Researchers have addressed the necessary degrees of ankle dorsiflexion and basal values.[1,6]
169 Biomechanically, the maximum ankle dorsiflexion during the stance-phase of a normal gait
170 occurs before heel lift with the knee extended.[1] The minimum ankle range of motion for normal
171 gait is 10° dorsiflexion and 20° plantarflexion.[1,2,6] The most deeply known range of movement
172 values for ankle dorsiflexion in the reviewed literature for static evaluation that the minimum
173 dorsiflexion movement for the ankle for normal gait is 10° of motion.[3, 18-23] GSE produces a
174 higher loading force to the foot and can lead to foot-ankle biomechanical pathologic (e.g.,
175 plantar fasciitis, pes planus, hallux abductus valgus, Achilles tendinosis, Charcot's midfoot
176 collapse, and diabetic ulcerations).[3] DiGiovanni et al. found GSE in patients with foot and ankle
177 pain.[1] However, GSE is also found in asymptomatic patients.[24]

178 Further studies will be needed to improve our knowledge of muscle condition and to establish
179 the clinical relevance of the association between temperature and cutaneous muscle projection
180 [25]. Based on our findings, we propose that IR-imaging can be a reliable tool for clinical
181 therapeutic assessment.

CONCLUSIONS

182

183 GSE participants had a higher TA muscle temperature after exercise that non-GSE participants.
184 The GSE groups showed a higher TA skin temperature. Therefore, Infrared thermography, in the
185 way it measures skin temperature, could serve as screening tool for preventing or therapeutic

186 actions. Further research is needed to identify other factors associated with GSE condition, as
187 well as to better understand the factors that contribute to different temperature pattern in the
188 lower limbs.

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