IOP Publishing Physiol. Meas. 47 (2026) 055002 https://doi.org/10.1088/1361-6579/ae63a4

Physiological Measurement

IPEM Institute of Physics and Engineering in Medicine

RECEIVED
9 January 2026

REVISED
11 April 2026

ACCEPTED FOR PUBLICATION
22 April 2026

PUBLISHED
6 May 2026

PAPER

Acute effects of FIFA 11+ warm-up on skin temperature in male and female amateur soccer players

Patricia Caudet[1,*], **Ernest Baiget**[2], **Abraham Batalla**[3,4,5], **Joshua Colomar**[6,7] **and Francisco Corbi**[8]

[1] National Institute of Physical Education (INEFC), University of Lleida, Lleida, Spain
[2] National Institute of Physical Education (INEFC), University of Barcelona, Barcelona, Spain
[3] EUSES School University of Health and Sport, Rovira I Virgili University, Tarragona, Spain
[4] Sport Science Group Research of National Institute of Physical Education (INEFC), University of Barcelona, Barcelona, Spain
[5] Department of Education and Specific Didactics, Faculty of Humanities and Social Sciences, University Jaume I, Castellón de la Plana, Spain
[6] University of Vic—Central University of Catalonia. Sports and Physical Activity Studies Center (CEEAF), Vic, Spain
[7] Sports Performance Analysis Research Group (SPARG), University of Vic-Central University of Catalonia, Vic, Spain
[8] Department of Clinical Sciences, Faculty of Medicine and Health Sciences, University of Barcelona, Spain
[*] Author to whom any correspondence should be addressed.

E-mail: patriciacaudet@gmail.com

Keywords: infrared thermography, soccer, acute effects, FIFA 11+

Abstract

Objective. Warm-up is a fundamental part of the training session and competition preparation, improving performance and reducing sports injuries. The FIFA 11+ is a specific evidence-based routine created to enhance neuromuscular performance and prevent lower-limb injuries. Infrared thermography (IRT) is a non-invasive tool for monitoring tissue state and thermoregulation responses. This study examined the acute effects of the FIFA 11+ warm-up on skin surface temperature (Tsk) patterns of the dominant lower limb in amateur football players using IRT. *Approach*. A pre-post observational design was applied to 120 amateur players (60 men, 60 women) before a match. Baseline and post-intervention Tsk measurements were acquired with a FLIR T540-EST camera following the TERMOINEF protocol. *Main results*. Significant post-warm-up Tsk reductions were detected in proximal muscle regions, particularly in quadriceps and adductors, with a reduction of −1.9 to −2.4 °C (ES = − 1.63 to −1.92, large) in women and −0.7 to −1.2 °C (ES = − 0.66 to −1.07, moderate) in men. Conversely, distal regions such as the anterior plantar arch showed marked Tsk increases of +2.6 °C (ES = 1.83, large) in women; +2.1 °C (ES = 1.42, large) in men. Men exhibited higher absolute Tsk values overall ($\eta^2 \approx 0.17$-0.26), whereas women displayed greater relative percentage changes, including sex-specific Achilles tendon response (a decrease in women versus a slight increase in men). *Significance*. FIFA 11+ induces heterogeneous, region- and sex- dependent thermal adaptations, supporting the use of IRT as a valid tool for individualized warm-up monitoring and optimization in football.

Glossary

The following abbreviations are used in this manuscript:

F-MARC	FIFA Medical Assessment and Research Centre
IRT	Infrared thermography
ROI	Region of interest
Tsk	Skin temperature
FIFA 11+	Warm-up protocol
RFEF	Royal Spanish Football Federation

ARG	Number of activated sweat glands
SGP	Greater sweat production per gland

1. Introduction

Warm-up protocols are a fundamental component in sports performance that aim to prime physiological systems for reducing musculoskeletal injury risk and to improve performance (He 2024). In football, warm-up is particularly important because it involves intermittent high-intensity activities as sprints, changes of direction, and complex technical-tactical demands. It was observed how at the beginning of the match the risk of injury is higher (Matas *et al* 2024) because high intensity and psychological demands impose substantial stress on neuromuscular coordination, metabolic readiness, and musculoskeletal integrity (Yıldız and Çebi 2025). To meet these demands efficiently and safely, an optimally designed warm-up should stimulate neuromuscular preparedness while avoiding pre-fatigue (Gok *et al* 2024).

The FIFA 11+ warm-up protocol, developed by the F-MARC, represents a structured, evidence-based approach designed for footballers across competition levels, with special applicability to amateur players who often lack access to specialized preventive programs (F-MARC, 2016). The program aims to enhance neuromuscular readiness and reduce injury risk, especially in the lower limbs. It uses plyometric drills, dynamic strength exercises, balance training, and agility sequences, all completed in a 20–25 min session (Asgari *et al* 2023). Development of the protocol was based on epidemiological injury data and expert consensus, with attention to being time-efficient and adaptable to diverse age groups and competition contexts (Pardos-Mainer *et al* 2019). In this context, FIFA 11+ warm-up protocol can be considered a standardized and reproducible physiological stimulus, providing an appropriate experimental model to examine the sensitivity of IRT for detecting acute, region-specific thermoregulatory responses at the skin surface (Tsk).

Scientific evidence supports the effectiveness of the FIFA 11+ protocol. Interventions over 6 weeks or longer have shown significant reductions in lower-limb injury incidence. Improvements in static and dynamic balance, core stabilization, and functional control have also been observed (Silvers-Granelli *et al* 2015, Magoshi *et al* 2023, Ramos *et al* 2024). However, its acute effects have been less studied and the research in this area has yielded inconsistent results. Some studies reported minimal or no improvements in muscle activation, stiffness, or agility immediately after the warm-up (Caudet *et al* 2025), while others observed transient declines in sprint performance or technical skills such as shooting accuracy (Dunsky *et al* 2017). These inconsistencies may be due to factors such as heterogeneity in study populations (elite vs amateur, male vs female), assessment methodologies, warm-up duration and intensity, and the inclusion of fatigue-inducing drills (Bizzini *et al* 2013). This variability highlights the need for objective, sensitive methods to evaluate true acute physiological impact of warm-up protocols.

In the field research, tracking such localized responses is challenging due to the impossibility of constant monitoring during competition. Heart rate monitoring and perceived exertion scales provide general workload estimates but lack sensitivity for detecting site-specific or rapid changes in neuromuscular and thermal status (Wu *et al* 2023). IRT offers a solution by non-invasively assessing Tsk patterns over specific ROI, reflecting the balance between metabolic heat production and peripheral heat dissipation (Formenti *et al* 2016). Tsk is regulated by vascular dynamics -vasodilation and vasoconstriction- which acts as indicators of localized metabolic demand and thermal conductance (Charkoudian 2003, Hillen *et al* 2023). IRT also facilitates the detection of Tsk asymmetries between limbs, which may reveal underlying physiological conditions such as inflammation, fatigue, or increased injury risk. In fact, previous studies have used IRT to analyze the influence of static and dynamic warm-up on Tsk knee before and after a change of direction (Trovato *et al* 2024) and to monitor fatigue after warm up exercises (Hadžić *et al* 2019). Also, sex-based differences using IRT have been studied (Casa *et al* 2010, Ghahramani *et al* 2016), resulting in sex specific responses in sweat rate, peripheral vasomotor control, body composition, and hormonal cycles. Furthermore, consensus statements in sports medicine endorse thermography as a reliable and valid tool for tracking acute and chronic thermoregulatory adaptations in athletes (Moreira *et al* 2017).

From a more practical perspective, IRT could lead to football-specific alterations such as those appearing in the dominant leg, preferentially used for tasks such as kicking the ball (Pieters *et al* 2022), which is often under higher mechanical and metabolic stress due to its involvement in high-intensity sport-specific actions (Dos Santos Bunn *et al* 2020, Binek *et al* 2022).

However, the extent to which a standardized preventive warm-up such as FIFA 11+ elicits measurable, regions-specific thermoregulatory responses at the skin surface remains unclear. During the warm up, the acute physiological response is characterized by rapid and transient adjustments in peripheral blood flow and heat transfer, which are not always captured by traditional performance or neuromuscular assessments (Formenti *et al* 2016, Hillen *et al* 2023). These vasomotor adjustments could result in region-specific Tsk changes that reflect transient peripheral thermoregulatory responses rather than uniform increases in Tsk. During the early stages of exercise, sympathetic activation can induce cutaneous vasoconstriction that transiently reduces skin blood flow and may decrease Tsk, despite increasing metabolic heat production (Charkoudian 2003, Formenti *et al* 2016). As exercise continues and thermal load increases, compensatory vasodilation mechanisms may progressively facilitate heat dissipation, which can subsequently increase Tsk (Hillen *et al* 2023). However, the magnitude and direction of these thermal responses are not uniform and appear to depend on factors such as exercise intensity, duration, anatomical region, and the timing of thermographic assessment.

Despite its potential, studies evaluating acute IRT responses of the FIFA 11+ protocol remain scarce. Accordingly, the present study aims to investigate the immediate effects of the FIFA 11+ warm-up on Tsk patterns of the dominant lower limb in amateur football players using IRT. A secondary aim from this study is to examine potential sex-related differences in the thermal response.

2. Materials and methods

2.1. Study design

To examine the acute effect of the FIFA 11+ warm-up on the Tsk of the dominant leg, a descriptive observational study with a pre-post intervention design was conducted. Participants performed the FIFA 11+ protocol. Baseline (PRE) Tsk measurements were obtained using a FLIR T540-EST infrared camera (FLIR Systems Inc., Wilsonville, OR, USA), following the standardized protocol of the TERMOINEF group (Fernández-Cuevas *et al* 2012, Sillero-Quintana *et al* 2015). Four thermal images were captured for analyses: (1) frontal view, (2) posterior view, (3) knee-specific view, and (4) feet in a supine position on an examination table (see figures 1 and 2). Subsequently, participants completed the FIFA 11+ warm-up. Post-intervention (POST) thermal assessments were then repeated following the same imaging protocol. One week prior to data collection, a familiarization session was conducted to ensure that participants were fully familiar with the FIFA 11+ warm-up protocol. In addition, the risks and benefits of their participation were explained, the intervention protocol was described in detail, a full warm-up simulation was performed, participant questions were addressed and informed consent documents were signed.

2.2. Participants

A total of 120 amateur footballers (60 men and 60 women) from the RFEF participated in this study (table 1). All participants engaged in regular training sessions lasting between 1.5 and 2 h, from three to four times per week with a weekend match. In the days preceding data collection, players were instructed to maintain their usual training, dietary, and rest routines. Prior to thermographic assessment, participants were instructed to avoid the use of topical products (e.g. creams or lotions) on the lower limbs and to refrain from hot shower, sauna, or any physical or thermal treatments that could influence Tsk before the measurements. Individuals with a history of musculoskeletal injuries to the lower limbs within the past 6 months were excluded. Participants did not receive any financial compensation or material incentives for their participation. All volunteers were provided with a detailed explanation of the study procedures, signed an informed consent form, and were informed of their right to withdraw from the study at any time without consequences. Confidentiality and anonymity of the data was guaranteed since each participant was assigned an anonymous registration number. The protocol was approved by the Bioethics Committee of the University of Barcelona (Institutional Review Board, IRB00003099; reference CER042418) and was in accordance with the principles outlined in the Declaration of Helsinki for human research (World Medical Association 2013), the Biomedical Research Act (BOE-A-2007-12 945, 2007), and the Data Protection Act (BOE-A-2018-16 673, 2018).

2.3. Procedures

2.3.1. Anthropometry

Before baseline measurements, anthropometric assessments were performed to determine height, using a Seca® 220 stadiometer (Seca GmbH, Hamburg, Germany, accuracy ±0.1 cm), and body mass, using a

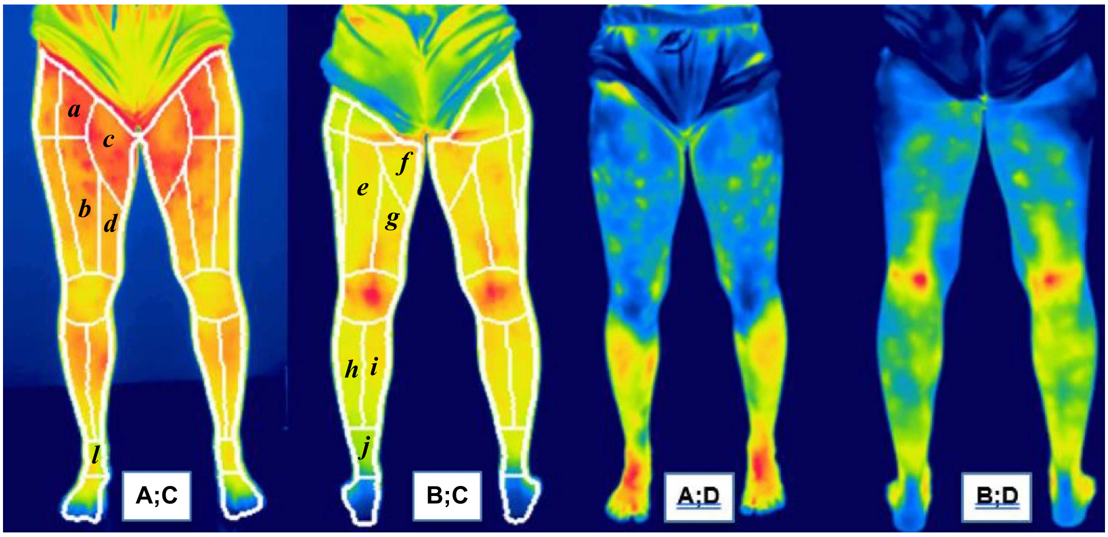

Figure 1. Representative thermographic images of a female player taken from the front (A) and back (B), before (C) and after (D) the warm-up. Images were obtained immediately after the warm-up; visible skin moisture reflects the acute post-exercise condition and does not affect the quantitative region-of-interest based temperature analysis. Thermal images were analyzed using Thermohuman® software (Thermohuman, Madrid, Spain).

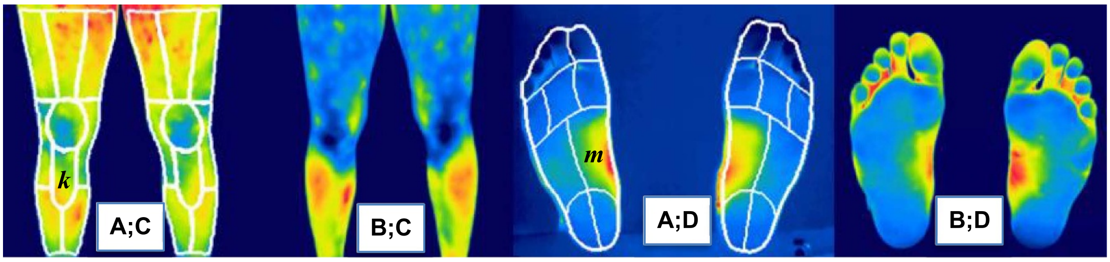

Figure 2. Representative thermographic images of a female player taken from the knee-specific view and feet in a supine position, front (A) and back (B), before (C) and after (D) the warm-up. Images were obtained immediately after the warm-up; visible skin moisture reflects the acute post-exercise condition and does not affect the quantitative region-of-interest based temperature analysis. Thermal images were analyzed using Thermohuman® software (Thermohuman, Madrid, Spain).

Table 1. Descriptive characteristics of participants.

	Sex groups		
	Male ($n = 60$)	Female ($n = 60$)	Total ($n = 120$)
Chronological age (years)	21.8 ± 5.3	22.6 ± 5.0	22.2 ± 5.2
Training background (years)	14.7 ± 5.3*	10.1 ± 5.0	12.4 ± 5.6
Training volume (h·week^{-1})	6.2 ± 1.4	5.9 ± 0.5	6.0 ± 1.0
Height (cm)	179.0 ± 5.5*	164.0 ± 5.8	171.5 ± 9.4
BM (kg)	75.2 ± 8.0*	60.2 ± 9.4	67.7 ± 11.5
BMI (Kg·m^{-2})	23.5 ± 2.3	22.5 ± 4.2	23.0 ± 3.4

The values presented are means ± SD. BM, body mass, BMI, body mass index.
*Significantly different from the female group ($p < 0.001$).

Seca® 700 column scale (Seca GmbH, Hamburg, Germany, accuracy ±0.05 kg). Body mass index (BMI) was calculated individually for each participant using the standard formula (body mass/height^2), and group values were expressed as mean ± standard deviation (SD) (table 1). Room temperature during the assessments was maintained at 21 °C.

2.3.2. Tsk

Tsk was measured using a FLIR T540-EST infrared camera (FLIR Systems Inc., Wilsonville, OR, USA) following the standardized TERMOINEF acquisition protocol (Fernández-Cuevas *et al* 2012, Sillero-Quintana *et al* 2015), in line with current methodological recommendations for IRT in sports and exercise medicine (Moreira *et al* 2017). Pre- and post-intervention thermographic images were acquired immediately after completion of the FIFA 11+ warm-up, without a post-exercise acclimatization period, to capture the acute Tsk response induced by the warm-up.

Emissivity ($\varepsilon = 0.98$) and acquisition parameters were configured directly in the camera system prior to image acquisition. A uniform matte black background (wall and support surface) was used during image acquisition to minimize thermal reflections and improve contrast between the skin surface and the surrounding environment. The thermographic images were subsequently uploaded to the Thermohuman® platform (Thermohuman, Madrid, Spain), where automated ROI segmentation and quantitative extraction of Tsk values were performed for each anatomical region.

Prior to data acquisition, the infrared camera was switched on in advance to allow thermal stabilization of the sensor. Four thermographic images were captured with the camera positioned perpendicular to the ROIs to ensure consistent image acquisition across participants: (1) frontal view at 1.5 m, (2) posterior view at 1.5 m, (3) knee-focused view at 1 m, and (4) supine position with exclusive focus on the feet. Thermographic images were acquired following a standardized sequence, with participants standing for frontal, posterior, and knee-focused views, and subsequently adopting a supine position on an examination table for plantar foot assessment.

In each image, thirteen specific ROIs were delineated: (a) upper central thigh, (b) anterior central thigh, (c) anterior adductor, (d) internal anterior thigh, (e) central posterior thigh, (f) internal posterior adductor, (g) internal posterior thigh, (h) external posterior leg, (i) internal posterior leg, (j) Achilles tendon, (k) patellar tendon, (l) ankle, (m) anterior arch of the foot.

As thermographic images were obtained immediately after completion of the warm-up, no active drying of the skin was performed to avoid altering the acute cutaneous thermal responses, any residual moisture was therefore considered part of the physiological response to exercise. During thermographic assessments, participants wore their usual training shorts, which were adjusted to fully expose the ROIs of the lower limb, ensuring consistent and unobstructed ROI delineation across participants.

The reliability of this protocol has been reported as excellent (ICC = 0.989) (Fernández-Cuevas *et al* 2012). All measurements were conducted at a constant room temperature of 21 °C, avoiding direct light exposure or airflow (Kalinowski *et al* 2022). Ambient temperature and relative humidity were monitored throughout data collection sessions using a digital thermo-hygrometer (PCE-THD 50, PCE Instruments, Meschede, Germany). Environmental conditions were recorded during each assessment session and averaged 20 °C ± 1 °C and 56% ± 3% HR relative humidity across all measurement sessions. Only data from the dominant leg -defined as the preferred leg for kicking the ball (Pieters *et al* 2022) -were considered for analysis. Measurements were obtained two days after competition, under comparable environmental conditions across sessions. Participants did not undergo any recovery interventions (e.g. massage, cryotherapy, or thermotherapy) or physical treatments affecting the lower limbs prior to the thermographic assessments.

2.3.3. FIFA 11+ warm-up

The FIFA 11+ program was implemented as a standardized warm-up for all participants, following the guidelines established by Bizzini *et al* (2013) and Impellizzeri *et al* (2013). The protocol lasted approximately 20–25 min and comprised three progressive phases (Daneshjoo *et al* 2012, Chen *et al* 2019, Pardos-Mainer *et al* 2019): (1) low -to moderate-intensity running with active stretching and partner-based exercises; (2) progressive drills targeting strength, plyometrics, agility, and balance; and (3) moderate -to high-intensity running incorporating changes of direction. The program integrates dynamic, functional strength, and coordination exercises to optimize physical and neuromuscular readiness before the main training or match activity.

2.4. Statistical analyses

Data are expressed as mean ± SD. Normality and homogeneity of variances were assessed using the Shapiro–Wilk test. Differences between sexes were analyzed using an independent samples *t*-test. A two-way repeated measures ANOVA with Bonferroni correction was used, considering sex (male vs female) as the between-subject factor and measurement moment (pre- vs post-intervention) as the within-subject factor. Effect size was calculated using partial eta squared (η^2) and interpreted as small (0.01–0.05), medium (0.06–0.13) or large (>0.14). Within-group changes were evaluated using Cohen's d and interpreted as trivial ($d = 0$–0.2), small ($d = 0.2$–0.6), moderate ($d = 0.6$–1.2), large ($d = 1.2$–2.0) or very large ($d > 2.0$), according to Hopkins *et al* (2009). Statistical significance was set at $p < 0.05$. All analyses were performed using IBM SPSS Statistics v23.0 software (IBM Corp., Armonk, NY, USA).

3. Results

Changes in the selected physiological variables between pre- and post-warm-up, stratified by sex, are presented in table 2. Following the standardized warm-up, a small main effect of measurement moment was observed for Tsk at the posterior medial lower leg ($F[1.117] = 5.23$; $p = 0.024$; $\eta^2 = 0.043$) and patellar tendon ($F[1.117] = 6.89$; $p < 0.009$; $\eta^2 = 0.056$). Medium main effects were found at the proximal anterior thigh ($F[1.117] = 14.27$; $p < 0.001$; $\eta^2 = 0.109$), central posterior thigh ($F[1.117] = 15.95$; $p < 0.001$; $\eta^2 = 0.12$), posterior medial adductor ($F[1.117] = 11.50$; $p < 0.001$; $\eta^2 = 0.089$), posterior medial thigh ($F[1.117] = 7.85$; $p = 0.006$; $\eta^2 = 0.063$) and posterior lateral lower leg ($F[1.117] = 8.60$; $p = 0.004$; $\eta^2 = 0.068$). Large main effects of moment were observed at the anterior adductor ($F[1.117] = 22.32$; $p < 0.001$; $\eta^2 = 0.160$) and anterior foot arch ($F[1.117] = 27.06$; $p < 0.001$; $\eta^2 = 0.188$).

For the moment $\times$ sex interaction, a medium effect was detected at the anterior medial thigh ($F[2.117] = 7.78$; $p < 0.001$; $\eta^2 = 0.117$), whereas large effects were found at the proximal anterior thigh ($F[2.117] = 16.53$; $p < 0.001$; $\eta^2 = 0.220$), central anterior thigh ($F[2.117] = 12.22$; $p < 0.001$; $\eta^2 = 0.173$), anterior adductor ($F[2.117] = 13.65$; $p < 0.001$; $\eta^2 = 0.189$), central posterior thigh ($F[2.117] = 21.24$; $p < 0.001$; $\eta^2 = 0.266$), posterior medial adductor ($F[2.117] = 20.45$; $p < 0.001$; $\eta^2 = 0.259$), posterior medial thigh ($F[2.117] = 14.98$; $p < 0.001$; $\eta^2 = 0.204$), posterior lateral lower leg ($F[2.117] = 7.89$; $p < 0.001$; $\eta^2 = 0.119$).

Post-hoc analyses revealed that in women, large decreases were found in all muscles region assessed ($p < 0.001$; $\Delta = -$ 8.1% to 9.6%; ES $= -$ 1.92 to -1.83), except for the patellar tendon ($p < 0.001$; $\Delta = -$ 2.6%; ES $= -$ 0.53), central anterior thigh ($p < 0.001$; $\Delta = -$ 4.3%; ES $= -$ 1.04), posterior medial lower leg ($p < 0.001$; $\Delta = -$ 3.2%; ES $= -$ 1.01) and anterior medial thigh ($p < 0.001$; $\Delta = -$ 3.1%; ES $= -$ 0.74). In men, moderate decreases were observed in most muscle regions ($p < 0.001$; $\Delta = -$ 3.9% to -1.7%; ES $= -$ 1.07 to -0.61), with small decreases in the posterior medial lower leg ($p < 0.001$; $\Delta = -$ 1.5%; ES $= -$ 0.57) and patellar tendon ($p < 0.001$; $\Delta = -$ 2.3%; ES $= -$ 0.54). Notably, men exhibited a large increase in the anterior foot arch ($p < 0.001$; $\Delta = +$ 7.7%; ES $= 1.42$).

Significant group $\times$ moment interactions were detected for all thigh and adductors regions, as well as for the posterior lateral lower leg. Not significant interactions were found for the remaining anatomical sites.

4. Discussion

The present findings demonstrate that IRT is sensitive to detecting acute, region-specific changes in Tsk following a standardized warm-up stimulus, supporting its applicability for monitoring transient peripheral thermoregulatory responses in applied settings. Following the FIFA 11+ warm-up, a marked reduction in Tsk was observed in most proximal lower-limb muscles, with mean decreases close to 2 °C in the quadriceps and adductors areas, whereas distal areas—particularly the plantar arch—showed an average thermal increase of approximately 1.2 °C. These results indicate that the acute thermal response to the FIFA 11+ warm-up is not uniform across anatomical regions, reflecting different physiological mechanisms regulating heat production and dissipation during the transition from rest to exercise. Specifically, proximal muscle regions such as the upper central thigh, central posterior thigh, and anterior adductor exhibited a pronounced post warm-up Tsk decrease, with reductions ranging from -6.7% to -8.1% (ES $= -$ 1.74 to -1.92, large) in women and -2.2% to -3.9% (ES $= -$ 0.66 to -1.07, moderate) in men. This proximal thermal reduction likely reflects a superficial vasoconstrictor response that limits skin blood flow in active proximal muscles to favor oxygen and nutrient delivery to deeper fibers, undergoing increased metabolic activity during warm-up (Neves *et al* 2016, Hargreaves and Spriet 2020).

These Tsk variations result from the coordinated action among physiological systems involved in thermoregulation, blood circulation, and muscle metabolism. Human thermoregulation is tightly controlled by the autonomic nervous system (Morrison and Nakamura 2019), which regulates skin blood flow through vasoconstriction, vasodilation and sweat gland activation (Charkoudian 2016) that facilitates evaporative heat loss (Hu *et al* 2018). These autonomic adjustments are coordinated by the

Table 2. Pre-and post-warm up skin temperature (Tsk) values across the analyzed region of interest.

	Gender groups								Two-Way ANOVA	
	Women ($N = 60$)				Men ($N = 60$)				Moment effect	Moment × gender effect
	Pre	Post	Δ (%)	ES	Pre	Post	Δ (%)	ES	*p*-value	
Proximal area										
Upper Central Thigh (°)	30.80 ± 1.17*	28.31 ± 1.30ǂ§	−8.1	−1.81	32.09 ± 1.25	30.99 ± 1.81§	−3.4	−0.86	<.001	<.001
Anterior Central Thigh (°)	29.93 ± 1.16*	28.65 ± 1.11ǂ§	−4.3	−1.04	31.19 ± 1.10	30.94 ± 1.42	−0.8	−0.23	0.1	<.001
Anterior Adductor (°)	30.50 ± 1.10*	28.10 ± 1.14ǂ§	−7.9	−1.92	31.74 ± 1.28	30.50 ± 1.87§	−3.9	−1.07	<.001	<.001
Internal Anterior Thigh (°)	29.84 ± 1.12*	28.92 ± 1.03ǂ§	−3.1	−0.74	31.00 ± 1.17	30.91 ± 1.46	−0.3	−0.08	0.231	<.001
Central Posterior Thigh (°)	29.94 ± 1.09*	27.95 ± 1.28ǂ§	−6.7	−1.74	31.39 ± 1.06	30.71 ± 1.46§	−2.2	−0.66	<.001	<.001
Internal Posterior Adductor (°)	30.13 ± 1.16*	27.98 ± 1.38ǂ§	−7.1	−1.63	31.57 ± 1.18	30.83 ± 1.66§	−2.4	−0.71	<.001	<.001
Internal Posterior Thigh (°)	30.09 ± 0.99*	28.42 ± 1.20ǂ§	−5.6	−1.43	31.35 ± 1.09	30.73 ± 1.41§	−2.0	−0.66	0.006	<.001
Distal area										
External Posterior Leg (°)	29.64 ± 1.06*	28.48 ± 1.13ǂ§	−3.9	−1.24	30.62 ± 1.05	30.11 ± 1.14§	−1.7	−0.61	0.004	<.001
Internal Posterior Leg (°)	30.11 ± 0.98*	29.15 ± 1.14ǂ§	−3.2	−1.01	30.94 ± 0.88	30.47 ± 1.04§	−1.5	−0.57	0.024	0.013
Achilles Tendon (°)	29.36 ± 1.20	29.32 ± 1.22#	−0.1	−0.04	29.73 ± 1.08	29.98 ± 0.96	0.8	0.26	0.968	0.264
Patellar Tendon (°)	29.93 ± 1.24#	29.17 ± 1.32#§	−2.6	−0.53	30.61 ± 1.10	29.90 ± 1.27§	−2.3	−0.54	0.01	0.54
Ankle (°)	29.62 ± 1.59	30.65 ± 1.29§	3.5	0.87	29.68 ± 1.52	31.05 ± 1.02§	4.6	1.11	0.054	0.181
Anterior Arch Foot (°)	27.46 ± 1.83	30.10 ± 1.97§	9.6	1.83	27.67 ± 1.67	29.81 ± 1.53§	7.7	1.42	<.001	0.168

Data are mean ± SD. Moment and moment × group interaction *p*-values were obtained by two-way ANOVA (2 gender groups × 2 moments). Intragroup significant differences from pre- to post-test:
§ $p < 0.001$ different to pretest values.
Differences between genders in the pre- and post-test:
Pre-test differences between men ($p < 0.01$)
* Pre-test differences between men ($p < 0.001$).
ǂ Post-test differences between men ($p < 0.001$).

hypothalamus—particularly the preoptic area—which preserves core temperature which integrates core and peripheral thermal inputs to regulate vascular and sudomotor responses in a dynamic balance between heat production and dissipation (Zhao *et al* 2017, Šijanec and Lenasi 2023). At the onset of exercise, sympathetic activation increases norepinephrine release to alpha-adrenergic receptors in the cutaneous vasculature, eliciting vasoconstriction that reduces skin blood flow and preserves core temperature (Katayama and Saito 2019), thereby prioritizing perfusion of active muscles and vital organs (González-Alonso *et al* 2000, Delorey 2021). During movement, muscles tend to reduce their temperature with applied speed because they require a greater blood supply to guarantee high levels from oxygen and nutrients (Formenti *et al* 2016, Neves *et al* 2016, Igarashi *et al* 2022). This supports the interpretation that immediate post-FIFA 11+ measurements capture the early vascular phase dominated by cutaneous vasoconstriction, prior to the onset of compensatory vasodilation for heat dissipation (Hillen *et al* 2020, 2023, Mota-Rojas *et al* 2021, Corral-Pérez *et al* 2023). Accordingly, thermographic images were obtained immediately after the warm-up without a post-exercise acclimatization period, trying to characterize the early, transient cutaneous thermal responses induced by the FIFA 11+ protocol rather than stabilized Tsk values. The relatively short duration and moderate intensity of the warm-up -focused on motor control and stabilization- may prolong this vasoconstrictive phase. These results agree with previous findings reporting that Tsk of certain distal areas of the body, such as the legs, tends to decrease with movement (Merla *et al* 2010).

Conversely, distal regions—particularly the anterior plantar arch—demonstrated significant Tsk increases, indicating a thermographic response distinct from that observed in proximal muscle regions. This different behavior may be explained by the specific biomechanical and thermoregulatory characteristics of the foot, which is exposed to greater mechanical load during actions and presents a high density of sweat glands that facilitate heat dissipation (Kawabata and Tokura 1993, Reddy *et al* 2017, Jimenez-Perez *et al* 2020). In addition, the plantar surface of the foot contains a thick subcutaneous adipose tissue layer (plantar fat pad), one of the most developed in the human body, which acts as both a mechanical shock absorber and a thermal insulator. This structural characteristic may also influence local heat transfer and contribute to the distinct thermographic response observed in the plantar region (Gefen 2003). In the present study, women showed increase of 9.6% (ES = 1.83, large) and men 7.7% (ES = 1.42, large). These findings align with previous studies where foot temperature increases during dynamic activities such as walking (Kawabata and Tokura 1993, Reddy *et al* 2017) and running (Moran-Cortes *et al* 2023, Liu *et al* 2024). This could be attributed to low intensity running and dynamic exercises in pairs developed during the warmup. In addition, the elevated traction speed and mechanical load generated during the changes of direction seems to increase thermal stress (Wan *et al* 2024). On the other hand, Tsk foot could increase because of intrinsic foot muscle activation and the mechanical tension generated by the windlass mechanism during static postures and proprioceptive strengthening exercise (Huffer *et al* 2017, Tourillon *et al* 2019). Contraction and stretching of these muscles increase local metabolic rate and blood flow demand, stimulating localized cutaneous vasodilation. Moreover, the foot answers as a specialized thermal radiator, with a high density of sweat glands that facilitate evaporative heat loss (Jimenez-Perez *et al* 2020). The interaction of these mechanisms explains the localized thermal rise, readily detected through IRT.

Interestingly, a notable sex-specific response was observed in the Achilles tendon, with a thermal drop in women versus a slight increase in men, suggesting underlying physiological and biomechanical differences in post-exercise thermoregulatory regulation between sexes. This finding is particularly relevant because previous evidence has shown a relationship between Achilles tendon temperature and its mechanical properties. Sasajima and Kubo (2025) observed that when the tendon was heating, despite no changes in oxygen consumption and in elastic energy during submaximal jumps, a reduction in tendon hysteresis and assessment in efficiency (lower electromyographic signal) were observed. This justifies the interest in raising the temperature in the tendon during warm-up, as it may enhance tendon mechanical efficiency and energy transfer during subsequent movements.

From a sex-differences perspective, men exhibited higher absolute Tsk values than women, whereas women showed greater relative percentage changes, with moderate-to-large effect sizes, particularly in regions displaying Tsk decreases. These results align with those of other studies (Kaciuba-Uscilko and Grucza 2001, Jimenez-Perez *et al* 2020, Binek *et al* 2022, Hillen *et al* 2023). Sex differences in thermoregulation are influenced by anatomical, hormonal, and neurovascular factors (Di Giminiani *et al* 2020). Women generally present lower muscle mass and higher proportions of subcutaneous adipose tissue, which reduces thermal conductivity and alters heat dissipation patterns (Kaciuba-Uscilko and Grucza 2001). In this context, differences in body fat distribution between sexes may also partially contribute to the observed thermographic responses, as subcutaneous adipose tissue acts as a thermal insulator that can modulate heat transfer from deeper tissues to the skin surface (Formenti *et al* 2016, Hillen *et al* 2023). Women also show a lower sweating response to heat than men (Hillen *et al* 2023). When comparing trained and untrained women, women have greater sweating, which is associated with a greater number of activated sweat glands (ARGs) and greater sweat production per gland (SGP). In contrast, the greater sweating in trained men compared to untrained individuals was due solely to greater SGP (Ichinose-Kuwahara *et al* 2010, Charkoudian and Stachenfeld 2014, Binek *et al* 2022). At the vascular level, estrogen promotes cutaneous vasodilation through endothelial nitric oxide synthesis, enhancing heat loss and enabling more dynamic thermal regulation (Somani *et al* 2019). Conversely, progesterone increases the central thermal threshold and reduces sweating sensitivity -particularly during the luteal phase- delaying sweat onset and altering thermal profiles during and after exercise (Charkoudian and Stachenfeld 2014). In addition, women usually have higher sweater rates under local and global heat stress than men, especially during the luteal phase of the menstrual cycle (Lee *et al* 2014). These hormonal modulations, combined with differences in adrenergic receptors distribution and sensitivity as well as body composition (Harada *et al* 2022), may explain why women, despite lower absolute Tsk, exhibit greater relative percentage changes. Specifically, greater tendon elasticity and extensibility in women could account for the Achilles tendon temperature decrease, possibly related to a distinct vascular response in connective tissues that require less perfusion or display different metabolic regulation during warm-up (Barnes and Charkoudian 2021). Furthermore, the female hormonal profile supports more variable vasomotor control, potentially enhancing immediate cutaneous vasoconstriction followed by a greater rebound in blood flow during recovery (Hillen *et al* 2023).

These findings indicate that the immediate thermal response following FIFA 11+ is not uniform but highly region- and sex-specific dependent. The interplay of vascular metabolic, mechanical, and hormonal factors generates a heterogeneous thermal profile that reflects the complexity of thermal homeostasis during the transition from rest to exercise.

From a measurement perspective, these results highlight the capacity of IRT to capture rapid and heterogeneous peripheral responses that may not be detected by global physiological or performance-based assessments. The ability to identify region- and sex-specific thermal patterns following a controlled physiological stimulus supports the use of IRT as a complementary, non-invasive tool for monitoring acute physiological states in sports and rehabilitation contexts. From a practical perspective, previous thermography studies suggest that Tsk differences of approximately 0.3 °C–0.5 °C may already represent physiologically meaningful variations in thermoregulatory responses (Fernández-Cuevas *et al* 2012, Moreira *et al* 2017), highlighting the sensitivity of IRT for monitoring subtle changes in peripheral thermal patterns.

Despite the relevance of the results, several limitations should be considered. The main limitation of the present study is the absence of a control condition (e.g. passive rest or alternative warm-up protocol). Therefore, although the observed changes in Tsk occurred immediately after the FIFA 11+ warm-up, it cannot be completely ruled out that part of the thermal variation may be influenced by temporal or environmental factors. However, the standardized protocol, controlled environmental conditions, and the short time interval between pre- and post- measurements were implemented to minimize potential external influences.

Second, temperature assessment was limited to the skin surface via infrared thermography. No additional physiological variables such as core temperature, intramuscular temperature, muscle oxygenation, or performance-related measures were collected, which would provide a more comprehensive understanding of the physiological mechanisms underlying the observed thermographic responses. Furthermore, variables related to peripheral circulation (e.g. skin blood flow or microvascular perfusion) were not directly assessed. Since Tsk is strongly influenced by cutaneous blood flow regulation, the thermographic changes observed in the present study should be interpreted as indirect indicators of thermoregulatory responses rather than direct measurements of vascular dynamics. Third, the menstrual cycle phase of female participants was not recorded in our study, despite its recognized influence on thermoregulatory responses. In these regard, different studies suggest thermoregulatory response could be altered by the menstrual cycle phase (Messaoudène *et al* 2025) and different mechanical responses have been observed in Achilles mechanical response between genders (Deng *et al* 2021). Although this factor could explain part of the variability observed among women, other studies indicated no differences in this response (Taş *et al* 2020). Taş and Salkın (2019) observed that despite the stiffness levels in Achilles tendon were higher in males, the changes in the stiffness of the assessed tissues caused by joint motion were similar in both sexes. Given the disparity in results, perhaps this should be taken into consideration for future studies. In addition, body composition variables such as BMI were recorded only for descriptive purposes and were not included as covariates in the statistical analysis. Furthermore, body fat percentage was not assessed, despite its potential influence on cutaneous thermoregulation due to the insulating properties of adipose tissue, which may affect heat transfer between deeper tissues and the skin surface (Hillen *et al* 2023). Therefore, the possible contribution of body composition to the observed thermographic responses cannot be completely ruled out. Future studies should consider including detailed body composition assessments to better understand their potential influence on Tsk responses. Finally, the evaluation protocol was restricted to the immediate post-exercise phase, preventing assessment of medium -and long-term recovery dynamics. This aspect would be particularly interesting to determine the time that can elapse between the warm-up and the start of the competition.

5. Conclusions

In conclusion, the FIFA 11+ warm-up produces, in both sexes, a significant reduction in Tsk in most of the assessed lower-limb muscles, except for the plantar arch and ankle, where an increase was observed. While men maintain higher absolute Tsk, women exhibit greater relative percentage changes, reflecting physiological and hormonal differences in thermoregulation responses.

These regional and sex-specific thermal responses enhance our understanding of the interplay between thermoregulation, muscle activation, and anatomical and endocrine factors during warm-up. Recognizing these patterns has practical implications for warm-up protocol design and thermographic data interpretation, providing a scientific foundation for coaches and conditioning specialists to individualize and monitor training load and recovery, optimizing physiological readiness and minimizing injury risk in football players.

Acknowledgments

The authors thank all the players for their enthusiastic participation and for their support in the testing.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.34810/data2690 (Caudet *et al* 2025).

Fundings

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare that they have no conflicts of interest.

Author contributions

Conceptualization, P. C., E. B. and F. C.; Methodology, P. C. and F. C.; Software, P. C., A. B. and E. B.; Validation, E. B., F. C.; Formal Analysis, P. C. and E. B; Investigation, P. C. and F. C.; Data Curation, P. C. A. B. and E. B.; Writing—Original Draft Preparation, P. C.; Writing—Review & Editing, P. C., E. B., J. C. and F. C.; Visualization, F. C.; Supervision, E. B. and F. C.; Project Administration, E. B. and F.

ORCID iDs

Patricia Caudet 0000-0003-0924-977X
Ernest Baiget 0000-0002-2059-2846
Abraham Batalla 0000-0003-4337-8890
Joshua Colomar 0000-0002-7686-6594
Francisco Corbi 0000-0003-2630-6684

References

Asgari M, Nazari B, Bizzini M and Jaitner T 2023 Effects of the FIFA 11+ program on performance, biomechanical measures, and physiological responses: a systematic review *J. Sport Health Sci.* **12** 226–35

Barnes J N and Charkoudian N 2021 Integrative cardiovascular control in women: regulation of blood pressure, body temperature, and cerebrovascular responsiveness *FASEB J.* **35** e21143

Binek M, Drzazga Z, Socha T and Pokora I 2022 Do exist gender differences in skin temperature of lower limbs following exercise test in male and female cross-country skiers? *J. Therm. Anal. Calorim* **147** 7373–83

Bizzini M, Junge A and Dvorak J 2013 Implementation of the FIFA 11+ football warm up program: how to approach and convince the Football associations to invest in prevention *Br. J. Sports Med.* **47** 803–6

Casa D J *et al* 2010 Influence of hydration on physiological function and performance during trail running in the heat *J. Athl. Train.* **45** 147–56

Caudet P, Baiget E, Batalla A, Colomar J and Corbi F 2025 Replication data for: acute effects of FIFA 11+ warm-up on skin temperature in male and female amateur soccer players *CORA Research Data Repository* (https://doi.org/10.34810/data2690)

Caudet P, Baiget E, Batalla A, Colomar J, Crespo M, Martínez-Gallego R and Corbi F 2025 Is the FIFA 11+ warm-up effective for inducing acute knee adaptations in recreational soccer players? *J. Funct. Morphol. Kinesiol.* **10** 216

Charkoudian N 2003 Skin blood flow in adult human thermoregulation: how it works, when it does not, and why *Mayo Clin. Proc.* **78** 603–12

Charkoudian N 2016 Human thermoregulation from the autonomic perspective *Auton. Neurosci.: Basic Clin.* **196** 1–2

Charkoudian N and Stachenfeld N S 2014 Reproductive Hormone Influences on Thermoregulation in Women *Comprehensive Physiology* ed R Terjung (Wiley) pp 793–804

Chen Y-S, Lai W-L, Hou C-W, Chen C-H, Chiu Y-W and Bezzera P 2019 Effect of post warm-up resting interval on static and dynamic balance, and maximal muscle strength followed by the FIFA 11+ and dynamic warm-up exercises *J. Sports Med. Phys. Fitness* **59** 366–75

Corral-Pérez J, Martinez-Tellez B, Velázquez-Díaz D, Ponce-Gonzalez J G, Carbonell-Baeza A and Jiménez-Pavón D 2023 Thermal resting pattern and acute skin temperature response to exercise in older adults: role of cardiorespiratory fitness *J. Therm. Biol.* **117** 103678

Daneshjoo A, Mokhtar A H, Rahnama N, Yusof A and Lucia A 2012 The effects of injury preventive warm-up programs on knee strength ratio in young male professional soccer players *PLoS One* **7** e50979

Delorey D S 2021 Sympathetic vasoconstriction in skeletal muscle: modulatory effects of aging, exercise training, and sex *Appl. Physiol. Nutr. Metab.* **46** 1437–47

Deng L, Zhang X, Xiao S, Wang B and Fu W 2021 Gender difference in architectural and mechanical properties of medial gastrocnemius–Achilles tendon unit in vivo *Life* **11** 569

Di Giminiani R, Rucci N, Capuano L, Ponzetti M, Aielli F and Tihanyi J 2020 Individualized whole-body vibration: neuromuscular, biochemical, muscle damage and inflammatory acute responses *Dose Response* **18** 155932582093126

Dos Santos Bunn P, Miranda M E K, Rodrigues A I, De Souza Sodré R, Neves E B and Bezerra Da Silva E 2020 Infrared thermography and musculoskeletal injuries: a systematic review with meta-analysis *Infrared Phys. Technol.* **109** 103435

Dunsky A, Barzilay I and Fox O 2017 Effect of a specialized injury prevention program on static balance, dynamic balance and kicking accuracy of young soccer players *World J. Orthop.* **8** 317

Fernández-Cuevas I, Marins J C, Gómez-Carmona P, García-Concepción M A, Arnaiz-Lastras J and Sillero-Quintana M 2012 Reliability and reproducibility of skin temperature of overweight subjects by an infrared thermography software designed for human beings *Thermol. Int.* **22** 130–7

Formenti D, Ludwig N, Trecroci A, Gargano M, Michielon G, Caumo A and Alberti G 2016 Dynamics of thermographic skin temperature response during squat exercise at two different speeds *J. Therm. Biol.* **59** 58–63

Gefen A 2003 The in vivo elastic properties of the plantar fascia during the contact phase of walking *Foot Ankle Int.* **24** 238–44

Ghahramani A, Castro G, Becerik-Gerber B and Yu X 2016 Infrared thermography of human face for monitoring thermoregulation performance and estimating personal thermal comfort *Built Environ.* **109** 1–11

Gok U, Gok Y, Kurt E I and Canikli A 2024 Investigation of the acute effect of different warm-up protocols on test performance in young soccer players *Pedagogy Phys. Cult. Sports* **28** 501–8

González-Alonso J, Quistorff B, Krustrup P, Bangsbo J and Saltin B 2000 Heat production in human skeletal muscle at the onset of intense dynamic exercise *J. Physiol.* **524** 603–15

Hadžić V, Širok B, Malneršič A and Čoh M 2019 Can infrared thermography be used to monitor fatigue during exercise? A case study *J. Sport Health Sci.* **8** 89–92

Harada N, Kubo K, Onishi T, Kitakaze T, Goto T, Inui H and Yamaji R 2022 Androgen receptor suppresses β-adrenoceptor-mediated CREB activation and thermogenesis in brown adipose tissue of male mice *J. Biol. Chem.* **298** 102619

Hargreaves M and Spriet L L 2020 Skeletal muscle energy metabolism during exercise *Nat. Metab.* **2** 817–28

He C 2024 The influence of pre-competition warm-up strategies on athletes' performance *Front. Humanit. Soc. Sci.* **4** 176–87

Hillen B *et al* 2023 Acute physiological responses to a pyramidal exercise protocol and the associations with skin temperature variation in different body areas *J. Therm. Biol.* **115** 103605

Hillen B, Pfirrmann D, Nägele M and Simon P 2020 Infrared thermography in exercise physiology: the dawning of exercise radiomics *Sports Med.* **50** 263–82

Hopkins W G, Marshall S W, Batterham A M and Hanin J 2009 Progressive statistics for studies in sports medicine and exercise science *Med. Sci. Sports Exerc.* **41** 3

Hu Y, Converse C, Lyons M C and Hsu W H 2018 Neural control of sweat secretion: a review *Br. J. Dermatol.* **178** 1246–56

Huffer D, Hing W, Newton R and Clair M 2017 Strength training for plantar fasciitis and the intrinsic foot musculature: a systematic review *Phys. Ther. Sport* **24** 44–52

Ichinose-Kuwahara T, Inoue Y, Iseki Y, Hara S, Ogura Y and Kondo N 2010 Sex differences in the effects of physical training on sweat gland responses during a graded exercise *Exp. Physiol.* **95** 1026–32

Igarashi T L, Fernandes T L, Hernandez A J, Keutenedjian Mady C E and Albuquerque C 2022 Behavior of skin temperature during incremental cycling and running indoor exercises *Heliyon* **8** e10889

Impellizzeri F M, Bizzini M, Dvorak J, Pellegrini B, Schena F and Junge A 2013 Physiological and performance responses to the FIFA 11+ (part 2): a randomised controlled trial on the training effects *J. Sports Sci.* **31** 1491–502

Jimenez-Perez I, Gil-Calvo M, Priego-Quesada J I, Aparicio I, Pérez-Soriano P and Ortiz De Anda R M C 2020 Effect of prefabricated thermoformable foot orthoses on plantar surface temperature after running: a gender comparison *J. Therm. Biol.* **91** 102612
Kaciuba-Uscilko H and Grucza R 2001 Gender differences in thermoregulation: curr *Curr. Opin. Clin. Nutr. Metab. Care* **4** 533–6
Kalinowski R, Pisz A, Kolinger D, Wilk M, Stastny P and Krzysztofik M 2022 Acute effects of combined isometric and plyometric conditioning activities on sports performance and tendon stiffness in female volleyball players *Front. Physiol.* **13** 1025839
Katayama K and Saito M 2019 Muscle sympathetic nerve activity during exercise *J. Physiol.* **69** 589–98
Kawabata A and Tokura H 1993 Effects of two kinds of sports shoes with different structure on thermoregulatory responses *Ann. Physiol. Anthropol.* **12** 165–71
Lee H, Petrofsky J, Shah N, Awali A, Shah K, Alotaibi M and Yim J 2014 Higher sweating rate and skin blood flow during the luteal phase of the menstrual cycle *Tohoku J. Exp. Med.* **234** 117–22
Liu Z, Nie J, Yang F, Zheng Y and Ding L 2024 Influence of shoe upper structure on shoe microclimate and human physiological characteristics during running *Technol. Health Care* **32** 487–99
Magoshi H, Hoshiba T, Tohyama M, Hirose N and Fukubayashi T 2023 Effect of the FIFA 11+ injury prevention program in collegiate female football players over three consecutive seasons *Scand. J. Med. Sci. Sports* **33** 1494–508
Matas S, Lalín C, Corbi F, Planas-Anzano A, Moya J M, Mas-Alòs S and Peirau-Terés X 2024 Content validity of a new soccer (football) return-to-play test: the RONDO-TEST *J. Funct. Morphol. Kinesiol.* **10** 3
Merla A, Mattei P A, Di Donato L and Romani G L 2010 Thermal imaging of cutaneous temperature modifications in runners during graded exercise *Annu. Rev. Biomed. Eng.* **38** 158–63
Messaoudène L, Arc-Chagnaud C, Renier F, Bretonneau Q, Bosquet L, Delpech N and Enea C 2025 Maximizing sleep quality and well-being in female athletes: the role of the menstrual cycle and whole-body cryostimulation *Cryobiology* **120** 105283
Moran-Cortes J F, Gómez-Martín B, Escamilla-Martínez E, Sánchez-Rodríguez R, Gómez-Carrión Á and Martínez-Nova A 2023 Thermoregulation in two models of trail run socks with different fabric separation *Life* **13** 1768
Moreira D G *et al* 2017 Thermographic imaging in sports and exercise medicine: a Delphi study and consensus statement on the measurement of human skin temperature *J. Therm. Biol.* **69** 155–62
Morrison S F and Nakamura K 2019 Central mechanisms for thermoregulation *Annu. Rev. Physiol.* **81** 285–308
Mota-Rojas D, Titto C G, Orihuela A, Martínez-Burnes J, Gómez-Prado J, Torres-Bernal F, Flores-Padilla K, Carvajal-de la Fuente V and Wang D 2021 Physiological and behavioral mechanisms of thermoregulation in mammals *Animals* **11** 1733
Neves E B, Cunha R M, Rosa C, Antunes N S, Felisberto I M V, Vilaça-Alves J and Reis V M 2016 Correlation between skin temperature and heart rate during exercise and recovery, and the influence of body position in these variables in untrained women *Infrared Phys. Technol.* **75** 70–76
Pardos-Mainer E, Casajús J A and Gonzalo-Skok O 2019 Adolescent female soccer players' soccer-specific warm-up effects on performance and inter-limb asymmetries *Biol. Sport* **36** 199–207
Pieters D, Wezenbeek E, De Ridder R, Witvrouw E and Willems T 2022 Acute effects of warming up on Achilles tendon blood flow and stiffness *J. Strength Cond. Res.* **36** 2717–24
Ramos A P, De Mesquita R S, Migliorini F, Maffulli N and Okubo R 2024 FIFA 11+ KIDS in the prevention of soccer injuries in children: a systematic review *J. Orthop. Surg.* **19** 413
Reddy P N, Cooper G, Weightman A, Hodson-Tole E and Reeves N D 2017 Walking cadence affects rate of plantar foot temperature change but not final temperature in younger and older adults *Gait Posture* **52** 272–9
Sasajima S and Kubo K 2025 Effects of heating on tendon mechanical properties and performance during stretch-shortening cycle exercises *Med. Sci. Sports Exerc.* **57** 1441–51
Šijanec J and Lenasi H 2023 The physiology of thermoregulation in exercise: a brief review *South East. Eur. J. Public Health* **7** 13–27
Sillero-Quintana M, Fernández-Cuevas I, Arnaiz-Lastras J and Marinos J 2015 TERMOINEF Group Protocol for thermographic assessment in humans *Pre-Congress XIII EAT Congress Course on Medical Applications of Human Thermography* ed K Ammer (INEF Madrid: Madrid) pp 1–57
Silvers-Granelli H, Mandelbaum B, Adeniji O, Insler S, Bizzini M, Pohlig R, Junge A, Snyder-Mackler L and Dvorak J 2015 Efficacy of the FIFA 11+ injury prevention program in the collegiate male soccer player *Am. J. Sports Med.* **43** 2628–37
Somani Y B, Pawelczyk J A, De Souza M J, Kris-Etherton P M and Proctor D N 2019 Aging women and their endothelium: probing the relative role of estrogen on vasodilator function *Am. J. Physiol. Heart Circ. Physiol.* **317** H395–H404
Taş S, Aktaş D and Gasparini M 2020 Menstrual cycle does not affect the mechanical properties of muscle and tendon *Muscle Ligaments Tendons J.* **10** 11
Taş S and Salkın Y 2019 An investigation of the sex-related differences in the stiffness of the Achilles tendon and gastrocnemius muscle: inter-observer reliability and inter-day repeatability and the effect of ankle joint motion *Foot Edinb. Scotl.* **41** 44–50
Tourillon R, Gojanovic B and Fourchet F 2019 How to evaluate and improve foot strength in athletes: an update *Front. Sports Act. Living* **1** 46
Trovato B, Sortino M, Petrigna L, Roggio F and Musumeci G 2024 The influence of static and dynamic warm-up on knee temperature: infrared thermography insights before and after a change of direction exercise *Front. Physiol.* **15** 1393804
Wan L, Wang J, Ma D and Zeng Q 2024 Thermo-mechanical coupling characteristics of the shearer's guiding shoe during the friction *Sci. Rep.* **14** 24825
World Medical Association 2013 World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects *JAMA* **310** 2191–4
Wu W, Li L, Li Z, Sun J and Wang L 2023 Extensible integrated system for real-time monitoring of cardiovascular physiological signals and limb health *Adv. Mater.* **35** 2304596
Yıldız M and Çebi M 2025 Proprioceptive neuromuscular facilitation warm-ups: a key to improved isokinetic performance *Int. J. Sports Med.* **46** 412–21
Zhao Z-D *et al* 2017 A hypothalamic circuit that controls body temperature *Proc. Natl Acad. Sci. USA* **114** 2042–7