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Article

Sex-Related Differences in Skin Temperature Responses Induced by Small-Sided Games Assessed Using Infrared Thermography

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Abstract

Background: Infrared thermography (IRT) has become a valuable non-invasive tool for monitoring exercise-induced physiological responses in soccer players. However, evidence regarding the influence of sex on skin temperature responses following soccer-specific exercise remains limited. This study compared changes in skin temperature (ΔT_{sk}) and thermal asymmetry between women and men soccer players following a standardised small-sided game (SSG). **Methods:** Forty-six university soccer players (22 women and 24 men) completed a standardised 4 vs. 4 SSG. Thermographic images were acquired before (Pre), immediately after (Post), and 10 min after exercise (Post_10). Skin temperature changes ($\Delta Post-Pre$, $\Delta Post_{10}-Post$, and $\Delta Post_{10}-Pre$) and bilateral thermal asymmetries were calculated for the anterior and posterior thigh and lower leg. Between-sex comparisons were performed using independent-samples Student's t-tests, and effect sizes were estimated using Hedges' g. **Results:** Women players exhibited significantly greater increases in ΔT_{sk} than men players across most anatomical regions. The largest differences were observed during recovery ($\Delta Post_{10}-Pre$), when all regions demonstrated greater thermal responses in women ($p < 0.001$), with large to very large effect sizes ($g = 1.42-1.89$). In contrast, thermal asymmetry did not differ significantly between sexes at any anatomical region or assessment time point ($p > 0.05$). **Conclusions:** Women soccer players demonstrated a greater acute thermoregulatory response than men players following an SSG, particularly during the early recovery period, whereas thermal asymmetry remained stable regardless of sex. These findings indicate that sex should be considered when interpreting exercise-induced skin temperature responses and suggest that assessment performed 10 min after exercise represents the most sensitive time point for detecting physiological differences using infrared thermography.

Keywords: infrared thermography; skin temperature; thermal asymmetry; soccer; sex differences; small-sided games

1. Introduction

Soccer is an intermittent sport characterised by repeated high-intensity actions, including accelerations, decelerations, changes of direction, jumps, and sprints, which impose substantial physiological and neuromuscular demands during both training and competition [1,2]. During these activities, approximately 70–80% of the metabolic energy produced is released as heat, activating thermoregulatory mechanisms that maintain thermal homeostasis through adjustments in cutaneous blood flow and heat dissipation [3,4]. Consequently, skin temperature (T_{sk}) represents an indirect

physiological biomarker of the metabolic and vascular processes associated with the acute response to exercise and subsequent recovery.

In recent years, infrared thermography (IRT) has become established as a valid, non-invasive, and rapid technique for assessing the spatial distribution of skin temperature in athletes [5]. Its growing application in sport science is attributed to its ability to detect temperature changes associated with muscle activation, fatigue, inflammation, and post-exercise recovery [6,7]. More recently, a systematic review concluded that IRT is a valid and promising tool for assessing skin temperature, monitoring structural and metabolic fatigue, evaluating thermal asymmetry, and supporting the development of individualised recovery strategies in soccer players [8].

Within soccer, small-sided games (SSG) are among the most frequently used training methods because they simultaneously reproduce the physical, physiological, technical, and tactical demands of match play [9,10]. These training tasks induce substantial increases in metabolic activity and muscle blood flow, resulting in acute changes in skin temperature that may persist during the early stages of recovery. In this context, IRT has proven useful for monitoring fatigue, recovery, and thermal asymmetry in soccer players, providing complementary information for training-load management and injury prevention [11]. Nevertheless, the systematic review by [8] highlighted the limited evidence regarding the influence of biological variables, such as sex, on thermal responses in soccer players, identifying this issue as a priority for future research.

Exercise-induced thermal responses are influenced by several physiological factors, including sex. Differences in body composition, muscle mass, adipose tissue percentage, body surface area-to-mass ratio, and cutaneous blood flow regulation may affect both heat production and heat dissipation during exercise [4,12]. Although previous studies have reported sex-related differences in resting skin temperature and post-exercise thermal responses [13,14], evidence remains scarce within the context of soccer-specific training. Most previous investigations have included only one sex or have been conducted under laboratory conditions. Consequently, it remains unclear whether women and men soccer players exhibit different thermal responses following small-sided games.

Understanding the influence of sex on exercise-induced thermal responses during SSG has important implications for the physiological interpretation of thermographic images and for the development of individualised strategies for training-load monitoring, recovery, and injury prevention in soccer players. Therefore, the aim of the present study was to compare changes in skin temperature and thermal asymmetry between women and men university soccer players before, immediately after, and 10 min after a small-sided game using infrared thermography. We hypothesised that women players would exhibit greater increases in skin temperature during both the acute response and the early recovery period following the SSG, whereas thermal asymmetry would remain similar between sexes.

2. Materials and Methods

2.1. Study Design

An experimental study with repeated measures was conducted to examine sex-related differences in skin temperature responses induced by a SSG in university soccer players. The between-subject factor was sex (women and men), whereas the within-subject factor was the time of skin temperature assessment: before the SSG (Pre), immediately after the SSG (Post), and 10 min after the completion of the SSG (Post_10). The dependent variables were changes in skin temperature (ΔT_{sk}) and bilateral thermal asymmetry calculated for the different regions of interest (ROIs) of the lower limbs.

2.2. Participants

Forty-six university soccer players (22 women and 24 men) from university representative teams volunteered to participate in the study. Body fat percentage was assessed using bioelectrical impedance analysis (BIA) with a Tanita BC-418 MA body composition analyzer (Tanita Corp., Tokyo,

Japan). (Table 1). All players had at least five years of competitive soccer experience, trained at least three times per week, and regularly competed in official matches.

Table 1. Participant characteristics (mean ± standard deviation).

Characteristic	Women (n = 22)	Men (n = 24)	p value
Age (years)	23 ± 4	24 ± 8	0.708
Body mass (kg)	60.6 ± 8.5	79.0 ± 6.7	<0.001
Height (cm)	158 ± 5	178 ± 6	<0.001
Body mass index (kg·m ⁻²)	24.0 ± 8.3	24.9 ± 2.1	0.685
Body fat (%)	24.5 ± 5.5	18.2 ± 2.5	<0.001

Note. Data are presented as **mean ± standard deviation (SD)**. *p* values refer to comparisons between women and men participants.

The inclusion criteria were: (i) regular participation in training sessions and competitive matches; (ii) absence of musculoskeletal injuries during the three months preceding data collection; and (iii) completion of all experimental assessments. Participants were excluded if they presented with an acute illness, sustained an injury during the experimental protocol, or failed to comply with the pre-assessment thermographic recommendations.

Before data collection, all participants received detailed information regarding the study procedures and provided written informed consent. The study protocol was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Politecnico Colombiano Jaime Isaza Cadavid (under Min No. 20, dated 6 December 2024).

2.3. Procedures

All participants attended a single experimental session conducted on the institution’s soccer field between 10:00 and 12:00 h to minimise the influence of circadian variation on skin temperature.

Before testing, participants were instructed to refrain from vigorous physical exercise for 24 h, avoid caffeine, alcohol, and other stimulants for 12 h, and refrain from applying creams, lotions, or cosmetic products to the skin on the day of testing. They were also instructed to maintain their usual dietary and hydration habits.

Upon arrival, participants remained in a controlled environment for 15 min to allow thermal stabilisation before thermographic image acquisition. During this period, clothing covering the anatomical regions of interest was removed, and any physical contact capable of altering skin temperature was avoided.

Following thermal stabilisation, baseline thermographic images (Pre) were acquired using a standardised body positioning and image acquisition protocol. Participants then completed a standardised warm-up before performing the SSG. Immediately after the intervention, a second thermographic assessment (Post) was conducted. Following 10 min of passive recovery, a third thermographic assessment (Post_10) was obtained.

All thermographic images acquired at the three assessment time points were analysed using the same processing procedure to determine the mean skin temperature of each ROI. These values were subsequently used to calculate changes in skin temperature between time points (Δ Post–Pre, Δ Post_10–Post, and Δ Post_10–Pre), as well as bilateral thermal asymmetry between the right and left sides of the body.

The entire experimental protocol was conducted under identical environmental conditions and supervised by the same investigators to ensure consistency and standardisation throughout all measurements (Figure 1).



Figure 1. Schematic representation of the experimental protocol.

2.4. Assessment of Skin Temperature

Before the assessments, participants remained seated at rest for 10 min in a controlled environment to promote skin thermal stabilisation. Subsequently, thermographic images were acquired using an infrared camera (HIKMICRO M31T, 384 × 288 pixels; thermal sensitivity [NETD] < 0.05 °C; accuracy ± 0.5 °C; HIKMICRO, Hangzhou, China) and analysed using HIKMICRO Analyzer software (HIKMICRO, Hangzhou, China). The camera was switched on 10 min before image acquisition to ensure sensor stabilisation and positioned 1 m from the participant, perpendicular to the ROI.

Thermographic images were obtained with participants barefoot, standing in the anatomical position, and wearing only underwear to ensure full exposure of the anatomical regions under investigation [15]. All assessments were performed under controlled environmental conditions (26 °C and 86% relative humidity). Furthermore, participants followed the pre-assessment recommendations for thermographic imaging, including abstaining from alcohol, caffeine, and tobacco consumption, vigorous physical exercise, prolonged sun exposure, large meals, and the application of creams, ointments, or cosmetic products before testing to minimise factors that could influence skin temperature [16]. Compliance with these recommendations was verified using the Thermographic Imaging in Sports and Exercise Medicine (TISEM) checklist [16].

Four ROIs of the lower limbs were analysed: anterior thigh (AT), posterior thigh (PT), anterior leg (AL), and posterior leg (PL) (Figure 2). Mean skin temperature (°C) was recorded for each ROI at the three experimental time points (Pre, Post, and Post₁₀). These measurements were subsequently used to calculate skin temperature changes and bilateral thermal asymmetries.

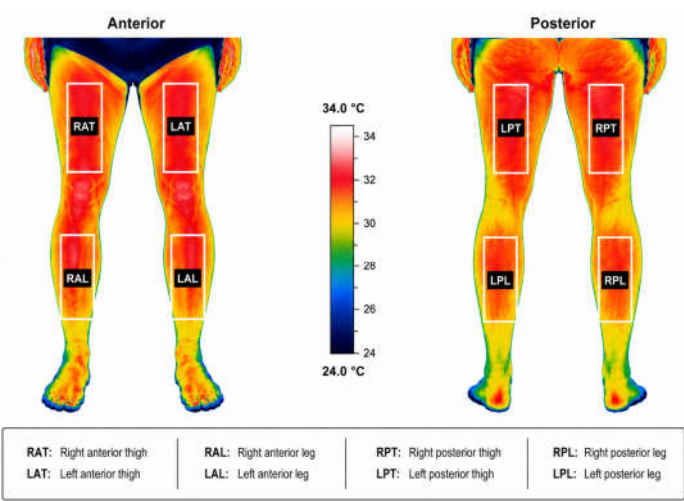


Figure 2. Representative infrared thermographic images of the regions of interest. **Note.** Representative infrared thermographic images showing the anterior (A) and posterior (B) regions of interest (ROIs) used for skin temperature analysis. The ROIs included the right anterior thigh (RAT), left anterior thigh (LAT), right anterior leg (RAL), left anterior leg (LAL), right posterior thigh (RPT), left posterior thigh (LPT), right posterior leg (RPL), and left posterior leg (LPL). The central color bar represents skin temperature (°C).

2.5. Calculation of Skin Temperature Changes and Thermal Asymmetry

Skin temperature changes were calculated from the mean skin temperature recorded in each ROI at the different assessment time points, as follows:

- $\Delta T_{sk} (\text{Post-Pre}) = \text{Post skin temperature} - \text{Pre skin temperature}.$
- $\Delta T_{sk} (\text{Post}_{10}\text{-Post}) = \text{Post}_{10} \text{ skin temperature} - \text{Post skin temperature}.$
- $\Delta T_{sk} (\text{Post}_{10}\text{-Pre}) = \text{Post}_{10} \text{ skin temperature} - \text{Pre skin temperature}.$

Bilateral thermal asymmetry was determined as the absolute difference in skin temperature between the right and left homologous anatomical regions using the following equation:

$$\text{Thermal asymmetry} = \{T_{\text{Right}} - T_{\text{Left}}\}$$

where T_{Right} and T_{Left} represent the mean skin temperature of the right and left homologous ROIs, respectively.

2.6. Small-Sided Game

The intervention consisted of a 4 vs. 4 SSG performed on a 30 × 15 m pitch, providing an individual playing area of 56 m² per player, with small goals. The offside rule was not applied, and ball replacement was performed manually whenever the ball left the playing area [17]. To minimise interruptions and maintain continuous play, more than four balls were strategically positioned around the pitch to allow rapid ball replacement. The protocol consisted of five 3-min bouts, interspersed with 1-min passive recovery periods.

No verbal encouragement was provided by the investigators during the SSG. Teams were selected by the head coach to ensure a balanced distribution of technical ability, tactical competence, and playing positions. Each team included at least one defender, one midfielder, and one forward. Team compositions were predetermined and remained unchanged throughout all experimental sessions to optimise team dynamics and ensure consistency between assessments.

Exercise intensity during the intervention was monitored continuously using Sigma Sport iD.RUN HR heart rate monitors (Sigma Sport, Germany). Participants were required to achieve at least 95% of their age-predicted maximal heart rate (HR_{max}), which was estimated using the equation proposed by [18]:

$$\text{HR}_{\text{max}} = 208 - (0.7 \times \text{age})$$

Immediately after completing the SSG, participants reported their session rating of perceived exertion (sRPE) using the Category Ratio-10 (CR-10) Borg scale by answering the question, “How intense was the session?” [18]. The CR-10 scale was administered individually to each participant to minimise the influence of peer responses.

2.7. Statistical Analysis

Statistical analyses were performed using JASP (version 0.97.1; JASP Team, Amsterdam, The Netherlands). Data normality was assessed using the Shapiro–Wilk test, while homogeneity of variances was evaluated using Levene’s test. Continuous variables are presented as mean ± standard deviation (SD). Statistical significance was set at $p < 0.05$.

Anthropometric characteristics were compared between women and men players using independent-samples Student’s *t*-tests. Between-sex comparisons of ΔT_{sk} and thermal asymmetry were conducted separately for each assessment interval (*Post-Pre*, *Post₁₀-Post*, and *Post₁₀-Pre*) using independent-samples Student’s *t*-tests. When the assumption of homogeneity of variances was violated, Welch’s *t*-test was applied.

The magnitude of between-group differences was quantified using Hedges’ *g* and interpreted according to the thresholds proposed by [19]: 0.20–0.49, small effect; 0.50–0.79, moderate effect; and ≥ 0.80 , large effect.

3. Results

3.1. Changes in Skin Temperature in the Thigh

Changes in ΔT_{sk} in the thigh regions are presented in Table 2. Compared with men players, women players exhibited significantly greater increases in ΔT_{sk} across most thigh ROIs. The largest between-sex differences were observed immediately after the SSG (*Post–Pre*), particularly in the right anterior thigh (RAT), left anterior thigh (LAT), right posterior thigh (RPT), and left posterior thigh (LPT), with moderate-to-large effect sizes ($g = 0.78$ – 1.15).

Table 2. Comparison of changes in skin temperature (ΔT_{sk}) between women and men soccer players in the thigh regions.

ROI	Time	Women ΔT_{sk} (°C)	Men ΔT_{sk} (°C)	<i>P</i>	Hedges’ <i>g</i>
		Mean $\pm$ SD	Mean $\pm$ SD		
RAT	Post–Pre	1.69 $\pm$ 0.92	0.43 $\pm$ 1.21	<0.001	1.15
	Post_10–Post	1.21 $\pm$ 1.06	0.17 $\pm$ 1.34	0.005	0.85
	Post_10–Pre	1.81 $\pm$ 1.04	0.10 $\pm$ 0.71	<0.001	1.89
LAT	Post–Pre	1.61 $\pm$ 0.95	0.45 $\pm$ 1.07	<0.001	1.13
	Post_10–Post	0.11 $\pm$ 0.94	–0.27 $\pm$ 1.06	0.199	0.38
	Post_10–Pre	1.72 $\pm$ 1.19	0.18 $\pm$ 0.73	<0.001	1.55
RPT	Post–Pre	1.32 $\pm$ 1.10	0.46 $\pm$ 1.06	0.010	0.78
	Post_10–Post	–0.01 $\pm$ 0.88	–0.31 $\pm$ 1.03	0.628	0.31
	Post_10–Pre	1.31 $\pm$ 0.98	0.15 $\pm$ 0.58	<0.001	1.43
LPT	Post–Pre	1.44 $\pm$ 0.96	0.36 $\pm$ 1.04	0.001	1.06
	Post_10–Post	–0.12 $\pm$ 0.91	–0.31 $\pm$ 0.95	0.800	0.20
	Post_10–Pre	1.32 $\pm$ 0.98	0.05 $\pm$ 0.50	<0.001	1.63

Note. ROI = region of interest; SD = standard deviation; RAT = right anterior thigh; LAT = left anterior thigh; RPT = right posterior thigh; LPT = left posterior thigh. Data are presented as mean $\pm$ standard deviation. Significant differences were considered at $p < 0.05$. g = Hedges’ *g*.

During the recovery period *Post_10–Post*, significant between-sex differences were identified only for the RAT, with women exhibiting greater ΔT_{sk} than men ($p = 0.005$, $g = 0.85$), whereas no significant differences were observed in the remaining thigh regions ($p > 0.05$).

The most consistent differences were found for *Post_10–Pre*, where women players demonstrated significantly greater ΔT_{sk} than men players in all thigh ROIs ($p < 0.001$). Effect sizes were large to very large ($g = 1.43$ – 1.89), with the greatest differences observed in the RAT ($g = 1.89$) and LPT ($g = 1.63$).

3.2. Changes in Skin Temperature in the Lower Leg

Changes in skin temperature in the lower-leg regions are presented in Table 3. Women players exhibited significantly greater ΔT_{sk} than men players in both the anterior and posterior lower-leg regions.

Table 3. Comparison of changes in skin temperature (ΔT_{sk}) between women and men soccer players in the lower-leg regions.

ROI	Time	Women ΔT_{sk} (°C)	Men ΔT_{sk} (°C)	P	Hedges' g
		Mean $\pm$ SD	Mean $\pm$ SD		
RAL	Post-Pre	1.74 $\pm$ 0.87	0.35 $\pm$ 1.22	<0.001	1.29
	Post_10-Post	-0.02 $\pm$ 1.05	-0.15 $\pm$ 1.14	0.685	0.12
	Post_10-Pre	1.72 $\pm$ 1.31	0.19 $\pm$ 0.47	<0.001	1.56
LAL	Post-Pre	1.89 $\pm$ 0.86	0.34 $\pm$ 1.21	<0.001	1.45
	Post_10-Post	-0.08 $\pm$ 1.10	-0.23 $\pm$ 1.24	0.671	0.12
	Post_10-Pre	1.81 $\pm$ 1.43	0.11 $\pm$ 0.46	<0.001	1.61
RPL	Post-Pre	1.61 $\pm$ 1.17	0.70 $\pm$ 0.98	0.006	0.84
	Post_10-Post	-0.11 $\pm$ 1.07	-0.47 $\pm$ 0.92	0.233	0.35
	Post_10-Pre	1.50 $\pm$ 1.12	0.23 $\pm$ 0.59	<0.001	1.42
LPL	Post-Pre	1.60 $\pm$ 1.10	0.74 $\pm$ 1.02	0.009	0.80
	Post_10-Post	-0.04 $\pm$ 0.96	-0.53 $\pm$ 0.94	0.093	0.50
	Post_10-Pre	1.56 $\pm$ 1.09	0.21 $\pm$ 0.43	<0.001	1.62

Note. ROI = region of interest; SD = standard deviation; RAL = right anterior leg; LAL = left anterior leg; RPL = right posterior leg; LPL = left posterior leg. Data are presented as mean $\pm$ standard deviation. Significant differences were considered at $p < 0.05$. g = Hedges' g .

Immediately after the SSG Post-Pre, significant between-sex differences were observed in all ROIs, with large effect sizes ($g = 0.80$ – 1.45). No significant differences were detected during the recovery interval Post_10-Post ($p > 0.05$).

The greatest between-sex differences occurred for Post_10-Pre, when all lower-leg ROIs demonstrated significantly greater ΔT_{sk} in women than in men ($p < 0.001$). Effect sizes ranged from large to very large ($g = 1.42$ – 1.62), with the largest values observed for the left posterior leg (LPL) ($g = 1.62$) and the left anterior leg (LAL) ($g = 1.61$).

3.3. Thermal Asymmetry

Overall, women players exhibited greater exercise-induced increases in skin temperature than men players across multiple lower-limb regions immediately after the SSG and throughout the recovery period. The most pronounced between-sex differences were observed for the Post_10-Pre comparison, in which all anatomical regions demonstrated large to very large effect sizes. In contrast, bilateral thermal asymmetry remained comparable between sexes across all ROIs and assessment intervals (Figure 3).

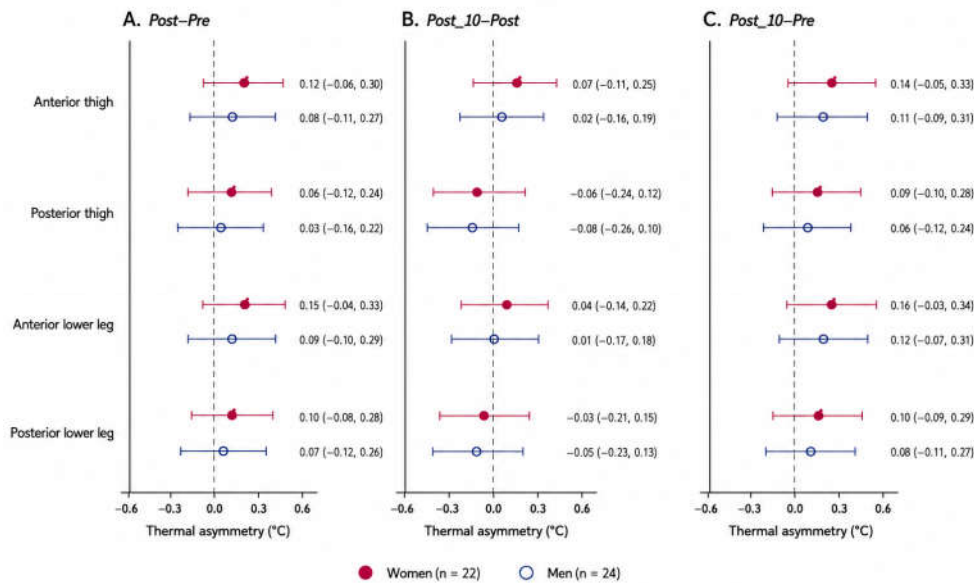


Figure 3. Between-sex comparison of thermal asymmetry following the small-sided game (SSG). Note. Anterior thigh (AT), posterior thigh (PT), anterior leg (AL), and posterior leg (PL) for the Post-Pre (A), Post_10-Post (B), and Post_10-Pre (C) comparisons. Points represent mean values, and horizontal bars indicate 95% confidence intervals (95% CI). No significant sex-related differences were observed for any thermal asymmetry variable ($p > 0.05$).

4. Discussion

The present study compared changes in ΔT_{sk} and thermal asymmetry between women and men soccer players following a standardised SSG using an IRT protocol. The principal findings were as follows: (i) women players exhibited greater increases in ΔT_{sk} across the anterior and posterior regions of both the thigh and lower leg; (ii) these between-sex differences became more pronounced during the recovery period, particularly for the Post_10-Pre comparison; and (iii) thermal asymmetry remained comparable between sexes across all assessment intervals. Collectively, these findings indicate that sex influences the magnitude of the acute thermoregulatory response induced by an SSG, whereas bilateral thermal symmetry remains preserved.

These findings extend the current evidence regarding the application of IRT in soccer. Although IRT has proven useful for monitoring exercise-induced responses, post-exercise recovery, and indicators associated with training load, most previous studies have been conducted in men soccer players or have not considered sex as an analytical variable [8,20]. Consequently, evidence regarding sex-specific thermal responses remains limited, particularly in women players performing intermittent high-intensity tasks such as SSGs.

The greater ΔT_{sk} observed in women players suggests a more pronounced peripheral thermoregulatory response during post-exercise recovery. It is important to note that skin temperature does not directly reflect muscle heat production, but rather represents the net result of the dynamic interplay between metabolic heat production, cutaneous blood perfusion, and heat dissipation mechanisms. Therefore, the observed between-sex differences are more likely to reflect alterations in cutaneous blood flow redistribution than differences in physiological load or exercise-induced muscle damage. This interpretation is consistent with recent reviews describing skin temperature as an indirect marker of the physiological response to exercise, the magnitude of which is influenced by multiple biological and environmental factors [8,20].

Our findings partially agree with those reported by [21], who observed that although men players exhibited higher absolute skin temperatures following the FIFA 11+ protocol, women players showed greater relative thermal changes. Similarly, in the present study, the between-sex differences

were more evident in the magnitude of ΔT_{sk} than in absolute skin temperature during the recovery period. Together, these findings suggest that women players may exhibit a greater thermal responsiveness to intermittent exercise, although the physiological mechanisms underlying this response remain incompletely understood.

Several physiological factors may contribute to this differential response. Sex-related differences in body composition, body surface area-to-mass ratio, cutaneous blood flow regulation, and sudomotor function may influence the rate at which exercise-generated heat is transferred to the skin surface [22]. However, these variables were not assessed in the present study, and skin temperature responses are also influenced by factors such as the relative exercise intensity, training status, and environmental conditions. Therefore, sex should be interpreted as a modulating factor of the thermal response rather than as an independent causal mechanism.

A particularly relevant finding was that the between-sex differences were more pronounced for the Post_10–Pre comparison than immediately after the SSG. This result indicates that skin temperature continues to evolve during the early recovery period, when cutaneous vasodilation, blood flow redistribution, and heat transfer from deeper tissues to the skin remain active. Recent studies have demonstrated that post-exercise thermal recovery kinetics may provide more sensitive physiological information than measurements obtained immediately after exercise [20,23]. Accordingly, assessment performed 10 min after exercise may represent a more appropriate time point for detecting physiological differences between women and men soccer players.

Furthermore, the observed differences across both the anterior and posterior regions of the thigh and lower leg indicate that the thermal response was not confined to a single muscle group but reflected the coordinated involvement of multiple anatomical segments during the mechanical demands imposed by SSGs. This observation is consistent with previous studies showing that regional skin temperature responses depend on both the type of exercise performed and the distribution of mechanical load during activity [21,24]. Consequently, analysing specific anatomical regions provides more physiologically meaningful information than using a single mean temperature for the entire lower limb.

In contrast to the differences observed in ΔT_{sk} , thermal asymmetry remained comparable between women and men players. This finding indicates that sex influences the absolute magnitude of the thermal response without altering the bilateral organisation of superficial heat distribution. Healthy athletes have consistently been shown to exhibit a high degree of bilateral thermal symmetry, with differences between homologous limbs generally remaining below 0.2 °C, supporting the stability of this parameter in the absence of pathological conditions [15,25].

Moreover, the absence of between-sex differences reinforces the concept that thermal asymmetry represents a physiological phenomenon distinct from the magnitude of ΔT_{sk} . Previous studies have reported inconsistent findings regarding its association with neuromuscular imbalances and physical performance. Whereas some authors found no relationship between thermal asymmetry and isokinetic imbalances, others reported associations with explosive performance variables, such as the rate of force development [26,27]. Collectively, these findings suggest that thermal asymmetry should be interpreted as a complementary indicator of physiological status rather than as an isolated marker of fatigue or injury risk.

From a practical perspective, the present findings suggest that the interpretation of post-exercise ΔT_{sk} following SSGs should consider the athlete's sex, particularly when assessments are performed during the recovery period. Conversely, the absence of between-sex differences in thermal asymmetry indicates that this parameter may be interpreted using similar criteria for women and men players. Furthermore, the greater sensitivity observed at the Post_10 assessment supports the inclusion of this time point in infrared thermography monitoring protocols.

The present study has several strengths, including the direct comparison of women and men soccer players using a standardised IRT acquisition protocol and a soccer-specific exercise task. Nevertheless, several limitations should be acknowledged. Internal and external training load variables were not recorded; therefore, it was not possible to determine the relationship between

thermal responses and the physiological demands imposed by the SSG. Likewise, potentially influential factors such as body composition, cutaneous blood flow, and menstrual cycle phase were not assessed and may have contributed to the observed between-sex differences. Finally, thermal assessments were limited to three time points (*Pre*, *Post*, and *Post_10*). Future studies should incorporate a longer recovery follow-up and combine infrared thermography with mechanical, physiological, and biochemical markers to provide a more comprehensive characterisation of recovery following soccer-specific exercise.

5. Conclusions

These findings provide new evidence that sex influences the magnitude of post-exercise skin temperature responses following soccer-specific exercise, whereas bilateral thermal symmetry remains preserved. Furthermore, the present results highlight that thermographic assessment performed 10 min after exercise provides greater physiological sensitivity than immediate post-exercise measurements, supporting the incorporation of sex-specific reference values and recovery-based assessment protocols when infrared thermography is used to monitor athletes.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

Author Contributions: Conceptualization, M.M.O; A.M.A and W.G-S; methodology, M.M.O., E.E.O and W.G-S; software, M.M.O; formal analysis, M.M.O and W.G-S; investigation, M.M.O; J.D.F.V; J.G.T; DGS; E.E.O, resources, M.M.O; J.D.F.V; J.G.T; DGS and WG-S; data curation, M.M.O. and W.G-S; writing—original draft preparation, M.M.O, writing—review and editing, D.G.S; A.M-A and E.E O; visualization, M.M.O; supervision, E.E.O. and M.M..O. All authors have read and agreed to the published version of the manuscript.

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

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request. The authors will make the raw data supporting the conclusions of this article available upon reasonable request. The datasets are not publicly available because they contain data from human participants and are subject to ethical and confidentiality restrictions established in the informed consent signed by the participants and approved by the Institutional Ethics Committee.

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Conflicts of Interest: The authors declare no conflicts of interest.

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