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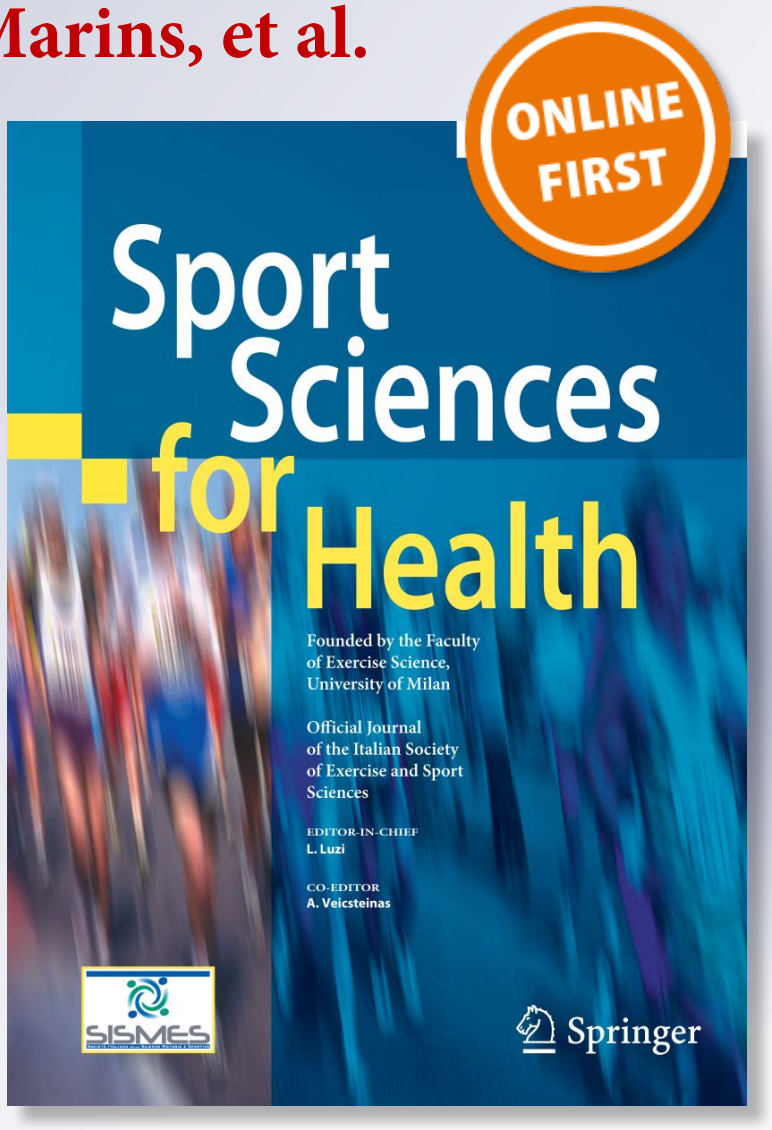

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ORIGINAL ARTICLE

Skin temperature changes of under-20 soccer players after two consecutive matches

Alex de Andrade Fernandes[1,4] · Eduardo Mendonça Pimenta[2] · Danilo Gomes Moreira[1] · Manuel Sillero-Quintana[3] · João Carlos Bouzas Marins[4] · Rodrigo Figueiredo Morandi[2] · Tane Kanope[5] · Emerson Silami Garcia[6]

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Abstract
Purpose To examine whether two consecutive soccer matches would affect skin temperature (t_{sk}) measured via infrared thermography (IRT) in under-20 (U-20) soccer athletes, as well as verify whether the t_{sk} changes would be different between regions of interest.
Methods A cross sectional study. Ten under-20 soccer athletes [age 19.0 ± 1.0 years; height 181.3 ± 6.6 cm; body fat percentage (BF%) 9.0 ± 1.8%, body surface area 1.9 m^2 and $\dot{V}O_{2max}$ 56.4 ± 3.2 ml min^{-1} kg^{-1}]. Skin thermal responses obtained by IRT and creatine kinase concentration (CK) were evaluated in response to two soccer matches with 3 days of recovery between each match.
Results The t_{sk} increased (≅1.0 °C) 24 h after the first match in all studied regions of interest (ROIs), returning to near pre-match values 48 h after the first match. However, after playing the second match, the t_{sk} increased even more (≅1.5 °C) 24 h after in all the considered ROIs, not returning to pre-match values 48 h after. Regarding CK analysis, its course during the experiment was similar to t_{sk}, with high values 24 h after (first match 763.8 ± 294.5 U/L; second match 784.1 ± 298.8 U/L) and recovering 48 h after (first match 526.4 ± 289.7 U/L; second match 672.2 ± 285.0 U/L) both matches. However, when the two matches are compared, CK showed a higher value 48 h after the second match in comparison to first match ($P = 0.002$). The t_{sk} and CK were moderately correlated in all ROIs analyzed, with higher correlation in the anterior right leg ($r = 0.425$) and anterior left leg ($r = 0.428$).
Conclusion The t_{sk} of lower limbs as well as CK markedly change in response to two consecutive matches separated by an interval of 3 days. There is indication of the highest inflammatory response after the second match, which was preceded by just a 3-day recovery. In addition, a general increase was obtained in thighs and legs in anterior and posterior views.

Keywords Infrared thermography · Thermal imaging · Muscle damage · Recovery · Creatine kinase

✉ Alex de Andrade Fernandes
alex.andrade@ifmg.edu.br

[1] Federal Institute for Education, Science and Technology of Minas Gerais, Ipatinga and Governador Valadares, Minas Gerais, Brazil

[2] Department of Physical Education, School of Physical Education, Physiotherapy, and Occupational Therapy, Federal University of Minas Gerais, Belo Horizonte, Minas Gerais, Brazil

[3] Faculty of Physical Activity and Sport Sciences, Universidad Politécnica de Madrid, Madrid, Spain

[4] Department of Physical Education, Human Performance Laboratory, Federal University of Viçosa, Viçosa, Brazil

[5] Medical and Physiology Department, Cruzeiro Esporte Clube, Belo Horizonte, Brazil

[6] UFMA/CAPES/FAPEMA, Federal University of Maranhão, Maranhão, Brazil

Introduction

Elite soccer players are often required to play consecutive matches with intervals of 3 or 4 days. Those matches are usually associated with long trips, sudden changes in weather conditions, and alterations in their playing time and sleep, making it difficult to reach a complete recovery [1, 2]. Additionally, several studies have reported that more than 72 h of recovery are required for athletes to achieve similar physical performance values to those obtained

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before the match, as well as for reestablishing muscle micro-injuries and the inflammatory processes generated by intense physical activity [3–6]. A higher load promoted by consecutive matches and consequent poor recovery is associated with increased injury risk during matches in professional soccer players [7, 8]. Therefore, mechanisms are of particular interest to evaluate fatigue status and provide adequate recovery time.

Many tools are commonly used to control training load, including heart-rate derived indices [9], neuromuscular indices [10], salivary and blood markers [6, 11], and subjective wellness scales [12]. Recently, skin temperature (t_{sk}) measured by infrared thermography (IRT) has been proposed as a method to indirectly analyze the level of muscle damage in exercise settings [13]. The rationale for measuring t_{sk} following exertion is that athletes' t_{sk} would increase in the exercised areas due to the local inflammatory response triggered by micro-injuries [14]. To identify such areas, IRT has some advantages to contact sensor, since contact sensor provide a temperature value of only one point on the anatomical region, whereas IRT provide a map of temperature values [15]. It is well established that high-intensity physical exercise involving many eccentric muscle contractions, such as those that soccer players usually perform in an official match where their actions are abruptly interrupted and restarted several times in a random way, may generate muscle fiber ruptures, cell membrane damage, disorganization of the myofilaments and loss in the Z-line integrity of the sarcomeres [1, 2, 16, 17]. This process is followed by an acute inflammatory response where some important signs are presented after soccer matches such as heat, redness, pain and swelling [17–19]. However, it is unclear whether this local inflammatory response can affect the t_{sk} of soccer players.

Previous studies have used IRT to investigate the relationship between t_{sk} response and physical exercise [20–22]. Bandeira et al. [22] compared the quadriceps t_{sk} of under-17 soccer players who performed an eccentric/concentric high-intensity quadriceps training (80% maximal load) with controls trained at moderate intensity (running at 50–60% of maximal heart rate). It was found that quadriceps t_{sk} increased 24 h after eccentric/concentric high-intensity exercise in comparison to control. However, no follow-up was performed to identify whether the quadriceps t_{sk} would return to initial values after 48 h. Similarly, Al-Nakhli et al. [21] examined the response of a high-intensity elbow flexions on t_{sk} of the biceps muscle in non-athlete men. The results showed a local increase of t_{sk} 24-h post-exercise when compared to pre-exercise temperature, and temperatures taken 48 h after. On the other hand, Silva et al. [20] investigated t_{sk} in physically active subjects and showed no differences 24 and 48 h after an anaerobic exercise protocol consisting of 100 Squat-jumps without any external weight. Nevertheless, all the aforementioned studies were performed in laboratory conditions which are far different from those of a high performance sport. In addition, considering the dynamics of activities performed in a soccer game and the absence of specific studies, it is still not possible to know whether the t_{sk} would alter after soccer activity, as well as what region would be more likely to express changes in t_{sk} of soccer players.

Physiological response following official soccer matches include depletion of glycogen, high muscle damage or/and severe inflammation [1, 23]. These responses are usually observed by an elevation of plasma creatine kinase activity (CK) and many other markers [5, 24]. However, less is known about the t_{sk} response following soccer matches. In addition, the relationship between a local response (skin temperature) and the overall response (CK) may be important to understand how these variables reacts in response to soccer matches. Therefore, the aim of this study was to examine whether two consecutive soccer matches would affect t_{sk} measured via IRT in under-20 (U-20) soccer athletes, as well as verify whether the t_{sk} changes would be different between regions of interest.

Methods

Participants

Ten under-20 soccer athletes who play in the Brazilian first division soccer league were analyzed [age 19.00 ± 1.00 years; height 181.3.0 ± 6.63 cm; percentage body fat (% BF) 9.02 ± 1.82%, body surface area (BSA) 1.92 m^2 and $\dot{V}O_{2max}$ 56.44 ± 3.20 ml min^{-1} kg^{-1}]. Selection criteria included: no recent history of febrile illness, muscle lesions, lower limb trauma, or metabolic diseases for at least 3 months before the study; no consumption of performance-enhancing supplements or medication for at least 3 months before the study; none of the participants were smokers; participation in at least five 2-h training sessions per week and playing at least one match per week. Participants represented all playing positions. The volunteers were informed about the procedures at all stages of the study and signed an informed consent form prior to commencement of the data collection. This study was approved by the local Ethics Committee on Human Research, and follows the principles outlined by the World Medical Assembly Declaration of Helsinki.

Procedures

A repeated measures design was used to study the skin thermal responses of soccer players in response to two

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soccer matches with 3 days of recovery between each match. The study was composed of seven distinct time points as follows: 24 h before the first match (Pre-match); 24 h after the first match (M1-24 h); 48 h after the first match (M1-48 h); 24 h after the second match (M2-24 h); and 48 h after the second match (M2-48 h). The participants underwent a medical examination 2 weeks before the start of the study in which they completed a health history questionnaire, and had their body weight, height, body fat, and $\dot{V}O_{2max}$ assessed. To characterize the participants, body mass in grams (Welmy, Santa Bárbara d'Oeste, Brazil), height in centimeters (Welmy, Santa Bárbara d'Oeste, Brazil) and skinfolds (subscapular, triceps, pectoral, axillary, suprailiac, abdominal and thigh) in millimeters (Lange, Cambridge, USA) were measured by a trained anthropometrist, according to the recommendations of the International Society for the Advancement of Kinanthropometry [25]. The values of each fold were used to obtain the sum of the folds and to calculate the percentage of fat [26]. Body surface area was calculated from body weight and height measurements, according to Du Bois and Du Bois [27]. VO_{2max} was indirectly evaluated through the YoYo Endurance Test (level 2) [28]. This is a specific test for soccer and intermittent sports in which the total distance traveled is positively related to athletes' aerobic capacity [29]. A clinical evaluation by the medical staff of the soccer team did not present any evidence of injury or pain.

Two days prior to the first assessment of the study, players did not participate in high-intensity training sessions to provide better recovery and not influence the Pre-match values. Data collection was performed in a period of two consecutive official matches; the first being held on a Sunday at 20:00 h, and the second 3 days later on a Wednesday at 18:00 h. These matches were part of the national championship qualifying phase of the Brazilian Cup U-20 category, organized by the Brazilian Football Confederation (CBF). Mean temperature and mean humidity during the matches was 27.8 °C and 62%, respectively, according to the Brazilian National Institute of Meteorology (www.inmet.gov.br). During the match, participants were allowed to only drink water ad libitum. At the course of this study, no intervention such as cryotherapy was applied. However, in the 2 days after each match, all participants performed 30 m of cycling exercise at 50% maximal heart rate [30]. This was part of the recovery strategy applied by the soccer team which the athletes were already used to. In addition, a normal soccer warm-up was performed on game day before the match, and a normal cool-down period after. At all times t_{sk} data were collected using IRT and blood samples for creatine kinase (CK) assessment.

The t_{sk} was collected in a room properly equipped with artificial fluorescent lamps, and the environmental temperature was maintained through a heating/cooling air conditioner (Komeco, Hi-wall Split, Palhoça, Brazil). The average temperature remained at 23.1 ± 0.5 °C, and the relative humidity was 50.1 ± 3.2%; both measurements were recorded with a digital weather station and anemometer (Instrutherm, AD-250, São Paulo, Brazil) with null (≅0.2 m/s) wind speed. The participants were previously instructed to avoid alcohol beverages, caffeine, large meals, ointments, cosmetics, and showering for 4 h before the assessment. A time of 10 min in a standing position was used for acclimation [31]. The participant remained in an anatomical position in front of the imager at a mean distance of 3 meters. Two thermograms (anterior and posterior regions of the body) were recorded with an infrared imager (FLIR®, T420, Flir Systems Inc., Wilsonville, Oregon, USA), with a measurement range from −20 to +120 °C, 2% accuracy, sensitivity ≤0.05 °C, IR spectral band of 7.5–13 µm, refresh rate of 60 Hz, auto-focus and a resolution of 320 × 240 pixels. The camera was turned on 30 min prior to the test to allow sensor stabilization following the manufacturer's guidelines and the images were recorded perpendicular to the region of interest. Body regions of interest (ROI) were manually selected in a specific software (Flir Tools®), with rectangles of 10 cm width × 20 cm height on the thighs (right and left) and 7 cm width × 19 cm in height on the legs (right and left), as previously reported (Fig. 1) [15, 31, 32]. The emissivity value adopted for human skin was 0.98 and temperature reflected from the room 23 °C. All assessments were carried out at 18:00 h to avoid circadian influence [33, 34]. The same evaluator collected t_{sk} and selected the ROIs, where the mean t_{sk} of each ROI was used for all analyses. Additionally, the t_{sk} value of each ROI and also the difference of t_{sk} at each time point in comparison to pre-match values (Δt_{sk}) were used to analyze the data.

Finger tips were cleaned with 95% ethanol to determine the enzymatic concentration of plasma CK. After drying with cotton, a lancet was used with an automatic puncture trigger and 32 µL of capillary blood was collected with a heparinized capillary tube (Reflotron, Barcelona, Spain), then immediately pipetted into a reactive CK strip and inserted into the analysis device (Reflotron Analyser, Barcelona, Spain).

Statistical analysis

Descriptive statistics of mean and standard deviation (±SD) were used to describe the variables. The Kolmogorov–Smirnov test was used to assess data normality. The required assumptions (dependence of observations,

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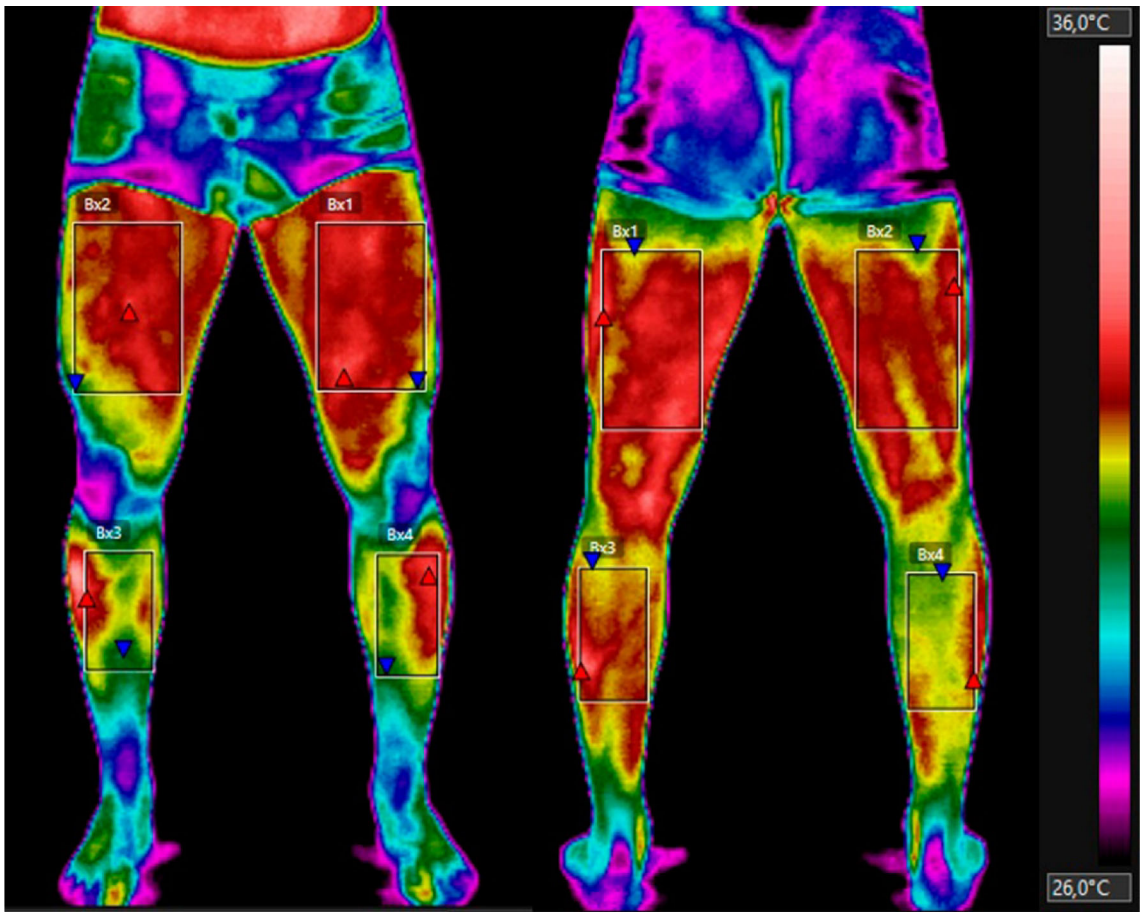

Fig. 1 Representative illustration of the regions of interest (ROI)

normality of sampling distribution, and uniformity of residuals) for repeated ANOVA were verified as previously described [35]. One-way repeated measures ANOVA with Bonferroni correction was performed with times (Pre-match, M1-24 h, M1-48 h, M2-24 h and M2-48 h) to test if there was differences in t_{sk} and CK over time. In addition, a two-way repeated measures ANOVA with times (Δ1-24 h, Δ1-48 h, Δ2-24 h and Δ2-48 h) and regions of interest ($n = 8$) as independent variables was applied to verify if the t_{sk} responses between ROIs were different over time. Mauchly's test was used to check for sphericity. If the sphericity assumption was violated ($P < 0.05$), the Greenhouse–Geisser correction was applied to adjust the degrees of freedom to test the interaction effect between different time points and different ROIs. Bonferroni post hoc test was used for multiple-comparisons. Effect sizes (ES) were determined using the partial Eta-squared method. When applied to ANOVA, it has been suggested that an effect size of 0.1 represents a small effect size; 0.25 a medium effect; and 0.4 a large effect [36]. The Spearman's correlation test was applied to investigate the association between t_{sk} and CK during the five time points analyzed. The adopted significance level was set at $\alpha = 0.05$. All analyzes were conducted on IBM SPSS statistical software (Version 22.0, Chicago, USA).

Results

The results of t_{sk} changes following the two consecutives soccer matches analyzed for all ROIs are presented in Table 1. There was a significant main effect between time points for all analyzed ROIs (thighs and legs in anterior and posterior view). In general, considering the several significant differences detected by post hoc test, the t_{sk} of all ROIs was markedly affected by the investigated matches, increasing 24 h after and decreasing 48 h after. In addition, the results of effect size in all ROIs were large.

A two-way repeated measures ANOVA was conducted to examine the effect of ROI and time point on t_{sk} variations (Δt_{sk} = difference between each time point and Pre-Match values). There was a statistically significant main effect for time points ($F = 29.304$, $P = 0.000$, ES = 0.81), but not for ROI ($F = 1.475$, $P = 0.256$,

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Table 1 Skin temperature of the right and left thighs, right and left legs, in the anterior and posterior views in °C

Region of interest	Time point					*F*	*P*	Effect size
	Pre-match	M1-24 h	M1-48 h	M2-24 h	M2-48 h			
Anterior right thigh	32.7 ± 0.3	33.6 ± 0.5[a]	32.7 ± 0.4[b]	34.2 ± 0.5[a,b,c]	33.3 ± 0.3[a,c,d]	26.43	<0.001	0.75
Anterior left thigh	32.7 ± 0.4	33.7 ± 0.4[a]	32.9 ± 0.4[b]	34.3 ± 0.3[a,b,c]	33.4 ± 0.3[a,d]	30.81	<0.001	0.77
Anterior right leg	32.1 ± 0.3	32.9 ± 0.3[a]	32.0 ± 0.5[b]	33.3 ± 0.2[a,b,c]	32.7 ± 0.4[c,d]	34.57	<0.001	0.79
Anterior left Leg	32.0 ± 0.4	33.0 ± 0.3[a]	32.1 ± 0.5[b]	33.4 ± 0.2[a,b,c]	32.7 ± 0.4[a,c,d]	29.05	<0.001	0.76
Posterior right thigh	33.1 ± 0.4	33.9 ± 0.4[a]	33.3 ± 0.4	34.2 ± 0.3[a,c]	33.3 ± 0.4[b,d]	21.10	<0.001	0.70
Posterior left thigh	33.1 ± 0.4	33.9 ± 0.4[a]	33.2 ± 0.3[b]	34.2 ± 0.3[a,c]	33.3 ± 0.4[b,d]	18.47	<0.001	0.67
Posterior right leg	31.9 ± 0.3	32.8 ± 0.4[a]	32.0 ± 0.6[b]	33.2 ± 0.3[a,b,c]	32.3 ± 0.4[b,d]	27.36	<0.001	0.75
Posterior left leg	31.9 ± 0.4	32.7 ± 0.3[a]	32.0 ± 0.6	33.2 ± 0.3[a,b,c]	32.2 ± 0.4[b,d]	32.88	<0.001	0.79

Pre-Match = baseline values; M1-24 h = 24 h after the first match; M1-48 h = 48 h after the first match; M2-24 h = 24 h after the second match; M2-48 h = 48 h after the second match

[a] Significant difference ($P < 0.05$) compared with pre-match

[b] Significant difference ($P < 0.05$) compared with M1-24 h

[c] Significant difference ($P < 0.05$) compared with M1-48 h

[d] Significant difference ($P < 0.05$) compared with M2-24 h

ES = 0.14). No interaction between ROI and time point was found ($P > 0.05$). The multiple-comparison between time points showed that Δt_{sk} 24 h after the first match was higher than 48 h after the first match ($P = 0.004$), but it was lower than Δt_{sk} 24 h after the second match ($P = 0.004$), whereas no differences were found 48 h after the second match ($P = 0.165$). The analysis showed that Δt_{sk} 24 h after second match was higher than 48 h after the second match ($P = 0.000$). In addition, Δt_{sk} 48 h after the first match was significantly different than all time points ($P < 0.05$). Therefore, compared to baseline values, it can be seen that t_{sk} increased 24 h after and decreased 48 h after both analyzed matches; however, the t_{sk} 24 h after the second match increased more in comparison with 24 h after the first match ($P = 0.004$). Furthermore, the t_{sk} 48 h after the second match was also higher than 48 h after the first match ($P = 0.008$). Figure 2 shows the Δt_{sk} observed in the different ROIs in the anterior and posterior view, throughout the different time points of the study (M1-24 h, M1-48 h, M2-24 h and M2-48 h), considering pre-match resting values as baseline.

The results of CK during the experiment were 221.8 ± 107.6 U/L at pre-match, 763.8 ± 294.5 U/L at 24 h after the first match, and 526.4 ± 289.7 U/L at 48 h after the first match; then 784.1 ± 298.8 U/L at 24 h after the second match, and 672.2 ± 285.0 U/L at 48 h after the second match. The main effects analysis presented a significant difference between time points ($F = 39.597$, $P = 0.000$, ES = 0.82). Post hoc analysis showed that CK was higher in all time points ($P = 0.000$) when compared to pre-match values. No significant difference was found between values of 24 h after the first match and 24 h after the second match ($P = 1.00$). However, the CK was significantly higher 48 h after the second match in comparison with 48 h after the first match ($P = 0.002$).

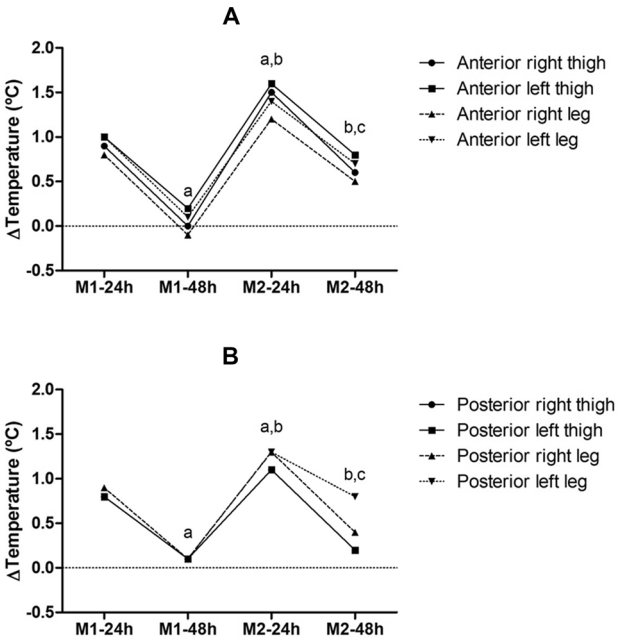

Fig. 2 ΔTemperature (difference of t_{sk} at each time point and pre-match values) recorded on the right and left thighs, right and left legs, in the anterior (**a**) and posterior (**b**) view. *a* Significant difference compared to M1-24 h; *b* Significant difference compared to M1-48 h; *c* Significant difference compared to M2-24 h

To measure the association between t_{sk} and CK during all time points of the experiment, a Spearman's rank-order

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correlation was applied and showed a median significant correlation between CK and all ROIs analyzed. The Table 2 presents the correlation for each ROI.

Discussion

The present study is the first to examine the t_{sk} response of high performance U-20 soccer athletes after performing two consecutive official matches with a 3-day interval between them. In summary, the results show that the t_{sk} increased 24 h after the first match in all the studied ROIs (thighs and legs in anterior and posterior view), and returned to near pre-match values 48 h after the match (Table 1). However, after playing the second match, the t_{sk} values 24 h after are even higher in all the considered ROIs, and did not return to pre-match values 48 h after (Fig. 1). Regarding CK analysis, the course during the experiment was similar to t_{sk}, with high values after 24 h and recovering 48 h after both matches. However, when the two matches are compared, CK showed a higher value 48 h after the second match in comparison to the first match. The t_{sk} and CK were moderately correlated in all ROIs analyzed, with higher correlation in the anterior right leg ($r = 0.425$) and anterior left leg ($r = 0.428$). These results support that t_{sk} of lower limbs highly reacted to the exertion of playing soccer, in agreement with previous studies [21, 22]. The findings of this study can help technical and medical staff of soccer teams to understand how t_{sk} responds to an official match, and how measuring this variable can assist in managing training load.

The magnitude of the temperature changes following a soccer match is unknown in the literature since most analyses performed to date have been focusing on differences between body sides [13, 32]. Hildebrandt et al. [13] showed that thermal asymmetry between contralateral ROIs higher than 0.7 °C is a signal that should be highly considered by technical and medical staff of soccer teams. In the current study, the Δt_{sk} for all the considered ROIs presented in Fig. 1 shows an increase of ($\cong$1.0 °C) in relation to rest values registered 24 h after the first match, and higher increases ($\cong$1.5 °C) 24 h after the second match. However, this appears to be a natural and normal condition for professional players after participating in an official soccer match. It is worth noting that the studied players underwent a clinical medical evaluation before and after the experiment, and no symptoms or injury complaints were found. Thus, considering that the increment of muscle temperature after high-intensity exertion is due to biochemical changes caused by inflammatory chemical mediators [19], it is reasonable to suppose that the t_{sk} changes found may be triggered by an inflammatory process.

Supporting this interpretation, the CK values throughout the time points of the current study presented a similar course to t_{sk}, with a significant increase 24 h after the first match (Pre-Match = 221.8 ± 107.6 U/L; M1-24 h = 763.8 ± 294.5 U/L; $P = 0.000$), a reduction 48 h after the first match (M1-48 h = 526.4 ± 289.7 U/L; $P = 0.000$), an increase again 24 h after the second match (M2-24 = 784.1 ± 298.8 U/L; $P = 0.000$), and a lower reduction 48 h after the second match (M2-48 = 672.2 ± 285.0 U/L; $P = 0.002$). These results are in agreement with those observed by Coelho et al. [37] with professional soccer players from a first division Brazilian club who presented resting values of 192 ± 23 U/L, 785 ± 95 U/L 12–20 h after the match, and 388 ± 37 U/L 36–48 h after the match. It is well established that consecutive matches may generate higher internal load and consequent increased muscle damage or/and inflammatory responses [1, 6]. This can be observed in the CK response of the present study, especially because of the higher value presented 48 h after the second match in comparison to 48 h after the first match. Therefore, 48 h does not appear to be a sufficient amount of time to recover from game-induced muscle damage and concomitant inflammation caused by repeated match play in soccer.

Alterations in CK concentrations have been applied as systemic indicators of general inflammation in scientific research [6, 10]. However, only a few studies have investigated the response of t_{sk} measured by IRT as an indirect method to measure local inflammation [20–22]. Where exercise protocols consisting of high-intensity elbow flexion exercise [21] and high-intensity quadriceps training [22] have increased the t_{sk} in the exercised areas 24 h after the analysis, no change was reported when a plyometric protocol was applied [20]. These controversial results could be explained by the differences between the

Table 2 Spearman's correlation for each ROI analyzed

	Anterior view				Posterior view			
	Right		Left		Right		Left	
	Thigh	Leg	Thigh	Leg	Thigh	Leg	Thigh	Leg
CK	0.345**	0.425**	0.353**	0.428**	0.276*	0.289*	0.299*	0.257*

* $P < 0.05$; ** $P < 0.01$

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protocols used, as well as the different applied intensities. Considering that lab protocols may not provoke a similar response to real games due to the lack of soccer game-specific actions [38], it is expected that the t_{sk} response of the current study may differ from those which applied no specific protocols. In fact, the increment of 0.8 °C 24 h after high-intensity elbow flexion exercise found by Al-Nakhli et al. [21] was lower than the values of the present study 24 after the first ($\cong$1.0 °C) and second match ($\cong$1.5 °C). On the other hand, it is important to highlight that there was a relationship between the t_{sk} and CK results, which can be noted by examining the second match. The elevated CK 48 h and the elevated t_{sk} 24 h/48 h after the second match suggest a higher inflammatory response, which is possibly the result of poor recovery due to the small interval period between matches [1, 6]. Therefore, these results suggest that t_{sk} is markedly affected by soccer match exertion, and its response is related to the inflammation level.

No significant difference was found when analyzing the response between the different selected ROIs (Fig. 1). Given the several numbers of high-intensity actions such as sprints with short distances of deceleration to stop or change direction, kicking a ball, shots on goal, tackles, and maximal jumps during a soccer match [1], the diversity of performed activities can explain the general t_{sk} response found instead of a more localized one. However, it is necessary to consider that a higher local temperature can be found in case of injury or severe pain [13, 14]. In addition, it has been investigated that unlike the CK analysis which presents a general idea of muscle damage, IRT can determine the locations where inflammatory processes are in muscles [13, 14, 21]. In this sense, although no injuries were identified in the analyzed athletes, it is expected to detect higher local t_{sk} in case of overuse and/or injury [13].

The moderate correlation found between t_{sk} and CK also suggests the relationship between a local response (skin temperature) and the overall response (inflammatory marker). In regard to the t_{sk} response, the approach used for the analysis of the data may be determinant to understand this relation. In the present study, the t_{sk} values were obtained by calculating the mean skin of a ROI; however, this analysis may be expanded. Recently, some studies [34, 39, 40] have emphasized the importance of analyzing not only the mean temperature, but also the temperature distribution within an ROI, to identify in more detail relevant responses. This approach may favor the identification of hot spots and help to analyze changes in temperature distribution within a given ROI. Although this approach has not been employed in this study, it may be useful for future studies on the subject.

This study presented limitations such as the lack of internal temperature data, the movements of the players through a GPS to quantify the work load during the match, and collection of other biochemical markers of muscle damage. As the intensity of the soccer matches was not measured, the relationship between external load and t_{sk} cannot be calculated. However, the intensity of an official soccer match and the inflammatory response after is well documented in the literature, especially indicating greater internal load and inflammation when performing consecutive games [1, 6]. A topic of interest for future studies may be to analyze the impact of internal load on t_{sk} during the in-season competitive period, where high-intensity loads are likely to impair players' physical performance [41]. Similarly, comparing the t_{sk} with other monitoring tools such as heart-rate derived indices [9], neuromuscular indices [10], salivary and blood markers [6, 11], and subjective wellness scales [12] would help to understand the sensitivity of t_{sk} to changes in training load. The results of the present study may provide two main practical applications for sports science. Firstly, skin temperature responsiveness to consecutive games suggests that thermographic evaluation should not be performed only considering contralateral asymmetry, but also considering the thermal response to training loads. Second, it is necessary to establish a routine of evaluations to identify how each athlete responds thermally to the different training loads, because this way it would be possible to identify relevant responses that could be linked to inflammation process. Finally, knowledge of the mechanisms underlying t_{sk} response and the facility to obtain this data using IRT may be helpful in assisting technical and medical staff of professional soccer clubs, thus becoming part of injury prevention protocols.

Conclusion

In conclusion, t_{sk} of lower limbs as well as CK markedly change in response to two consecutive matches separated by a 3-day interval. There is an indication of higher inflammatory response after the second match, which was preceded by a 3-day recovery. In addition, a general increase was observed in all investigated ROIs.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional or national research committee and with the 1964 Helsinki declaration and its later amendments or compatible ethical

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standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in this study.

References

1. Nedelec M, McCall A, Carling C, Legall F, Berthoin S, Dupont G (2012) Recovery in soccer: part I—post-match fatigue and time course of recovery. Sports Med 42(12):997–1015
2. Nédélec M, Halson S, Abaidia A-E, Ahmaidi S, Dupont G (2015) Stress, sleep and recovery in elite soccer: a critical review of the literature. Sports Med 45(10):1387–1400
3. Ascensão A, Rebelo A, Oliveira E, Marques F, Pereira L, Magalhães J (2008) Biochemical impact of a soccer match—analysis of oxidative stress and muscle damage markers throughout recovery. Clin Biochem 41(10):841–851
4. Ispirlidis I, Fatouros IG, Jamurtas AZ, Nikolaidis MG, Michailidis I, Douroudos I, Margonis K, Chatzinikolaou A, Kalistratos E, Katrabasas I (2008) Time-course of changes in inflammatory and performance responses following a soccer game. Clin J Sport Med 18(5):423–431
5. Fatouros IG, Chatzinikolaou A, Douroudos II, Nikolaidis MG, Kyparos A, Margonis K, Michailidis Y, Vantarakis A, Taxildaris K, Katrabasas I (2010) Time-course of changes in oxidative stress and antioxidant status responses following a soccer game. J Strength Cond Res 24(12):3278–3286
6. Mohr M, Draganidis D, Chatzinikolaou A, Barbero-Álvarez JC, Castagna C, Douroudos I, Avloniti A, Margeli A, Papassotiriou I, Flouris AD (2015) Muscle damage, inflammatory, immune and performance responses to three football games in 1 week in competitive male players. Eur J Appl Physiol 116:179–193
7. Dellal A, Lago-Peñas C, Rey E, Chamari K, Orhant E (2015) The effects of a congested fixture period on physical performance, technical activity and injury rate during matches in a professional soccer team. Br J Sports Med 49:390–394
8. Drew MK, Finch CF (2016) The relationship between training load and injury, illness and soreness: a systematic and literature review. Sports Med 46(6):861–883
9. Buchheit M (2014) Monitoring training status with HR measures: do all roads lead to Rome? Front Physiol 27:5–73
10. Silva JR, Rebelo A, Marques F, Pereira L, Seabra A, Ascensão A, Magalhães J (2013) Biochemical impact of soccer: an analysis of hormonal, muscle damage, and redox markers during the season. Appl Physiol Nutr Metab 39(4):432–438
11. Owen AL, Wong DP, Dunlop G, Groussard C, Kebsi W, Dellal A, Morgans R, Zouhal H (2016) High-intensity training and salivary immunoglobulin a responses in professional top-level soccer players: effect of training intensity. J Strength Cond Res 30(9):2460–2469
12. Gastin PB, Meyer D, Robinson D (2013) Perceptions of wellness to monitor adaptive responses to training and competition in elite Australian football. J Strength Cond Res 27(9):2518–2526
13. Hildebrandt C, Raschner C, Ammer K (2010) An overview of recent application of medical infrared thermography in sports medicine in Austria. Sensors 10(5):4700–4715
14. Ring EF, Ammer K (2012) Infrared thermal imaging in medicine. Physiol Meas 33(3):R33–R46
15. Moreira DG, Costello JT, Brito CJ, Adamczyk JG, Ammer K, Bach AJ, Costa CM, Eglin C, Fernandes AA, Fernández-Cuevas I, Ferreira JJ, Formenti D, Fournet D, Havenith G, Howell K, Jung A, Kenny G, Kolosovas-Machuca E, Maley MJ, Merla A, Pascoe DD, Priego Quesada JI, Schwartz R, Seixas A, Selfe J, Vainer B, Sillero Quintana M (2017) Thermographic imaging in sports and exercise medicine: a Delphi study and consensus statement on the measurement of human skin temperature. J Therm Biol 69:155–162
16. Pimenta EM, Coelho DB, Cruz IR, Morandi RF, Veneroso CE, de Azambuja Pussieldi G, Carvalho MRS, Silami-Garcia E, Fernández JADP (2012) The ACTN3 genotype in soccer players in response to acute eccentric training. Eur J Appl Physiol 112(4):1495–1503
17. Tidball JG, Villalta SA (2010) Regulatory interactions between muscle and the immune system during muscle regeneration. Am J Physiol Regul Integr Comp Physiol 298(5):R1173–R1187
18. Paulsen G, Mikkelsen UR, Raastad T, Peake JM (2012) Leucocytes, cytokines and satellite cells: what role do they play in muscle damage and regeneration following eccentric exercise. Exerc Immunol Rev 18(1):42–97
19. Page P (1995) Pathophysiology of acute exercise-induced muscular injury: clinical implications. J Athl Train 30(1):29–34
20. Silva YA, Santos BH, Andrade PR, Santos HH, Moreira DG, Sillero-Quintana M, Ferreira JJA (2017) Skin temperature changes after exercise and cold water immersion. Sport Sci Health 13(1):195–202
21. Al-Nakhli HH, Petrofsky JS, Laymon MS, Berk LS (2012) The use of thermal infra-red imaging to detect delayed onset muscle soreness. J Vis Exp 59:e3551
22. Bandeira F, Muniz de Moura MA, Abreu de Souza M, Nohama P, Borba Neves E (2012) Can thermography aid in the diagnosis of muscle injuries in soccer athletes? Rev Bras Med Esporte 18(4):234–239
23. Thorpe R, Sunderland C (2012) Muscle damage, endocrine, and immune marker response to a soccer match. J Strength Cond Res 26(10):2783–2790
24. Heisterberg MF, Fahrenkrug J, Krustrup P, Storskov A, Kjær M, Andersen JL (2013) Extensive monitoring through multiple blood samples in professional soccer players. J Strength Cond Res 27(5):1260–1271
25. Marfell-Jones M, Olds T, Stewart A, Carter L (2006) International standards for anthropometric assessment. The International Society for the Advancement of Kim Anthropometric (ISAK), Potchefstroom, South Africa
26. Jackson AS, Pollock ML (1978) Generalized equations for predicting body density of men. Br J Nutr 40(3):497–504
27. Du Bois D, Du Bois EF (1989) A formula to estimate the approximate surface area if height and weight be known. Nutrition 5(5):303–311
28. Bangsbo J, Iaia FM, Krustrup P (2008) The Yo-Yo intermittent recovery test. Sports Med 38(1):37–51
29. Castagna C, Impellizzeri FM, Chamari K, Carlomagno D, Rampinini E (2006) Aerobic fitness and yo-yo continuous and intermittent tests performances in soccer players: a correlation study. J Strength Cond Res 20(2):320–325
30. Tanaka H, Monahan KD, Seals DR (2001) Age-predicted maximal heart rate revisited. J Am Coll Cardiol 37(1):153–156
31. Marins JCB, Moreira DG, Cano SP, Sillero-Quintana M, Soares DD, Fernandes AA, Silva FS, Costa CMA, Amorim PRS (2014) Time required to stabilize thermographic images at rest. Infrared Phys Technol 65:30–35
32. Marins JCB, Fernandes AA, Moreira DG, da Silva FS, Costa CMA, Pimenta E, Sillero-Quintana M (2014) Thermographic profile of soccer players' lower limb. Rev Andal Med Deporte 7(1):1–6
33. Costa CM, Sillero-Quintana M, Pinonosa Cano S, Moreira DG, Brito CJ, Fernandes AA, Pussieldi GA, Marins JC (2015) Daily oscillations of skin temperature in military personnel using thermography. J R Army Med Corps 162(5):335–342

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34. Formenti D, Ludwig N, Rossi A, Trecroci A, Alberti G, Gargano M, Merla A, Ammer K, Caumo A (2017) Skin temperature evaluation by infrared thermography: comparison of two image analysis methods during the nonsteady state induced by physical exercise. Infrared Phys Technol 81:32–40
35. Hopkins WG (2000) A new view of statistics. Internet Society for Sport Science. http://www.sportsci.org/resource/stats/
36. MacCallum RC, Browne MW, Sugawara HM (1996) Power analysis and determination of sample size for covariance structure modeling. Psychol Methods 1(2):130
37. Coelho DB, Morandi RF, Melo MAAd, Silami-Garcia E (2011) Creatine kinase kinetics in professional soccer players during a competitive season. Rev Bras Cineantropometria Desempenho Hum 13(3):189–194
38. Magalhães J, Rebelo A, Oliveira E, Silva JR, Marques F, Ascensão A (2010) Impact of Loughborough Intermittent Shuttle Test versus soccer match on physiological, biochemical and neuromuscular parameters. Eur J Appl Physiol 108(1):39–48
39. Ludwig N, Formenti D, Gargano M, Alberti G (2014) Skin temperature evaluation by infrared thermography: comparison of image analysis methods. Infrared Phys Technol 62:1–6
40. Ammer K, Formenti D (2016) Does the type of skin temperature distribution matter? Thermol Int 26(2):51–54
41. Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W (2015) Monitoring fatigue during the in-season competitive phase in elite soccer players. Int J Sports Physiol Perform 10(8):958–964