Fatigue Detection In Elite Footballers Through The Use Of Thermography

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Abstract

Football is a very demanding sport where many injuries take place because of fatigue. Thermography can be used to detect fatigue and prevent its consequences, through thermal asymmetries in the bilateral body areas, but its adequacy for elite footballers has not been widely studied. Therefore, the objective of the present investigation was to determine the suitability of thermography to detect fatigue in male football players. Twenty elite male football players were gathered into pair of subgroups (low [<0,2 ºC] vs high thermal asymmetry [≥0,2 ºC]) based on a thermography session of the lower limbs (anterior and posterior part). Afterwards, players performed a vertical jump test (CMJ) before and after a Repeated Sprint Test (RSA) (6x30 m/20"). No significant differences ($p \leq 0,05$) were found in any of the RSA test variables between the low and high thermal asymmetry groups in thighs and calves, while the low thermal asymmetry hamstring group reported lower %Diff and higher %Best in some sprints. As for vertical jump, the low thermal asymmetry hamstring group reported significantly higher values in the CMJ Post-RSA. In accordance with these results, thermography seems to be an useful tool to detect fatigue in elite footballers, as hamstrings temperature asymmetries over 0,2 ºC seem to be an indicative of it.

1. Introduction

Football is a sport characterized by continuous changes in activity, alternating high intensity actions with short resting periods to recover from them [1]. In addition, the game also demands tackles, shoots, jumps, accelerations, decelerations, changes of direction and dribbles [2], making the sport highly physiologically demanding [3]. This is why muscle injuries of the lower extremities are frequent in male elite and amateur football players [4], but most of these injuries do not take place because of physical contact, as only 5% of the injuries occur during foul play, which means that it may be possible to prevent at some extent these injuries [5]. A congested calendar of matches and training can induce fatigue, as some player can be unable to assimilate these matches and training loads, increasing the risk of injury and underperformance [6]. This was specially remarkable in 2020–2021 season, where the post lockdown congestion schedule after a home-based training impacted negatively in some team´s number of injuries and players performance [7]. In this sense, coaches and researchers agree about the importance of managing fatigue for optimal muscular adaptations, decrease injury risk and improve performance [8]. However, very few studies have investigated actively how to measure fatigue and modify the training accordingly to it [9]. Which is especially important in the situation COVID-19 has provoked in football, where clubs need to be prepared for circumstances never experienced before [7].

There are many methods to measure fatigue, but most of them present some disadvantages: heart rate measurements are the most common, but require qualified staff and its precision for high intensity training is under question [10]. Blood and bone markers are invasive and very difficult to administer, which makes them unsustainable during regular season training [11], and questionaries are very simple to administer, but very subjective, which make them a measure with a high risk of bias [12].

On the other hand, it has been evidenced that velocity loss is a reliable marker of neuromuscular fatigue [13], which is described as the decreased in the voluntary force in a muscle group [14]. This is the reason why most of the scientific literature use the Repeated Sprint Ability test (RSA) to measure fatigue, especially in team sports such as football [15], as RSA and the ability to exercise at high intensity are key capacities for optimal performance [16], and a decreased sprint repetition capacity is a good indicative of fatigue in sport [17]. This method with the incorporation of a stretching- shortening movement, like Countermovement Jump (CMJ) can provide very deep information about fatigue [18] as good relationships between sprint ability and CMJ capacity has been verified [18].

Thereby, scientific evidence have found CMJ performance to be an objective marker of fatigue and supercompensation [19,20], as neuromuscular fatigue have been associated with a decrease in the average CMJ height [9], making this method also very usual to asses neuromuscular fatigue [19,21]. However, when using RSA to assess neuromuscular fatigue, the number of sprints induces great variability between athletes [22], and when using CMJ it is important to consider that the same fatiguing stimuli can elicit different effects between individuals in the results [23]. That is why it can be considered to use other technologies, like Infrared Thermography (IRT) which is a non-radiating, contact-free, safe and non-invasive technology that monitors physiological variables through the control of the skin temperature [24].

This technology emerges from the correlation between muscle activation and skin temperature [25]. When someone exercises the muscles can increase or decrease the temperature depending on the activity and the intensity of it, and thermography is a reliable method to asses this temperature [26], as the stress caused by physical efforts can cause changes in blood flow that influence skin temperature [27]. Athletes are presumed to keep constant the thermal patron in baseline conditions [28], and thermal asymmetries are linked to factor related to injuries, such as inflammation or secondary trauma [29], IRT can detect these asymmetries comparing bilateral body areas [27], showing potential injury risk due to incorrect work assimilations provoked by factor like excessive training, bad technique or muscle overload [30]. The relevance of IRT is that it can detect the temperature asymmetries (and consequent risks) before other markers such as pain, making this method extraordinary effective and applicable to prevent injuries before they happen [30]. If IRT provides coaches the ability to asses neuromuscular fatigue before exercises, it can allow coaches to modify the training load proactively, decreasing injury risk and increasing performance [9]. This advantage is especially remarkable in sports like football, where high-intensity interval training combined with the weekly competition can lead locomotor system to its anatomical and physiological limit [24], incrementing exponentially the risk of minor injuries, overuse injuries, lower leg injuries and muscle strains [24]. In recent years some authors have explained the efficiency of this technology for injury prevention in medicine [31,32], however, research with IRT in athletes, like football players, have not been widely investigated, as only a couple of studies have explore the use of IRT for preventing football injuries [27,33], nevertheless, none of the studies realized with thermography aimed to use it to detect fatigue in football players, to adapt training loads depending of it, so this concept demands research.

Therefore, the purpose of this study was to determine the suitability of thermography to detect fatigue in male football players through bilateral body asymmetries. RSA and CMJ will be used as control variables to check if thermography really detects fatigue, as they are methods more developed and studied in the literature with good relationships between then.

2. Results

Figure 1 shows the results in the RSA variables (RSAt, %Diff, and %Best) based on thermal asymmetry clusters (group with low asymmetry and group with high asymmetry in each of the three muscle groups). Thighs and calves asymmetry did not show a significant effect in any variable ($p > 0.050$). No significant interaction was also found between thighs and calves asymmetry and the number of sprint ($p > 0.050$). Hamstrings asymmetry did not show a significant effect in RSA and %Diff ($p > 0.050$), but yes in %Best ($F = 6.59$; $p = 0.018$; ES = 0.25). Furthermore, a significant interaction was found between hamstrings asymmetry and the sprint number in RSAt ($F = 2.42$; $p = 0.041$; ES = 0.11), and in %Diff ($F = 2.50$; $p = 0.049$; ES = 0.11), but not in % Best ($p > 0.050$). About pair-wise comparison, hamstring high asymmetry group showed higher %Diff in sprint 2 ($F = 7.40$; $p = 0.013$; IC: -4.20 to -0.55; ES = 0.27) and there was also found higher %Best in hamstring low asymmetry group in sprint 2 ($F = 5.76$; $p = 0.026$; IC: 0.11 to 1.55; ES = 0.22), 3 ($F = 15.59$; $p = 0.001$; IC: -1.55 to -0.11; ES = 0.44) and 4 ($F = 9.36$; $p = 0.006$; IC: 0.67 to 2.22; ES = 0.32).

Table 1 shows the differences in CMJ variables between all defined groups. There are no significant differences in any of the variables between the low and high thermal asymmetry groups in thighs and calves. However, in hamstrings, while there are no significant differences between the low and high thermal asymmetry groups in the CMJ Pre-RSA and Diff CMJ ($p > 0.05$), the low asymmetry group has significantly higher values in the CMJ Post-RSA ($F = 7.55$; $p = 0.013$; IC: 1.06 to 7.84; ES = 0.28).

Table 1
Differences in CMJ variables depending on low and high asymmetry.

		Low asymmetry			High asymmetry		
Thighs Asymmetry	CMJ Pre	39,30	±	3,59	38,78	±	4,74
	CMJ Post	34,35	±	4,07	35,13	±	4,64
	Diff CMJ	-4,96	±	3,12	-3,65	±	3,17
Hamstrings asymmetry	CMJ Pre	40,80	±	3,62	37,79	±	3,95
	CMJ Post	37,23	±	3,78	32,78	±	3,59*
	Diff CMJ	-3,58	±	3,28	-5,01	±	3,01
Calves asymmetry	CMJ Pre	38,98	±	4,41	39,19	±	3,77
	CMJ Post	34,15	±	3,97	35,27	±	4,64
	Diff CMJ	-4,83	±	2,53	-3,92	±	3,77

*: Significant differences between groups ($p < 0.05$).

3. Discussion

The purpose of this study was to determine the suitability of thermography to detect fatigue in male professional football players, using RSA and CMJ to control if thermography is really appropriate for this application. In line with this, the present investigation has observed that thermography can be an indicator of fatigue in players with hamstrings asymmetry over 0,2 ºC

Results related with RSA test showed a significant interaction between hamstrings asymmetry and the number of sprint in RSAt, and in the %Diff; but there was not any interaction between the asymmetry of any muscle group (hamstrings, thigs and calves) and % Best. Comparing by pairs, hamstring high asymmetry group showed higher %Diff in sprint 2, which means that they have a significative higher time respect to sprint 1 (worse performance) than the low asymmetry group. On the other hand, the hamstring low asymmetry group reported higher %Best in sprint 2, 3 and 4. The cause of this differences in hamstring %Best may be attributable to the fact that low asymmetry group had a best sprint very fast, so the following best ones are significative different (to worse). On the other hand, there were no differences found in the thighs and calves groups for any variable. The reason why the only thermal asymmetry that influenced performance were hamstrings can be due to its importance in sprinting, as they play a crucial role generating force in the propulsive part of the sprint [34], and are clearly the most frequently injured muscle during sprinting [5], a proof of the effort these muscles do in the sprint is that an increase in running speed of 80–100% is linked with an increase in net hamstring muscle force and energy absorption of 1.4 and 1.9 times respectively [35], however, this study took the data from athletes running on a treadmill, and the mechanical properties of treadmill surfaces are different to the surfaces where athletes train and compete usually (e.g. artificial turf or athletic track) [36]. This factor may influence running anatomy, so results should be interpreted with caution.

About CMJ results, the low thermal asymmetry hamstrings group has significantly higher values in the CMJ Post-RSA, while in the calves and thighs groups there are not significant differences in either CMJ Pre or CMJ Post RSA. So, in concordance with this results, high thermal asymmetry hamstrings group performed similar to the low asymmetry hamstring group before de RSA, and then decreased it performance in the CMJ Post-RSA. This can be an indicative of fatigue, as a decreased average CMJ jump height can indicate neuromuscular fatigue [37], the reason why only significant differences are found in the high asymmetry hamstring groups (and not in calves and thighs) maybe is because hamstrings are the most implicated and frequently injured group in sprinting [34], while calves and thighs seems to play a less crucial role in sprinting, so it asymmetry takes longer to turn into fatigue when doing an RSA test, as they are less implicated in this activity.

From a practical point of view, if coaches can access to thermographs of their players they should focus specially on hamstrings (over calves and thigs), and modify the training if needed, as thermal asymmetries of this muscles over 0,2 ºC may indicate fatigue, with its consequent increased injury and/or underperformance risk in football players.

Although the results of this study seem to provide evidence in terms of using and interpreting thermography to detect fatigue in football players, the results must be interpreted with caution, as certain limitations should be considered. First, thermography was carried out in just one session, applying thermography in a higher number of sessions would allow us to corroborate the results of the study. Second, the asymmetry cut point was stablished low, settling a higher asymmetry cut point probably would show stronger correlations. And finally, the sample was very low, so future research should be carried out to look for deeply evidence and to check if these results apply to different sex, ages, and competitive levels.

In conclusion, thermography seems to be an useful tool to detect fatigue in elite footballers through thermal asymmetries in the bilateral areas. Hamstrings temperature asymmetries over 0,2 ºC seem to be an indicative of fatigue, while there isn´t evidence that thermal asymmetries over 0,2 ºC in thighs and calves indicate fatigue in male football players. Even thought, more research is needed to deeply link thermal asymmetries with fatigue.

4. Material And Methods

4.1. Experimental Approach to the Problem

This study used repeated measures within participants to determine the relationship between skin temperature and/or thermal asymmetries in the bilateral body areas, CMJ performance and RSA performance. The protocol consisted in a thermography session of the lower limbs (anterior and posterior part) of each player, followed by an standardized warm-up which included 5 min of continuous running, 5 min of joint mobility and two sprints of 30 m with a recovery process of 2 min, and a vertical jump test (CMJ) + Repeated Sprint Ability test (RSA) (6x30 m/20") + vertical jump test (CMJ).

4.2. Participants

20 male football players from a professional team of the Smartbank league (2nd Spanish football Division) (age 28.9 ± 3.9 years; height 178.7 ± 9 cm; body mass 74.8 ± 6.4 kg). Players with recent injuries or pain were excluded, as it could interfere with the results. Each player signed an informed consent with the explanation of the study procedure, as well as the associated risks.

<u>4.3. Ethical Statement</u>

The study was conducted according to the requirements of the Declaration of Helsinki (2013) and was approved and followed the guidelines stated by the Ethics Committee of the European University of Madrid (CIPI35/2019). The research also received formal approval from the professional football club involved.

4.4. Measures

4.4.1. Thermography

The collection of thermography data followed the standards proposed by the European Association of Thermology. Thermograms were evaluated before the protocol and used as a control variable prior to testing. Thermograms were performed in an air-conditioned room, temperature was set at 22ºC (+-1,5ºC) and about 40-60% of relative humidity, recording the skin temperature of the lower limbs at the anterior and posterior part. The camera was placed 3 m away from the participants and in a perpendicular angle respect to them. Players were instructed to keep rest 24 h previous to the thermograms and to avoid behaviours that could interfere with the assessment of thermal images, like drinking alcohol, smoking, or taking caffeine. During testing, participants were dressed in underwear, barefoot and without socks, so selected areas of skin were continuously exposed during exercises and measurements. Following the Thermohuman technology protocol, the body regions of interest (ROI) analyzed included the thighs, calves, and hamstrings [30]. Computerized image analysis allowed the selection of the measurement area in thermograms (See figure 2). These areas were selected by a rectangle delimited by Flir Tools software (FLIR Systems Inc., Wilsonville, OR, USA), which provided the average temperature (Tmean) of each ROI analyzed.

Players were gathered into pairs on subgroups (low [<0,2 ºC] vs high thermal asymmetry [≥0,2 ºC]) based on the results of the thermography session. Previous literature consider that a clinical significant skin temperature asymmetry is that one over 0.5 ºC, but it was decided to stablish the cut point at 0,2 ºC because sample is from a professional club and they were highly supervised, the physical department of the club have the political decision to start following, taking care and monitoring players when they have a ≥0,2 ºC asymmetry. So not many players get to 0,5ºC asymmetry. Therefore, the sample was divided in low and high thermal asymmetry of thighs, hamstrings, and calves

4.4.2. Vertical jump

Players completed 2 CMJ test; 1) after warming up, 2) after the RSA test, with some minutes to recover from it. To measure the height of the jumps an infrared technology was used (Optojump Next, Microgate, Bolzano, Italy). Participants were already familiarized with the movement, and they were instructed to realize it in the more precisely way, keeping their hands on their hips to eliminate the influence of arm movement on jump performance. Each player performed 3 jumps before and after the RSA test (with 2 min of recovery between jumps). The average of the 3 jumps was calculated for statistical analysis.

4.4.3. Repeated Sprint Ability (RSA)

The RSA test included 6 sprints of 30 m with 20 s recovery between sprints. Two pairs of photocells (Witty, Microgate, Bolzano, Italy) placed at 0 and 30 m were used. The following measures were calculated; Sprints Time (RSAt), Best Sprint Time, Average Time, Total Time, percentage difference between the first and rest of sprints during the RSA test -%Diff - [((Sprint Time – First Sprint Time) / First Sprint time) ∗ 100], percentage difference between the best and rest of sprints during the RSA test -%Best- [((Sprint Time - Best Time) / Best Time) ∗ 100]. The previous two sprints performed during warm-up were used as a control measure to ensure that players did the RSA test at maximum speed. If the time of the first RSA test sprint was longer (> 5%) that the best individual sprint performed before the start of the test, the RSA test was not considered valid, and the player had to repeat the test after 5 min of recovery.

4.5. Statistical analysis

Data is presented as means ± standard deviations. The normal distribution of the variables was confirmed by Shapiro–Wilk distribution test. A two-way analysis of variance was performed to analyze the effect of the level of thermal asymmetry on the RSA variables depending on the sprint number (e.g., sprint 1, sprint 2, etc.). Post-hoc pairwise comparisons were performed to compare the RSA variables between the two groups of thermal asymmetries in each of the sprints including the confidence interval (95%). Effect size was calculated for all inference tests using the partial eta squared ($\eta p2$=ES) value with the following interpretation: small (ES = 0.01–0.059); medium (ES = 0.06- 0.14); and large effect (ES > 0.14). The level of significance was set at $p \leq 0.05$ for all the tests and all data was statistically analyzed using SPSS V24.0.

Declarations

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Authors Contribution

All authors participated importantly and collaboratively in this study. C.M. participated in the interpretation of the data and the writing of the paper, J.G.U. realized the analysis and contributed to the data interpretation, A.H.M. contributed taking the data of the study and helping in the writing, J.S.S. participated in the design of the study, L.G.G. revised the study, and finally, J.L.F. contributed to the acquisition of data and interpretation of it.

Competing Interests

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

Data availability statement

All the data of the study can be found in the Supplementary File “SF1. Data of the Study”.

References

1. Rebelo, A., *et al.* Anthropometric characteristics, physical fitness and technical performance of under-19 soccer players by competitive level and field position. Int J Sports Med **34**, 312–317 (2013).
2. Bangsbo, J. The physiology of soccer–with special reference to intense intermittent exercise. Acta Physiol. Scand. Suppl. **619**, 1–155 (1994).
3. Iaia, F.M., Ermanno, R. & Bangsbo, J. High-intensity training in football. Int J Sports Physiol Perform. **4**, 291–306 (2009).
4. Hägglund, M., Waldén, M. & Ekstrand, J. Risk factors for lower extremity muscle injury in professional soccer: the UEFA Injury Study. Am J Sports Med. **41**, 327–335 (2013).
5. Ekstrand, J., Hägglund, M. & Waldén, M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med. **39**, 1226–1232 (2011).
6. Ekstrand, J. Epidemiology of football injuries. Science & sports **23**, 73–77 (2008).
7. Mohr, M., *et al.* Return to elite football after the COVID-19 lockdown. Manag. Sport Leis. 1–9 (2020).
8. Gabbett, T.J. & Jenkins, D.G. Relationship between training load and injury in professional rugby league players. J Sci Med Sport. **14**, 204–209 (2011).

9. Watkins, C.M., *et al.* Determination of vertical jump as a measure of neuromuscular readiness and fatigue. J. Strength Cond. Res. **31**, 3305–3310 (2017).
10. Alexiou, H. & Coutts, A.J. A comparison of methods used for quantifying internal training load in women soccer players. Int J Sports Physiol Perform. **3**, 320–330 (2008).
11. Buchheit, M., *et al.* Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. J Sci Med Sport. **16**, 550–555 (2013).
12. Impellizzeri, F.M., Rampinini, E., Coutts, A.J., Sassi, A. & Marcora, S.M. Use of RPE-based training load in soccer. Med Sci Sports Exerc. **36**, 1042–1047 (2004).
13. Sanchez-Medina, L. & González-Badillo, J.J. Velocity loss as an indicator of neuromuscular fatigue during resistance training. Med. Sci. Sports Exerc. **43**, 1725–1734 (2011).
14. Gandevia, S.C. Spinal and supraspinal factors in human muscle fatigue. Physiol. Rev. (2001).
15. Barbero-Álvarez, J.C., Coutts, A., Granda, J., Barbero-Álvarez, V. & Castagna, C. The validity and reliability of a global positioning satellite system device to assess speed and repeated sprint ability (RSA) in athletes. J Sci Med Sport. **13**, 232–235 (2010).
16. Rampinini, E., *et al.* Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. Int. J. Sports Med. **28**, 228–235 (2007).
17. Turner, A.N. & Stewart, P.F. Repeat sprint ability. Strength Cond J. **35**, 37–41 (2013).
18. Morcillo, J.A., *et al.* Relationships between repeated sprint ability, mechanical parameters, and blood metabolites in professional soccer players. J. Strength Cond. Res. **29**, 1673–1682 (2015).
19. Balsalobre-Fernández, C., Tejero-González, C.M. & del Campo-Vecino, J. Relationships between training load, salivary cortisol responses and performance during season training in middle and long distance runners. PloS one **9**, e106066 (2014).
20. Cormie, P., McBride, J.M. & McCaulley, G.O. Power-time, force-time, and velocity-time curve analysis of the countermovement jump: impact of training. J. Strength Cond. Res. **23**, 177–186 (2009).
21. Taylor, K., Chapman, D., Cronin, J., Newton, M.J. & Gill, N. Fatigue monitoring in high performance sport: a survey of current trends. J Aust Strength Cond **20**, 12–23 (2012).
22. Morin, J.-B., Dupuy, J. & Samozino, P. Performance and fatigue during repeated sprints: what is the appropriate sprint dose? J. Strength Cond. Res. **25**, 1918–1924 (2011).
23. Gathercole, R., Sporer, B., Stellingwerff, T. & Sleivert, G. Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. Int J Sports Physiol Perform. **10**, 84–92 (2015).
24. Hildebrandt, C., Zeilberger, K., Ring, E.F.J. & Raschner, C. The application of medical infrared thermography in sports medicine. An international perspective on topics in sports medicine and sports injury **534**(2012).
25. Kenny, G.P. & Jay, O. Sex differences in postexercise esophageal and muscle tissue temperature response. Am. J. Physiol. Regul. Integr. Comp. Physiol. **292**, R1632-R1640 (2007).
26. Alfieri, F.M. & Battistella, L.R. Body temperature of healthy men evaluated by thermography: a study of reproducibility. Technol Health Care. **26**, 559–564 (2018).

27. Gómez-Carmona, P., Fernández-Cuevas, I., Sillero-Quintana, M., Arnaiz-Lastras, J. & Navandar, A. Infrared thermography protocol on reducing the incidence of soccer injuries. J. Sport Rehabil. **29**, 1222–1227 (2020).
28. Zhang, S., Zhu, N. & Lu, S. Responses of human perception and skin temperature to directed thermal radiation in hot environments. Build Environ. **197**, 107857 (2021).
29. Fernández-Cuevas, I., *et al.* Classification of factors influencing the use of infrared thermography in humans: A review. Infrared Phys. Technol. **71**, 28–55 (2015).
30. Fernández-Cuevas, I., Lastras, J.A., Galindo, V.E. & Carmona, P.G. Infrared thermography for the detection of injury in sports medicine. in *Application of infrared thermography in sports science* 81–109 (Springer, 2017).
31. Barcelos, E.Z., Caminhas, W.M., Ribeiro, E., Pimenta, E.M. & Palhares, R.M. A combined method for segmentation and registration for an advanced and progressive evaluation of thermal images. Sensors **14**, 21950–21967 (2014).
32. Costello, J., Selfe, J., Donnelly, A.E., Karki, A.I. & Stewart, I.B. Use of thermal imaging in sports medicine research: a short report: short article. Int. J. Sports Med. **14**, 94–98 (2013).
33. Côrte, A.C., *et al.* Infrared thermography study as a complementary method of screening and prevention of muscle injuries: pilot study. BMJ Open Sport Exerc. **5**, e000431 (2019).
34. Howard, R.M., Conway, R. & Harrison, A.J. Muscle activity in sprinting: a review. Sports Biomech. **17**, 1–17 (2018).
35. Chumanov, E.S., Heiderscheit, B.C. & Thelen, D.G. The effect of speed and influence of individual muscles on hamstring mechanics during the swing phase of sprinting. J. Biomech. **40**, 3555–3562 (2007).
36. Colino, E., *et al.* Mechanical properties of treadmill surfaces compared to other overground sport surfaces. Sensors **20**, 3822 (2020).
37. Claudino, J.G., *et al.* The countermovement jump to monitor neuromuscular status: A meta-analysis. J Sci Med Sport. **20**, 397–402 (2017).

Figures

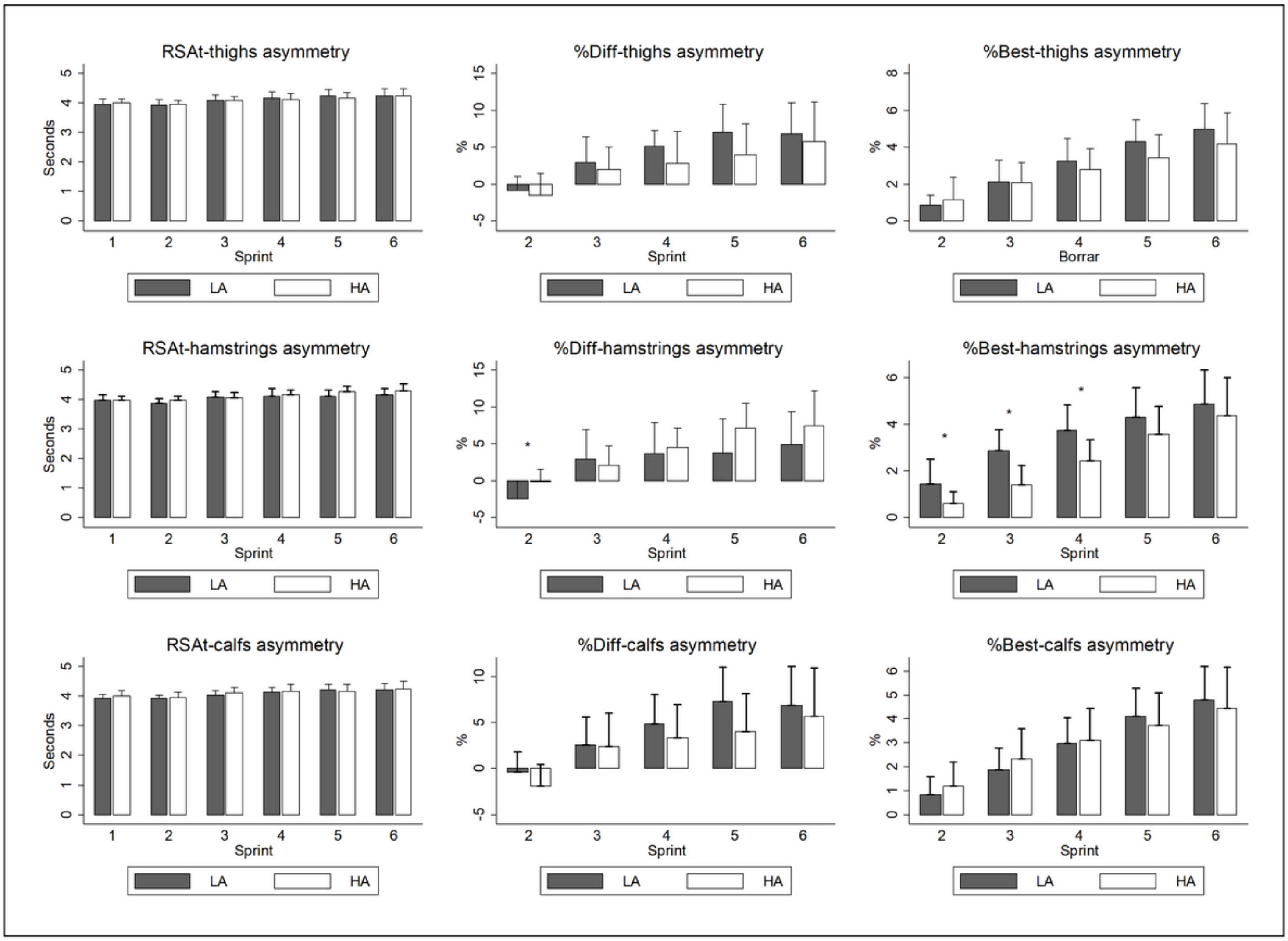

Figure 1

shows the results in the RSA variables (RSAt, %Diff, and %Best) based on thermal asymmetry clusters (group with low asymmetry and group with high asymmetry in each of the three muscle groups). Thighs and calves asymmetry did not show a significant effect in any variable (p>0.050). No significant interaction was also found between thighs and calves asymmetry and the number of sprint (p>0.050). Hamstrings asymmetry did not show a significant effect in RSA and %Diff (p>0.050), but yes in %Best (F=6.59; p=0.018; ES=0.25). Furthermore, a significant interaction was found between hamstrings asymmetry and the sprint number in RSAt (F=2.42; p=0.041; ES=0.11), and in %Diff (F=2.50; p=0.049; ES=0.11), but not in % Best (p>0.050). About pair-wise comparison, hamstring high asymmetry group showed higher %Diff in sprint 2 (F=7.40; p=0.013; IC: -4.20 to -0.55; ES=0.27) and there was also found higher %Best in hamstring low asymmetry group in sprint 2 (F=5.76; p=0.026; IC: 0.11 to 1.55; ES=0.22), 3 (F=15.59; p=0.001; IC: -1.55 to -0.11; ES=0.44) and 4 (F=9.36; p=0.006; IC: 0.67 to 2.22; ES=0.32).

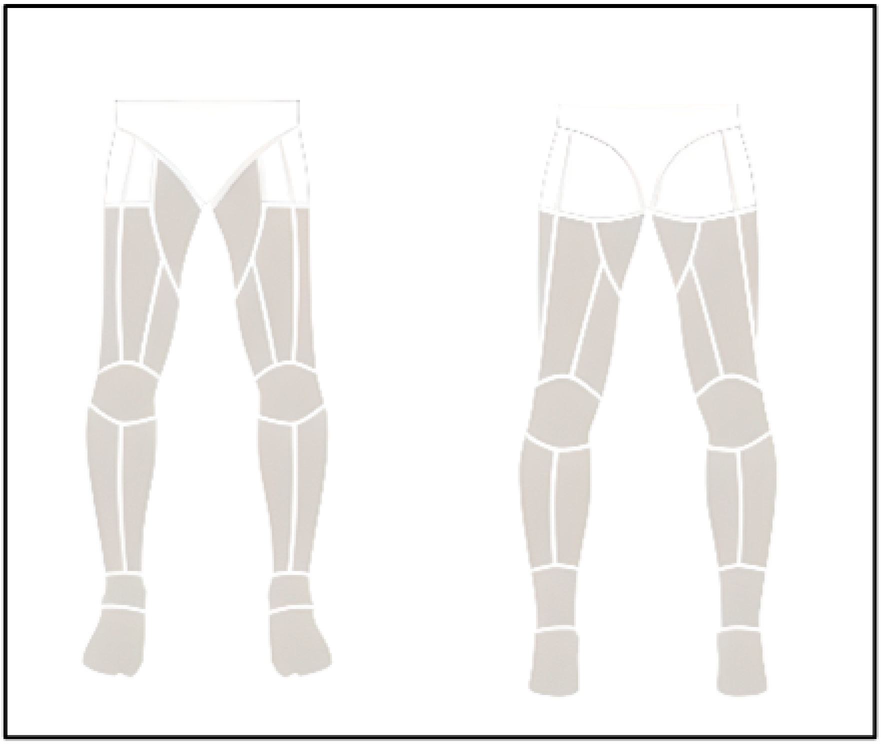

Figure 2

Measurements areas provided by Thermohuman Software (Anterior and Posterior part)

Players were gathered into pairs on subgroups (low [<0,2 ºC] vs high thermal asymmetry [≥0,2 ºC]) based on the results of the thermography session. Previous literature consider that a clinical significant skin temperature asymmetry is that one over 0.5 ºC, but it was decided to stablish the cut point at 0,2 ºC because sample is from a professional club and they were highly supervised, the physical department of the club have the political decision to start following, taking care and monitoring players when they have a ≥0,2 ºC asymmetry. So not many players get to 0,5ºC asymmetry. Therefore, the sample was divided in low and high thermal asymmetry of thighs, hamstrings, and calves

Supplementary Files

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- SF1.DataoftheStudy.xls