POLITÉCNICA

Trabajo para la obtención del Título de Doctor en
Ciencias de la Actividad Física y del Deporte

**“MONITORING THE ACUTE EFFECTS OF
RECOVERY, TRAINING AND
COMPETITION ON FOOTBALL PLAYER’S
SKIN TEMPERATURE WITH INFRARED
THERMOGRAPHY”**

Autor: Francisco Javier Arnaiz Lastras (Máster en Ciencias de la Actividad Física y del Deporte).

Dirigido por: Manuel Sillero Quintana (Doctor en Ciencias de la Actividad Física y del Deporte).

Departamento de Deportes de la Facultad de Ciencias de la Actividad Física y del Deporte (INEF). Universidad Politécnica de Madrid.

Madrid, [2017]

AGRADECIMIENTOS / ACKNOWLEDGEMENTS

Me resulta fácil acordarme de todas aquellas personas que han pasado por mi vida y me han ayudado habiéndome influido de manera positiva. Lo difícil, hacerlo en una cantidad limitada de páginas. Lo imposible, agradecerlos con las palabras apropiadas para sentirme tranquilo por haberos honrado, aun así, os quisiera dedicar unas líneas desde mi sinceridad más profunda.

Probablemente no estaría realizando esta tesis si durante mi infancia no hubiese asistido al Colegio Público Nuestra Señora de La Paloma en el castizo barrio madrileño de La Latina. De este pequeño lugar en pleno centro de Madrid guardo mis mejores recuerdos y los primeros indicios de que esto del deporte iba para algo muy serio para mí. Seguramente la “culpa” sea de Dori, mi profesora de la asignatura Educación Física. Aún soy capaz de rememorar las clases de última hora de la tarde en la que junto a mis compañeros de la letra B (Samu, Pedro, Kike, Alfredo, Pedrito) y de la A (Jorge) no queríamos salir del colegio para seguir con los juegos de nuestra profesora preferida. Lo mejor de todo es que después de Educación Física venían los partidos de fútbol en la Plaza de los Carros, dónde dos árboles conformaban una portería y una chaqueta o una mochila junto a una papelería hacían la otra. Después de partidos de 2 horas sin descanso venía la hora de entrenar en las mismas canchas del colegio, donde nuestro conserje llevaba el equipo de fútbol sala de La Paloma y del que me hizo parte de él aun siendo 2 años menor que todos los jugadores (Yasine, Kiko, Yeray, Alex, Manuel, Adrián, Boris, Yuris...). Sin duda alguna, sin estas dos personas del colegio el deporte para mí no hubiese significado lo mismo y tampoco sin mis equipos Paideia, Racing Retiro, Rayo Majadahonda y Galácticos de Lavapiés (Ibra, Amine, Moha, Elmir, Edu, Gabi, Óscar...).

Después en el Instituto Público Cervantes del barrio Embajadores (Madrid) también tuve la suerte de tener a dos personas que me enseñaron a tener carácter al salir a la pizarra y no intimidarme al hablar (el profesor de Lengua y Literatura de 1º y 2º de ESO) y a realizar las tareas de manera profesional, pulcra y directa (Santiago de Tecnología Industrial). Dos características que creo que ellos fueron capaces de activar cuando aún era un adolescente y que, de no haber hecho click en mí, quizás no estaría leyendo esto.

Todo esto me llevo a estudiar Ciencias de la Actividad Física y del Deporte en el INEF de Madrid, igual que los Últimos de Filipinas nosotros fuimos los Últimos Licenciados, los dinosaurios, los casi extintos. Las pruebas no las podría haber pasado sin la desinteresada ayuda de un amigo, casi familia, como Sergio Acuña, mi entrenador en el Basic (el equipo del Retiro en el que jugaba al fútbol 7 cuando tenía 12 años) y que posteriormente acabaría INEF años antes que yo... él fue otro de los “culpables” de que me dedicase a la preparación física al invitarme a trabajar con el en el club Alcobendas Sport durante mi primer año de universidad.

Una mención a todos mis amigos de INEF de los que guardo mil buenos recuerdos imborrables y que aún hoy seguimos viéndonos en cuanto tenemos oportunidad para rememorar nuestras andanzas en la calle Martín Fierro: Adrián Castillo, Arturo de Blas, Álvaro Blázquez, Carlos Aneiros, Cristina Arranz, David Castillo, Diego Antoranz, Pablo Abadía, Sara Cano, Nacho Camacho y otros tantos compañeros con los que compartí asignaturas y que no entrarían todos los nombres ni en la bibliografía de esta tesis.

De todos los profesores que he tenido y he apreciado siempre me acordaré de César Hernández (voleibol), Miguel Ángel Ruano (metodología), Pedro J. Benito (musculación), Fátima (sistemática), Javier Calderón (fisiología). Pero principalmente guardaré en mi corazón al único que no me dio clase durante la carrera. Al único que se ha convertido en un amigo, una persona especial que mirando en lo más profundo de él sólo encontrarás bondad, trabajo y humildad, Manuel Sillero Quintana.

Gracias a la flexibilidad del Laboratorio de Análisis de la Actividad Física comandado por Manolo, a su iniciativa y al ser impulsor de ideas tan locas como esa de utilizar cámaras termográficas en humanos para ver la posibilidad de lesión de un atleta, ha sido capaz de iniciar el proyecto tecnológico más prometedor del INEF inicialmente llamado PEMAGROUP y ahora THERMOHUMAN, para cambiar en nuestra Facultad el paradigma y la relación empresa-universidad al ser los pioneros en formar un equipo que quedase finalista del programa de creación de empresas ActúaUPM comandado por Arístides Senra. Sin esto no hubiese sido posible conocer a las personas más increíbles que me han acompañado en los últimos 10 años de mi vida y que ya considero mi familia como son Ismael Fernández Cuevas y Pedro Gómez Carmona. La termografía infrarroja me ha permitido personalmente vivir experiencias como dar clase en el campo de entrenamiento de Valdebebas al Cuerpo Técnico del Real Madrid, apoyar a la Selección de España de Fútbol y Baloncesto a ganar el Mundial de Sudáfrica 2010 y la Eurocopa de Baloncesto de 2015, formar a personas de equipo de baseball estadounidense profesional de MLB como Houston Astros, visitar y compartir experiencias con profesionales de la NFL, NBA e instituciones y selecciones nacionales de todo el mundo. Esto ha posibilitado compartir grandes momentos con otros amigos y profesionales de mi ámbito como Miguel Ángel García de la Concepción, Javier Butragueño, Blanca Romero, César Bustos, Lena Grams, Sergio Piñonosa, Carlos Martínez, David Mahamud, Esther Morencos, Rocío Cupeiro, Carlos Jesús López Díaz, Ciro Brito, Danilo Gomes Moreira, João Carlos Bouzas Marins, Altamiro Bottino y Miguel Ángel Rojo.

También a todas las personas increíbles que he conocido en mi última etapa en México, desde el staff de la selección de baloncesto (Sergio Valdeolmillos, Ramón Díaz, Cindy Bernal, Alberto Alcocer, Jhony Villegas, Felipe Becerra, Saúl Torres, Manuel Mújica y Alejandra Romo) con el que recientemente conseguimos el Bronce en el FIBA Americup 2017 así como los jugadores de la selección, en especial a Jorge Gutiérrez y Pery Meza, los cuales confiaron en mi trabajo para ser preparador físico de la Selección de México de Baloncesto. A todos los atletas que he podido ayudar y que siento que me han ayudado más ellos a mí que al revés, de prácticamente todos los deportes del Centro Nacional de Alto Rendimiento de Ciudad de México como esgrima (Nataly Michel, Julián Ayala, Erick Trujillo, Leticia Rebolledo, Josué Morales y Mauricio Lara), lucha libre (Alejandra Romero), Triatlón (Edson Gómez y Eduardo Moreno), Judo (Gilberto Cardoso, Gibrán Torres y Naím Roldán) y mis favoritas de Nado Sincronizado, desde la entrenadora Adriana Loftus y su equipo de trabajo (Ofelia Pedrero, Alberto, Gaby y Héctor) así como todas las atletas que han pasado: Regina Alferez, Karem Achach, Jessy Sobrino, Joana Betzabé, Wendy Mayor, Sami Rodríguez, Sami Flores, Erandi Aguirre, Pamela Toscano, Glenda Inzunza, Ale Moguel, Amaya Velázquez, Teresa García, Karen Soto, Madison López y por último a una persona brillante por dentro y por fuera, Nuria Diosdado.

Me gustaría agradecer también a la persona que me acompañó durante los últimos 9 años de mi vida hasta el pasado marzo, Cristina Mena Jiménez y toda su familia (Dani, Vicen y Mari) de la que sólo guardo buenos momentos, apoyo y cariño.

Gracias a toda mi familia empezando por los patriarcas y matriarcas de los Lastras (abuela Tina y abuelo Leoncio) y los Arnaiz (abuelo Curro D.E.P. y abuela Tere) así como todos mis tíos, en especial a Jesús (mi segundo padre) e Isabel junto a mis primos David y Raquel (mi madrina y segunda madre) con sus parejas Alicia y Raúl. Además de mi tía Puri y tío Fernando con mis primos que los consideraré siempre hermanos como Nandi y Javi por haber estado en el momento más difícil de mi vida y acogerme en Vellisca (Cuenca) como si fuese mi casa. También a mi tía Vero y mi tío Ignacio por ser siempre una alegría saber de vosotros, así como a Dolores, Gonzalo y Tere. Gracias a mi gata Michu (también llamada Mitsubishi, Muchobicho o Michurra), aunque no entienda lo que escribo es una personilla que nos da paz y alegría cada día que la vemos.

Gracias Papá por haberme apoyado al estudiar INEF, por esa forma de ser tan desinteresada en todo y que hace que tenga la sensación de libertad de poder hacer lo que quiera sin tener ese arraigo mental a nada ni nadie, evitando sentirme mal por tomar decisiones en mi vida. Aún recuerdo los días que venías desde Ceuta sólo para pasar el fin de semana con nosotros aprovechando a verme jugar al fútbol. Para mí es un recuerdo imborrable el levantar la cabeza y verte sentado en las gradas animándome junto a Mamá y Julia. De ti he aprendido a amar mi trabajo y trabajar para el ciudadano, nuestro deber es ayudar a las personas, tú desde la arquitectura y yo desde la preparación física para hacer sentir al atleta que está un paso más cerca de su victoria.

Por último, agradecer a mis dos Julias, mis ángeles que me cuidan a diario. De mi hermana Julia, me acompañó desde 1991 hasta que falleció en 2005 habiendo nacido con Atrofia de Muscular Espinal (síndrome de Werdnig-Hoffman) me enseñó a sonreír a la vida a pesar de tener una enfermedad rara incurable. Recuerdo cuando durante los Reyes Magos le dije a mi madre que quería que Julia caminase, que no quería que fuese en silla de ruedas. A lo que antes de que me respondiera, mi hermana, con una sonrisa en la cara dijo que no quería andar, que con su silla era feliz porque podía ir a todas partes. Ahí me di cuenta de que ella era más realista que nadie, sabía que no podría caminar y aun habiendo pasado la mitad de su vida en una silla de ruedas, la aparición de una silla de ruedas eléctrica que la permitía poder moverse donde quisiera de la casa fue un salto cualitativo en su vida con el que se sentía realizada. Sigo acordándome de su cara de felicidad cuando movió el joystick y la silla se desplazó por primera vez, también recuerdo los jarrones rotos por jugar al fútbol y echarle la culpa a ella diciendo que la golpeó con la silla de ruedas, las regañinas cada vez que me pasaba por encima del pie y los tirones de moflete que le daba cuando me enfadaba. Sin duda un ángel que cayó en un cuerpo delicado pero que enseñó a vivir a todas las personas que pasaron por su lado porque en esa persona no existía la maldad, fue y será la viva representación de la bondad y el amor sobre toda la tierra.

Mamá, fuiste una guerrera toda su vida, creo que en otra vida debiste ser espartana. Sacaste adelante a tu hija mientras que vivió, infatigable trabajadora que aún sin dormir una noche completa durante los 13 años de vida de Julita, fuiste capaz de criarme con unos valores de honestidad, nobleza y trabajo que serán imborrables en mí. Superaste un cáncer de mama, te recuperaste, rehiciste tu vida y por unos u otros motivos una metástasis ósea pudo con tu cuerpo, pero no con tu mente. Gracias Mamá por cuidarme en tu vientre, por darme una infancia y adolescencia sanas a pesar de la situación tan extraordinaria que vivimos en casa. Nuestros paseos por la playa de La Ribera en Ceuta hablando sobre el futuro finalmente se han hecho realidad, te dije que terminaría la tesis y que acabaría entrenando al más alto nivel, espero que estés orgullosa de lo que he conseguido y lo que conseguiré. Ojalá me puedas seguir cuidando desde el cielo junto a Julia y os pueda ver pronto.

INDEX OF ABBREVIATUES.

AR = Active Recovery
CK = Creatine Kinase
CMJ = Counter Movement Jump
COD = Change of Direction
CoolPower = Cooling power
CR10 = Category ratio scale
CR10-F = Perception of general fatigue
CR10-F% = Relative decrement of general fatigue perception
CR10-MS = Perception of muscle soreness
CR10-MS% = Relative decrement of muscle soreness perception
CRP = C-reactive protein
CWI = Cold-water immersion
CWT = Contrast-water therapy
D =Dominant
DOMS = Delayed-onset muscle soreness
DR = Dominant region
EMG = Electromyography
FMS = Functional Movement Screen
GPS = Global Positioning System
HIIT = High Intensity Interval Training
HR = Heart Rate
HRT = Heart Rate Variability
IL = Interleukin
IRT = Infrared Thermography
L = Left
LDH = Lactate dehydrogenase
ND = Non-dominant
PR = Posterior region
R = Right
RAA= Repeated Acceleration Ability
ROI = Region of interest
ROM = Range of Motion

RPE = Ratings of Perceived Exertion
RPA = Repeated Power Ability
RSA = Repeated Sprint Ability
RST = Repeated Sprint Training
SD = Standard deviation
SIT = Sprint Interval Training
TMG = Tensiomyography
TRIMP = Training Impulse
Tsk = Skin Temperature
TskAsy = Skin Temperature Asymmetry
TWI = Thermoneutral-water immersion
UPM = Technical University of Madrid
V02max = Maximal Oxygen Consumption
WBC = Whole Body Cryotherapy

INDEX OF CONTENTS

	Page Number
1. INTRODUCTION	
1.1. INFRARED THERMOGRAPHY	3
1.1.1. HISTORY OF INFRARED THERMOGRAPHY	3
1.1.2. BASIC CONCEPTS OF THERMOLOGY	5
1.1.2.1. Thermal energy, heat and temperature	5
1.1.2.2. Human thermoregulation	6
1.1.2.2.1. Human body mechanisms for heat exchange interaction	8
1.1.2.2.2. Laws of thermodynamics	10
1.1.3 APPLICATIONS OF INFRARED THERMOGRAPHY	10
1.1.4 INFLUENCE FACTORS OF INFRARED THERMOGRAPHY ON HUMANS	12
1.1.5 THERMOREGULATION DURING EXERCISE	13
1.1.6 THERMOREGULATION DURING CRYOTHERAPY	17
1.2. FOOTBALL	19
1.2.1. PHYSICAL DEMANDS	19
1.2.1.1 Activity profile	20
1.2.1.2 Positional demands	21
1.2.1.3 Playing level	21
1.2.1.4 Congested calendar	22
1.2.1.5 Contextual factors	23
1.2.1.6 Fatigue during and after games	23
1.2.1.7 Emerging required abilities RSA, RPA & RAA	25
1.2.2 EPIDEMIOLOGY OF INJURIES	26
1.2.3 TRAINING METHODS	27
1.2.3.1 Generic	28
1.2.3.1.1 High-Intensity Interval Training (HIIT)	28
1.2.3.1.2 Repeated Sprint Training (RST)	29
1.2.3.1.3 Sprint Interval Training (SIT)	29
1.2.3.2 Specific	30
1.2.4 TRAINING LOAD MONITORING	30
1.2.4.1 Internal load	31
1.2.4.1.1 Heart Rate (HR)	31

1.2.4.1.2 Training Impulse (TRIMPs).....	32
1.2.4.1.3 Heart Rate Variability (HRV)	33
1.2.4.1.4 Ratings of Perceived Exertion (RPE).....	34
1.2.4.1.5 Questionnaires	35
1.2.4.1.6 Biomarkers	35
1.2.4.2 External load	37
1.2.4.2.1 Global Positioning Systems (GPS)	37
1.2.4.2.2 Accelerometers.....	38
1.2.5 RECOVERY STRATEGIES	38
1.2.5.1 Cryotherapy.....	39
1.2.5.2 Stretching	40
1.2.5.3 Sleep.....	40
1.2.5.4 Nutrition & hydration.....	41
1.2.5.5 Electrical stimulation.....	42
1.2.5.6 Massage & myofascial release	43
1.2.5.7 Active recovery	44
1.2.5.8 Compression garments	44
1.2.5.9 Led therapy.....	45
1.2.6 TESTING ASYMMETRIES.....	46
1.2.6.1 Thermal asymmetries	47
1.2.6.2 Strength asymmetries	50
1.2.6.3 Range of motion asymmetries.....	52
1.2.6.4 Functional movement asymmetries.....	54
1.3 JUSTIFICATION OF THE WORK.....	55
2. HYPHOTHESIS AND OBJECTIVES OF THE STUDY	57
2.1. HYPHOTHESIS	57
2.2. OBJECTIVES	57
2.1.1 PRIMARY OBJECTIVES	57
2.1.2 SECONDARY OBJECTIVES	57
3. METHODOLOGY.....	58
3.1. COLD-WATER IMMERSION STUDY	59
3.1.1 STUDY SAMPLE.....	59
3.1.2 STUDY DESIGN.....	60
3.1.3 PROCEDURE.....	60
3.1.4 VARIABLES	61

3.1.5 STATISTICAL ANALYSIS	63
3.2. HIGH-INTENSITY INTERVAL TRAINING STUDY.....	64
3.2.1 STUDY SAMPLE	64
3.2.2 STUDY DESIGN	64
3.2.3 PROCEDURE.....	64
3.2.4 VARIABLES	66
3.2.5 STATISTICAL ANALYSIS	67
3.3. MATCH STUDY	68
3.3.1 STUDY SAMPLE	68
3.3.2 STUDY DESIGN	68
3.3.3 PROCEDURE.....	68
3.3.4 VARIABLES	69
3.3.5 STATISTICAL ANALYSIS	70
4. RESULTS	71
4.1. COLD-WATER IMMERSION STUDY	71
4.1.1 DOMINANCE VS LATERALITY: ABSOLUTE TSK ANALYSIS.....	71
4.1.2 DOMINANCE VS LATERALITY: COOLING AND REWARMING PROCESSES	72
4.2. HIGH-INTENSITY INTERVAL TRAINING STUDY.....	74
4.2.1 RIGHT-LEFT ABSOLUTE TSK CHANGE ANALYSIS	74
4.2.2 TSK ASYMMETRIES ANALYSIS	77
4.2.3 SUBJECTIVE MEASUREMENTS OF FATIGUE	79
4.3. MATCH STUDY	79
4.3.1 RIGHT-LEFT ABSOLUTE TSK ANALYSIS	79
4.3.2 RIGHT-LEFT TSK ASYMMETRIES ANALYSIS	80
5. DISCUSSION	83
5.1. COLD-WATER IMMERSION STUDY	83
5.1.1 ACUTE SKIN TEMPERATURE DECREMENT	83
5.1.2 REWARMING PROCESS	84
5.1.3 THERMAL REWARMING IMBALANCES IN FOOTBALL.....	85
5.2. HIGH-INTENSITY INTERVAL TRAINING STUDY	87
5.3. MATCH STUDY	93
5.4. PRACTICAL APPLICATIONS.....	94
6. CONCLUSIONS	97
6.1. CONCLUSIONS OF 1 ST MAIN OBJECTIVE	97

6.2. CONCLUSIONS OF 2 ND MAIN OBJECTIVE	97
6.3. CONCLUSIONS OF 3 RD MAIN OBJECTIVE	98
7. LIMITATIONS OF THE WORK	99
8. FUTURE RESEARCH LINES	101
9. REFERENCES.....	103

INDEX OF TABLES AND FIGURES

	Page Number
Table 1. Applications of IRT on sports.	11
Table 2. Applications of IRT on health.	11
Table 3. Estimated heat loss during rest and prolonged exercises (Adapted from Wilmore & Costill, 2010).	13
Table 4. Tsk responses to exercise before (BE), during (DE), immediately after (IAE) and some minutes after exercise using IRT. AMBTEM (Ambient Temperature) (Adapted from Fernández-Cuevas, 2012).	16
Table 5. Injury incidence during competition in Spanish Football First Division (Noya, 2014).	27
Table 6. Normal Tsk Asymmetries depending on type of subject and ROI. Reproduced from (Fernández-Cuevas et al., 2015b)	49
Table 7. Attention level in regards of Tsk asymmetry (Marins, 2015).	49
Table 8. Descriptive data of the sample from the CWI study.	60
Table 9. Characterization of the variables for each HIIT protocol.	65
Table 10. Environmental conditions for data collection (room and football field).	69
Table 11. Absolute Skin temperature filtered by Dominance. Differences between D – ND sides * ($p < 0.05$).	72
Table 12. Absolute Skin temperature filtered by Laterality. Difference between R-L sides * ($p < 0.05$).	72
Table 13. Increase in Skin Temperature (ΔT_{sk} in $^{\circ}C$) by Dominance at Cooling, Rew10, Rew15, Rew20 and Rewarming. Differences between D-ND sides: * ($p < 0.05$). & ($p = 0,087$).	73
Table 14. Increase in Skin Temperature (ΔT_{sk} in $^{\circ}C$) by Laterality at Cooling, Rew10, Rew15, Rew20 and Rewarming. Differences between right (R) and left (L) sides * ($p < 0.05$).	73
Table 15. Average skin temperatures and statistic data for right and left ROIs in E-1 training protocol. Δ = Pre-Post. Grey background indicates significant differences $p < 0.05$	75
Table 16. Average skin temperatures and statistic data for right and left ROIs in E-2 training protocol. Δ = Pre-Post. Grey background indicates significant differences $p < 0.05$	76
Table 17. Average skin temperatures and statistic data for right and left ROIs in E-3 training protocol. Δ = Pre-Post. Grey background indicates significant differences $p < 0.05$	76
Table 18. Average skin temperatures and statistic data for right and left ROIs in E-4 training protocol. Δ = Pre-Post. Grey background indicates significant differences $p < 0.05$	76

Table 19. Results depending on the HIIT protocol. Tsk asymmetries between Right and Left limbs before the training (PRE) and immediately after the training (POST). N= number of subjects; Δ = POST-PRE; * significant differences between R-L ROIs ($p<0.05$); **= significant difference between POST-PRE.	78
Table 20. Descriptive measurements of RPE for each HIIT protocol. ⁰ Significant differences between Pre and Post. Significant differences with E-1 ⁽¹⁾ , E-2 ⁽²⁾ , E-3 ⁽³⁾ or E-4 ⁽⁴⁾	79
Table 21. Results depending on the group. Tsk between Right and Left ROIs before the match (PRE) and immediately after the match (POST). N= number of subjects; Δ = POST-PRE; * significant differences between Right-Left ROIs ($p<0.05$); **= significant difference between POST-PRE.	81
Table 22. Results depending on the group. Tsk asymmetries (Right-Left) before the match (PRE) and immediately after the match (POST). N= number of subjects; Δ = POST-PRE; * = significant difference between POST-PRE.	82
Figure 1. Dynamic bodily heat balance from (Jones and Plassmann, 2002).....	8
Figure 2. Human body mechanisms for heat exchange interaction	9
Figure 3. IRT influence factors classification on humans. Reproduced with permission from (Fernández-Cuevas et al., 2015b).	12
Figure 4. Anterior (left) and posterior (right) views of a judo athlete characterized by a thermal asymmetry in favor of the right grasping forearm (Arnaiz-Lastras, 2011).	50
Figure 5. Joint by joint Gray Cook's approach (Cook, 2010).	53
Figure 6. Protocol description. Official football match followed by 36 hours of rest. Pre IRT, CWI, Post IRT and Post10, Post15 and Post20 IRT screenings.	60
Figure 7. ROI division for anterior view.	62
Figure 8. ROI division for posterior view.	62
Figure 9. ROI division for the anterior (left picture) and posterior (right picture) views. Dark zones were not considered into data analysis.	66
Figure 10. ROI division for the anterior (left picture) and posterior (right picture) views. Dark zones were not considered into data analysis.	70
Figure 11. Effects of the different HIIT protocols on lower limb Tsk. Triangles indicate significant differences Pre-Post, blue corresponds with Tsk decrements and red with Tsk increments.	75
Figure 12. Lines connecting Tsk significant differences to overview the thermal tendencies of ROIs with crossing-patterns (E-3 posterior) or unilateral-patterns predominance (E-2 and E-4).	91

ABSTRACT

Introduction: Cold-water immersion (CWI) is one of the most frequently used recovery protocols in sports. Infrared thermography (IRT) can be used to identify and quantify thermal abnormalities in skin temperature (Tsk) and therefore to prevent injuries. The objective of the first study was to understand the thermal acute response of professional football players to CWI measured 36h after a football match. IRT could be applied to know the thermal impact of training on each region of interest (ROI) of the human body. High-Intensity Interval Training (HIIT) is one of the most efficient methods for improving performance in team sports and has different neuromuscular implications depending on the type, duration and intensity of each protocol. The objective of the second study was to determine the acute thermal response of 4 protocols of HIIT on the lower limb Tsk in youth football players. Several studies used IRT for understanding how the training load impacts on each ROI of the human body. No studies tried to understand how the human body react to a football game. The objective of the third study was to determine the acute thermal response of football players after a 80 minutes game.

Methods: For the first study 9 professional Brazilian football players (age 28.3 ± 5.1 years, $8.9 \pm 3.9\%$ fat mass) followed a CWI protocol (10 minutes of lower limb immersion at 3°C) with 36 hours of full rest after playing a regular league match. The Tsk of selected regions of interest (ROIs) were registered before (Pre), immediately after (Post), and at 10 (Post10), 15 (Post15) and 20 (Post20) minutes after the CWI protocol. ΔTsk were obtained to measure the cooling and rewarming processes of the ROIs from Pre to Post (Cooling), Post to Post10 (Rew10), Post15 (Rew15) and Post20 (Rew20). In the second study, 37 youth football players for the U-16 1st division of Spain (15.6 ± 0.3 years, 1.74 ± 0.1 meters and 63.4 ± 6.7 kg) randomly followed 4 different HIIT training protocols at the same time after a standardized warm-up: HIIT 1 (n=10): Short Intervals. 6 sets of 30'' running bouts with 30'' of passive rest between sets. HIIT 2 (n=9): Sprint Interval Training. 6 sets of 30'' running bouts with 120'' of passive rest between sets. HIIT 3 (n=8): Repeated Sprint Sequences. 3 sets of 6 sprints of 40m (20m + 180° change of direction + 20m) with 10'' passive rest between sprint and 6' of passive rest between sets. HIIT 4 (n=10): Long Interval. 6 sets of 3' of work and 1' passive rest between sets.

Tsk of the lower limb was measured before and after the training to establish which of the 18 ROIs had significant Tsk differences after HIIT. Finally, for the third study 21 players (15.7 ± 0.4 years, 1.74 ± 0.1 meters and 63.7 ± 6.3 kg) from a Spanish 1st Division U-16 team which plays in the highest U-16 division in Madrid area were divided in 3 groups. Group 1 (n=7) played the whole match since the beginning, Group 2 (n=8) played, but not the whole match and Group 3 (n=6) did not play. Football players were measured before and after the game to evaluate the Tsk response.

Results: The evolution of Tsk after CWI in the first study differed depending on the ROIs. The Tsk decrement after CWI (Cooling) for ROIs was between 12-13°C and could reduce Tsk by 39.7%. Rewarming of the posterior thigh was greater on the dominant side at Rew10 (6.2°C vs. 5.8°C; $p < 0.05$) and Rew20 (8.3°C vs. 8.0°C; $p < 0.05$). On the second study (HIIT), significant Tsk differences were found after training in Short Intervals for 94,4% (17/18) of the ROIs, Sprint Interval Training group had 61.1% (11/18), Repeated Sprint Training group had 11.1% (2/18) and Long Interval group for 33.3% (6/18) of the ROIs. Finally, Tsk obtained in before the game for the third study was similar for all the ROI except for both Right and Left Anterior and Posterior Leg ROIs between the groups because of the player were wearing socks during acclimation. After the game only Left Posterior Knee was significantly higher than the other groups and the Δ Tsk between the groups was only different for the Left Posterior Leg. After the game Tsk increased in Group 1 for Right Anterior Leg (32.6°C vs 30.8°C), Left Anterior Leg (32.73°C vs 30.83°C), Right Posterior Leg (31.79°C vs 30.67°C) and Left Posterior Leg (31.80°C vs 30.54°C). Group 2 after the game had a Δ Tsk in Left Posterior Leg in comparison with the right side (0.45°C vs 0.14°C) while Group 3 did not change their values.

Conclusion: The Tsk of elite football players rewarms faster on the Dominant posterior thigh after a CWI protocol suggesting that this region, one of the most injured ones in football, had a different response if compared with all lower limb ROIs. Fatigue and muscle soreness perceived were reduced 10 minutes after CWI. Tracking the individualized thermal response after CWI could be a useful tool to detect thermal imbalances in professional football players. HIIT Tsk responses were different depending on the protocol. Thermal activation of the ROIs that biomechanically are more demanded could allow strength & conditioning coaches to measure which muscle zones have been

targeted by training, thus, quantifying training load. On the other hand, match responses were not significantly different when analyzing the data. Only Right vs Left Posterior Legs within group 2 (who played, but not the whole match) it was found a significant ΔT_{sk} in Left (0.45°C) vs Right (0.15°C), supporting the idea of a possible acute adaptation of the weak leg within the match because of the asymmetrical technical elements performed during a football match.

Keywords: Cryotherapy, CWI, infrared thermography, recovery, elite, football, HIIT, training, thermal imaging, match, game, youth, soccer.

RESUMEN

Introducción: La inmersión en agua fría es una de las técnicas de recuperación más usadas en el deporte. La termografía infrarroja puede ser útil para identificar y cuantificar anomalías en la temperatura de la piel y prevenir lesiones. El objetivo del primer estudio fue entender la respuesta aguda de la piel de la inmersión en agua fría en jugadores de fútbol profesional medido 36 horas después de un partido de fútbol. La termografía puede ser aplicada para conocer el impacto térmico de un entrenamiento en las diferentes regiones corporales del ser humano. El entrenamiento de intervalo de alta intensidad (HIIT) es uno de los más eficaces para mejorar el rendimiento en deportes de equipo y tiene diferentes implicaciones dependiendo del tipo, duración e intensidad de cada protocolo. El objetivo del segundo estudio fue determinar la respuesta aguda de la piel ante 4 protocolos diferentes de HIIT en la temperatura de la piel del miembro inferior de jugadores adolescentes de fútbol. Diferentes estudios han usado la termografía para entender cómo la carga de trabajo incide sobre las diferentes regiones del cuerpo humano, sin embargo, ninguno ha estudiado cómo responden después de un partido de fútbol. El objetivo del tercer estudio fue comprender la respuesta aguda de la temperatura de la piel inmediatamente después de un partido oficial.

Métodos: El primer estudio contó con la participación de 9 jugadores de 1ª División de Brasil (edad $28,3 \pm 5,1$ años, $8,9 \pm 3,9\%$ porcentaje de grasa) los cuales siguieron un protocolo de inmersión en agua fría de 10 minutos de inmersión a 3°C con 36 horas de descanso completo entre el partido y el estudio. La temperatura de la piel se midió antes (Pre), inmediatamente después (Post), a los 10 (Post10), 15 (Post15) y 20 (Post20) minutos después de la crioterapia. El incremento de temperatura fue obtenido para medir el enfriamiento y el recalentamiento de las zonas de Pre a Post (Cooling), Post a Post10 (Rew10), Post a Post15 (Rew15) y Post a Post20 (Rew20). En el Segundo estudio, 37 jugadores adolescentes de fútbol de la categoría Sub-16 de 1ª División de España ($15,6 \pm 0,3$ años, $1,74 \pm 0,1$ metros y $63,4 \pm 6,7$ kg) siguieron aleatoriamente uno de los 4 protocolos de HIIT al mismo tiempo después de un calentamiento estandarizado HIIT 1 (n=10): Short Intervals. 6 series de 30'' de Carrera con 30'' de descanso pasivo entre series. HIIT 2 (n=9): Sprint Interval Training. 6 series de 30'' de carrera con 120'' de descanso pasivo entre series. HIIT 3 (n=8): Repeated Sprint Sequences. 3 series de 6

sprints de 40m (20m + 180° cambio de dirección + 20m) con 10'' de descanso pasivo entre sprint y 6' de descanso pasivo entre series. HIIT 4 (n=10): Long Interval. 6 series de 3' de carrera 1' de Descanso pasivo entre series. La temperatura de la piel del miembro inferior fue medida antes y después del entrenamiento para establecer cuáles de las 18 áreas corporales tuvieron diferencias significativas después del HIIT. Finalmente, el tercer estudio constó de 21 jugadores (15,7±0,4 años, 1,74±0,1 metros y 63,7±6,3 kg) de un equipo sub16 de 1ª División cadete de España que juega en la máxima división de Madrid dividido en 3 grupos. Grupo 1 (n=7) jugó todo el partido desde el inicio, Grupo 2 (n=8) jugó, pero no todo el partido y Grupo 3 (n=6) no jugó. Los jugadores fueron medidos antes y después del partido térmicamente para evaluar la respuesta de la temperatura de la piel.

Resultados: La evolución de la temperatura de la piel después de la inmersión en agua fría del primer estudio fue diferente dependiendo de las áreas corporales. La temperatura de la piel descendió después de la crioterapia alrededor de 12-13°C y redujo la temperatura en un 39,7%. El recalentamiento del isquiotibial fue superior en el lado dominante que el no dominante en Rew10 (6,2°C vs. 5;8°C; p<0,05) and Rew20 (8,3°C vs. 8,0°C; p<0,05). En el segundo estudio (HIIT), la temperatura de la piel fue significativamente diferente después del entrenamiento en el protocolo Short Intervals para el 94,4% (17/18) de las áreas analizadas, el grupo Sprint Interval Training tuvo un 61,1% (11/18), el grupo Repeated Sprint Training tuvo un 11,1% (2/18) y el Grupo Long Intervals 33,3% (6/18). Finalmente, la temperatura de la piel obtenida antes del juego para el tercer estudio fue similar en todas las áreas analizadas excepto en el gemelo y la tibia porque los jugadores vistieron calcetines durante el período de aclimatación. Después del partido, solo la zona poplítea izquierda fue significativamente más caliente que la de los demás grupos y el incremento de la temperatura solo difirió para el gemelo izquierdo. Además, después del partido la temperatura incremento en el Grupo 1 para la zona tibial de la pierna derecha (32,6°C vs 30,8°C) e izquierda (32,7°C vs 30,8°C), así como el gemelo derecho (31,9°C vs 30,7°C) e izquierdo (31,8°C vs 30,5°C). El Grupo 2 después del partido tuvo un incremento de temperatura en el gemelo izquierdo en comparación con el derecho (0,4°C vs 0,1°C) mientras que el Grupo 3 no alteró sus valores.

Conclusión: La temperatura de la piel en los jugadores de fútbol profesionales analizados se recalentaron más rápido en el isquiotibial de la pierna dominante en

comparación con la no dominante después del protocolo de crioterapia. Podríamos sugerir que el isquiotibial, al ser una de las zonas que muscularmente más se lesionan durante los partidos de fútbol tenga una respuesta diferente en comparación con otras regiones del miembro inferior menos propensas a lesionarse. La fatiga y el dolor percibido se redujeron 10 minutos después de la crioterapia. Como conclusión, individualizar la respuesta térmica post-crioterapia podría ser una herramienta útil para detectar desequilibrios térmicos en jugadores de fútbol profesional que puedan estar ligados a procesos fisiológicos alterados en la recuperación. El entrenamiento HIIT tuvo una respuesta diferente sobre la temperatura de la piel dependiendo del protocolo. La activación térmica de áreas corporales que biomecánicamente son más demandadas podría ayudar al preparador físico a medir qué regiones musculares se dirige más el entrenamiento, cuantificando por ende la carga de entrenamiento impuesta sobre dicha región. Por otro lado, las respuestas térmicas de la piel post partido no fueron significativamente diferentes al analizar los datos. Sólo el gemelo izquierdo y derecho del grupo 2 (jugaron, pero no todo el partido) tuvieron un incremento de temperatura del izquierdo (0,4°C) frente al derecho (0,1°C), posiblemente por una adaptación aguda de la pierna débil o los elementos técnicos realizados durante el partido.

Palabras clave: Crioterapia, termografía infrarroja, recuperación, elite, fútbol, HIIT, entrenamiento, visión térmica, partido de fútbol, adolescente.

1. INTRODUCTION

Infrared Thermography (IRT) is a quick, objective and non-invasive technique for measuring the irradiated energy released by the human body. Infrared cameras provide us a detailed map of the different areas of the human body in which each pixel from the thermal picture corresponds with a temperature data.

Infrared thermography was firstly used around 1960 for medical purposes, and through history some uses into the field of sport sciences has been added (Hildebrandt et al., 2012). Some of the uses in sports are muscle injury prevention and monitoring (Gómez Carmona et al., 2008, Gómez Carmona, 2012, Bandeira et al., 2012); detection of muscle imbalances (Sillero Quintana et al., 2009, Abate et al., 2010); relationship with shoulder pain (Rossignoli et al., 2016); quantification of thermal responses to the training load (Čoh and Širok, 2007, Fernández-Cuevas, 2012); detection of delayed-onset muscle soreness (DOMS) (Al-Nakhli et al., 2012) and lactate threshold (Akimov and Son'kin, 2011); and fitness and performance conditions assessments (Chudecka and Lubkowska, 2012, Chudecka and Lubkowska, 2010, Akimov et al., 2009, Merla et al., 2010, Arfaoui et al., 2012b).

Since the beginnings IRT has evolved technically and methodologically. Technically, at this moment a thermal camera can reach resolutions of 2048x1536 pixels (INFRATEC models), therefore offering more detailed data than the standards 160x120 pixels. If we compare both resolutions, the first one would give us a total amount of 3.145.728 pixels while in the second just 19.200, in other words, we would have 164 times more information depending on the model. Methodologically, it has been discovered that a large list of factors could influence body skin temperature (Tsk) (Fernández-Cuevas et al., 2015a), the ignorance of those could lead to misunderstanding and erroneous analysis of thermal images. This way, we propose that increasing the necessity of detailed and standardized protocols is a must for minimizing the effects of those factors.

One of the best achievements in the last years was passing from qualitative analysis (just monitoring the colors) to a quantitative one by the delimitation of Regions of Interest (ROI). The delimitation of ROIs is a subjective and hand-made method as every single researcher has done his own division.

They have been designed some computer applications for objective delimitation of the ROI into a thermogram. Some examples of these are ThermoTracker® developed in the Technical University of Madrid (UPM) and validated in the doctoral dissertation of (Cuevas, 2012), and ThermoHuman® developed by a technological startup who developed an artificial vision method for ROI division with and on-line based app (www.thermohuman.com).

Solved the aspect of a homogeneous ROI division for identical analysis, there is still a lack of knowledge regarding the interpretation of IRT in sports. One of the key points about the thermographic interpretation is the way in which information about the variables, the thermographic asymmetries based on the dominance (dominant vs non-dominant) (D-ND) or the laterality (right vs left) (R-L) should be considered depending on, for example, the type of training generic or specific performed by the athlete in the previous training session. In terms of dominance, a generic, bilateral and cyclic training (running, strength training, drills without ball) would not be as affected by using the dominant leg as specific training (ball drills, small sided games).

Other important questions are: how to manage thermal data in sport? and how could this data help the thermologist or the thermography user in the day-to-day practice?, are the variables obtained after acute responses of training, match and recovery in football enough to extract useful practical information?; if so, what variables should be considered and when?

This doctoral dissertation pretends to get away of the laboratory to go deep into daily sport routines to solve some simple questions:

- 1) What is the acute skin thermal response of a football player immediately after a recovery strategy like cold-water immersion?
- 2) What is the acute skin thermal response of a football player immediately after different types of generic training?
- 3) What is the acute skin thermal response of a football player immediately after a competitive match depending on the played minutes?

The aim of this work is to analyze Tsk responses with special focus on asymmetries and imbalances to behold if IRT could provide valuable information in

recovery, training and competitive football settings. And, at the end, giving to future sport scientist and applied vision with relevant tips that could enhance the application of IRT.

1.1. INFRARED THERMOGRAPHY

Thermography's etymology comes from the Greek word *thermos*- which means "hot, heat or temperature" and *-graphia* "description of". IRT cameras detect radiation from wavelengths 9.000 to 14.000 nanometers corresponding with the electromagnetic spectrum, far from the visible light which goes from 450 until 750 nanometers. The total radiation that an object emits increase with temperature, hence we can see variations in heat exchange.

IRT is a safe, non-invasive and low-cost technique that allows for the rapid recording of radiating energy that is released from the body or analyzed object in a non-invasive way (Ring, 2014), thus, generating bidimensional infrared pictures called thermograms or radiometric images in which each of the pixels include a temperature data point. The radiation measured by IRT is directly related to Skin Temperature (T_{sk}).

1.1.1. HISTORY OF INFRARED THERMOGRAPHY

Technology evolves every day, but the usefulness of it will last forever if the principles in those are based remains applicable. We could think that thermography is quite new, but the origins of it dates back 2500 years ago in ancient Greek where Hippocrates stated that "should one part of the body be hotter or colder than the rest, then disease is present in that part" (Hildebrandt et al., 2012). He observed that a mud slurry spread over the person would dry at different speeds depending on the zones, thus indicating underlying organ pathologies because different heat distributions. After that, he continued researching and observing that certain temperatures on human body would be related with normal or abnormal physiological processes. In Italy at the end of the 16th century, Galileo invented a tool to measure variations in temperature: the thermoscope, in which a tube was fulfilled by a liquid that rises or falls depending on depending on temperature. That was the origin of the thermometer in the early 18th century.

It is not until the beginnings of the 19th century that infrared rays are discovered by the German-British astronomer William Herschel. A few years later, his son John Herschel took the first thermogram using the evaporograph technique (Ring and Ammer,

2000, Ring, 2006). This technique converts an infrared image into a visible one by means of evaporation or condensation of oil on a thin membrane (McDaniel and Robinson, 1962). During this 19th century researchers were focused on the development of tools for measuring and quantifying infrared radiation. All these efforts were finally worth when Italian physicist Leopoldo Nobili, inventor of many instruments that were critical to investigating thermodynamics and electrochemistry designed the first thermocouple. This instrument could determine the surface temperature of a contacted body by means of thermoelectric effect (Bentley, 1998). Finally, at the end of this century the American astronomer Samuel Pierpont Langley developed the bolometer, a device used for measuring the electromagnetic radiation from the heating of a material with a temperature-dependent electrical resistance.

Far from the medical uses, during the 20th century, the advances in the use of infrared thermography came via military applications during the First and Second World War. Military applications last from detection of buried mines until thermal guided missiles. Just after the information was declassified, IRT began to spread through civilian uses. In the 60s and 70s technological companies like Inframetrics in United States and AGA in Sweden distributed the first scanner for infrared detection in 1965, being purchased by FLIR Systems, one of the leading manufacturers of infrared technology available today with German InfraTec. (Kong).

The development of microbolometers allowed in the early 80s the reduction of technology cost because of the smallest size and weight of the sensors (Rogalski, 2012). That represented quite a big progress, higher resolutions and improved quality of cameras without making noise (Maldague, 2001) made possible an advance in quantitative IRT (Balageas, 2007). Thus, technological improvements let IRT to be used not only in laboratory but also in day to day activities (Lee and Cohen, 2008).

Nowadays, specialized research groups focused on thermography in sports like LAPEH (Universidade Federal de Viçosa) leaded by João Carlos Bouzas Marins, TermoINEF (Universidad Politécnica de Madrid) guided by Manuel Sillero Quintana and ThermoHuman^{TM} a company originated from this research group who has been elected between the best biotech startups in Spain has appeared to give some light into the practical application of this technique in high performance and medical settings. Thus, providing evidence-based information about how to use IRT (Ring, 2014).

1.1.2. BASIC CONCEPTS OF THERMOLOGY

Thermology is the science that studies the heat. Increments in the temperature of a body is directly related to (with) a faster movement of its molecular structure and vice versa. In this section, we will review some basic concepts of thermology which are crucial to understand the skin temperature behavior.

1.1.2.1. Thermal energy, heat and temperature

Thermal energy or calorific energy is the internal energy of a balanced thermodynamic system that integrates a matter (atoms, molecules and electrons). **Heat** is the transference of energy between bodies at different temperatures that are associated with the random motion of molecules and atoms (number, size, speed and type of particles) that compounds a certain substance. **Temperature** is not energy, it reflects the kinetic energy (atoms movement) that a body holds (Arora, 2001).

While thermal energy refers to quantity, temperature refers to intensity. The coldest substance in the world could be thermally measured, as it would have a small amount of energy released, that is to say a minimum intensity or temperature (Planck, 2013).

Thermal energy is a potential energy that a body contains (static) and can transform into heat (dynamic). Heat and thermal energy units are the same: Jules, Watts per second and Kilowatts per hour. But temperature is used for comparing different kinetic energies from different bodies. It is measured in Kelvins or Celsius degrees (°C). However, for simplicity the temperature has been commonly accepted as the most used term between both (Arora, 2001).

Thermal energy is absolute and temperature relative. When you mix two objects with the same temperature at 100°C they will remain equal but with double volume (Arora, 2001). But if you mix two substances with a thermal energy of 100 Jules you get 200 Jules.

To sum up, thermal energy is the amount of energy inside a single matter and temperature refers to his kinetic energy (average speed collision and movement between atoms and molecules). On the other hand, heat is the thermal energy transfer between matters (Planck, 2013).

1.1.2.2. Human thermoregulation

Thermoregulation is the ability of an organism to maintain its body temperature within certain limits, even when the surrounding temperature is quite different. Homeostasis is a situation of dynamic stability inside an organism, therefore, internal thermoregulation is part of that process. An organism without this capacity would adopt the environmental temperature as his own body temperature. In humans, the core body temperature remains stable around 37°C with diurnal variations along the day. However, skin temperature has lower values nearly 34°C (Lee and Cohen, 2008).

The thermal behavior of the human body is a combination of heat transfer and heat generation at various levels, micro (molecular and cellular), meso (tissue and organs) and macro (thermal interaction with the environment) (Bhowmik et al., 2013). Heat conductance within tissues inside the human body depends on the temperature gradient between muscle and skin and the thermal conductivity of the muscle (Gonzalez-Alonso, 2012).

The body is constantly absorbing radiation and emitting it. If the energy generated by the body is eventually radiated or the body temperature goes up (simple thermodynamics) it could be possible to measure every single ATP and other chemical reactions inside the body. So, calories consumed or absorbed must be equal to the calories radiated, otherwise temperature will raise.

Metabolic energy is converted into mechanical and thermal energy by means of heat production inside body cells. However, this process is very inefficient and between 30-70% of the energy is lost during muscle contraction as thermal energy (Gonzalez-Alonso et al., 2000). Heat liberation during ATP production at the onset of the exercise is matched with the elevation of heat production in contracting skeletal muscle (Gonzalez-Alonso et al., 2008). It has been shown that *in vitro* heat production during ATP utilization last from 35 to 72 kJ (mol ATP)⁻¹ depending on the energetic way for ATP resynthesis (Wilkie, 1968). Muscle movement generate heat if it uses energy that must be radiated or exchanged via conduction. At rest, the human body thermal output is almost 1600 calories per minute while during active periods is 2900 calories per minute.

Heat storage in body tissues is related with heat production, heat dissipation and energy exchanged during mechanical work (Gonzalez-Alonso, 2012). Abnormalities in

tissue heat storage will be related with Tsk imbalances, as skin is the most superficial but is interconnected with deeper layers (cells, muscles, and organs). As said before, temperature is the kinetic variable of heat which measures the intensity of molecules' movement inside the cells, consequently, Tsk will be influenced by tissue layers with heat problems like ischemia and inflammation (Bhargava et al., 2014). That will be linked with blood perfusion (Charkoudian, 2003), metabolic heat generation and temperature modification. The body should be balanced thermally, healthy subjects has not shown asymmetrical values bigger than 0,2°C in Tsk between contralateral limbs (Marins et al., 2014a).

Human metabolic activity generates a huge amount of thermal energy that needs to be dissipated for maintaining balanced physiological processes (Wilmore and Costill, 2007). Mechanisms of the body for interacting with surrounding temperature are: Conduction, convection, radiation and evaporation (sweat and breathe) (figure 1) and the predominance of these mechanisms differ between children and adults. While the first rely more on “dry” heat exchange, the second ones use the evaporative heat loss way for heat dissipation (Falk and Dotan, 2011). That does not mean a lower adaptive response in any case, just the utilization of different paths.

Figure 1. Dynamic bodily heat balance from (Jones and Plassmann, 2002).

1.1.2.2.1. Human body mechanisms for heat exchange interaction

Figure 2 summarize the different mechanism to release the heat generated by the practice of any physical activity or exercise.

Conduction is the direct exchange of thermal energy between molecules when they collide between them. The faster a molecule moves the higher the temperature, the slower the molecule moves the lower temperature. When both collides, the temperature will be transferred from the faster (warmer) to the slower (colder).

Heat transfer can generate a steady state in normal conditions. What leaves a body need to be placed in another one therefore, no heat transfer will occur if the energy of both bodies is equal.

Convection is the dominant form of heat transfer through a moving fluid (either gas or liquid). Convection is produced within the fluid (Incropera and DeWitt, 1999), not between fluids or between fluid and solid surfaces as conduction perform.

Radiation occurs in a vacuum or any solid or liquid medium, is propagated without the presence of matter. Thermal radiation transfers energy by means of photons in electromagnetic waves, and is the way IRT captures the temperature. Human bodies emit thermal radiation due to temperature, and more temperature is related with higher thermal radiation emitted according to Stefan-Boltzmann Law. This emitted radiation would vary between matters (Serway and Beichner, 2002), depending on the emissivity we would find perfect irradiators like a black body (close to 1) and skin (0.98) until worst ones as could be the aluminum (0.05). That means that the higher the emissivity the more “trustable” or similar the temperature is compared with the real one.

Evaporation is the vaporization of the surface of a liquid into a gaseous state. It accounts for 10-20% of total body heat loss, while during exercise is exacerbated until 80% (Wilmore et al., 2008). Human body reacts to the increment of core temperature by trying to keep it stable by sweating and breathing.

Figure 2. Human body mechanisms for heat exchange interaction during exercise.

1.1.2.2.2. Laws of thermodynamics

Thermodynamic systems are characterized by four laws in which fundamental physical quantities as temperature, energy, and entropy are defined. Thermodynamic laws delineate the behavior of these quantities. It is worth to note that the laws of thermodynamics are applicable to thermography as infrared cameras generates thermograms by means of electromagnetic waves. Thus, becoming essential to outline the four laws of thermodynamics, which are simplified below (Gaussorgues and Chomet, 2012, Rolle, 1999):

Zero law of thermodynamics: *Two bodies separated which are in thermal balance with a third, also are balanced between them.*

First law of thermodynamics: *Energy can neither be created nor destroyed. It just can change forms.*

Second law of thermodynamics: *No thermal system can produce a net work exchanging heat with a region at a single fixed temperature.*

Third law of thermodynamics: *The entropy of a system approaches a constant minimum as the temperature approaches to absolute zero.*

1.1.3 APPLICATIONS OF INFRARED THERMOGRAPHY

During the last years IRT has been used in multiple fields. The main applications fall on both objects and living beings. Applications on objects have been described by (Maldague, 2001) and more recently, (Bagavathiappan et al., 2013) reviewed the advances of IRT in non-destructive testing for monitoring these items: civil structures, electrical and electronic components, deformation, inspection of machineries, corrosion, weld and the application in nuclear industries. As the topic of this paper is based on sport, we suggest the reader to go deep into the original publications of both authors if interested in non-human applications.

On the other hand, IRT has been used on living beings either on humans and animals. Below are listed the uses of IRT on living beings for the sport and medical fields (Tables 1 and 2). Most of them have been previously cited in the excellent reviews of Lahiri et al. (2012), Marins (2015) and Ring and Ammer (2012).

Table 1. Applications of IRT on sports.

Field	Application
Sport	Injury prevention and monitoring (Hildebrandt et al., 2010, Gómez Carmona, 2012) (Vardasca and Mendes, 2017) (Barcelos et al., 2014) Location of muscle damage post-exercise (Bandeira et al., 2012) Training load monitoring (Čoh and Širok, 2007) Quantification of training load (Sillero-Quintana and Fernández-Cuevas, 2013) Detection of postural imbalances (Abate et al., 2010) Efficiency of the thermoregulatory process (Chudecka and Lubkowska, 2012) Detection of delayed onset muscle soreness (DOMS) (Al-Nakhli et al., 2012) Detection of heat illness patterns (Garza et al., 2008) Detection of lactate threshold (Akimov and Son'kin, 2011) Thermal response monitoring to exercise (Fernández-Cuevas, 2012) Clothing design and thermal comfort (Purvis and Tunstall, 2004)

Table 2. Applications of IRT on health.

Health	Fracture detection in paediatric emergencies (Sanchis-Sanchez et al., 2014a) Musculoskeletal injury diagnosis (Sanchis-Sanchez et al., 2014b) Breast cancer detection (Ng, 2009) Screening and early diagnosis (Sillero-Quintana et al., 2015) Diagnosis of diabetic neuropathy (Sivanandam et al., 2012) and vascular disorder (Bagavathiappan et al., 2009) Fever screening (Chiang et al., 2008) Dental diagnosis (Sudhakar et al., 2011) Dermatological applications (Zalewska and Wiecek, 2005) Diagnosis of rheumatic diseases (Cherkas et al., 2003) Diagnosis of dry eye syndrome and ocular diseases (Azharuddin et al., 2014) Blood pressure monitoring (De Cesaris et al., 1985) Kidney transplantation (Kopsa et al., 1979) Diagnosis of testicular disease (Tiktinskii et al., 1989) Detection of liver disease (Mansfield et al., 1970) Detection of intracoronary high risk vulnerable plaques (Schmermund et al., 2003) Gynecology (Abramowicz and Sheiner, 2007) Inflammatory arthritis (Denoble et al., 2010) Osteoarthritis (Arfaoui et al., 2012a) Muscle spasm and injury (Affairs, 1987) Enthesiopathies (Busoni et al., 1988) Tennis elbow (Binder et al., 1983) Fibromyalgia (Ammer et al., 1999) Complex regional pain syndrome (Wasner et al., 2002) Peripheral circulation (Allen and Howell, 2014) Burn evaluation (Renkielska et al., 2014)

1.1.4 INFLUENCE FACTORS OF INFRARED THERMOGRAPHY ON HUMANS

One of the weakest points of IRT is the wide list of factors that could significantly influence the interpretation of thermal data (Figure 3). Trying to manipulate all these factors seems impossible, but at least they have to be controlled or known for understanding the limitations of the studies (Fernández-Cuevas, 2012). In the must-read review of (Fernández-Cuevas et al., 2015b), these factors are divided into three groups:

- Environmental factors: Directly related with the location where the thermal evaluation is completed.
- Individual factors: Intrinsic and Extrinsic factors that relies on the subject.
- Technical factors: Connected with the technological equipment used.

Figure 3. IRT influence factors classification on humans. Reproduced with permission from (Fernández-Cuevas et al., 2015b).

Through this document, information will be added for individual intrinsic factors (anthropometry) and extrinsic factors (therapies and physical activity). In the first group, we will analyze how anthropometrical measurements can influence the effects of Cold-

Water immersion (CWI) on Tsk rewarming process. And on the second group, thermal responses will be profiled for football specific physical activities like High-Intensity Interval Training (HIIT) and competitive match.

1.1.5 THERMOREGULATION DURING EXERCISE

One of the key aims of the cardiovascular system is to exchange heat between internal body tissues, organs and the skin. Homeostasis is a hazardous war waged to keep the internal temperature as constant as possible, far from the extremely high or low temperatures that the body is pushed on by external and internal thermal loads (González-Alonso, 2012). During exercise, exacerbated thermoregulatory responses impact on homeostasis, being strongly affected by muscular, nervous and cardiovascular systems. Trying to isolate reactions for each one of these systems becomes hard as all are interconnected and will be targeted by physical activity. Regardless, the basis would be to prevent hyper or hypothermia by activating central and peripheral detection mechanisms of blood temperature and blood pressure alterations via hypothalamus. Vasoconstriction and vasodilation will be the main responsible for homeostasis regulation by restricting or increasing blood flow to selected areas (Charkoudian, 2010).

External loads like environmental conditions (hot or cold) and the duration, intensity and type of exercise would become determinant for knowing the circulatory adjustments inside the human body. Thus, the combination of an intense whole-body exercise and heat stress will be the most challenging scenario of temperature regulation (González-Alonso, 2012).

In comparison with rest, heat loss during exercise modifies the percentage of the mechanisms that account for moving out the heat produced inside the body (Table 2).

Table 3. Estimated heat loss during rest and prolonged exercises (Adapted from Wilmore & Costill, 2010).

Heat loss mechanism	Rest		Exercise	
	% of total	Kcal/min	% of total	Kcal/min
Conduction & convection	20	0,3	15	2,2
Radiation	60	0,9	5	0,8
Evaporation	20	0,3	80	12
Medicine	100	1,5	100	15

Knowledge about physiological responses to extreme environments has increased its presence within the last decade, specifically focus on heat and altitude topics (Buchheit et al., 2013). In football, key understanding of how the environment modifies human performance is needed to compete with highest chances of success in elite competitions (Born et al., 2014b). Past World Cups like South Africa 2010 and Brazil 2014 has challenged national teams' technical staffs to implement specific routines for hydration and acclimation. However, coping with extreme climatological conditions will continue to be a trending research topic, as the 2022 World Cup is planned to be celebrated in Qatar. Part of the interest will continue because of the challenge to maintain performance within extreme hot conditions (over 40°C) that has been demonstrated that impairs physical performance (No and Kwak, 2016).

Responses in Tsk before, during and immediately after the exercise have been studied by many authors (table 4). Each one, using his own designed ROIs under different training conditions (intensity, duration, specialization of the subjects, environmental conditions and discipline).

It is hard to deduce a unanimous conclusion as some studies has drawn opposite thermal responses to the same exercise (Fernández-Cuevas, 2012). In any case, main reactions were an increment of the Tsk during constant and prolonged exercises (Wang and Toh, 2001, Zaïdi et al., 2007, Ferreira et al., 2008, Hildebrandt et al., 2012, Fernández-Cuevas, 2012) and Tsk decrease while performing intermittent or maximal exercises in short periods of time (Merla et al., 2010, Merla et al., 2005, Chudecka and Lubkowska, 2012, Chudecka and Lubkowska, 2010, Chudecka et al., 2008, Akimov and Son'kin, 2011, Cuevas, 2012). However, the advances in thermal imaging analysis has provide the possibility of analyzing the Tsk response of the different body segments, thus, becoming important to determine the Tsk alterations region by region. This way, within a moderate aerobic exercise the different muscles can react with both Tsk increment or decrement depending on the heat flux of each one (Fernandes Ade et al., 2016).

As the focus of the majority of the studies is the overall response without comparing asymmetries, we will focus on determining those and understanding if the body gets more asymmetrical after these specific stimuli of HIIT, CWI and match demands.

Table 4. Task responses to exercise before (BE), during (DE), immediately after (IAE) and some minutes after exercise using IRT. AMBTEM (Ambient Temperature) (Adapted from Fernández-Cuevas, 2012).

Author, Year	n	Population	Exercise	Type	Time	Intensity	Temp.	Hum.	Analyzed ROIs	When	Trend	Results
(Wade and Veghte, 1977)	4	male	Constant	Swimming	500m	Training pace	23.5°C		Deltoideus, trapezius, biceps and triceps	BE-IAE	Increase	Unclear
(Clark et al., 1977)	2	athletes	Constant	Running-out	75'	16km/h	20°C			BE-DE-IAE	Decrease	Unclear
(Clark et al., 1977)	2	athletes	Constant	Running-tread	90'	16km/h	11°C			BE-DE-IAE	Decrease	5°C
(Veghte et al., 1979)				Hand gripping		from 20-80%				BE-IAE	Increase	1.7°C
(Nakayama et al., 1981)	2	male	Graded	Ergo	10'	300-600kpm/'				BE-IAE-10'	Decrease	1-1.4°C
(Nakayama et al., 1981)	3	male	Graded	Ergo	10'	150-450kpm/'	28°	40%	Chest, arms, hands and abdominal	BE-DE-IAE-5'	Decrease	0.5-3°
(Torii et al., 1987)	2	male	Maximal	Ergo	10'	50W	20°		Chest, arms, hands and abdominal		Decrease	0.7°C
(Torii et al., 1987)	2	males	Maximal	Ergo	6'	150W	20°		Forehead, arms, trunk and chest		Decrease	2.5°C
(Hirata et al., 1989)	8	male	Constant	Ergo	30'	90W 120bpm	20° water		Forehead, arms, trunk and chest		Increase	0.7°C
(Hirata et al., 1989)	8	male	Constant	Ergo-arm	30'+30'	33W 120bpm			Hand (17cm2) and forearm (52cm2)	BE-DE-IAE-30'	Increase	0.7°C
(Torii et al., 1992)	2	Healthy men	Constant	Ergo	20'	50-150W	10-20°		Leg (36cm2) and Foot (28cm2)	BE-DE-IAE-30'	Decrease	0.6°C
(Pascoe et al., 1992)	10	students	Constant	Ergo	90'	61% Vo2max	27°C	55%	8 ROI upper trunk	BE-IAE	Decrease	1.5-2°C
(Hunold et al., 1992)	6	5 males 1 woman	Constant	Ergo supined	10'	100W	23°C	55%	Back	BE-DE-IAE	Decrease	0.3°C
(Zontak et al., 1998)	10	active male	Graded	Ergo	12'	23±1°C	23±1°C	60±10%	Thigh and forearm	BE-DE-IAE	Increase	0.46°C
(Zontak et al., 1998)	10	active male	Constant	Ergo	20'	50% 70%	23±1°C	60±10%	Hand	BE-DE-IAE	Decrease	3.52°C
(Wang and Toh, 2001)	8	volunteers	Streight	Dumbbell	1'	25±0.2°C	23±1°C		Hand	BE-DE-IAE	Decrease	0.3°C
(Merla et al., 2002)	35	male female	Graded-sub	Ergo	12'±3'	up to 65% HR	23±1°C	55±10%	Forearm	BE-DE-IAE-10'	Increase	1°C
(Liu et al., 2003)	20	skill and not		Taijiquan					Thigh	BE-DE-IAE-10'	Decrease	Unclear
(Vainer, 2005)	1	young	Constant	Ergo	35'				Face, neck	BE-DE-IAE	Increase	2.1°C
(Vainer, 2005)	1	male trained	Constant	Ergo	60'				Neck, upper trunk, shoulder, facr	BE-DE-IAE-13'	Decrease	2.5°C
(Merla et al., 2005)	18	football+inactive	Maximal	Running-tread	12'	1			Upper trunk, shoulder, forearm	BE-IAE	Decrease	3.2°C
(Bonnelt et al., 2006)	7	female no active	Graded	Running-tread	12'	1			Thigh	BE-DE-IAE-10'	Decrease	2.55°C
(Zaidi et al., 2007)	1	swimmers	Submaximal	Swimming	4x100	50-175W	22±1°C	40%	Thigh	BE-IAE	Increase	1°
(Ferreira et al., 2008)	29	Old & young	Streight	1 kg kicking	3'	23%-14%	22-24°C	<50%	18 ROIs	BE-IAE-10'	Increase	2°C
(Chudecka et al., 2008)	17	handball females	End - speed	Handball	90'		25°C	60%	Hamstrings	BE-IAE-10'	Decrease	0.3°
(Merla et al., 2010)	15	male runners 2w	Submaximal	Running	12'	1	22-23°C	50±5%	Arms	BE-DE-IAE-8'	Decrease	2.2°C
(Chudecka and Lubkowska, 2010)	16	handball players	Endurance	Handball	90'		25°C	55%	Different ROIs	BE-DE-IAE-10'	Decrease	3°C-5°C
(Temuissen and Daanen, 2011)	10	6 males	Maximal	Ergo	10'+8'	1	30°C		Arms	BE-IAE-10'	Decrease	2.5°C
(Akimov and Son'kin, 2011)	20	athletes	Maximal	Ergo	14'	1	21-22°C	40%	Inner canthus	BE-DE-IAE	Increase	1.5°C
(Hildebrandt et al., 2012)	12	male athletes	Constant	Ergo	45'	60% 80rpm			Front	BE-DE-IAE	Decrease	2.4°C
(Hildebrandt et al., 2012)	12	male athletes	Anaerobic	Ergo	5'	90% 80rpm			Thigh	BE-IAE	Increase	0.7°C
(Chudecka and Lubkowska, 2012)	12	volleyball	End - speed	Volleyball	90'		25°C	60%	Thigh	BE-IAE-10'	Decrease	1.5°C
(Arfaoui and Polidori, 2012)	11	master cyclist	Graded	Bicycle	18'	100w-250W			Upper limbs, arms, forearms	BE-DE-IAE-10'	Decrease	2.76°C
(Formenti et al., 2013)	14	female trained and not	Constant	Heels raise	2'				Calf	BE-DE-IAE-7'	Decrease	0.7°C
(Bertucci et al., 2013b)	2	Young males	Maximal	Ergo	30'	4' 100w/c4'+100W			Calf	BE-DE-IAE-7'	Increase	1.2°C
(Arfaoui et al., 2014)	11	master cyclist	Graded	Bicycle	18'	100W(10')-50W/3'			Thigh	BE-DE-IAE	Decrease	2.4-2.9°C
(Cuevas, 2012)	14	active male	Constant	Running	45'	75% HR	20.01±0.7	41.3±2.53	Calf	BE-DE-IAE	Decrease	0.9°C
(Cuevas, 2012)	14	active male	Streight	Hypertrophy	4x4x10	70% IRM	20.07±1.1	42.3±3.39	25 ROI	BE-IAE-8 hours	Increase	0.2°C
(Cuevas, 2012)	14	active male	Maximal	Speed running	2x3 40m	100%	20.12±1.03	41.3±2.55	24 ROI	BE-IAE-8 hours	Decrease	0.7-1.6°C
									27 ROI	BE-IAE-8 hours	Decrease	±1.5°C

1.1.6 THERMOREGULATION DURING CRYOTHERAPY

Body heat must be dissipated at the balance with the metabolic heat production. The body has different adjustment mechanisms for the protection of the deep-body temperature if the environment is too cold, vasoconstriction reduces heat transport from deep tissues to skin surface, skin temperature is thus lowered and heat dissipation rate decreases.

One of the mechanisms the body uses for maintaining core temperature is shivering, which appears as a response for hypothermia. On the other hand, when the environment is too warm, heat dissipation is restricted, vasodilation increases heat transport to the surface, raise T_{sk} , thereby increasing the heat dissipation rate.

It has been demonstrated that Cold Water Immersion (CWI) reduces muscle blood flow (Gregson et al., 2011), core temperature and increases arterial blood pressure by an increase of the total peripheral resistance (Muller et al., 2012). A natural response to prevent core temperature cooling is as said before, shivering (an involuntarily increased metabolic heat production) that depending on the body parts we have immersed in water, this mechanism could be activated or deactivated (Pretorius et al., 2011). For example, when the head is submersed, shivering would not be activated but the opposite will happen if someone get immersed with the head out of the water.

The study of how cold affects thermoregulation is important in terms of knowing its influence on both **safety** and **performance**. Considering safety aspects, we have to be aware of the human limits for being immersed in cold-water, how challenging the environment is depending on the time someone is inside the water, and the temperature drop he is able to tolerate. Therefore, providing specific recommendations for secure settings (Bleakley and Hopkins, 2010) if following a recovery strategy on cold water. On the other hand, thinking on performance is not only crucial in sport but in war. As sport is a free and individual way for pushing your limits to the maximum in an almost-controlled competitive scene, in war you are pushed into a chaotic and destructive survival environment. That fact has encourage researchers to study the thermal and metabolic responses of military divers dealing with cold exposure during 6 hours of whole-body immersion (Riera et al., 2014) at different temperatures. Thus, valuable data could be provided in terms of what kind of material the divers should vest for maintaining

stable core temperatures, consequently having more chances to survive. As in sport these limits would be hard to be overpassed, it is important to know the greater response a human could give to the strongest stimuli that would challenge his thermoregulatory system, in the case of our study, we used CWI as a factor to challenge that response.

Water-based recovery strategies are hard to manage if the team plays away and there is no chance to have a water tank. Usually CWI is used just after the game if possible, if not, on the following day. Additional problems could appear if the technical staff gives a free day to the players after the game, moving the beginning of CWI two days after the competition. Glycogen depletion has been determined as a cause of fatigue in football, and it could be impaired between 48 and 72h after a football match (Nedelec et al., 2012). Low-glycogen storage levels could be one of the main determinants for increasing the possibility of obtaining greater eccentric damage after exercise (Gavin et al., 2014), and CWI is one of the most used treatments for muscle damage recovery (Gregson et al., 2011). Thus, a frequently asked question is if using CWI with low levels of glycogen as we have seen that are impaired up to 72 hours after the game, could be potentially risky in terms of thermoregulation. In this regard, thermoregulation has been shown as an element that is not impaired by low levels of glycogen (Young et al., 1989), that is to say, no extra risks will be added if using CWI with glycogen fiber depletion.

1.2. FOOTBALL

Football is the most played team-sport along the world, as well as the one who mobilizes more souls partly because of the worldwide event that happens every four years, the World Cup, the completion in which each citizen on the earth supports his country to win this title that will allow them to proudly hold the crown of world champions until the next tournament.

Year by year, football continuously breaks economic records in terms of salaries and transfers with clubs like Real Madrid and Barcelona paying up to 100M€ for different players like Cristiano Ronaldo, Neymar or Gareth Bale and other countries bidding for the future like China. Chinese Superleague has spent 385M€ at the end of the winter market of 2016 closing on February 26th, overpassing most of the quantities spent by European leagues.

1.2.1. PHYSICAL DEMANDS

One of the key aspects of football, is that needs an efficient spatial organization (Gil et al., 2007) between all the players, becoming more important that organization than the physical capacities itself. The aim is determined by scoring a goal, and locating each player in different positions on the field with specific roles will increase the chance of winning.

Football demands continuous activities as walking and jogging with alternating intermittent high-intensity actions like sprinting, jumping, kicking the ball and dribbling (Mohr et al., 2003b, Esposito et al., 2004, Carling et al., 2006) (Reilly, 2005) adds that these high-intensity efforts are produced in a chaotic and acyclic way. Success requires elevated physical levels (Stolen et al., 2005) in elite sport, as an adequate fitness influences technical and tactical performance as well as minimizes the risk of suffering injuries.

In the last 7 years, physical demands have changed in a dramatic way in professional football, increasing sprint distance a 35% (from 232 to 350 m) and the number of sprints by an 85% (from 31 to 57) comparing the 2006-07 season with 2012-13 in English Premier League (Barnes et al., 2014). On the other hand, Vigne et al. (2013) showed non-significant differences in high-intensity during 3 seasons following an Italian

“A” series team, they only found a reduction at submaximal speed and increased ball possession. Anyway, the professionalization of football could be seen not just in the evolution of the physical capacities during games but looking at the emerging new roles that technical staffs are incorporating little by little to deeply understand the game requirements: Fitness Coach, Strength & Conditioning Coach, Sport Scientist, Movement Coaches and some others.

1.2.1.1 Activity profile

An official competitive football match is composed by two halves of 45 minutes, with a total of 90 minutes per game until a maximum of 120 if the overtime is reached. Research confirms that football is intermittent in nature, where approximately 1000 changes of activity are produced during this 90 minutes (Reilly, 2005)

Following (Hoff and Helgerud, 2004), players perform between 150-250 short high-intensity efforts, that is to say each 30 second, with maximum intensity each 90 seconds. High-intensity running each 60 seconds and maximum sprint once per 4 minutes (Strudwick and Reilly, 2001). Randers et al. (2007) demonstrated that teams with higher success rates performed a higher number of sprints and high-intensity running during the game. We do not have to fall in the mistake that our team must run more to become successful, as correlation does not mean causation.

Several studies tried to deeply specify high-intensity efforts (Reilly, 2005) until the point of describing them as those actions that rarely overpass the 20 meters and 4 seconds in time.

Andrzejewski (2013) studied the sprinting profile of 10 matches from 147 players of UEFA Europa League during 2008-2009 and 2010-2011 seasons. The average number of sprints performed by the soccer players was 11.2 and about 90% of the sprints performed were shorter than 5 seconds, where only 10% were longer than 5 seconds.

The ability to quickly accelerate is in most of the times, more important than maximum speed. In many occasions because of the internal logic of the game, players are not able to reach peak speed because of tactical time-spatial motives. Sprints are common during running to the free space and counter-attacks, but is not only about running, in fact, Carling et al. (2008) studied Premier League players in which players showed an

average of 54.1 deceleration movements and 558 change of direction movements per game, suggesting the importance of these actions during training.

1.2.1.2 Positional demands

Not all the players cover the same total distance on games (Di Salvo et al., 2007). Midfielders run an average of 12km, strikers and wingers 11.5km and central defenders 10km that is in consonance with previous data published by Mohr (2013), who established an average of 11-12 km per game in elite football players. There are differences in the activity profile if we compare professional with young football players. Stroyer et al. (2004) determined that in youth categories the percentage of the time dedicated to walking was a 55%, standing time was 3%, and low and high-intensity running were respectively a 31.5% and 8.5%.

Furthermore, differences in sprinting profile between positions are often visible (Andrzejewski et al., 2013). Mean total sprint distance covered by players (>24 km/h) was nearly 240m. With forwards covering the longest sprint distances (345m), longer than midfielders (313m) and the double than central midfielders (167m).

It is important to create a fitness profile for each position to better understand the possibilities of each player. Sporis et al. (2009) studied 270 football players divided by different positions, they found that goalkeepers were the tallest and heaviest players in the teams and also the slowest players, on the other hand attackers were the fastest ones in 5, 10 and 20 meters. Goalkeepers had the greater explosive power tests (squat jump and countermovement jump). Midfielders had better values of maximum oxygen consumption, maximal running speed, and blood lactate than defenders and attackers. Defenders had more body fat than attackers and midfielders. Thus, specific profiles will better fit with specific positions depending on the physical demands that the game requires for each role.

1.2.1.3 Playing level

Rampinini et al. (2009) analyzed Italian “A” series successful teams. They showed that the players from the more successful teams covered more total distance in ball possession, covered more high-intensity running with the ball, had more involvements

with the ball, and completed more short passes, successful short passes, tackles, dribbling, shots and shots on target compared to the less successful teams.

Playing level can also be determined by age, as youth footballers has lower values of physical and technical levels that increases over time. Some studies had correlated some anthropometric and physiological characteristics in this population, Wong et al. (2009) observed that body mass was significantly correlated with ball shooting speed and 30 m sprint time. Body height was significantly correlated with vertical jump height, 10 m and 30 m sprint times, Yo-Yo intermittent endurance run distance, and running time during maximal oxygen uptake. Body mass index was significantly correlated with ball shooting speed, 30 m sprint time, Hoff test dribble distance, Yo-Yo intermittent endurance run distance, submaximal running cost and the corresponding running time. That could help us to understand why body height and body mass, both increases over life, could be determinant to have significant greater values of all these aspects.

1.2.1.4 Congested calendar

It has been demonstrated that playing 3 matches in 3 days produced fatigue in football players (Ra et al., 2014). The use of new techniques like capillary electrophoresis and time-of-flight mass spectrometry allows sport scientists to detect salivary markers of fatigue in different metabolites. 3-methylhistidine, glucose 1- and 6-phosphate and taurine are some of the metabolites involved in skeletal muscle catabolism, glucose, lipid, amino-acid and energy metabolisms.

Rey et al. (2010) studied with other collaborators how accumulated fatigue affected several matches during the same week. Elite football players who played 2 games separated by 3 days did not present significant differences between the number of sprints and high-intensity running distance neither decrements in peak and average. They only observed that total distance covered was higher in the first game in comparison with the second. Carling et al. (2008) suggested that intensity should be coded in terms of the speed of each action, this way the higher the average of the player's submaximal efforts like changes of direction, pace change, ball protection etc. the higher the possibility of the athlete to hold the specific football demands.

Lago-Peñas (2012) analyzed 27 Spanish La Liga matches and they found that the activity profiles of professional football players were not influenced by short recovery

between matches. Non-significant differences were found for the players who played 2 matches per week, those players covered less distance at maximal, submaximal and medium intensities than those who just played once a week. They concluded that elite soccer players' distance covered at various speeds is dependent on match contextual factors.

1.2.1.5 Contextual factors

Different studies confirm that the game model, playing home or away, the final result of the game and even the type of competition (regular league, world cup, group phase or finals) can influence the distance covered by the players. Obviously, is not the same having a right back with freedom to incorporate to offensive plays than other in the same position with limited function giving by the technical staff. Also, cultural differences exist not only depending on the team you play, but in which country. Dellal et al. (2011) observed that English Premier League players covered more sprint distance than Spanish La Liga players that could be mainly explained by opposite tendencies of counter-attack (England) or ball possession (Spain).

Following the same study of Lago-Peñas (2012), elite players perform less high-intensity activity when winning than when losing. On the other side, they usually cover more distance by walking and jogging when winning. If playing at home, teams often perform greater distances than away teams at low intensity. Finally, the better the opponent, the more total distance the team will cover by walking and jogging.

1.2.1.6 Fatigue during and after games

Fatigue during games could be easily explained as a performance decrement within the match. We will experience fatigue if we are not able to perform at the same level as the beginning. On the other hand, fatigue after the match is about to recover of a previous stress, not about perform.

During games, temporary fatigue appears after periods of intense exercise. That does not appear to be directly linked with the accumulation of lactate, muscle glycogen concentration, acidity or creatine phosphate breakdown (Mohr et al., 2005). Instead, it may be related to changes in the homeostasis of the muscle ion and an impaired excitation of the sarcolemma.

Fatigue could be divided in two big groups: central or peripheral. While in the first group the quantity and quality of information that we possess is still anecdotic because of the relative invasiveness, restrict applied use and time constraints surrounding the neurophysiological measures used to evaluate central factors (transcranial magnetic stimulation, computed tomography magnetic resonance imaging, electroencephalography and near-infrared spectroscopy) (Minett and Duffield, 2014). The second group has obtained the majority of the studies, indicating that several factors strongly affect measurements like peak speed, total distance covered and high-intensity running efforts (Mohr et al., 2003a).

If we compare the beginning of the game with the end of the half time, distance covered in high-intensity running was 18% lower in the last than in the first 15-minute period of the game (391 vs. 478 m) (Bradley et al., 2010). That could probably be explained by the glycogen depletion in the muscle fiber toward the end of the game (Bangsbo et al., 2006). In hot and humid environments, dehydration and a reduced cerebral function may also contribute to the deterioration in performance. Likewise, Rampinini et al. (2009) compared physical and technical performance during both 1st and 2nd halves of 416 games in Italian “A” series, he founds that not only physical capacities declined but also technical performance during the 2nd half. A decrement in both physical and technical factors could give us an indication of something that is not right. As fatigue could be leaded by both central (nervous system) and peripheral factors (the muscle fiber), it is important to understand what kind of responses are generated after the specificity of a game, not during but after.

Ispirlidis et al. (2008) studied how a single football game influenced the short-term muscle damage and inflammatory responses in elite football players. Anaerobic performance was deteriorated for at least 72-hour post-game. This response consisted of a post-game peak of leukocyte, cytokines, and cortisol. The acute inflammatory response in football appears to follow the same pattern as in other forms of exercise.

- 24-hour peak of C-reactin protein (CRP), thioburbituric acid-reactive substances, and delayed-onset muscle damage (DOMS).
- 48-hour peak of creatine kinase (CK), lactate dehydrogenase, and protein carbonyls.
- 72-hour peak of uric acid.

Nedelec et al. (2014) analyzed the effects of the playing actions on the recovery kinetics after a football match. They found as well as Ispirlidis that neuromuscular fatigue was up to 72 hours and that was priority dependent on the number of sprints and hard changes in direction performed during the match. During the 72-hour recovery period, muscle soreness increased while countermovement jump (CMJ), isometric strength of the hamstring muscles, and peak sprint speed significantly decreased.

Importance should also be given to the increment of the levels of oxidative stress registered after games (Ascensao et al., 2008). The definition of oxidative stress is a disturbance in the balance between the production of reactive oxygen species and antioxidant defenses (Betteridge, 2000) and can affect the player during his recovery process. The signaling molecules within the cells have the potential of regulating different mechanisms by switching those on or off (Betteridge, 2000), thus, becoming important to monitor oxidative stress to avoid a conflict of activating mechanisms that could impair the recovery of our athletes because of overtraining (Rago, 2016).

Silva et al. (2014) followed 14 professional football players during a season, analyzing the changes in performance, muscle function, and stress-related biochemical markers. They concluded that football players face significant changes in biomarkers of physiologic strain (muscle damage and oxidative stress-related markers) during the season, but values return to normal during the off-season. Additionally, they found that the accumulated playing time in matches influenced physical, hormonal, and oxidative stress-related parameters. The more you play, the more likely to alter your values.

1.2.1.7 Emerging required abilities RSA, RPA & RAA

Sport scientists, in their way for discovering and categorizing the abilities that are important in team sports, considered this three as necessary to improve: Repeated Sprint Ability or RSA (Bishop et al., 2011), Repeated Power Ability or RPA (Gonzalo-Skok et al., 2014) and Repeated Acceleration Ability or RAA (Barbero-Alvarez et al., 2014).

Essentially, those three concepts are related with the ability to repeat high-intensity efforts such as sprints (RSA), power (RPA) or short accelerations (RAA). The first ability has been widely studied in the last years, while RPA and RAA have started to be analyzed recently with basketball players and football referees.

1.2.2 EPIDEMIOLOGY OF INJURIES

Injuries have a potential negative effect on team performance (Häggglund et al., 2013) and a tremendous economic impact not only in sport (Fernández Cuevas et al., 2010) but in terms of healthcare (15,243 injuries were reported in Spain during 2010-11 season) (Herrero, 2013). A professional football team will have an average of nearly 81 injuries per season (Noya Salces and Sillero Quintana, 2012, Noya and Sillero, 2012) and will expect 15 muscle injuries between a squad of 25 players where 92% of those will correspond with the following muscle zones: hamstrings (37%), adductors (23%), quadriceps (19%) and calf muscles (13%) (Ekstrand et al., 2011). If we focus only on those muscles we would be able to manage information in regard to 92% of the total muscle injuries produced in football. So that, it is important closely monitoring these four zones by means of specific testing as force imbalances, mobility impairments or thermal asymmetries.

One of the studies that better illustrate the epidemiology of injuries during a whole season was performed by Noya Salces et al. (2014) in Spanish La Liga 2008-09. They reported a total of 228.743 hours (12.038 hours of competition exposure and 216.705 hours of training exposure) with a total of 1293 injuries reported by the 427 players (524 competition injuries and 769 training injuries), obtaining an overall injury incidence of 5.65 injuries/1000 hours of exposure, with 43.53 in competition and 3.55 in training. Recurrent injury index was greater in competition than in training (4.7 vs 0.4 injuries/1000 hours of exposure). 89.6% of the injuries involved the lower extremities. Muscle and tendon injuries had the highest incidence rate (3.04), followed by injuries of the joints and ligaments (1.38) and contusions (0.8). More than 50% of the injuries were related to muscles and tendons, where 2/3 of the injuries were due to overuse (59.5% during competition and 70.0% during training), and 1/3 of the injuries was due to trauma.

The incidence of injuries in training during the pre-season was higher than in the rest of the competition phase. Usually, players are not yet adapted to specific loads in this initial phase reaching small overloads that provokes injuries if mismanaged. On the other hand, injuries during competition peaked at the end of the season (from March to May) when players are more likely to accumulate more minutes (Noya Salces et al., 2014).

Table 5. Injury incidence during competition in Spanish Football First Division (Noya, 2014).

IRT has been demonstrated as a powerful tool to decrease the number of injuries during a pre-season in a professional football team (Gómez-Carmona, 2012). Obtaining rates of ~90% decrease in muscle injuries and a ~70% less of days of absence by giving daily feedback of the thermal images to the technical staff. During this dissertation, this work will focus in explaining how thermography could aid in different chapters of day-to-day football protocols like recovery (monitoring asymmetries), training (workload assimilation of training stimuli) and competition (acute responses to specific stimuli).

1.2.3 TRAINING METHODS

The evolution of training tendencies in football in the last years has led to a reduction of time and an extremely increment of intensity with the so-called high-intensity interval training (HIIT).

The overcrowded calendars of some elite teams do not let them to train with high-volume as players will excessively be overloaded. Anyway, the importance of the strength and conditioning coach will reside in managing the load and training block contents intelligently.

Training could be divided into two groups: generic and specific. The first one will gather all the types of trainings in which players will not perform with ball. While in specific training there are technical or tactical situations as the ball part of it. Discussion is open about what kind of training is better depending on what coaches are looking for to improve. Generally, generic training will appear in situations when time is gold and you must precisely control the intensity. On the other hand, specific training is not as boring as generic, and you can improve technical skills and tactical situations. The problem here will be the limited control of the intensity for each player, as the chaos of the ball will not allow you to prescribe easily the load imposed (Hill-Haas et al., 2011).

There are a few studies that compared EMG with thermography (Priego Quesada et al., 2015, Bartuzi et al., 2012) to evaluate the activation and fatigue of the muscles. One of the objectives of the study will be to establish which zones are thermally activated depending on the kind of HIIT performed. That will allow us to detect the active muscles and provide valuable information to the staff about how their training impacted on the players. The problem of this study is that EMG was not compared with thermography, avoiding us to discuss anything about the activated muscles in terms of non-thermal information.

1.2.3.1 Generic

1.2.3.1.1 High-Intensity Interval Training (HIIT)

Buchheit and Laursen (2013b) defines HIIT as “either repeated short (<45 s) to long (2–4 min) bouts of rather high- but not maximal-intensity exercise, or short (<10 s, repeated-sprint sequences [RSS]) or long ([20–30 s, sprint interval session [SIT]) all-out sprints, interspersed with recovery periods. These varying-length efforts combine to create training sessions that last a total of ~5–40 min (including recovery intervals).”

There are nine pieces of the puzzle that need to be controlled: work (modality, duration and intensity), relief (duration and intensity) and series (number of series, duration, time between series and between series recovery intensity). By combining these variables, different approaches of HIIT could be obtained.

1.2.3.1.2 Repeated Sprint Training (RST)

Girard et al. (2011) defined Repeated Sprint Exercise as “*repeatedly produce maximal or near maximal efforts (i.e. sprints), interspersed with brief recovery intervals (consisting of complete rest or low- to moderate-intensity activity), over an extended period of time (1-4 hours), and this has been termed repeated-sprint ability (RSA).*”

The limiting factors are still to be known, as there is no global one that impact fatigue. Two parameters that are often used to quantify the quality of RSA are Fatigue Index (decrement in percentage of each one of the running bout times) and “RSA best” (best time achieved during a RSA test). This way two key values are obtained: how fast you get fatigued and how quickly you are.

1.2.3.1.3 Sprint Interval Training (SIT)

Sprint Interval Training (SIT) as defined by as Sloth et al. (2013) is “*an interval training regime, which has recently received increased attention since studies have suggested that intervals of very high intensity, short duration (<30 s) and relatively long recovery periods between intervals (~4 min) may induce improvements in aerobic power and metabolic function resembling those of traditional endurance training*”. Manipulating variables as recovery time a number of series and reps, could modify the neuromuscular responses. In our case, SIT was set as 6 reps of 30 seconds’ all-out straight line running bouts without Change of Direction (COD) with 2 minutes of recovery per repetition for achieving a greater neuromuscular load. This kind of SIT has been recommended by (Buchheit and Laursen, 2013a) to elicit greater values of blood lactate accumulation and to impact on hamstrings.

ATP resynthesis during SIT bouts would rely on anaerobic metabolism (McCartney et al., 1986), whereas traditional endurance training and most forms of HIT predominantly relies on aerobic metabolism. In the case of SIT, depending on the duration, there will be a progressive shift in energy metabolism with greater relevance of the aerobic metabolism when sprints are repeated (Bogdanis et al., 1996) (Parolin et al., 1999).

1.2.3.2 Specific

Players are players because of the enthusiasm that the ball provides them when playing with it. One of the keys in football is to optimize training time along the week to obtain more time with the ball than without it. Thus, if optimal fitness is achieved with more playing time both tactical and technical skills would be improved.

The aim of the specific circuits and the small-sided games (SSG) relies on that objective. As well as in generic training, variables could also be manipulated in SSG to modify the physiological responses (Halouani et al., 2014b, Hill-Haas et al., 2011, Aguiar et al., 2012). Some of them are the number of players (Aguiar et al., 2013), pitch size (Casamichana and Castellano, 2010), presence of goalkeeper (Koklu et al., 2013), presence of mini-goals or goals (Gaudino et al., 2014) (Halouani et al., 2014a), presence of absence of coach encouragement (Halouani et al., 2014b, Hill-Haas et al., 2011), rule changes or tasks constraints (Aguiar et al., 2012), continuous or intermittent format (Casamichana et al., 2013), ball contact (Dellal, 2011) and man-marking (Ngo et al., 2012).

1.2.4 TRAINING LOAD MONITORING

Training load monitoring in sports has evolved in the past decades. Usually, coaches started with quantifying the number of kilometers, sets, reps and even the number of kilograms lifted in the weight room. In contrast to most endurance sports, team sport athletes usually compete once or twice a week for 10 months of the year. And, in order to keep a progression of loads day by day and to know how to alternate hard and easy days, different periodization approaches began to be used in different sports (Bompa and Buzzichelli, 2015).

Most common ones were those related with track & field and weightlifting, little by little importance was transferred into team sports like football with divergent styles as block (Sainz, 2013) and tactical periodization (Tamarit and Gimeno, 2007). Whereas those models are mostly based on informal experimentation by coaches, whatever the periodization model you use, controlling your training with parameters remains essential.

Appropriate periodization to improve fatigue removal and fitness maintenance during the competitive period of professional team sport athletes is a difficult task. An

imbalance in stress and recovery leads to decrement performance in strength, power and team sport athletes. Normally, two types of load are distinguished: internal load and external load (Halsen, 2014a). The combination of both will give Strength & Conditioning coaches better insights into how exercise affects their players. Because controlling the influence of these parameters will allow them to better monitor the physiological and psychological stress on the athlete, thus, improving the chances to obtain a greater performance.

However, sometimes there are no guarantees that monitoring training load will result in successful performances (Halsen, 2014a). Extracted from Halsen (2014) we can obtain a valuable fragment: *“A lack of knowledge or experience with monitoring techniques can result in an inability to implement a practical and sustainable system and/or an inability to interpret the data collected. In addition, a clear rationale identifying **why** the monitoring is occurring, **what** will be monitored, **how often** monitoring will occur, and **how** the data are interpreted and presented back to the coaching staff is required”*.

1.2.4.1 Internal load

Internal load is described as a physiological stress imposed on players and can be measured through physiological variables like heart rate (HR), subjective measurements of fatigue or biomarkers and requires quantification of the physiological stress imposed on an athlete by exercise (Scott et al., 2013).

1.2.4.1.1 Heart Rate (HR)

Heart rate (HR) is one of the most commonly used physiological variables to determine exercise internal training load and is often used to both prescribing and monitoring intensity. During a match a player normally achieves 70–80% of VO₂max and 80-90% of the maximal HR, with independence of the playing level (Alexandre et al., 2012). Almost 65% of the total time during matches is spent at an intensity of 70–90% of the maximal HR, rarely below 65%. Nevertheless, although maximal HR is employed in scientific literature, monitoring should be expressed in relation to reserve HR (maximal HR – resting HR), as it has been described as a more reliable indicator of HR, allowing inter-individual comparisons (Alexandre et al., 2012).

The use of HR appears to be convenient for an indirect estimation of the aerobic energy production in soccer (Eniseler, 2005) but not for an anaerobic energy production, speed and power exercises because of HR inertia.

Interpretations based on the linear HR-%VO₂ relationship need to be carefully read. Soccer is intermittent in nature, and this relationship is based on a continuous treadmill running test so there is little point in extrapolating these assumptions.

1.2.4.1.2 Training Impulse (TRIMPs)

Training Impulse (TRIMPs) are obtained after multiplying the average HR by a fixed factor depending on the different zones in % of the maximal HR for mixing intensity and duration. There are various methods of quantifying training load with TRIMPs: Banister (Banister, 1991) , Edwards (Edwards, 1993), Lucia (Lucia et al., 2003) and individual TRIMP (iTRIMP) (Manzi et al., 2009, Akubat et al., 2012).

Banister uses the exponential relationship between fractional elevation in HR and blood lactate. The effective training session duration (in minutes) is multiplied with HRratio (based on heart rate recovery). The formula modified by Morton et al. (1990) is the following one:

$$\text{TRIMP} = D \times (\Delta\text{HR ratio}) \times 2.718^{\text{exp}(b \times \Delta\text{HR ratio})}$$

, where D = duration of training session; and b = 1.92 for men and 1.67 for woman, and $\Delta\text{HR ratio}$ is defined as:

$$\Delta\text{HR ratio} = (\text{HR}_{\text{ex}} - \text{HR}_{\text{rest}}) - (\text{HR}_{\text{max}} - \text{HR}_{\text{rest}})$$

, where HR_{rest} is equal to the average heart rate during rest; and HR_{ex} is equal to the average heart rate during exercise and HR_{max} is the maximal heart rate of the player.

The heart rate-based method proposed by Edwards (Edwards, 1993) to determine internal training load involved both the total volume of the training session and the total intensity of the exercise session. The relative intensity corresponds to five divisions of HR. Thus, the total (internal training load) score is the sum of the calculated load (duration in each zone times the multiplier) in each zone (50–60 % maximal HR = 1, 60–70 %

maximal HR = 2, 70–80 % maximal HR = 3, 80–90 % maximal HR = 4, and 90–100 % maximal HR = 5).

Lucia's TRIMP model approach (Lucia et al., 2003) is similar to Edward's methods. The only point in which both differ is that instead of using 5 arbitrary zones, Lucía uses ventilatory thresholds. That means a greater individualization of internal training load. Zone 1 is defined as “below the ventilatory threshold” (<2 mmol/l), Zone 2 as “between the ventilatory threshold and the respiratory compensation point (2- 4 mmol/l); and Zone 3 as above the respiratory compensation point > 4 mmol/l). The duration spent in each zone is then multiplied by a coefficient relative to each zone, respectively 1 for Zone 1, 2 for Zone 2 and 3 for Zone 3.

Individual TRIMP (iTRIMP) (Manzi et al., 2009, Akubat et al., 2012) is a product from heart rates values (based on Banisters TRIMP), the total training time and a nonlinear coefficient for an individual player. The nonlinear coefficient derives from individual blood lactate measurements during a performance test and, therefore displays one of the most individualized approaches to monitor internal load.

1.2.4.1.3 Heart Rate Variability (HRV)

Heart Rate Variability (HRV) is the physiological phenomenon of variation in the time interval between heartbeats and is measured by the variation in the beat-to-beat interval. HRV is a sensitive and selective measure of mental stress (Hjortskov et al., 2004) and has been used in sports for understanding the autonomic nervous system reactions to training (Buchheit et al., 2010) (Plews et al., 2014) and recovery (Al Haddad et al., 2012, Al Haddad et al., 2010, Bucheit et al., 2009). Unwanted HRV values has been correlated with lower total high-intensity distance running covered in professional football players (Thorpe et al., 2015). The aim is to achieve an optimum equilibrium between parasympathetic and sympathetic reactions (Rodas, 2008). A higher HRV index would be related with greater parasympathetic activity (recovery reactions) whereas lower HRV index with a greater sympathetic activity (mental and physical stress reactions). Basically, a higher HRV means that heartbeats intervals between R waves are different, thus, with good adaptation ability. While low HRV appear as a depressed ability of the heart to adapt. Consequently, more than a parameter to monitor training load, HRV could be used as a fatigue marker for being aware of the status of the nervous system after exercising.

1.2.4.1.4 Ratings of Perceived Exertion (RPE)

One of the most economical tools that every coach can use regardless of having technology or not is to monitor the subjective player measurements of fatigue or the ratings of perceived exertion (RPE). Usually named as Borg Scale, the original scale introduced by Gunnar Borg rated exertion on a scale of 6-20. But years later constructed a category (C) ratio (R) scale, the Borg CR10 Scale. The Borg scale can be compared to other linear scales such as the Likert scale or a visual analogue scale. The sensitivity and reproducibility of the results are very similar. The scale was firstly graded from 6-20 because of the similarities from the heart rate of an adult when multiplied by ten.

CR10 scale is affected by external load like high-speed running distance, and the number of impacts and accelerations (Gaudino et al., 2015) and players need to follow and educational period for familiarizing themselves. As this scale could be a good marker for monitoring training load, is still a general parameter. The problem of CR10 is that is a mix of aerobic and anaerobic elements. It has been demonstrated that HR explains RPE in a 50% and a 57.8% if blood lactate is added (Coutts et al., 2009). Hence, is difficult to extract what percentage of the subjective fatigue corresponds with what factors. Also, RPE cannot be used as a predictor of performance (Brink et al., 2010), lowest or higher scores of RPE would not mean better marks in a test as there is a strong inter-individual response. Therefore, it is not the best way to interpret the values inter-personally but longitudinally intra-personally.

The evolution of RPE is the session-RPE (Coutts, 2003), something similar to TRIMPs, unifying duration (time) and intensity (CR10-scale instead of HR). This method was proposed to quantify the internal training load (Foster, 1998) and was developed to eliminate the necessity of using HR monitors or other methods of assessing exercise intensity. Session-RPE is the result of multiplying the whole training RPE and the total time of a particular training session. Session-RPE in soccer has been demonstrated as a good indicator of internal load (Coutts, 2003, Impellizzeri et al., 2004) and has strong correlations with HR zones (Borresen and Lambert, 2008). RPE method is a simple, valid, and reliable tool. However, the addition of HR monitoring and blood lactate may aid in understanding some of the variance that session RPE does not explain.

1.2.4.1.5 Questionnaires

The use of questionnaires can be a simple and inexpensive tool for monitoring the training load and training responses. Nevertheless, the data obtained from these questionnaires rely on subjective information. As well as the RPE, athletes are able to manipulate overestimating or underestimating provided info. The most commonly used questionnaires are the Daily Analysis of Life Demands for Athletes (DALDA) (Freitas et al., 2014), the Profile of Mood States (POMS) (Morgan et al., 1987), Recovery-Stress Questionnaire for athletes (REST-QSport) (Martinent et al., 2014) and the Total Recovery Scale (TQR) (García-Concepción et al., 2015).

One of the problems for that kind of tool is that some factors has to be controlled like the time taken to complete the questions (avoiding fatigue), sensitivity of questionnaire, type of response required (written answers or check list) and the time of day of completion. In any case, questionnaires can provide simple and useful subjective information but they need to be carefully administrated.

1.2.4.1.6 Biomarkers

One of the first biomarkers in the world of sport and popularized in athletics was the use of lactate (Foster et al., 2017). Lactate was considered a must-have control test by physiologists during the last decades as they could monitor if their athletes were training below their respective anaerobic thresholds when exercising (Foster et al., 2017). As a precursor of live monitoring, let us call it almost-live monitoring, because results were quite fast in comparison with blood analysis. Some physiologist started to use it in football, but one of the biggest problems they found was the incapacity of testing 20 players at the same time during drills and also some scientific approaches that did not correspond with the football demands. The irrelevant importance of lactate in football where all the players will perform actions in which this substrate will peak during games and would not be important to control, as they will inevitably appear. Athletics, are purely conditioning based in some disciplines, with exclusive importance in not overpassing these thresholds. For example, long distance running, where the higher your aerobic threshold the greater constant pace you will be able to perform. Obviously, if you do not get into an anaerobic state you will last longer in the race. Lactate monitoring here could be helpful to check between sets that you are on the right training way. However, there

are a several potential limitations to the use of regular monitoring of lactate concentrations during training and competition. These include inter-individual and intra-individual differences in lactate accumulation depending on hydration status, diet, ambient temperature, glycogen content, previous exercise and amount of muscle mass utilized (Borresen and Lambert, 2008).

As well as lactate, another biomarker is creatine kinase (CK) and myoglobin that are indirect markers of muscle damage in the cells. Increments in CK after games has been correlated with the distance and the number of sprints performed during the game, while myoglobin just with the number of sprints (Thorpe and Sunderland, 2012). This information is useful in terms of understanding the anticipatory response of the body without measuring biomarkers. If our fastest players who usually rely more on their speed, perform more number of sprints, they will probably have a greater muscle damage response than others, thus, nutritional intake and recovery methods could be adjusted properly in a predictive way. Nevertheless, caution in the use of CK must be considered as there is a large variation of ~30-40% between games and post 24h and 48h (Russell et al., 2015).

Measurements of salivary cortisol and testosterone have been shown to be related to performance in the overreached athlete (Papacosta and Nassis, 2011). Another hormonal measures like the salivary immunoglobulin A (immune functions) are still expensive, equally elevated times for analysis are required to analyze the results (Robson-Ansley et al., 2009) becoming useful but with regarding with limited application in daily basis.

In any manner, the future resides in merging different methods. For example, measuring general markers of muscle damage as CK with infrared thermography images that could give us the specific location of the problem (Bandeira et al., 2012). This way, the thermal camera could delimitate the regions with abnormal temperature asymmetries and biomarkers just confirm us the gravity of this damage.

In summary, the use of biomarkers as indicators of internal load are currently not justified based on the limited research in this area and because they can be costly, time consuming and impractical in a football context (Halsen, 2014a).

1.2.4.2 External load

External load is defined as the work completed by the athlete, measured independently of his or her internal characteristics (Wallace et al., 2009). It can be derived from measures of a player's movement during exercise (Scott et al., 2013) and is defined by variables such as time, distance, weight etc. that is opposed on players.

1.2.4.2.1 Global Positioning Systems (GPS)

The relevance of Global Positioning Systems (GPS) in football has recently increased. From 2005- 2010 indexed papers in Pubmed about “GPS and soccer” were 4 and increased in the period of 2010-2015 until 56. Tracking and monitoring player’s displacements has become interesting to specify movement demands during competition, thus creating more specific approaches to the game analysis. GPS technology in team sport permits measurement of player position, velocity, and movement patterns via satellite-based navigational technology. This tool was originally devised for military purposes, but after some years it was unveiled and authorized for commercialization in other fields like sports science.

Modern GPS devices has different technical aspects, one of the most important is the sampling rate in hertz (Hz). Usually, GPS has 1-Hz, 5-Hz and 10-Hz (Cummins et al., 2013). The higher the sampling rate is the better because more data will be transferred per second. Therefore, that will allow sport scientists to measure precisely variables that otherwise would be difficult to control because of the remarkable necessity of more data points per unit of time like accelerations and high-speed running.

GPS is used to extract data from movement demands, most used parameters are among others: total distance covered, relative distance covered per minute, high-speed running, high-speed running per minute, total number of sprints, relative sprint distance covered per minute, number of impacts, body load, collisions, accelerations and decelerations.

This technology could be useful to monitor the specific demands of each one of the positions (defender, midfielders and attackers) (Suarez-Arrones et al., 2014a) and to categorize both absolute and relative physical parameters that a player will expect to perform during a competitive game (Suarez-Arrones et al., 2014b). In addition, injured

players could be controlled by comparing their metrics with previous data or test of the same drills repeated after the injury as a return to play criteria. Besides, to study the relationship between training load and the probability of suffer and injury (Gabbett and Domrow, 2007) (Gabbett, 2010), as well as to monitor fatigue within and between matches (Higham et al., 2012). GPS data could also help us to predict of how external load will affect internal load in soccer players (Gaudino et al., 2015).

1.2.4.2.2 Accelerometers

The triaxial accelerometer measures a composite vector magnitude by recording the sum of accelerations measured in three axes, which corresponds with X, Y, and Z planes. As part of the micro technology devices, accelerometers are the responsible for measuring accelerations, decelerations, ground contact, collisions, impacts and body load (expressed as G-force) (Cummins et al., 2013). Combining both accelerometers and GPS is the best way to record the external load. In addition, there are some cases in which GPS signal is unable to reach the device, mainly when perform indoor training. In those cases, accelerometers would be the only one to measure external load parameters.

1.2.5 RECOVERY STRATEGIES

Professionalization of elite football has lead players to play consecutive matches every 3 or 4 days, in the case of Spain because of multiple competitions like Copa del Rey, Europa League, Champions League Even Euro Cup and World Cup, as well as the Qualifiers for each one. Maximal performance is continuously demanded throughout the entire competitive season, which creates difficulty in achieving optimal fitness in all competitive games (Reilly and Ekblom, 2005). The complete recovery of the physical performance may not be achieved in some cases, which might result in underperformance or injury. During congested calendars, recovery strategies are required to reduce the risk of injury, decrease post-match fatigue, regain performance faster and to optimize the physical fitness of the players (García-Concepción et al., 2015, Nedelec et al., 2013).

Recovery is an individualized process, mainly because each person responds in different ways to the same standardized training (high-responders vs low-responders) (Mann et al., 2014). That will vary amongst individuals due to factors such as training status, sleep, psychological stress, and habitual physical activity. There are several

recovery methods that will aid in the recovery process; most used ones are described below.

1.2.5.1 Cryotherapy

Cryotherapy is defined as the cooling of an area with a medical aim. One of the most used recovery methods is the use of cold in several ways like cold-water immersion (CWI) and whole-body cryotherapy (WBC). Unless CWI and WBC are extremely different in nature (cold water vs cold dry air), both are able to achieve physiological benefits. CWI acute analgesic effects could be produced by both temperature and pressure factors (Wilcock et al., 2006) whereas pressure does not affect WBC. The cold dry-air of the WBC is usually between -100°C and -140°C, advantages include decreased tissue temperature, reduction in inflammation, analgesia, and enhanced recovery following exercise (Bleakley et al., 2014).

The different cold water immersion (CWI) protocols that have been described in the scientific literature present a wide variety of times and temperatures (Nedelec et al., 2013, Elias et al., 2013, Poppendieck et al., 2013, Wegmann et al., 2012). CWI protocols range from intermittent (Rowell et al., 2011, Delextrat et al., 2013) to continuous (Ascensao et al., 2011, Elias et al., 2012, Elias et al., 2013), with a total immersion time established as between 10-14 minutes at 10-14°C (Ascensao et al., 2011, Elias et al., 2013, Elias et al., 2012, Delextrat et al., 2013, King and Duffield, 2009).

When CWI is applied after the effort relevant physiological responses are observed: lower CK and myoglobin concentrations (Ascensao et al., 2011, Bailey et al., 2007), lower levels of inflammation (Ascensao et al., 2011), fatigue (Delextrat et al., 2013, Rowell et al., 2009) and muscle soreness (Rowell et al., 2009, Ascensao et al., 2011, Bailey et al., 2007). Additionally, improved performance in anaerobic performance activities, such as sprinting (Ingram et al., 2009), maximal strength (Ingram et al., 2009, Bailey et al., 2007) and counter-movement jump (CMJ) (Delextrat et al., 2013, King and Duffield, 2009), have been noted. Other benefits are those related to the nervous system, with higher levels of parasympathetic reactivation after CWI in comparison with active recovery methods (Bastos et al., 2012), thermoneutral-water immersion (TWI) (Al Haddad et al., 2010) or the absence of a recovery protocol (Bucheit et al., 2009).

Thermography could be useful to determine the acute cooling effects of CWI in skin temperature of professional athletes and the evolution of the temperatures of the different body regions during the rewarming process. As cryotherapy is one of the most studied topics in the IRT field (Karki et al., 2004, Costello et al., 2012b, Boerner et al., 2015), there is a lack of scientific literature assessing thermal recovery after CWI by means of IRT specifically in professional football players.

Recent cryotherapy guidelines published by Bleakley and Hopkins (2010) recommend Tsk reductions between 5 and 15°C whereas experts consider 12°C as the Tsk limit due to the risk of injuries.

The objective of one of the studies from this dissertation was to determine the acute effects of CWI on the skin temperature (Tsk) of professional football players by means of IRT, focusing on the cooling and rewarming processes and differences between dominant and non-dominant sides.

1.2.5.2 Stretching

Stretching is performed by many teams around the world, usually with the idea of preventing injuries and promoting recovery. Those benefits are thought to be gained via increment of the range of motion (ROM) and the decrement of musculotendinous stiffness. Static stretching produces greater changes in ROM holding the position between 15-30 seconds (McHugh et al., 1992) (Bandy and Irion, 1994). However no scientific evidence has been provided yet for stretching as a way to improve subjective perception of muscle soreness (Herbert et al., 2011) or increment football player's recovery (Dawson et al., 2005, Kinugasa and Kilding, 2009).

1.2.5.3 Sleep

Sleep is probably the best method to recover as well as the most economical one. 8 hours of sleep are required to prevent the neurobehavioral deficits associated with sleep loss (Belenky et al., 2003). One of the aims of sleep is to enhance recovery, and deep sleep has been unveiled as a way to get anabolism via an increase in growth hormone release (Halsen, 2014b). Differences in sleep/wake behaviors has been reported between individual and team players in terms of total sleep time, with team-sport players sleeping 7 hours vs 6.5 of individual athletes (Lastella et al., 2015). Usually, team athletes before

playing important matches such as finals or play-offs, often report sleep disruptions. The majority of humans could bear with it, but sleep loss could reduce on the following day physical performance (Reilly and Piercy, 1994), cognitive performance (Belenky et al., 2003) as well as metabolic and immune functions (Vgontzas et al., 2004).

After games, players also suffer from those problems as normally their nervous systems continuous to be altered. However, any loss of sleep could be partially recovered on the next night, or at least, during the afternoon with a small nap. Depending on the time the match finishes, travel schedules, time zones crossed during flights and other external factors could affect players' sleep-wake cycle, thus not recovering completely from the efforts of the game.

1.2.5.4 Nutrition & hydration

Considered as one of the main pillars, nutrition in sport could have a complete doctoral dissertation to discuss about. Basically, nutrition has been used for maximizing muscle-damage repair and replenish substrate stores. However, the quantity (how much), timing (when) and composition (what) of each meal is required for improving the effectiveness of the intake. Whereas the hypothesis of how sleep affects glycogen regulation remains to be fully elucidated (Petit et al., 2015), it is known the importance for avoiding sleep deprivation as it is negatively associated with performance (Thun et al., 2014). After exercise, muscle accelerates protein breakdown and muscle protein synthesis (Bowtell et al., 1998). Consequently, importance shifts into obtaining a positive protein balance to regenerate muscle damage (Ivy, 2004) and to decrease the metabolic stress produced in the organism by means of training adaptations (Katz and Westerblad, 2014). Whereas adding proteins to a carbohydrate intake could reduce both CK and myoglobin concentrations as well as reduced muscle soreness in comparison with just carbohydrate (Nedelec et al., 2013). There is still insufficient information to consider that fact as an evidence-based statement, as it is difficult to conclude that there is a relationship between protein and carbohydrate intake and muscle function recovery, muscle soreness and markers of muscle damage (Pasiakos et al., 2014). Nevertheless, essential amino acids must be included along with carbohydrate for enhancing anabolism and maximizing the stimulation of muscle protein synthesis (Tipton and Wolfe, 2001). The intake of both amino acids and carbohydrates has been demonstrated to be more effective in increase muscle protein synthesis when taken before than after exercise (Wolfe, 2001).

Often called as the “window of opportunity”, because of the more active period in which enzymes associated with glycogen synthesis. It is assumed that there is an optimal time for post-match energy replacement of the 2 hours after the completing the training or game (Ivy et al., 1988). During this period, it would be interesting to fight not only glycogen depletion but dehydration.

Dehydration counts for nearly a 2% of the total body weight loss during a competitive game (Edwards and Noakes, 2009) but there is a large individual variability in sweat loss and hydration status between players (Maughan et al., 2007), hence, the importance of individualizing fluid-replacement strategies. If possible, nutritional strategies during exercise should be added to decrease the impact of glycogen depletion and sustain football skill performance by consuming sucrose or maltodextrin at rates of 30-60 g/h (Russell and Kingsley, 2014). In case of impossibility for in-exercise replenishment, glycogen repletion could be achieved by ingesting a high glycemic index beverage immediately after exercise composed by a beverage of 1.2 g carbohydrate/kg/h, took with intervals of 15–60 min for up to 5 hours (Jentjens and Jeukendrup, 2003).

1.2.5.5 Electrical stimulation

Electrical muscle stimulation, also known as neuromuscular electrical stimulation (NMES) or electromyostimulation, is the elicitation of muscle contraction with surface electrodes to stimulate motor neurons using electric impulses.

The expected reactions of NMES in recovery are related with physiologic responses like increased muscle blood flow (greater rates of muscle metabolites removal) and the analgesic effects (pain reduction) (Babault et al., 2011).

Benefits of NMES are equivocal, whereas greater decrements in muscle soreness has been reported in comparison with other recovery methods like passive rest or water-aerobic exercises, non-significant differences has been found in anaerobic tests like CMJ, squat jump and 10-meter sprint (Tessitore et al., 2007, Tessitore et al., 2008).

NMES effects have been reviewed in terms of how they affect in the recovery of athletic performance and incidence on muscle soreness reduction, results confirmed positive effects on lactate removal (Neric et al., 2009) and CK activity (Vanderthommen et al., 2007), but there is a lack of scientific evidence regarding performance indicators

including muscle strength (Babault et al., 2011). Despite the fact that NMES has potential advantages for athlete recovery, there is still a necessity of more studies (Kovacs and Baker, 2014).

1.2.5.6 Massage & myofascial release

There are several modalities of massage that depending on the pressure and rhythm of the tissue manipulation would be differently denominated. Expected benefits for massage are the increased metabolic waste product clearance by means of increased blood flow to the region, however, research has been unable to demonstrate that (Tiidus and Shoemaker, 1995, Shoemaker et al., 1997, Wiltshire et al., 2010).

Massage could attenuate inflammatory signaling after exercise-induced muscle damage (Crane et al., 2012). Some studies obtained better lactate removal rates (Ali Rasooli et al., 2012) whilst others could not (Hemmings et al., 2000, Wiltshire et al., 2010). Additionally, improved mood state (Micklewright et al., 2005), delayed onset muscle soreness (DOMS) (Farr et al., 2002) (Zainuddin et al., 2005), subjective perceptions of muscle soreness and increased recovery could be found in literature (Hemmings et al., 2000).

Auto-massage or self-myofascial release with foam-rollers has become a common and economical modality to supplement traditional methods of massage. One of the strongest keys of foam-rolling is to increase ROM without a subsequent decrease in muscle activation and force (MacDonald et al., 2013, Macdonald et al., 2014). Physiologically, can reduce arterial stiffness and improves vascular endothelial function (Okamoto et al., 2014). Whilst benefits on perceptions of DOMS has been observed (Pearcey et al., 2015, Macdonald et al., 2014), performance indicators has been unable to be improved (Healey et al., 2014) as well as contractile markers and Tsk increment (Murray et al., 2016). The problem of these methods is the difficulty of determining the exact pressure necessary for each muscle and the time required for it as well as how the type of material of the foam rollers affects the myofascial release.

1.2.5.7 Active recovery

Active recovery (AR) strategies involve prolonged (15-30 minutes) low intensity activities like running, biking or swimming. Used in professional football with a penetration of 81% in some countries (Nedelec et al., 2013), the efficacy of AR methods remains unclear (Rey et al., 2012, García-Concepción et al., 2015). García-Concepción et al (in press) studied the responses to 3 types of AR methods during 4 weeks: Jogging-Stretching, Jogging-Leg elevation and Stretching-Leg elevation. They concluded that there were non-significant differences between all the methods for RPE and HR, as well as Rey et al (2012), who were also unable to find benefits on RPE and HR with a 12 minutes submaximal running and 8 min of static stretching in comparison with 20 minutes of passive rest. AR had no effects on the recovery pattern of four neuromuscular (sprint, CMJ, isokinetic strength and perceived muscle soreness) and three biochemical parameters (blood CK, urea and uric acid) between the active and passive recovery groups (Andersson et al., 2008). Neither oxidative stress markers nor antioxidants were improved after it (Andersson et al., 2010). In fact, unwanted results could exist like lower rates of muscle glycogen re-synthesis if compared with passive rest (Choi et al., 1994) despite greater lactate removal rates and enhanced pH recovery (Sairyo et al., 1993, Sairyo et al., 2003, Fairchild et al., 2003). According to these results, AR performed immediately after exercise would not present additional benefits as a recovery strategy. Further research is needed in terms of the type of exercise, duration and intensity.

1.2.5.8 Compression garments

The aim of compression garments is to increase lower limb blood flow and venous return by the application of pressure with a tight piece of clothing. Usually worn because they are thought to increase post-exercise recovery, there is still a lack of evidence-based to support the use of compression garments as a recovery method (MacRae et al., 2011). There is no visible relation between applied pressure and obtained benefits after exercise, since these effects has been obtained with both low and high pressures (Beliard et al., 2015). Miyamoto and Kawakami (2014) confirmed that a pressure intensity of 15-20 mm Hg at the thigh is enough to reduce the development of fatigue of exercising muscles during submaximal running, however the same author concluded in another study that a graduated pressure is not essential for reducing the development of muscle fatigue (Miyamoto and Kawakami, 2015).

Faulkner et al. (2013) found that athletes perceived a lower effort perception after a training composed by 6 sets of 400-meters sprint training, despite not detecting differences in overall athletic performance. Coza et al. (2012) concluded that compression improved oxygenation during short-term exercise by means of changes in tissue blood flow and perfusion, positively affecting performance because of greater oxygen availability during exercise bouts. Whereas reported better rates of comfort (Hooper et al., 2015) and lower perceived muscle soreness in multiple studies (Duffield et al., 2010, Kraemer et al., 2010, Hill et al., 2014), effects on performance beyond subjective measurements remains to be fully elucidated (MacRae et al., 2011).

Neither positive nor negative effects has been found for markers of exercise-induced muscle damage (CK) and inflammation (CRP) (Hill et al., 2014), repeated-sprint performance (Duffield and Portus, 2007, Duffield et al., 2008), maximal voluntary isometric contraction (Hill et al., 2014), peak power output (Duffield et al., 2008), isokinetic strength (Duffield et al., 2010), sprint, agility and CMJ (Davies et al., 2009). Although there is a positive trend towards athletic performance and recovery, consideration should be given to the magnitude and practical relevance of these effects (Born et al., 2014a) as in our case, should be proved in athletes and not in general population.

1.2.5.9 Led therapy

The use of phototherapy in sport implicates the therapeutic use of light to attend musculoskeletal injuries. Low-level laser is a form of laser medicine used in physical therapy treatment that uses low-level (low-power) lasers or light-emitting diodes to alter cellular function. This technique has become beneficial in animals for the treatment of both acute and chronic musculoskeletal disorders by enhancing blood flow circulation (Ihsan, 2005), improving tissue repair (Enwemeka et al., 2004) and pain control (Ferreira et al., 2005, Laakso and Cabot, 2005).

Led therapy has different modes depending on the wavelength (between 600-850 nm) and the applied dose, which depends on the number of diodes (single or multi) and energy irradiated (Jules per point). However, there is still a lack of evidence to translate the exact dose from animal models to that required in humans (Borsa et al., 2013). Biologically, light particles or photons are absorbed by chromophores (molecules

responsible for its color). Then, the light energy is converted into chemical energy inside the plasma membrane, which induces changes in membrane permeability and transport mechanisms. That promotes intracellular changes in pH, ion concentrations, and membrane excitability (Klebanov et al., 2001).

Muscle damage after exercise has 2 phases: primary and secondary. Whereas the mechanical stress of exercise is related with primary muscle damage, secondary muscle damage results after the inflammatory response caused by the cascade of biochemical reactions (Borsa et al., 2013). Hence, phototherapy provided before exercise could protect muscle cells from primary and secondary damage, whilst if provided after injury it would protect cells only from secondary damage (Borsa et al., 2013).

Leal Junior et al. (2009b) studied the effects of low-level led therapy on 10 professional volleyball players. They could postpone the development of skeletal muscle fatigue, as well as obtain lower post-exercise blood lactate levels and CK and CRP release inhibition. These results are similar to other studies performed with athletes (volleyball, soccer and runners) and general population that observed benefits in the application of phototherapy (Leal Junior et al., 2009a, Leal Junior et al., 2011, De Marchi et al., 2012, de Almeida et al., 2012, Ferraresi et al., 2015).

1.2.6 TESTING ASYMMETRIES

Symmetry comes from the Greek word *symmetria* and means "agreement in dimensions, due proportion, arrangement". The theory of sexual selection suggest that men would prefer symmetry in women's faces, the more attractive the more symmetrical (Grammer and Thornhill, 1994). Furthermore, human body is characterized for bilateral symmetry that is a good indicative of health and genetic fitness (Jones et al., 2001, Rhodes and Zebrowitz, 2002) but this is hardly seen in competitive sport as the majority of disciplines are considered asymmetrical.

Symmetry is an important property of both physical and abstract systems. The nature of asymmetries has been studied not only in humans but in different disciplines like chemistry, physics and mathematics. Louis Pasteur, a French chemist who studied the biological molecules, said that these molecules were asymmetric because the physical forces that lead their formation were asymmetric by themselves.

Whereas some studies failed in finding significant interactions between symmetrical characteristics and physical fitness (Tomkinson and Olds, 2000, Tomkinson et al., 2003), other research found that symmetry was related with greater performance parameters (Manning and Pickup, 1998). In our case, football players rarely uses both legs equally, tending to be asymmetrical in terms of strength imbalances between limbs (Zakas, 2006) because of limb dominance. Careful should be taken as asymmetries are thought to be linked with increased chances of sustaining an injury (Kiesel et al., 2014).

However, the type of asymmetry should be stated and categorized about the modes of measuring it as there are several ones. In this section, asymmetries will be only focus on: thermal, strength & power, range of motion and functional movement.

1.2.6.1 Thermal asymmetries

Human Tsk in a healthy state should be distributed symmetrically between ROIs (Niu et al., 2001, Uematsu et al., 1988b). Side-to-side comparisons of bilateral body areas has been used to detect abnormal Tsk patterns (Uematsu et al., 1988a). Different populations has been studied in regards of thermal asymmetries, from general healthy population of Taiwanese (Niu et al., 2001) and Brazilian subjects (Marins et al., 2014a), as well with specific population like football (Marins et al., 2014b, Gómez Carmona, 2012) and basketball players (Sampedro et al., 2012).

Thermal asymmetry (TskAsy) could allow to detect training overload and skeletal muscle fatigue and may therefore aid to prevent injuries (Gómez Carmona et al., 2008, Gómez Carmona, 2012 (Badža et al., 2012, Sands et al., 2011, BenEliyahu, 1990, Barcelos et al., 2014)). Despite the inability of thermography to diagnose musculoskeletal injuries (Sanchis-Sanchez et al., 2014b), IRT can help as a support tool for screening and early diagnosis in emergencies (Sillero-Quintana et al., 2015) likewise for ruling out fractures (Sanchis-Sanchez et al., 2014a).

Tsk asymmetries were firstly studied by Uetmatsu in 1988, where he quantified the normal values of contralateral Tsk differences in healthy persons for both upper and lower limbs ROIs. In the same study, the author followed four subjects during a period of almost 5 years, finding differences in Tsk asymmetry year by year. In our opinion, with just two or three thermal pictures per year, is impossible to conclude anything as there are a lot of factors that could affect the data (Fernández-Cuevas et al., 2015b).

In the first studies, the asymmetry considered as normal was set with a difference of 1.0°C (Feldman and Nickoloff, 1984, Barnes, 1963); nevertheless, during the last year IRT has become more accurate, thus narrowing the asymmetry ranges (Fernández-Cuevas et al., 2015b) (table 6). Asymmetries in the lower limb (anterior and posterior thigh, knee and leg) has been found to be below 0.3°C both in normal population (Niu et al., 2001, Uematsu et al., 1988b, Marins et al., 2014a, Marins et al., 2014b) and soccer players (Marins et al., 2014b).

A more practical approach has been established in the review of (Marins, 2015), where they proposed a classification of asymmetrical risk depending on Tsk bilateral differences (table 7). They explained that controlling the asymmetries would aid not only to prevent injuries, but to monitor injuries, and to monitor and quantifying the assimilation of training load.

Table 6. Normal Tsk Asymmetries depending on type of subject and ROI. Reproduced from (Fernández-Cuevas et al., 2015b)

Year	Author	N	Subjects	ROI	Asymmetries
1963	Barnes (Barnes, 1963)	100	Patients	Breast	$> 1^{\circ}\text{C}$
1984	Feldman & Nickoloff (Feldman and Nickoloff, 1984)	100	Healthy	Normative data	$> 1^{\circ}\text{C}$
1985	Uematsu (Uematsu, 1985)	32	Healthy	Knee	0.24°C
1988	Uematsu et al. (Uematsu et al., 1988a)	90	Healthy	Forehead, leg & foot	$0.18 (\pm 0.18)$ to $0.38^{\circ}\text{C} (\pm 0.31)$
1990	Ring (Ring, 1990)	150	Healthy	Legs	$0.17 (\pm 0.16)$ to $0.28^{\circ}\text{C} (\pm 0.22)$
1992	BenEliahu (BenEliahu, 1990)	70	Patients and healthy	Knee	0.5°C
1999	Zhu & Xin (Zhu and Xin, 1999)	233	Healthy	Different ROIs	0.6 to 1.8°C
2001	Niu et al. (Niu et al., 2001)	57	Healthy	Different ROIs	0.2 to 0.5°C
2009	Hildebrandt & Raschner (Hildebrandt and Raschner, 2009)	10	Healthy	Knee	0.1°C
2012	Vardasca (Vardasca et al., 2012)	39	Healthy	Total body	$0.4 \pm 0.3^{\circ}\text{C}$
2014	Bouzas Marins et al. (Bouzas Marins et al., 2014)	100	Healthy athletes	Legs	$< 0.2^{\circ}\text{C}$

Table 7. Attention level in regards of Tsk asymmetry (Marins, 2015).

TSK ASYMMETRY	ATTENTION LEVEL
$\leq 0.4^{\circ}\text{C}$	Normal
$0.5 - 0.7^{\circ}\text{C}$	Follow-up
$0.8 - 1^{\circ}\text{C}$	Prevention
$1.1 - 1.5^{\circ}\text{C}$	Alarm
$\geq 1.6^{\circ}\text{C}$	Gravity

IRT is sensible to detect the thermal evolution of an injury by diminishing the Tsk asymmetry between acute (0.8°C), short (0.7°C), intermediate (0.5°C) and long term injuries (0.4°C). Thus, becoming a useful tool to provide feedback about thermal re-stabilization. However, those asymmetries need to be understood in terms of

individualizing thermal responses in non-injured subjects. For example, a judoka could show an average asymmetry of 0.4°C (figure 4) in the grasping forearm (Arnaiz Lastras et al., 2011), that would probably not lead to a future injury, as that is part of his thermal profile (predominance of asymmetries in time), anyway we should observe the evolution of this asymmetry level as that 0.4°C could be his baseline value. The same would happen in different sports and ROIs determined by the specific demands required, becoming a necessity to study each thermal profile itself. There are many factors that could affect Tsk asymmetry like past injuries or clinical interventions, however, analyzing all this factors in a holistic way could give us enough information to understand what is critical from the injury prevention perspective or not.

Figure 4. Anterior (left) and posterior (right) views of a judo athlete characterized by a thermal asymmetry in favor of the right grasping forearm (Arnaiz-Lastras, 2011).

1.2.6.2 Strength asymmetries

There are different forms of monitoring strength asymmetries: bilateral or inter-limbs (differences between limbs) and unilateral or intra-limbs (ratios between muscles of the same limb) usually performed with isokinetic tools at different angular velocities (Fousekis et al., 2010).

Bilateral asymmetries could be expressed in terms of the difference in % of dominant vs non-dominant or right vs left limbs power production, this way, one leg would have for example a 12% asymmetry in favor of the dominant side. On the other

hand, unilateral asymmetries are often expressed as ratios 66/100 or 2/3. Thus, asymmetries could be considered risk factors for sustaining future injuries (Fousekis et al., 2011).

Some of the features that affects strength asymmetry are training background, which has been demonstrated that influence more than the age of the players (Gur et al., 1999), maturity status (Rumpf et al., 2014), training level (Cometti et al., 2001), playing position (Daneshjoo et al., 2013) and type of sport (Magalhaes et al., 2004).

In football, Rahnema et al. (2005) studied the preferred leg for kicking the ball in 41 elite and sub-elite players. He observed a lower knee flexor strength on the preferred leg, aspect usually considered as a risk factor that would lead to a possible injury. A few years later, Valderrabano et al. (2007) found differences in muscle electromyographic signal and torque between the dominant and non-dominant lower limbs. Schiltz et al. (2009) found no dominant side effect on the explosive strength isokinetic imbalances in basketball players. In an opposed way, subjects with a history of knee injury obtained greater percentage of asymmetries for leg asymmetry ratios (>10%) and unilateral variables (>15%).

Fousekis and collaborators (2011) studied isokinetic variables as a predictive element of non-contact hamstring strain. They found that the players with functional asymmetries were at a higher risk of being injured in hamstrings. Furthermore, if the hamstring injury is not avoided with preventive strategies, there would be variables strongly affected like the ability to produce horizontal force (Mendiguchia et al., 2014), thus, creating the necessity to develop special drills to target and improve that parameter. Whereas strength imbalances presents conflicting evidence in terms of predicting a hamstring injury (van Beijsterveldt et al., 2013) and there is a large inter-subject variability in terms of asymmetries (Buckeridge et al., 2014), a cohort study on 462 players done by Croisier et al. (2008) showed that a isokinetic strength imbalance could led to a future injury if these ratios are not normalized along the season. Nevertheless, Zvijac et al. (2013) after studying data from the NFL Scouting Combine from 2006 until 2011 was unable to predict the risk of hamstring injuries with isokinetic strength values collected from collegiate players.

As movement activity, itself is hard to be fully symmetrical, one of the biggest problems is that symmetry impairments during running exists beyond having or not an injury. Rumpf et al., (2014) measured power, horizontal and vertical force variables while running in a non-motorized treadmill, finding that non-injured population could have a typical asymmetry of 15-20% during running tasks, while on the other hand other studies found a normal value of 10% in healthy pain-free population walking (Lathrop-Lambach et al., 2014). The difference between percentages could be explained because of the increased speed and required coordination for running in comparison with walking. Moreover, those asymmetries are the same whether the athlete is injured or not (Zifchock et al., 2008) and there is no relationship between the metabolic cost of running and limb asymmetry when comparing occasional vs skilled runners (Seminati et al., 2013), therefore becoming difficult to assess if symmetry (in terms of movement gait) could affect performance or future injuries.

However, in terms of training, coaches should not be afraid of working with asymmetrical movements. Lauder et al (2008) studied the movement patterns of the unilateral power snatch, finding that unilateral variations of weightlifting were beneficial in terms of providing a different training stimulus to athletes. One of the key aspects of using unilateral loads is that stability is more targeted than during bilateral exercises.

1.2.6.3 Range of motion asymmetries

Range of motion (ROM) refers to the distance and direction a joint can move between the flexed position and the extended position. ROM is a critical factor that could affect movement dysfunctions at different levels. Following Gray Cook's joint by joint approach (Cook, 2010), performance specialists will look for joint mobility or stability depending on the region as seen in figure 5. Therefore, we will specially focus on lower limb ROM for ankle and hips, given little detail to thoracic spine, neck and shoulder to explain how ROM impairments affect performance.

Figure 5. Joint by joint Gray Cook's approach (Cook, 2010).

In squat exercises, a restriction in ankle dorsiflexion results in a decreased quadriceps activation and inappropriate movement patterns that could lead to patellofemoral pain (Macrum et al., 2012).

In terms of groin pain, adductors strength and hip rotation appears as the strongest key points to be controlled (Taylor et al., 2011, Malliaras et al., 2009). Ellison (1990) studied how it affected low back pain in healthy subjects, finding that this pathology was linked to ROM imbalances in consonance with other studies (Cibulka et al., 1998, Roach et al., 2015). Almeida et al. (2012) also demonstrated that judo athletes with low back pain history had hip rotation deficits and greater asymmetry between limbs. (Ellenbecker et al., 2007) examined elite tennis players and professional baseball pitchers hip active range of motion rotation, determining that asymmetries targeted in there may indicate abnormalities and further evaluations for applying rehabilitation in that zone. Particularly in American Football, anterior cruciate ligament injuries has been associated with hip internal rotation restrictions (Bedi et al., 2014). Partly explained because of the increased resistance to femoral internal axial rotation that is found in movements like cutting and pivoting activities included in change of directions (Beaulieu et al., 2014). However, caution is needed as an increment in passive hip ROM does not translate into better functional movement patterns (Moreside and McGill, 2013).

Another aspect to consider is the load imposed to both joints and muscles after training and competitive matches. That load needs to be carefully managed as it impacts on the impairment of hip strength and flexibility (Paul et al., 2014) as well as could

increase the risk of suffering lower body soft-tissue injuries if mismanaged (Gabbett and Ullah, 2012).

Despite the importance of lower limb ROM (ankle and hips), core or central mobility must be handled. The concept of rotation involves the use of kinetic chains as the movement is often generated through the hips to the distal extremities. Here, the thoracic spine regulates the link between upper and lower limb, which if it has a lack of endurance in the trunk muscles as well as deficits in hip and pelvis muscle strength and joint restrictions, will finish in spinal instability (Donatelli et al., 2012). Finally, in the upper limb it can be found that a shoulder mobility internal rotation deficit could be a good predictor of future injury in rugby players (McDonough and Funk, 2014) as well as a reduced cervical ROM (Lark and McCarthy, 2007).

1.2.6.4 Functional movement asymmetries

Before, we talked about Gray Cook's joint by joint approach, who is the inventor of the Functional Movement Screen test (abbreviated as FMS), FMS is composed by seven movements: Deep Squat, Hurdle Step, In-Line Lunge, Shoulder Mobility, Active Straight Leg Raise, Trunk Stability Push-Up, and Rotary Stability. These seven movements mix strength, flexibility, ROM, coordination, balance and proprioception and evaluate the kinetic chains as interdependent segments. Five of those movements are measured by a left-right analysis, this way asymmetries are obtained for determining potential injury risks factors. Depending on the quality of the movement punctuation would be achieved for each one (3=no compensation, 2=with compensation, 1= cannot perform the movement and 0=pain) and then added to the global result. The maximum score is 21 (7 movements per 3 points) and 14 is the cutoff for predicting time-loss injuries.

Whereas FMS has been correlated with performance outcomes in elite track and field athletes (Chapman et al., 2014) others could not find any relationship (Parchmann and McBride, 2011), however FMS was not created for measuring performance but for screening the quality of the movement patterns. Conflicting results has been obtained in reference to use FMS as an injury prevention predictor, whereas some studies has found that it could be a good tool for detecting future injuries (Chorba et al., 2010, Garrison et

al., 2015, Kiesel et al., 2007), others stated that FMS asymmetries were poor predictors of non-contact and overuse injury (Warren et al., 2014).

McGill et al. (2013) found that movement quality was not powerfully correlated neither with fitness or age. Previous studies of the same author (McGill et al., 2012) examined during 2 years a team of basketball players trying to predict injuries by means of movement quality test. They concluded that this question remains to be clarified in future studies.

1.3 JUSTIFICATION OF THE WORK

After this review, we think that the evaluation of the asymmetries in soccer could be an interesting method that could be included into the injury prevention protocols of the football teams and that the periodically quantification of the skin temperature could be an innovative method to understand how the recovery methods, and the training and match workloads affect the players thermal profile.

2. HYPHOTHESIS AND OBJECTIVES OF THE STUDY

2.1. HYPHOTHESIS

The training and recovery methods performed by soccer players could acutely affect their skin temperature profiles.

2.2. OBJECTIVES

2.1.1 PRIMARY OBJECTIVES

- a) To determine the acute effects of cold water immersion recovery protocols on Tsk.
- b) To determine the acute effects of different high intensity interval trainings in on Tsk.
- c) To investigate the acute effects of a football game on Tsk.

2.1.2 SECONDARY OBJECTIVES

- a.1 To compare the differences between two types of analysis Dominant and Non-Dominant vs Right and Left.
- a.2 To describe the thermal recovery process of Tsk during cooling and rewarming process after CWI in professional football players for both laterality (R-L) and Dominance (D-ND).
- b.1 To determine which are the thermal responses of Tsk in young football players between four common HIIT protocols in football.
- b.2 To determine the significant ROIs with skin temperature differences depending on the kind of HIIT.
- b.3 To assess the level of thermal asymmetry on different HIIT protocols.
- b.4 To determine subjective perception response depending on the HIIT protocol.
- c.1 To determine the thermal Tsk responses in young football players after a competitive football match.

3. METHODOLOGY

This dissertation is composed by three studies with different methodologies that are explained below. The ethical committee of the Technical University of Madrid (UPM) and the Faculty of Sciences for Physical Activity and Sport (INEF) approved all the studies as a part of the project “TermoRECOV” in accordance with the Code of Ethics of the World Medical Association (Williams, 2008).

In all the studies, the IRT Camera was placed 3 meters away from the subject, with a constant height of 0.7 meters and a subtending angle of 90° between the camera axis and the frontal plane of the lower limb (Tkacova et al., 2010). A non-reflective homogenous black background was located behind the subject to prevent IR reflections (Fernández-Cuevas, 2012). Values of 28°C for ambient temperature and 0.98 for emissivity were entered in the camera and were not modified during the study. The camera was turned on and auto-calibrated one hour before the data collection (Ammer, 2008) and it was not turned off to prevent any variability caused by the initial calibration process.

3.1. COLD-WATER IMMERSION STUDY

3.1.1 STUDY SAMPLE

The study sample was composed of the professional male football players of a first-division team in the Brazilian league ranked between the first four places. The exclusion criteria were a) having an injury, b) performing any type of training or undergoing any physiotherapy session in the 36 hours before the data collection, and c) being a goalkeeper.

After the exclusion criteria were applied, the sample was reduced to 9 players (table 8) who trained for at least 5 days per week during the previous 8 months. The team’s medical department approved the study as it was based on their recovery routine, which was the same throughout the season.

Table 8. Descriptive data of the sample from the CWI study.

	Mean	SD
Age (years)	28,49	5,02
Height (cm)	181,89	5,46
Mass (kg)	80,5	3,64
Body Mass Index “BMI” (kg/m ²)	24,40	1,90
Fat Free Mass Index “FFMI” (kg/m ²)	22,29	1,64
Fat Mass Index “FMI” (kg/m ²)	2,05	0,57
Body Surface Area “BSA” (m ²)	2,02	0,06
Lean mass (kg)	73,75	2,94
Body fat percentage (%)	8,35	2,16
BSA:Mass (cm ² /kg)	2,02	0,05

3.1.2 STUDY DESIGN

A repeated-measures design without a control group was performed to observe the effects of cold-water immersion on skin temperature for D-ND and R-L ROIs.

3.1.3 PROCEDURE

Figure 1 illustrates the protocol for the data collection. The players arrived at the training facilities at 10:00 A.M. 36 hours after playing an official match. They had not performed any kind of physical effort between the end of the match and the start of the data collection in order to decrease the effects of competition. The first thermograms were collected between 11:00 and 11:20 AM.

Figure 6. Protocol description. Official football match followed by 36 hours of rest. Pre IRT, CWI, Post IRT and Post10, Post15 and Post20 IRT screenings.

After donning training clothes, the players went directly to a room in which they analyzed the last match for one hour with the coach. Those players who met the inclusion criteria entered the data collection room and, after being informed by the physiologist of the medical staff about the protocol and aims of the study, signed their consent to

participate in the study. No one of the players reported factors that could influence IRT data acquisition (Fernández-Cuevas et al., 2015b) except that the temperature of the data collection room was a higher than the standard $28.1 \pm 0.28^{\circ}\text{C}$ vs $21\text{-}25^{\circ}$, with a humidity of $57.9 \pm 0.42\%$ as measured by a thermometer (Extech RHT20, FLIR® Systems, Sweden).

The cooling protocol consisted of 10 minutes of CWI (between $2\text{-}5^{\circ}\text{C}$) at hip level and a 20-minute follow-up. During that time, thermal images of the lower limb (anterior and posterior) were obtained before the immersion (Pre), immediately after the immersion (Post), and at 10 minutes (Post10), 15 minutes (Post15) and 20 minutes (Post20).

The first thermal image was obtained after 10 minutes of acclimation to room temperature (Marins et al., 2014c) in underwear in a standing position without contact with any of the body parts to be analyzed. The second thermogram was recorded immediately after the CWI and after removing the layer of water on the body with a microfiber towel without rubbing or pressing strongly against the skin. The third, fourth and fifth thermograms were taken, respectively, 10, 15 and 20 minutes after the CWI. Between thermograms, the players waited in the same room lying on a hammock with the back declined at 60° and the knees bent at 120° to avoid the contact of the analyzed regions of interest (ROIs) with any surface.

3.1.4 VARIABLES

Recorded variables were: water temperature pre-immersion and post-immersion, measured with a laser thermometer MINIPA MT-360, (MINIPA®, Brazil); skin temperature (T_{sk} in $^{\circ}\text{C}$) measured by IRT with a FLIR® T440 (FLIR® Systems, Sweden).

The software ThermaCam Reporter (FLIR® Systems, Sweden) was used to delimitate 6 ROI on the anterior part of the lower limb and 6 ROI on the posterior lower limb (Figure 2) corresponding with thigh, knee and leg for both anterior and posterior sides. The data collection and delimitation of the ROI was performed by the same thermography technician with more than 2 years of experience.

Figure 7. ROI division for anterior view in the right limb.

Figure 8. ROI division for posterior view in the left limb

The increments of skin temperatures (ΔT_{sk}) were obtained to quantify the acute temperature decrement between the Pre and Post moments (Cooling); the temperature rewarming between Post and Post10 (Rew10), between Post and Post15 (Rew15), and between Post and Post20 (Rew20); and the total rewarming between the initial temperature and after 20 minutes of water immersion (Rewarming). The cooling power (CoolPower) was calculated as the average of the percentage of Tsk decrement from Pre to Post for all ROIs.

The D-side was considered as the ROIs that pertain to the leg with which the player more effectively strikes the ball, while the ND-side as the opposite. All the ROIs were delimited with the same number of pixels per zone by creating a ROI within the limits marked by white bars (Figure 2) and cloning it by rotating it with the Y axis as a reference. Of note, the ROIs never included the border of the subject to prevent measurement errors by adding pixels from the background.

Anthropometric values of FFMI, FMI, lean mass and body fat percentage were calculated based on Jackson and Pollock equation for men (Jackson and Pollock, 1978) by a specialist certified in anthropometry with more than 10 years of experience.

Body surface area (m²) and BSA: mass ratio were calculated using the Du Bois equation using height (cm) and mass (kg) (Du Bois and Du Bois, 1989).

$$\text{Body surface area} = 0,007184 \times \text{height}^{0,725} \times \text{mass}^{0,425} \quad [1]$$

3.1.5 STATISTICAL ANALYSIS

The data are reported as the mean $\pm$ standard deviation (SD) in the text and tables. Exploratory data analysis was performed for identification and correction of extreme values. Normality and homoscedasticity were tested using the Kolmogorov-Smirnov test and the Bartlett's criterion, respectively. The analysis of variance (ANOVA) with two factors was performed twice (Time x Dominance and Time x Laterality) was used to establish the difference between means of the effect of CWI on absolute Tsk and Δ Tsk. For validation of repeated measurements, the Mauchly sphericity test was used and, whenever necessary, Greenhouse-Geisser correction was applied. If a significant difference was observed in the ANOVA, the post-hoc Bonferroni test was used. When main effect and interaction were found, only the interaction effect was reported. The magnitude of treatment effects was calculated using eta squared effect size. The statistical data were analyzed using SPSS 20.0 (Chicago, USA) considering a confidence interval (CI) of 95% and with the level of significance established at $\alpha=0.05$. One-way repeated measures ANOVA was conducted on TskAsy.

3.2. HIGH-INTENSITY INTERVAL TRAINING STUDY

3.2.1 STUDY SAMPLE

The study sample was composed by two U-16 teams for a Spanish 1st Division Team of the National Football League. These two teams played in the highest U-16 division in Madrid area (Spain), and both were ranked between the first four places by the time the study was done. The exclusion criteria were a) having an injury, b) performing any type of training or undergoing any physiotherapy session in the 36 hours previous to the data collection.

After the exclusion criteria were applied, the sample was reduced to 37 players (15.6 ± 0.3 years, 1.74 ± 0.1 meters and 63.4 ± 6.7 kg) who trained for at least 3 days per week during the last year, those players were randomly assigned to one of the four groups of HIIT. The ethical committee of the Technical University of Madrid (UPM) and the Faculty of Sciences for Physical Activity and Sport (INEF) approved this study as a part of the project “TermoRECOV” in accordance with the Code of Ethics of the World Medical Association (Williams, 2008).

3.2.2 STUDY DESIGN

A pre-post design without a control group was performed to observe the effects of different HIIT protocols on absolute Tsk for R-L ROIs and Tsk asymmetries.

3.2.3 PROCEDURE

The players arrived at the training facilities at 18:00 A.M. With 36 hours of rest after the last competitive match. They had not performed any kind of physical effort between the end of the match and the start of the data collection in order to decrease the effects of competition.

The players who met the inclusion criteria entered the data collection room after bringing the informed consent signed by their respective parents/tutors to participate in the study. After donning training clothes, the players went directly to a room in which they stayed for 10 minutes for acclimatizing to the room temperature. 10 point Borg's Retrieved Perception Scale (RPE) was taken individually during acclimation time for measuring the effects of training on subjective perception of fatigue. No one of the players

reported factors that could influence IRT data acquisition (Fernández-Cuevas et al., 2015b). Then, the first thermograms or baseline thermal pictures for both anterior and posterior lower limb were collected at night, without the presence of the sun, between 18:20 and 19:00 AM.

The temperature of the data collection room was $17.1 \pm 0.4^\circ\text{C}$ with a humidity of $59.0 \pm 0.2\%$ as measured by a thermometer (Extech RHT20, FLIR® Systems, Sweden) and the temperature outside, where the players performs the protocol was $8.7 \pm 0.3^\circ\text{C}$ with a humidity of $46.1 \pm 0.3\%$.

The training protocol consisted of 4 groups of HIIT with different durations (Table 9) with a similar warm-up.

The warm-up last 15', divided into 4 phases:

- a) 5' of continuous running.
- b) 5' joint mobility on both upper and lower limb.
- c) 3' of explosive actions like accelerations, decelerations, jumps, change of directions, progressive running and sprint.
- d) 2' of ballistic movements of the lower limb.

After the warm-up each player went with one of the four coaches, who were in the football field for guiding the exercise protocols based on Buchheit and Laursen (2013a). All the HIIT protocols performed the running bouts in a linear way and had passive rest between sets and bouts. Whereas E-1, E-2 and E-4 were performed by running bordering the football pitch, E-3 was marked with a reference to delimitate the end of the 20m.

Table 9. Characterization of the variables for each HIIT protocol.

Name	N	Density	Intensity	Sets	Bouts/set	Duration/Bout	Rest * Bout	Rest * Set	Total Work	Total Rest	Total Work + Rest
E-1	10	1:1	Max.	6	1	30"	-	30"	3'	3'	6'
E-2	9	1:4	Max.	6	1	30"	-	120"	3'	10'	13'
E-3	8	1:6.5	Max.	3	6	20m + 180° COD + 20m	10"	360"	2'	13' 30"	15' 30"
E-4	10	3:1	70-80% RPE	6	1	180"	-	60"	18'	5'	23'

Right after the players performed the training protocol, they came back into the data collection room, where another thermogram was taken. Thermograms time between the different players of the same group did not differ in more than 1' and 30'', as each player did not last more than 10'' for taking both anterior and posterior lower limb thermograms. Warm-up and HIIT was performed at night to avoid the influence factors of excessive sweating and sun radiation. Even when it has been demonstrated that sweating large inter and intra segmental variation in Caucasian male athletes (Smith and Havenith, 2011) as the ones of the study. We also refer that the athletes did not use a towel immediately after the training. There were no significant changes of temperature in the data collection room neither in the field during the exercise protocols.

3.2.4 VARIABLES

Recorded variables were collected before (Pre) and after (Post) the training protocol. Those variables were the skin temperature (T_{sk} in $^{\circ}\text{C}$) measured by IRT with a FLIR® T335 (FLIR® Systems, Sweden) and 10 point RPE.

The data collection was performed by a technician with more than 4 years of experience. ThermoTracker software (pemaGROUP®, Spain) (Fernández-Cuevas et al., 2012) was used to automatically get lower limb ROIs for both the anterior and posterior views (Figure 9) corresponding with the following right and left sides of the Anterior Thigh, Anterior Knee, Anterior Internal Leg, Anterior External Leg, Posterior Internal Thigh, Posterior External Thigh, Posterior Knee, Posterior Internal Leg and Posterior External Leg. The ROIs with dark background were not considered into data analysis.

Figure 9. ROI division for the anterior (left picture) and posterior (right picture) views. Dark zones were not considered into data analysis.

The increments of Tsk (Δ Tsk) were obtained to quantify the Tsk change Pre and Post moments for each group as well for Tsk Asymmetries.

3.2.5 STATISTICAL ANALYSIS

The data are reported as the mean $\pm$ standard deviation (SD) in the text and tables. Exploratory data analysis was performed for identification and correction of extreme values. Normality and homoscedasticity were tested using the Kolmogorov-Smirnov test and the Bartlett's criterion, respectively. The analysis of variance (ANOVA) with GROUP fixed factor was performed to establish the difference between means of the inter and intra groups effects of each training protocol on absolute R-L Tsk, Δ Tsk, TskAsy and RPE. For validation of repeated measurements, the Mauchly sphericity test was used and, whenever necessary, Greenhouse-Geisser correction was applied. If a significant difference was observed in the ANOVA, the post-hoc Bonferroni test was used. When main effect and interaction were found, only the interaction effect was reported. The magnitude of treatment effects was calculated using eta squared effect size. Pearson correlation was used to determine relationships between thermal and RPE variables. One-way repeated measures ANOVA was conducted on TskAsy. Pearson correlation was used to determine relationships between thermal and anthropometrical variables. The statistical data were analyzed using SPSS 20.0 (Chicago, USA) considering a confidence interval (CI) of 95% and with the level of significance established at $\alpha=0.05$.

3.3. MATCH STUDY

3.3.1 STUDY SAMPLE

The sample was composed by 21 players (15.7 ± 0.4 years, 1.74 ± 0.1 meters and 63.7 ± 6.3 kg) from a Spanish 1st Division U-16 team which plays in the highest U-16 division in Madrid area and ranked between the first four places by the time the study was done. Exclusion criteria were: a) Injured b) Physical activity in the last 8 hours c) Not bringing the informed consent signed by their parents. The ethical committee of the Technical University of Madrid (UPM) and the Faculty of Sciences for Physical Activity and Sport (INEF) approved this study as a part of the project “TermoRECOV” in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

3.3.2 STUDY DESIGN

A pre-post design with a control group was performed to observe the effects of a competitive match on absolute Tsk for R-L ROIs and Tsk asymmetries.

3.3.3 PROCEDURE

Thermal images of the anterior and posterior lower limb were taken before and after a competitive football game. The players arrived at the sport facilities at 15:00 P.M. They did not perform any kind of physical effort in the last 8 hours before the data collection. The head coach, prior to getting the first thermograms said who were the players selected to participate in the match. After that, a specialized technician with more than 4 years of experience took the thermograms.

After a 10-minute motivational talk those who met the inclusion criteria entered the data collection and after donning training clothes, stayed in a stand position in the same room acclimatizing for 10 minutes. No one of the players reported factors that could influence IRT data acquisition (Fernández-Cuevas et al., 2015b).

Then, the first thermograms or baseline thermal pictures for both anterior and posterior lower limb were collected between 15:20 and 15:40 AM following the guidelines of Fernández-Cuevas (2012) in all the participants. Players who were selected by the head coach to play in the first half wore shin guards during the acclimation time

and were removed by the time they were measured with the infrared camera, after that, they went to the field to warm-up with the strength & conditioning coach. Players who were selected to play in the game, but not initially, went to the bench. Players who were not selected to play in the game went to the stands to stay in the same environmental conditions as those who were going to play. After the match, the players were divided in 3 groups: 1) Played 80 minutes (the whole game time in this category) 2) played between 1-79 minutes and 3) did not played. In the cases where the players were replaced during the game, they directly went to the data collection room to get the thermal image as soon as possible. After the game, thermograms were taken for those who finished the match, and right after for the ones who did not play any minute. That allowed the participants of the three groups to stay in the same environmental conditions.

Table 10 shows the environmental conditions for the study. The temperature of the data collection room was $19.9\pm0.3^{\circ}\text{C}$ with a humidity of $36.0\pm0.3\%$ measured by a thermometer (Extech RHT20, FLIR® Systems, Sweden) and the temperature outside, where the players played the football match was $20.2\pm0.5^{\circ}\text{C}$.

Table 10. Environmental conditions for data collection (room and football field).

	Pre	Halftime	Post
Room temperature	$19.9\pm0.3^{\circ}\text{C}$	$19.4\pm0.5^{\circ}\text{C}$	$18.0\pm0.3^{\circ}\text{C}$
Outside temperature	$20.2\pm0.5^{\circ}\text{C}$	$18.7\pm0.3^{\circ}\text{C}$	$18.7\pm0.4^{\circ}\text{C}$
Room humidity	36%	49%	56%
Hour	15:34	16:53	17:45

3.3.4 VARIABLES

Recorded variables were collected before (Pre) and after (Post) the game. Those variables were the skin temperature (T_{sk} in $^{\circ}\text{C}$) measured by IRT with a FLIR® T335 (FLIR® Systems, Sweden).

The data collection was performed by a technician with more than 4 years of experience. ThermoTracker software (pemaGROUP®, Spain) (Fernández-Cuevas et al., 2012) was used to automatically get lower limb ROIs for both the anterior and posterior views (Figure 10) corresponding with the following right and left sides of the Anterior Thigh, Anterior Knee, Anterior Internal Leg, Anterior External Leg, Posterior Internal Thigh, Posterior External Thigh, Posterior Knee, Posterior Internal Leg and Posterior External Leg. The ROIs with dark background were not considered into data analysis.

Figure 10. ROI division for the anterior (left picture) and posterior (right picture) views. Dark zones were not considered into data analysis.

The increments of Tsk (ΔT_{sk}) were obtained to quantify the Tsk change Pre and Post moments for each group as well for Tsk Asymmetries.

Absolute values were corrected with the formula of Carmona (2012) $T_{SKstandar} = T_{SKreal} - [0,184 * (\text{Room temperature} - 21^{\circ}\text{C})]$ to adjust the Tsk in 21°C . This way, comparisons between different ambient temperatures can be done avoiding this influence factor.

3.3.5 STATISTICAL ANALYSIS

The data are reported as the mean $\pm$ standard deviation (SD) in the text and tables. The Kolmogorov-Smirnov test, asymmetry and kurtosis were used to ascertain the normal distribution of the data for all variables. One-way ANOVA and Tukey post-hoc tests were used to analyze game effects on Tsk values for all the sample. Student's t-tests were conducted between pre and post moments to examine the differences in ΔT_{sk} between the R and L sides of each group. The statistical data were analyzed using SPSS 20.0 (Chicago, USA) considering a confidence interval (CI) of 95% and with the level of significance established at $\alpha=0.05$.

4. RESULTS

Results for each study are shown below in different sections to simplify reader's lecture.

4.1. COLD-WATER IMMERSION STUDY

Water temperature measurements, pre-immersion and post-immersion, indicated non-significant differences between Pre and Post values for all the players ($2.94 \pm 1.18^\circ\text{C}$ vs. $2.55 \pm 0.88^\circ\text{C}$) ($p=0.244$), with a maximum value of 4.99°C and a minimum value of 2.03°C . There was an isolated effect of Moment on all measured ROIs for each moment ($p=0.001$) for both D-ND and R-L analysis. Different Dominance and Laterality effects were found and described above.

4.1.1 DOMINANCE VS LATERALITY: ABSOLUTE TSK ANALYSIS

Absolute Tsk measurements were different depending on the type of analysis. When analyzing D vs ND sides (table 11). It was found an isolated effect of Dominance on Anterior Thigh ($F=6,902$; $p=0.03$; $ES=0.463$) in Pre moment ($p=0.036$; $ES=0.18$) and Anterior Knee ($F=10,993$; $p=0.011$; $ES=0.577$) in Post15 ($p=0.023$; $ES=0.98$). The interaction effect (Dominance vs Time) was found for Posterior Thigh ($F=3,613$; $p=0.040$; $ES=0.311$) in Post ($p=0.047$; $ES=0.24$).

On the other hand, analysis of R vs L sides (table 12) brought similar results for Anterior Thigh at Pre ($p=0.036$; $ES=0.18$), but different on the other ROIs as seen on Anterior Knee at Post10 ($p=0.043$; $ES=0.44$) and Posterior Leg at Pre ($p=0.031$; $ES=0.20$).

Table 11. Absolute Skin temperature filtered by Dominance. Differences between D – ND sides * ($p<0.05$).

Tsk (°C)			Pre		Post		Post10		Post15		Post20	
			Mean	SD	Mean	SD	Mean	Mean	SD	Mean	SD	Mean
Anterior	Thigh	D	33.22*	0.67	20.02	0.57	27.07	0.47	28.28	0.48	29.10	0.48
		N	33.10	0.66	19.91	0.53	26.98	0.52	28.18	0.45	29.05	0.46
	Knee	D	32.59	1.03	18.90	0.63	24.46	0.60	25.48*	0.40	26.11	0.39
		N	32.46	1.21	18.64	0.70	24.23	0.55	25.16	0.23	25.87	0.42
	Leg	D	32.66	0.95	19.73	0.81	24.97	0.72	26.22	0.74	27.07	0.67
		N	32.57	0.86	19.83	0.77	24.99	0.53	26.39	0.53	27.21	0.67
Posterior	Thigh	D	33.28	0.85	19.70*	0.84	25.89	0.59	27.16	0.56	27.96	0.46
		N	33.30	0.78	19.89	0.73	25.72	0.63	27.12	0.70	27.90	0.54
	Knee	D	33.30	0.76	20.68	0.61	25.37	0.67	26.79	0.70	27.77	0.50
		N	33.21	0.77	20.66	0.61	25.38	0.57	26.94	0.70	27.84	0.55
	Leg	D	32.94	0.84	20.13	0.48	25.48	0.31	26.73	0.34	27.44	0.28
		N	32.82	0.82	20.18	0.66	25.39	0.59	26.66	0.67	27.37	0.61

Table 12. Absolute Skin temperature filtered by Laterality. Difference between R-L sides * ($p<0.05$).

Tsk (°C)			Pre		Post		Post10		Post15		Post20	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Anterior	Thigh	R	33.22*	0.69	19.96	0.58	27.03	0.52	28.27	0.50	29.11	0.48
		L	33.10	0.64	19.97	0.52	27.01	0.47	28.19	0.44	29.04	0.45
	Knee	R	32.53	1.10	18.83	0.76	24.47*	0.64	25.46	0.38	26.08	0.40
		L	32.51	1.14	18.71	0.58	24.22	0.49	25.18	0.29	25.90	0.43
	Leg	R	32.52	0.95	19.68	0.75	24.90	0.67	26.18	0.71	27.02	0.64
		L	32.70	0.85	19.89	0.82	25.06	0.59	26.43	0.55	27.26	0.68
Posterior	Thigh	R	33.34	0.78	19.73	0.81	25.91	0.54	27.20	0.53	27.97	0.45
		L	33.23	0.85	19.86	0.77	25.70	0.66	27.08	0.72	27.89	0.55
	Knee	R	33.30	0.77	20.64	0.59	25.31	0.65	26.79	0.76	27.78	0.58
		L	33.21	0.75	20.69	0.63	25.43	0.58	26.94	0.63	27.83	0.47
	Leg	R	32.97*	0.81	20.08	0.53	25.49	0.36	26.74	0.42	27.45	0.38
		L	32.80	0.85	20.24	0.60	25.39	0.56	26.65	0.63	27.37	0.55

4.1.2 DOMINANCE VS LATERALITY: COOLING AND REWARMING PROCESSES

An acute ΔT_{sk} registered in the cooling phase ranged between the maximum decrement of $-13.81 \pm 0.64^\circ\text{C}$ for the ND anterior knee and the minimum decrement of -12.56°C for the ND posterior knee. CWI reduced Tsk on average by 39.74%.

Table 13 shows that ΔT_{sk} filtered by Dominance was significantly different for Posterior Thigh at Rew10 ($p=0.050$; $ES=0.53$) and Rew20 ($p=0.028$; $ES=0.33$) and almost significant in Rew15 ($p=0.087$; $ES=0.32$).

On the other hand, in terms of Laterality (table 14), ΔT_{sk} was found to be significantly different for R-L comparison on Posterior Leg at Cooling ($p=0.038$; $ES=0.58$), Rew10 ($p=0.002$; $ES=0.40$), Rew15 ($p=0.002$; $ES=0.36$) and Rew20 ($p=0.013$; $ES=0.35$).

Table 13. Increase in Skin Temperature (ΔT_{sk} in $^{\circ}C$) by Dominance at Cooling, Rew10, Rew15, Rew20 and Rewarming. Differences between D-ND sides: $*$ ($p<0.05$). $\&$ ($p=0.087$).

ΔT_{sk} ($^{\circ}C$)			Cooling		Rew10		Rew15		Rew20		Rewarming	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Anterior	Thigh	D	-13.20	0.64	7.05	0.68	8.26	0.78	9.08	0.81	-4.12	0.55
		N	-13.18	0.58	7.06	0.79	8.27	0.79	9.14	0.81	-4.05	0.64
	Knee	D	-13.69	0.65	5.56	0.71	6.58	0.73	7.21	0.53	-6.48	0.75
		N	-13.81	0.64	5.59	0.80	6.51	0.68	7.22	0.61	-6.59	1.01
	Leg	D	-12.92	0.58	5.23	0.54	6.49	0.59	7.33	0.58	-5.59	0.75
		N	-12.73	0.77	5.16	0.55	6.56	0.70	7.38	0.86	-5.36	0.87
Posterior	Thigh	D	-13.58	0.65	6.19*	0.61	7.46 $\&$	0.64	8.26*	0.66	-5.32	0.64
		N	-13.41	0.63	5.83	0.75	7.23	0.91	8.01	0.83	-5.40	0.77
	Knee	D	-12.62	0.64	4.69	0.67	6.11	0.59	7.09	0.59	-5.53	0.82
		N	-12.56	0.42	4.72	0.67	6.29	0.73	7.19	0.80	-5.37	0.85
	Leg	D	-12.81	0.67	5.35	0.70	6.60	0.64	7.31	0.65	-5.50	0.84
		N	-12.64	0.50	5.21	0.64	6.47	0.74	7.19	0.74	-5.45	0.99

Table 14. Increase in Skin Temperature (ΔT_{sk} in $^{\circ}C$) by Laterality at Cooling, Rew10, Rew15, Rew20 and Rewarming. Differences between right (R) and left (L) sides $*$ ($p<0.05$).

ΔT_{sk} ($^{\circ}C$)			Cooling		Rew10		Rew15		Rew20		Rewarming	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Anterior	Thigh	R	-13.26*	0.61	7.08*	0.74	8.31	0.77	9.15	0.79	-4.11	0.55
		L	-13.12*	0.60	7.04*	0.74	8.21	0.80	9.07	0.82	-4.05	0.63
	Knee	R	-13.70	0.56	5.63	0.73	6.62	0.78	7.24	0.55	-6.46	0.79
		L	-13.80	0.72	5.51	0.78	6.47	0.61	7.19	0.59	-6.61	0.97
	Leg	R	-12.84	0.68	5.22	0.54	6.50	0.55	7.34	0.57	-5.50	0.79
		L	-12.81	0.71	5.17	0.56	6.54	0.74	7.37	0.87	-5.44	0.85
Posterior	Thigh	R	-13.61	0.59	6.18	0.61	7.47	0.65	8.23	0.70	-5.38	0.56
		L	-13.38	0.68	5.84	0.75	7.22	0.90	8.03	0.80	-5.34	0.83
	Knee	R	-12.66	0.63	4.67	0.67	6.14	0.66	7.13	0.64	-5.52	0.82
		L	-12.52	0.43	4.74	0.67	6.26	0.67	7.14	0.76	-5.38	0.85
	Leg	R	-12.89*	0.51	5.41*	0.70	6.66*	0.64	7.37*	0.65	-5.52	0.78
		L	-12.56*	0.63	5.15*	0.61	6.41*	0.73	7.13*	0.72	-5.43	1.04

4.2. HIGH-INTENSITY INTERVAL TRAINING STUDY

The Tsk obtained before the study (Pre) was similar for all the ROI in all the training groups ($p > 0.05$) except for Left Anterior External Leg ($F(3,33)=0,604$; $p < 0,05$) and Left Posterior External Thigh ($F(3,33)=3,668$; $p < 0,05$) between groups 2 and 3. On the other hand, Tsk after HIIT (post) was significantly different depending on the HIIT protocol ($p < 0.05$). In general, Tsk post-HIIT in groups 1 and 2 decreased while in 3 and 4 increased.

4.2.1 RIGHT-LEFT ABSOLUTE TSK CHANGE ANALYSIS

There were differences on absolute Tsk between groups 2-3 in PRE moment on Right Posterior External Thigh ($p=0.023$; $ES=0.94$). And in POST moment between groups 1-4 for Right Anterior Thigh ($p=0.021$; $ES=0.22$), Right Anterior Knee ($p=0.028$; $ES=1.24$), Left Anterior Knee ($p=0.021$; $ES=1.22$), Right Anterior Internal Leg ($p=0.016$; $ES=1.36$), Left Anterior Internal Leg ($p=0.046$; $ES=1.23$), Right Anterior External Leg ($p=0.011$; $ES=1.54$), Left Anterior External Leg ($p=0.038$; $ES=1.37$), Right Posterior Internal Thigh ($p=0.031$; $ES=1.34$), Left Posterior Internal Thigh ($p=0.039$; $ES=1.36$); between groups 1-3 for Right Anterior External Leg ($p=0.031$; $ES=1.12$) and between groups 2-4 for Left Anterior Thigh ($p=0.032$; $ES=1.34$) and Left Anterior Knee ($p=0.036$; $ES=1.36$).

Differences between R-L Tsk variables are observed in Table 14. It is to note that ROIs thermally behave in divergent ways for each HIIT protocol. Considering that Tsk change was calculated as Post-Pre moment [ΔTsk] for each ROI, in Figure 11 it is represented graphically the main thermal behavior of significant ΔTsk for each individual group (Tables 15-18).

Figure 11. Effects of the different HIIT protocols on lower limb Tsk. Triangles indicate significant differences Pre-Post, blue corresponds with Tsk decrements and red with Tsk increments.

For the 18 analyzed ROIs, E-1 presented a 94,4% (17/18) with a significant variation on Tsk, E-2 a 61.1% (11/18) whilst E-3 and E-4 respectively had a 11.1% (2/18) and 33.3% (6/18).

Table 15. Average skin temperatures and statistic data for right and left ROIs in E-1 training protocol. Δ = Pre-Post. Grey background indicates significant differences $p < 0.05$.

E-1 (n=10)	LEFT							RIGHT						
	PRE		POST		Δ	P	ES	PRE		POST		Δ	p	ES
	X	SD	X	SD				X	SD	X	SD			
Ant. Thigh	29.05	0.77	27.37	1.84	-1.68	0.001	1.19	29.37	0.83	27.48	1.9	-1.89	0.001	1.28
Ant. Knee	27.83	1.56	26.31	1.99	-1.52	0.006	0.85	27.85	1.34	26.47	1.46	-1.39	0.012	0.98
Ant. Internal Leg	28.98	1.15	27.42	1.98	-1.56	0.001	0.96	29.1	1.16	27.65	1.86	-1.45	0.001	0.93
Ant. External Leg	29.48	1.5	27.18	1.95	-2.3	0.001	1.32	29.15	1.22	26.78	1.73	-2.38	0.001	1.58
Post. Internal Thigh	29.57	0.82	28.22	1.59	-1.35	0.001	1.07	29.22	0.83	28.03	1.66	-1.19	0.003	0.91
Post. External Thigh	28.95	0.96	27.63	1.83	-1.32	0.002	1.93	29.18	0.86	27.65	1.8	-1.53	0.001	1.08
Post. Knee	30.29	1.15	29.12	1.68	-1.17	0.004	0.81	30.13	1.06	29.21	1.6	-0.91	0.009	0.68
Post. Internal Leg	28.87	1.17	27.97	1.98	-0.91	0.149	0.55	28.6	1.11	27.82	2.14	-0.79	0.021	0.46
Post. External Leg	28.32	1.41	27.26	2.43	-1.06	0.012	0.53	28.57	1.22	27.52	2.61	-1.05	0.009	0.51

Table 16. Average skin temperatures and statistic data for right and left ROIs in E-2 training protocol. Δ = Pre-Post. Grey background indicates significant differences $p < 0.05$.

E-2 (n=9)	LEFT							RIGHT						
	PRE		POST		Δ	p	ES	PRE		POST		Δ	p	ES
	X	SD	X	SD				X	SD	X	SD			
Ant. Thigh	29.46	1.31	27.79	1.89	-1.67	0.002	1.02	29.4	1.36	27.74	1.75	-1.66	0.005	1.02
Ant. Knee	28.08	0.99	26.41	1.36	-1.67	0.004	1.40	27.86	1.08	26.64	1.19	-1.22	0.033	1.07
Ant. Internal Leg	29.05	0.68	28.35	1.43	-0.70	0.093	0.62	29.13	0.79	28.52	1.28	-0.62	0.088	0.57
Ant. External Leg	29.45	0.72	28.02	1.96	-1.43	0.003	0.97	29.03	0.67	27.75	1.62	-1.28	0.001	1.03
Post. Internal Thigh	29.83	0.99	28.78	1.62	-1.06	0.007	0.78	29.58	0.96	28.84	1.54	-0.74	0.072	0.58
Post. External Thigh	29.32	1.21	28.14	1.90	-1.18	0.007	0.74	29.45	1.20	28.38	1.91	-1.07	0.017	0.67
Post. Knee	30.69	0.72	29.76	1.62	-0.93	0.024	0.74	30.38	0.74	29.85	1.75	-0.53	0.135	0.40
Post. Internal Leg	29.25	0.71	28.52	1.54	-0.73	0.265	0.61	29.1	0.81	28.67	1.47	-0.44	0.212	0.36
Post. External Leg	28.68	0.92	27.77	2.02	-0.91	0.039	1.02	28.94	0.95	28.19	1.82	-0.75	0.071	0.52

Table 17. Average skin temperatures and statistic data for right and left ROIs in E-3 training protocol. Δ = Pre-Post. Grey background indicates significant differences $p < 0.05$.

E-3 (n=8)	LEFT							RIGHT						
	PRE		POST		Δ	p	ES	PRE		POST		Δ	p	ES
	X	SD	X	ST				X	SD	X	ST			
Ant. Thigh	28.41	1.28	29.35	1.18	0.93	0.090	0.76	28.63	1.32	29.41	1.38	0.78	0.193	0.58
Ant. Knee	26.91	0.98	27.28	1.37	0.37	0.568	0.31	27.75	1.27	28.07	1.86	0.32	0.591	0.20
Ant. Internal Leg	28.28	0.97	28.72	1.48	0.44	0.314	1.37	28.57	0.9	29.25	1.29	0.68	0.077	0.61
Ant. External Leg	28.84	0.88	28.84	1.23	0.00	0.998	0.01	28.4	0.94	28.77	1.2	0.37	0.298	0.34
Post. Internal Thigh	28.6	1.28	29.1	1.45	0.50	0.213	0.37	28.5	1.23	29.08	1.36	0.58	0.179	0.45
Post. External Thigh	27.76	1.3	28.72	1.45	0.96	0.034	0.70	28.212	1.44	28.72	1.82	0.51	0.269	0.31
Post. Knee	29.87	0.99	30.06	1.36	0.19	0.645	0.16	29.58	1.02	30.38	0.94	0.80	0.037	0.82
Post. Internal Leg	28.67	0.87	28.97	1.3	0.30	0.668	0.27	28.55	0.68	29.16	0.69	0.62	0.098	0.89
Post. External Leg	28.07	0.97	28.43	1.26	0.36	0.420	0.32	28.31	0.93	28.78	1.18	0.47	0.272	0.44

Table 18. Average skin temperatures and statistic data for right and left ROIs in E-4 training protocol. Δ = Pre-Post. Grey background indicates significant differences $p < 0.05$.

E-4 (n=10)	LEFT							RIGHT						
	PRE		POST		Δ	P	ES	PRE		POST		Δ	p	ES
	X	SD	X	SD				X	SD	X	SD			
Ant. Thigh	29.31	0.77	30.01	1.42	0.70	0.153	0.61	29.25	0.82	29.88	1.69	0.63	0.235	0.47
Ant. Knee	28.07	1.24	28.74	1.97	0.67	0.252	0.41	27.71	1.13	28.85	2.27	1.14	0.036	0.23
Ant. Internal Leg	28.81	0.9	29.33	0.95	0.52	0.184	0.56	28.97	0.72	29.67	0.96	0.70	0.044	0.83
Ant. External Leg	29.31	1.07	29.22	0.78	-0.09	0.832	0.09	28.96	0.66	28.9	0.88	-0.07	0.833	0.08
Post. Internal Thigh	29.56	0.74	30.11	1.14	0.55	0.125	0.57	29.1	0.67	29.96	1.17	0.86	0.029	0.90
Post. External Thigh	28.99	0.57	29.33	1.24	0.34	0.393	0.35	29.19	0.61	29.54	1.33	0.35	0.396	0.34
Post. Knee	30.09	0.79	30.56	0.85	0.46	0.222	0.57	29.92	0.82	30.63	1.06	0.71	0.039	0.75
Post. Internal Leg	28.95	0.49	29.53	0.64	0.59	0.014	1.02	28.71	0.48	29.47	0.74	0.76	0.025	1.22
Post. External Leg	28.43	0.48	29.03	0.81	0.60	0.141	0.90	28.84	0.55	29.42	0.79	0.58	0.137	0.85

4.2.2 TSK ASYMMETRIES ANALYSIS

Tsk asymmetries analysis is observed in Table 19. Only the players of E-1 presented pre-exercise asymmetries on the Anterior Thigh, Posterior Internal Thigh and Posterior Internal Leg ($p < 0.05$). On the other hand, HIIT normalized E-1 asymmetries after training not finding significant $\Delta TskAsy$ in this group. Furthermore, E-2 had an 0.40°C asymmetry increment on Posterior Knee, E-3 achieved -0.45°C in Posterior External Thigh and 0.61°C on Posterior Knee and finally E-4 0.31°C on Posterior Internal Thigh and 0.24°C on Posterior Knee.

Table 19. Results depending on the HIIT protocol. Tsk asymmetries between Right and Left limbs before the training (PRE) and immediately after the training (POST). N= number of subjects; Δ = POST-PRE; * significant differences between R-L ROIs ($p<0.05$); **= significant difference between POST-PRE.

			E-1 (n=10)						E-2 (n=9)						E-3 (n=8)						E-4 (n=10)					
			PRE		POST		Δ	PRE		POST		Δ	PRE		POST		Δ	PRE		POST		Δ				
								X	SD	X	SD		X	SD	X	SD		X	SD	X	SD		X	SD	X	SD
Ant. Thigh	0.32*	0.35	0.11	0.37	-0.21	-0.06	0.23	-0.05	0.24	0.01	0.21	0.44	0.06	0.49	-0.16	-0.07	0.33	-0.13	0.67	-0.07						
	0.03	0.58	0.16	0.96	0.13	-0.22	0.39	0.23	0.76	0.45	0.84	1.68	0.79	1.64	-0.05	-0.36	0.61	0.11	1.06	0.47						
Ant. Knee		0.12	0.36	0.23	0.51	0.11	0.08	0.34	0.16	0.65	0.08	0.29	0.27	0.53	0.24	0.16	0.26	0.34	0.27	0.18						
Ant. Internal Leg		-0.32	0.70	-0.40	0.61	-0.08	-0.42	0.24	-0.27	0.61	0.15	-0.44	0.56	-0.06	0.47	0.37	-0.35	0.73	-0.32	0.46	0.02					
Ant. External Leg		-0.35*	0.36	-0.19	0.30	0.16	-0.25	0.17	0.06	0.52	0.32	-0.10	0.21	-0.02	0.16	0.08	-0.46	0.20	-0.15	0.37	0.31**					
Post. Internal Thigh		0.23	0.45	0.02	0.23	-0.21	0.13	0.25	0.24	0.25	0.10	0.45	0.24	0.00	0.52	-0.45**	0.20	0.24	0.21	0.27	0.01					
Post. External Thigh		-0.16	0.39	0.09	0.62	0.25	-0.31	0.25	0.09	0.33	0.40**	-0.29	0.37	0.32	0.62	0.61**	-0.18	0.23	0.07	0.33	0.24**					
Post. Knee		-0.27*	0.29	-0.15	0.49	0.12	-0.15	0.33	0.15	0.23	0.30	-0.12	0.28	0.20	0.77	0.32	-0.24	0.31	-0.07	0.39	0.17					
Post. Internal Leg		0.26	0.41	0.27	0.55	0.01	0.26	0.27	0.42	0.45	0.16	0.24	0.28	0.35	0.25	0.11	0.41	0.39	0.39	0.38	-0.03					

4.2.3 SUBJECTIVE MEASUREMENTS OF FATIGUE

All HIIT protocols incremented the perception of the effort for the four groups ($p < 0.005$), not showing between-groups differences before the exercise ($p > 0.05$). On the other hand, immediately after the exercise (table 20) only E-1 was perceived as harder than E-2 ($p = 0.007$) and E-3 ($p = 0.001$) but not than E-4 ($p = 0.064$).

Table 20. Descriptive measurements of RPE for each HIIT protocol. ⁰Significant differences between Pre and Post. Significant differences with E-1 ⁽¹⁾, E-2 ⁽²⁾, E-3 ⁽³⁾ or E-4 ⁽⁴⁾.

Group	RPE Pre		RPE Post		ES
	Mean	SD	Mean	SD	
E-1 Short ⁽¹⁾	1.40	1.26	8.80 ²³⁴	0.42	7.88
E-2 SIT ⁽²⁾	0.56	0.88	6.78 ¹	1.86	4.27
E-3 RSA ⁽³⁾	0.87	0.99	5.75 ¹	1.49	3.86
E-4 Long ⁽⁴⁾	1.1	1.29	7.24 ¹	1.62	4.19

4.3. MATCH STUDY

One-way ANOVA showed that the Tsk obtained in Pre moment was similar for all the ROI except for Right Anterior Leg ($F_{(2,18)} = 4.001$; $p < 0.05$), Left Anterior Leg ($F_{(2,18)} = 4.089$; $p < 0.05$), Right Posterior Leg ($F_{(2,18)} = 3.775$; $p < 0.05$) and Left Posterior Leg ($F_{(2,18)} = 4.575$; $p < 0.05$) between the groups. In Post moment only Left Posterior Knee was significantly different than the other groups ($F_{(2,18)} = 3.601$; $p < 0.05$) and comparing the ΔTsk , just the Left Posterior Leg had a different response between groups ($F_{(2,18)} = 4.780$; $p < 0.05$).

Tukey Post-hoc test showed that Pre Tsk was different for the Left Posterior Leg ($F_{(2,18)} = 4.575$; $p < 0.05$) between the groups 1-2 & 2-3, Post Tsk for Right Anterior Leg ($F_{(2,18)} = 4.001$; $p < 0.05$) and Left Anterior Leg ($F_{(2,18)} = 4.089$; $p < 0.05$) between groups 1-3. Finally, ΔTsk obtained a different response between groups 1-3 for the Right Posterior Leg ($F_{(2,18)} = 3.450$; $p < 0.05$) and Left Posterior Leg ($F_{(2,18)} = 4.780$; $p < 0.05$).

4.3.1 RIGHT-LEFT ABSOLUTE TSK ANALYSIS

Differences between groups are showed below in table 21. Group 2 in Pre moment had the Right Posterior Leg with a higher temperature ($p < 0.05$) than the Left side

($t(7)=2.617$; $p<0.05$) (30.71°C vs 30.52°C). Also, had a greater ΔTsk in Left Posterior Leg in comparison with the right side ($t(7)=4.772$; $p<0.05$) (0.45°C vs 0.14°C).

Significant differences Post-Pre were found in group 1 for the ΔTsk of the Right Anterior Leg ($t(6)= 3.895$; $p<0.05$) (32.6°C vs 30.8°C), Left Anterior Leg ($t(6)=-4.209$; $p<0.05$) (32.73°C vs 30.83°C), Right Posterior Leg ($t(6)=3.092$; $p<0.05$) (31.79°C vs 30.67°C) and Left Posterior Leg ($t(6)=3.503$; $p<0.05$) (31.80°C vs 30.54°C).

4.3.2 RIGHT-LEFT TSK ASYMMETRIES ANALYSIS

One-way ANOVA did not bring significant differences between groups. Tsk asymmetries analysis is observed in Table 22. Only the players from Group 2 presented significant differences in Post-Pre Tsk asymmetries for the Posterior Leg ($t(7)=4.772$; $p<0.05$) where there was a total decrease in the asymmetry from 0.19°C (Pre) to -0.12°C (Post).

Table 21. Results depending on the group. Tsk between Right and Left ROIs before the match (PRE) and immediately after the match (POST). N= number of subjects; Δ = POST-PRE; * significant differences between Right-Left ROIs ($p<0.05$); **= significant difference between POST-PRE.

		GROUP 1 (n=7)						GROUP 2 (n=8)						GROUP 3 (n=6)						
		PRE		POST		Δ		PRE		POST		Δ		PRE		POST		Δ		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Anterior	Thigh	R	31.56	0.48	31.67	0.74	0.11	0.99	31.50	0.39	30.33	2.01	-1.16	1.83	31.21	0.54	30.21	1.27	-0.99	1.36
		L	31.56	0.37	31.64	0.88	0.09	1.03	31.43	0.39	30.36	1.86	-1.06	1.72	31.09	0.90	30.01	1.34	-1.08	1.53
	Knee	R	30.08	0.90	30.95	1.38	0.86	1.68	29.94	0.51	29.78	1.98	-0.16	1.90	30.10	0.68	29.21	1.22	-0.88	1.51
		L	30.16	0.74	30.88	1.26	0.71	1.46	30.09	0.76	29.77	2.11	-0.32	2.30	30.38	0.97	29.31	1.16	-1.08	1.36
	Leg	R	30.86	0.65	32.67	0.92	1.81**	1.23	30.91	0.52	31.60	1.22	0.69	1.47	31.00	0.91	30.95	1.18	-0.05	1.36
		L	30.83	0.76	32.73	0.83	1.90**	1.19	30.79	0.73	31.57	1.32	0.78	1.53	30.88	1.17	30.97	1.18	0.08	1.41
Posterior	Thigh	R	31.13	0.94	31.33	1.20	0.20	1.19	31.02	0.58	30.39	1.71	-0.63	1.70	31.59	0.88	30.48	1.28	-1.11	1.37
		L	31.21	0.95	31.33	1.21	0.12	1.14	31.02	0.59	30.53	1.50	-0.49	1.63	31.68	0.87	30.53	1.11	-1.15	0.93
	Knee	R	32.09	0.51	32.70	0.72	0.62	1.08	32.25	0.58	31.63	1.27	-0.62	1.56	32.29	0.99	31.73	1.17	-0.56	0.90
		L	32.05	0.61	32.89	0.65	0.84	0.99	32.14	0.50	31.65	1.17	-0.49	1.48	32.32	0.78	31.82	0.89	-0.49	0.66
	Leg	R	30.67	0.66	31.79	0.79	1.12**	0.96	30.71*	0.54	30.85	1.34	0.14*	1.53	31.58	0.83	30.94	0.84	-0.64	0.96
		L	30.54	0.82	31.80	0.77	1.26**	0.95	30.52*	0.59	30.97	1.11	0.45*	1.45	31.58	0.74	30.85	0.97	-0.73	0.89

Table 22. Results depending on the group. Tsk asymmetries (Right-Left) before the match (PRE) and immediately after the match (POST). N= number of subjects; Δ= POST- PRE; * = significant difference between POST-PRE.

		GROUP 1 (n=7)						GROUP 2 (n=8)						GROUP 3 (n=6)					
		Pre		Post		Δ		Pre		Post		Δ		Pre		Post		Δ	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Anterior	Thigh	0.00	0.32	0.02	0.39	0.02	0.20	0.07	0.11	-0.03	0.32	-0.10	0.33	0.11	0.43	0.20	0.43	0.09	0.28
	Knee	-0.08	0.60	0.07	0.69	0.15	0.36	-0.15	0.49	0.01	0.53	0.16	0.71	-0.29	0.48	-0.09	0.63	0.19	0.42
	Leg	0.03	0.33	-0.07	0.28	-0.09	0.32	0.12	0.34	0.03	0.40	-0.09	0.30	0.11	0.28	-0.02	0.32	-0.14	0.25
Posterior	Thigh	-0.08	0.29	0.00	0.22	0.08	0.24	0.00	0.15	-0.15	0.35	-0.15	0.37	-0.09	0.26	-0.05	0.38	0.05	0.49
	Knee	0.04	0.34	-0.18	0.44	-0.22	0.49	0.11	0.25	-0.02	0.24	-0.13	0.29	-0.02	0.24	-0.09	0.44	-0.06	0.34
	Leg	0.12	0.41	-0.01	0.12	-0.14	0.38	0.19	0.21	-0.12	0.26	-0.32*	0.19	0.00	0.35	0.09	0.28	0.09	0.48

5. DISCUSSION

The results of the three studies will be discussed independently from each other as the individuality of each one made it hard to compare.

5.1. COLD-WATER IMMERSION STUDY

Some of the factors that may influence skin temperature data collection and interpretation must be considered in this study (Fernández-Cuevas, 2012). We are aware that the room temperature in this first study (28°C) was higher than the 18 to 25 °C established as standard environmental temperatures (Ring and Ammer, 2000). This fact could slightly affect the absolute Tsk of the players, generating higher values than others provided in specific literature; so that, our absolute data should not be considered as a reference for determining the thermal profile of football players under standard environmental conditions. However, the higher ambient temperatures should not affect the ΔT_{sk} comparison between D-ND values in the rewarming process because ambient temperatures were constant during the entire data collection process, thereby equally influencing both the D and ND sides.

5.1.1 ACUTE SKIN TEMPERATURE DECREMENT

Thermal imaging is a non-invasive technique that has been previously used to assess the Tsk after cryotherapy (Costello et al., 2012a, Cholewka et al., 2012, Cholewka et al., 2010, Vaile et al., 2008, Cholewka et al., 2004). Limbs, joints, hands and feet are the areas that has been observed to have greater thermal decrements in Tsk after cryotherapy (Oosterveld et al., 1992, Ammer, 1996, Hardaker et al., 2007, Herrera et al., 2010, Kennet et al., 2007, Kim et al., 2002, Selfe et al., 2007). Meanwhile, core areas (i.e., pectoral or back regions) do not undergo decreases of more than 7°C (Ring et al., 2004a, Ring et al., 2004b, Cholewka et al., 2010, Cholewka et al., 2012).

Tsk cooling has been studied after whole-body cryotherapy (WBC) in a cryo-cabin (Savic et al., 2013). Although WBC and CWI protocols are extremely different in nature (cold air at -195°C vs. cold water at 2-5°), they demonstrated a decrement in the Tsk of 15°C for the anterior and posterior thigh, which might be considered similar to our 13°C decrement after CWI. However, other studies (Cholewka et al., 2012) obtained a

decrement of 8.7°C for the anterior leg after 2 minutes of WBC at -120°C in a cryo-chamber that was not comparable to our 12.8°C Tsk decrease for the same region. The Tsk decrease for the knee in previous studies (Costello et al., 2014) was 9.0°C for CWI and 10.3°C for WBC versus our obtained 13.7°C for the same ROI. These results might differ because of the CWI dose (4 minutes at 8°C vs 10 minutes at 2-5°C, respectively), which might also confirm that greater Tsk reductions are obtained with longer and colder exposures to cold-immersions. These results are between the recent cryotherapy guidelines that recommend reductions of Tsk between 5 and 15°C (Bleakley and Hopkins, 2010).

Regarding the duration of the thermal effect, most of the studies were not able to report returns to baseline levels of Tsk even 120 minutes after the treatment where the temperature was indeed a few degrees below the initial Tsk (Kennet et al., 2007, Hardaker et al., 2007, Ring et al., 2004a, Ring et al., 2004b, Kim et al., 2002). However, there are a few studies in which baseline Tsk was reached some minutes following the cold test (Ammer, 1996, Rasmussen and Mercer, 2004), even reporting a small hyperthermia of 1°C in the extremities. Nevertheless, except these investigations the normal Tsk tendency is to remain lower for at least 2 hours after cryotherapy.

Anyway, further research is needed to establish the influence of different cryotherapy protocols on all Tsk ROIs in regard to duration, temperature and bath modality.

5.1.2 REWARMING PROCESS

Thermal rewarming has been studied (Savic et al., 2013) in WBC (3 minutes at -195°C), obtaining anterior and posterior thigh Tsk values between 29-30,5°C from 20 to 60 minutes. For the same ROIs, our results were between 28-29°C after 20 minutes, which were approximately the same. Notably, Costello (2014) reported higher knee Tsk reductions and rewarming after WBC (4 minutes at -110°C) than after CWI (4 minutes at 8°C). In the CWI protocol of Costello's work, the Tsk of the knee after 20 minutes of recovery was nearly 25°C, a similar response to that observed in our study (knee Tsk of 26°C at 20 minutes). Our faster recovery data (one-degree) might be due to our warmer room temperature (22°C vs. 28°C).

Currently, it seems difficult to compare results from different studies measuring Tsk rewarming responses after CWI by infrared thermography. Basic protocol guidelines should be provided by future research in order to standardize methodologies in terms of the cooling method (CWI or WBC), dose (duration and temperature), room conditions (temperature and humidity) and ROI delimitation.

5.1.3 THERMAL REWARMING IMBALANCES IN FOOTBALL

The thermal behavior of the human body is a combination of heat transfer and heat generation at various levels, micro (molecular and cellular), meso (tissue and organs) and macro (thermal interaction with the environment) (Bhowmik et al., 2013). CWI might exacerbate these thermoregulatory processes and IRT might be a useful tool to detect altered responses in Tsk after CWI. In our study, almost three significant points were founded when comparing the D and ND posterior thigh at 10 and 20 minutes during the rewarming process. It is worth noting that at 15 minutes, the results of the same ROI were almost significantly different ($p=0.087$), thus, we can consider that the dominant hamstring perform an accelerated rewarming after CWI because there were more active.

Hamstrings imbalances in force production have been related with injury risk (Croisier et al., 2008) being this area the most injured muscle in football (Ekstrand et al., 2011). Fatigue reduces the stride length and diminishes sprint performance (Small et al., 2009), increasing the probability of being injured. In football, that could be explained as 90% of sprints in professional football players are below 5 seconds (Andrzejewski et al., 2013) and the hamstrings are one of the most impaired muscle groups at a neuromuscular level after maximal efforts longer than 3 seconds (Buchheit and Laursen, 2013a), this combination of repeated actions with higher levels of accumulated fatigue could lead to inflammation because of repeated microtraumas along the season.

As seen with the fastest rewarm of the D posterior thigh, the application of cold stressors like CWI could exacerbate the rewarming response, which may be related with a greater blood flow to the area (Garagiola and Giani, 1990). We consider that IRT could be a useful tool for monitoring inflammatory processes provoked by accumulated fatigue in critical ROIs, this tool should be considered for sport scientist to prevent sport injuries in elite teams. We consider that dynamic thermography which is the application of cold stress followed by a monitorization of Tsk hot spots and asymmetrical ROI temperature

increments could lead to deeply understand the relationship between inflammatory processes and thermography.

However, the use of this tool should be carefully interpreted. The knowledge of individualized thermal profiles are important when applying IRT to sports (Marins et al., 2014b). Constant asymmetries in Tsk along the time are produced among others by the specialization of the sport, as seen in the comparison between D and ND forearms in judo athletes (Arnaiz Lastras et al., 2011). The thermal profile in football was firstly defined in the doctoral dissertation of Gomez-Carmona (2012), who observed that in non-injured Spanish 1st division professional football players, the only Tsk differences observed were for the D ankle, possibly because of the repetitive action of ball kicking. In recent studies (Marins et al., 2014b), after analyzing the thermal profiles of 100 young football players, the authors concluded that Tsk asymmetries between contralateral ROIs (right and left) were set at 0.2°C, in agreement with our initial Tsk values.

Applying CWI procedures and recording dynamically the Tsk by thermal imaging analysis (Tsk and Δ Tsk) led to the evaluation of the acute effects of cooling and rewarming behavior in the different ROIs, thereby generating valuable data for the medical and technical staff. In this regard, we propose that faster rewarming could be related to inflammatory processes or higher metabolic activities of the structures within the considered ROI.

Čoh and Širok (2007) observed that higher training loads elicited greater Tsk increments. Human body should react equally by rewarming contralateral ROIs at the same speed, and if the rewarming process is altered, it could be provoked by poor workload assimilation, with the muscle demanding more blood flow unilaterally to it as a maladaptive response. Thus, IRT must be used to monitor these unilateral responses and absolute Tsk increments or decrements to understand the response of athletes to training loads.

The acute analgesic effects could be produced by both temperature and pressure factors (Wilcock et al., 2006); however, there is little evidence regarding the optimal parameters of CWI to achieve better results. A recent study (Glasgow et al., 2014) compared four different protocols of CWI, concluding that the best protocol for reducing

delayed-onset muscle soreness (DOMS) was a continuous 10-minute immersion at 6°C, which approximates the time and protocol used in this study.

Glasgow et al. (2014) suggested that the trend to achieve better improvements in athlete's recovery are colder and longer protocols. In the future, different CWI protocols should be compared in order to achieve guidelines for understanding the optimal time of immersion and safe Tsk reductions as this questions remain to be fully elucidated (Costello et al., 2012a).

5.2. HIGH-INTENSITY INTERVAL TRAINING STUDY

This study presents new evidence in terms of how IRT can aid in the location of Tsk changes in specific body regions after different types of running-based HIIT exercises. Thus, becoming a first step for detecting if there is a link between thermography and ROI Tsk changes depending on the type of HIIT based on intensity and duration.

Our results showed that the shorter the exercise, the greater the absolute Tsk differences on the ROIs either increasing or decreasing. Obtaining Tsk changes in 94%, 61%, 11% and 33% on the overall ROIs analyzed if filtered from shorter to longer HIIT duration (from E-1 to E-4). This trend was also seen with RPE measurements respectively 8.8, 6.8, 5.7 and 7.3, with just the first being significantly different from the rest. Hence suggesting with this data, a possible relationship between exercise intensity and Tsk modifications.

Regarding duration, whereas there was drop in Tsk due to exercise in the shortest HIIT protocols (Short Intervals E-1 and Sprint Interval Training E-2), temperature increased in the longer ones (Repeated Sprint Sequences E-3 and Long Intervals E-4). That temperature drop was observed by other authors in brief and intense maximal exercises (Zontak et al., 1998) (Akimov and Son'kin, 2011) (Bonnett et al., 2006) (Nakayama et al., 1981) (Hildebrandt et al., 2012) as well as in our study. This could be related with a vasoconstrictor response, attributable to increments in catecholamines and vasoconstrictor hormones released (Bregelmann et al., 1977, Vainer, 2005).

However, in addition to the type and duration of the exercise, intensity has been suggested to increase Tsk (Malkinson, 2002) while other studies has found the opposite,

an indirect relationship of higher intensity and lower Tsk (Arfaoui et al., 2014, Nakayama et al., 1981). Thus, being hard to deduce if the intensity itself is the responsible of the overall Tsk increase/decrease or, on the other hand, if it is a mixture of duration, intensity and type of exercise the responsible of this Tsk modification.

In the doctoral dissertation of Fernández-Cuevas (2012), Tsk decrements were observed immediately after the effort in both strength and speed training protocols, the opposite was found in a 45' treadmill-running (constant aerobic exercise), where Tsk increased. One of the explanations to this first phenomenon could be explained by the mechanisms activated by the hypothalamus to prevent dangerous temperature increments: vasoconstriction (in inactive areas) and vasodilation (in active muscles) (Charkoudian, 2010).

A larger Tsk drop during exercise is associated with better thermoregulatory responses and greater efficiency in submaximal graded exercise (Bertucci et al., 2013a); however, is it is not the aim in this study to elucidate whether our results in Tsk changes are related with performance in this study. Nevertheless, a general conclusion could be suggested, and is that if we modify the total time expended in HIIT (time + rest), intensity and type of running drill (COD or not) we would be able to target our thermoregulatory system in different ways. Provoking hypothalamus shocking Tsk reductions in brief and maximal efforts or on the other hand, more prolonged exercises to impact on extending the heat exchange work rate, thus increasing Tsk and challenging the human body to properly work in heat environments. Also, knowing the ROIs who had his Tsk modified will inform professionals to know the impact of HIIT in the different muscle structures when mixed with EMG and other technologies like TMG.

The study was planned to be done at night to avoid any environmental factor like sun or extremely heat conditions, because it is known that performance is impaired in heat environments, becoming a limiting factor in both constant and self-paced exercises (Marino, 2008). This way, players who participated in the study could train at the same hour of the regular sessions during all the year, therefore restricting the influence of modifying the training time and performing the HIIT without the limitation of exercise in heat and circadian rhythms.

The importance of the analysis of this study does not reside on global Tsk behavior (overall increase or decrease) but in the ROIs who significantly changed depending on the activity profile of each HIIT protocol. Thus, the key point remains in which are the muscles that are involved during exercise, and if those muscles are thermally stimulated and detected via IRT.

When analyzing E-1 (Short Interval HIIT), we observed that was the most demanding exercise in terms of both subjective perception RPE=8.8 and the ROI that presented higher Tsk changes (94% of the analyzed body areas with Tsk modification). Considering the ROIs that significantly changed their temperature, all except those corresponding with the calves showed modifications. Both E-1 (Short Interval) and E-2 (Sprint Interval HIITs) were performed running at the maximum speed for 30'' but with different rest times, consequently increasing the eccentric musculoskeletal load on quadriceps and hamstrings (Yu et al., 2008) because of the higher forces biomechanically produced in the lower limb during high intensity running if compared with E-4 (Long Interval HIIT). Timmins et al. (2014) studied the isokinetic force and EMG activity of the hamstring complex after sprint training (3 sets x 6 reps x 20m maximal sprint with a 10m acceleration and 15m deceleration distance), finding a reduction in the eccentric knee flexor strength with a subsequent reduction in the myoelectrical activity of the biceps femoris. While there are substantial differences between this protocol and ours, the aim was to show that sprint activities trigger muscle fatigue in the hamstrings, that transferred to thermal behavior, could significantly impact on the Tsk of that ROI.

To our knowledge, there are only two studies that investigated both effects on fatigue via EMG and Tsk, one in sports (Priego Quesada et al., 2015) and another with general population (Bartuzi et al., 2012). The first research was focused on understanding which ROIs better represent the link between changes in EMG and Tsk during aerobic exercise (cycling), finding that cyclists with greater neuromuscular activation had limited Tsk increments compared with their counterparts. The key point was not to observe the overall response, the most important thing was that there was one ROI which was better associated with these changes, the vastus lateralis. Therefore, changes in Tsk could be related with muscle fatigue in specific ROIs.

The same pattern was also seen in a second study performed by Bartuzi et al. (2012), who examined how different isometric loads affects Tsk on physical education

students, obtaining bigger Tsk following the load increment, thus with greater fatigue (decreased EMG signal). The authors noticed that “the larger the force exerted during tests, the greater the changes in the temperature in the joints over time. This means that the level of load affects the changes in the temperature in the joints, which is a result of fatigue”. Thereby, IRT could be a valuable tool for measuring muscle fatigue although more studies are needed to strongly confirm it as in our study we did not compare our results with EMG signals.

Nonetheless, in our study, we obtained a significant increase of Tsk in E-3 (external posterior thigh and popliteus) and E-4 (knee, anterior leg, internal posterior thigh, popliteus and posterior leg). Following this information, that could be possibly related with fatigue in this ROIs. In the future the importance will be to compare IRT with both tensiomyography (TMG) and electromyography (EMG) to see if this Tsk increase really reflects fatigue.

Analyzing the longer protocols, Repeated Sprint Sequences and Long Intervals presented significant Tsk increases considering the resting conditions as a reference, which differs from the Tsk decreases in Tsk after shorter HIITs. (Short Intervals and Sprint Interval Training) As said before, that augmentation of temperature could be a signal of challenged thermoregulation. That concentration of heat may be explained because of the heat transfer from the exercised muscles to the skin and the inability of the human body to remove that excess. (Charkoudian, 2010)(Merla et al., 2010).

Another finding of the study was detected on Repeated Sprint Sequence protocol, in which hamstrings significantly increased their Tsk probably due to the 180° change of direction (COD). Cutting ability or COD involves deceleration forces that mostly affect knee extensors eccentrically as well as the knee flexors (hamstring) decelerating the leg. Lower limb muscle activation increases during cutting tasks compared with straight-line runs, hence the importance of quadriceps and hamstrings for being the responsible of knee stabilization (Besier et al., 2003). Facing the rotational movements of the joint could imply either an in-training injury risk (Alentorn-Geli et al., 2009, Tsai et al., 2009) or a better performance adaptation (Hader et al., 2014), that will depend on the ability of the fitness coach to properly manage training load associated to cutting. The significant modification on hamstrings Tsk found on our study provides promising results for future research to deeply analyze that fact.

Another aspect observed after Repeated Sprint Sequence was the cross-pattern found on the left hamstring and right popliteal ROIs. Which may be in line with the idea of repeated unilateral landing and cutting with the same leg, maybe because players performed COD rotation to the same direction in a high percentage, therefore showing crossing thermal patterns (ROIs from both left and right sides with Tsk changes) and greater activations (figure 12).

Figure 12. Lines connecting Tsk significant differences to overview the thermal tendencies of ROIs with crossing-patterns (E-3 posterior) or unilateral-patterns predominance (E-2 and E-4).

Finally, the trend ascertained in the Long Interval HIIT was also an increment on the overall ROI Tsk, but detecting significant Tsk alterations in calves. Calf region is composed by gastrocnemius (more external) and soleus (more internal), Tsk changes indicated that both right and left gastrocnemius Tsk had a thermal modification. It is to note that this protocol was the longest one as well as the most continuous. If we decrease running speed, ground contact time will increase and biomechanically will impact less on hamstrings and more on knee and ankle extensors. That will be caused by the lower propulsive horizontal forces which are the objective of knee flexors and the smaller

implication of hamstrings on the powerful hip extension needed during high speed running (Kyrolainen et al., 2005). Thereby, gastrocnemius which is almost composed by fast fibers could experience greater loads as its physiology optimized for explosive movements rather than for constant and prolonged ones.

Regarding Tsk asymmetries, the ROI corresponding with Posterior Knee or popliteal zone was the most significant one in terms of incrementing bilateral differences. We hypothesize that while running, popliteal is the only ROI which stays in contact with another part, as the knee is flexed and then it exists the possibility of friction of the superficial region of upper calves with the hamstring being the popliteal zone in the middle, therefore, being influenced by the running cycle itself, and compromising the results. Also, the vascularization of popliteal zone could be incremented as the temperature of the hamstrings because of their proximity could efflux more blood to proximal zones (popliteal zone). Surprisingly, asymmetries in hamstrings were found in E-3 Repeated Sprint Sequence HIIT in which there was a 0.45°C decrement in the Tsk which reestablished values to zero-asymmetry, contrary to what happened in E-4 Long Interval HIIT, where slightly increased in 0.24°C.

The first fact could be explained as it was the only one HIIT that involved COD, then providing a more powerful unilateral response that could compensate the significantly higher initial Tsk obtained in the Left Posterior External Thigh in pre-moment for E-3 or Repeated Sprint Sequences. The second fact could be explained as an impaired running technique produced for the prolonged effort of a self-paced submaximal intensity, where players modify the way they run because of fatigue. Also, one thing that could compromise the results of E-4 was that the players were running around the football pitch always in the same direction, maybe that fact could explain having the asymmetries in the right-side.

Based on the previous facts, future studies must focus on the relationship of IRT and localized fatigue in ROIs immediately after different HIIT.

5.3. MATCH STUDY

For our knowledge, this is the first study that compares how young football players reacts to a competitive match measured by infrared thermography, providing new information about the thermal response immediately after the match depending on the number of minutes played. Another studies has studied the response of volleyball players to generic endurance training but not specific competition (Chudecka and Lubkowska, 2012) founding direct relationships between VO2 max and temperature drop.

Results showed that there were significant differences before the game between the groups for the Anterior and Posterior Leg (calf region). This response could be directly explained because the initial players were wearing socks and shin guards during the acclimation time, thus becoming an external influence factor to be considered (Fernández-Cuevas et al., 2015b).

Football is an asymmetrical sport in which the actions are not performed bilaterally. After the game the only ROI with a significant difference was the Left Posterior Knee and Leg, that could be explained as most of the players (except 2) were right footed thus using the left leg for maintaining the stability while performing asymmetrical actions like shooting and passing and being a technique specific acute adaptation. The research of Chudecka et al. (2015) evaluated Tsk changes of symmetric body surfaces over scullers after exercising on a two-oared rowing ergometer (symmetrical movements) and handball players after an endurance training session with game elements (asymmetrical movements). While the scullers showed no significant differences in ΔT_{sk} between the opposite sides the handball players did. Hence the technical elements of the sport affects Tsk immediately after the exercise resulting in side to side temperature changes confirming that asymmetrical elements during the competition may affect Tsk. Even when comparing the same symmetrical element, depending on how the movement is performed there is a strong influence in Tsk as Priego Quesada et al. (2016) found while analyzing cyclists with lower knee flexion obtained higher ΔT_{sk} in popliteus and higher knee flexion elicited lower ΔT_{sk} in the tibialis anterior than intermediate knee flexion. An interesting research for the future could be to thermal analyze symmetrical movement in sports with asymmetrical elements and confirm if the side to side Tsk change is because of the acute elements performed in the

activity or the long-term thermal adaptations that are reflected even in symmetrical actions like running.

Comparing both Right and Left Posterior Legs (calf region) of group 1 (who played the whole match) vs group 3 (who did not play), we found that the ΔT_{sk} for group 1 was significantly higher than 1°C while for group 3 only reach a non-significant maximum of $0,73^{\circ}\text{C}$ which we argue that might be related with 1) the total workload accumulated within the match or 2) the socks used by the players during the match even when they completed the acclimation time wearing it. It could be possible that if the player would not wear the socks during the acclimation time we would have found less ΔT_{sk} . When comparing the T_{sk} response immediately after the activity Fernández-Cuevas (2012) found a significant T_{sk} increment in strength and endurance training if compared with speed training (T_{sk} decrement).

On the other side, when analyzing Right vs Left Posterior Legs within group 2 (who played but not the whole match) we found that there was a significant ΔT_{sk} in Left (0.45°C) vs Right (0.15°C), again supporting the idea of a possible acute adaptation of the weak leg within the match because of the asymmetrical technical elements performed during a football match.

Only the players from Group 2 presented significant differences in Post-Pre T_{sk} asymmetries for the Posterior Leg where there was a total decrease in the asymmetry from 0.19°C (Pre) to -0.12°C (Post) which is within the normal parameters established by Marins et al. (2014b) below 0.2°C in football players thus becoming our sample similar to other football samples studied in the past.

5.4. PRACTICAL APPLICATIONS

Results obtained in the three studies open a new way of practical applications within the field of IRT in sports.

The first study about applying cryotherapy and then monitoring the speed of T_{sk} rewarming could be an idea to quantify the level of inflammation for each ROI.

Future studies should demonstrate if the in-muscle inflammation is related with T_{sk} rewarming speed, that would allow sport scientist to quantify the post-match quantity

of inflammation by getting instant thermograms after freezing all the ROIs with the same level of temperature equally. Thus, we consider that individualizing the recovery intervention depending on the grade of Tsk rewarming speed as well as monitoring the degree of asymmetry between speeds in both limbs, will allow the physiotherapist to choose the better technique to use as well as the intensity of the recovery methods.

On the other hand, the second study (HIIT) presents a nice opportunity to strength and conditioning coaches to measure how different HIIT protocols in nature affects in different ways each one of the muscles when measured via IRT.

Future studies should compare IRT and TMG to fully understand how temperature is related with modified muscle properties.

Finally, the third study about how Tsk is affected by a football game gives us an insight of how important could be to relate the movement demands by GPS systems with the thermal responses of the player.

The next idea must be to compare how total running volume, high speed running, number of sprints, running balance (right vs left predominance), number of accelerations and decelerations etc. affects Tsk in different ROIs. Widening the scope how external load is linked with human thermal reactions to fully understand how to manage the load mixing both technologies.

6. CONCLUSIONS

Main conclusion: HIIT protocols and a CWI recovery protocol acutely affect the skin temperature profiles of a soccer player, but not a football match.

6.1. CONCLUSIONS OF 1ST MAIN OBJECTIVE

- **a.1.1.** After a CWI protocol, Dominant vs Non-Dominant provides different information than Right vs Left ROI analysis.
- **a.1.2.** After a CWI protocol the absolute Tsk differed significantly just in one moment but not in subsequent ones when the D vs ND sides were compared on the Anterior Thigh, Anterior Knee and Posterior Thigh; while when R vs L sides were compared, the significant changes were on the Anterior Thigh, Anterior Knee and Posterior Leg.
- **a.2.1.** Professional football players have equal cooling Tsk in both sides for all ROIs except for Posterior Leg when R vs L limbs are compared.
- **a.2.2.** Professional football players have a significantly faster rewarming of the Dominant Posterior Thigh when D vsND limbs are compared.

6.2. CONCLUSIONS OF 2ND MAIN OBJECTIVE

- **b.1.** Young football players present different Tsk reactions depending on the HIIT protocol followed.
- **b.2.1.** E-1 (Short Bouts) significantly decreased the Tsk in 94,4% (17/18) of the considered ROIs.
- **b.2.2.** E-2 (SIT) significantly decreased the Tsk in 61.1% (11/18) of the considered ROIs and the rest exhibit non-significant decrements.
- **b.2.3.** E-3 (RSA) increased overall the Tsk of the considered ROIs but only 11.1% of the total (2/18) showed significant changes.
- **b.2.4.** E-4 (Long Bouts) increased overall the Tsk of the considered ROIs but the significant Tsk changes were limited to 33.3% of the total (6/18).

- **b.3.** Posterior Knee or Popliteus had the biggest Tsk asymmetry in the 4 groups followed by Posterior Thigh (both Internal in E-4 and External in E-3) immediately after the exercise.
- **b.4.** Subjective Perceptions were significantly higher for E-1 (8.80) in comparison with E-2 (6.78), E-3 (5.75) and E-4 (7.24).

6.3. CONCLUSIONS OF 3RD MAIN OBJECTIVE

c.1.1 After the game, Anterior Leg and Posterior Leg Tsk increased for Group 1 (played the whole match) and just Posterior Leg for Group 2 (who did not play the whole match). Group 3 remained with no change in Tsk.

c.1.2 After the game, posterior Leg had a significant Tsk asymmetry only in Group 2.

7. LIMITATIONS OF THE WORK

- The room temperature was different depending on the study.
- Two studies were analyzed using ThermoTracker and another one using manual ROI delimitation because of the inability of the software to analyze post cryotherapy images due to the extremely low temperature after water immersion.
- Absence of control groups in two of the three studies.
- Due to the absence of budget, there are no additional markers of fatigue to compare the results, except for the RPE provided by the soccer player after the effort.

8. FUTURE RESEARCH LINES

In the future, it will be important not only to describe the profile of each sport (Marins et al., 2014b) but also the thermal profile and skin thermal response for each athlete. It would be interesting to generate individualized Tsk recovery profiles at 24, 48 and 72 hours after a match (or intense training) to identify any alteration in the players' Tsk recovery behaviors. Such information could allow the sport scientist to monitor the thermal imbalances produced by maximal-intensity efforts to aid in the implementation of individualized injury-prevention protocols.

The IRT results should be considered together with other tools, such as wellbeing questionnaires and the levels of many physiological variables, including CK, myoglobin or C-reactive protein (Ascensao et al., 2011), interleukins (IL), lactate dehydrogenase (LDH) (Rowell et al., 2009), insulin-like growth factor (IGF), testosterone or cortisol, in protocols for reducing the incidence of sport injuries.

9. REFERENCES

- ABATE, M., CARLO, L. D., ROMUALDO, S. D., IONTA, S., FERRETTI, A., ROMANI, G. L. & MERLA, A. 2010. Postural adjustment in experimental leg length difference evaluated by means of thermal infrared imaging. *Physiol Meas*, 31, 35-43.
- ABRAMOWICZ, J. S. & SHEINER, E. 2007. In utero imaging of the placenta: importance for diseases of pregnancy. *Placenta*, 28 Suppl A, S14-22.
- AFFAIRS, A. C. O. S. 1987. AMA Council Report: Thermography in neurological and musculoskeletal conditions. *Thermology*, 2, 600-7.
- AGUIAR, M., BOTELHO, G., LAGO, C., MAÇAS, V. & SAMPAIO, J. 2012. A Review on the Effects of Soccer Small-Sided Games. *Journal of Human Kinetics*.
- AGUIAR, M. V., BOTELHO, G. M., GONCALVES, B. S. & SAMPAIO, J. E. 2013. Physiological responses and activity profiles of football small-sided games. *J Strength Cond Res*, 27, 1287-94.
- AKIMOV, E. & SON'KIN, V. 2011. Skin temperature and lactate threshold during muscle work in athletes. *Human Physiology*, 37, 621-628.
- AKIMOV, E. B., ANDREEV, R. S., ARKOV, V. V., KIRDIN, A. A., SARYANC, V. V., SONKIN, V. D. & TONEVITSKY, A. G. 2009. Thermal "portrait" of sportsmen with different aerobic capacity. *Acta Kinesiologiae Universitatis Tartuensis*, 14, 7-16.
- AKUBAT, I., PATEL, E., BARRETT, S. & ABT, G. 2012. Methods of monitoring the training and match load and their relationship to changes in fitness in professional youth soccer players. *J Sports Sci*, 30, 1473-80.
- AL-NAKHLI, H. H., PETROFSKY, J. S., LAYMON, M. S. & BERK, L. S. 2012. The Use of Thermal Infra-Red Imaging to Detect Delayed Onset Muscle Soreness. *J Vis Exp*, e3551.
- AL HADDAD, H., LAURSEN, P. B., CHOLLET, D., LEMAITRE, F., AHMAIDI, S. & BUCHHEIT, M. 2010. Effect of cold or thermoneutral water immersion on post-exercise heart rate recovery and heart rate variability indices. *Auton Neurosci*, 156, 111-6.
- AL HADDAD, H., PAROUTY, J. & BUCHHEIT, M. 2012. Effect of daily cold water immersion on heart rate variability and subjective ratings of well-being in highly trained swimmers. *Int J Sports Physiol Perform*, 7, 33-8.
- ALENTORN-GELI, E., MYER, G. D., SILVERS, H. J., SAMITIER, G., ROMERO, D., LAZARO-HARO, C. & CUGAT, R. 2009. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: Mechanisms of injury and underlying risk factors. *Knee Surg Sports Traumatol Arthrosc*, 17, 705-29.
- ALEXANDRE, D., DA SILVA, C. D., HILL-HAAS, S., WONG DEL, P., NATALI, A. J., DE LIMA, J. R., BARA FILHO, M. G., MARINS, J. J., GARCIA, E. S. & KARIM, C. 2012. Heart rate monitoring in soccer: interest and limits during competitive match play and training, practical application. *J Strength Cond Res*, 26, 2890-906.
- ALI RASOOLI, S., KOUSHKIE JAHROMI, M., ASADMANESH, A. & SALESI, M. 2012. Influence of massage, active and passive recovery on swimming performance and blood lactate. *J Sports Med Phys Fitness*, 52, 122-7.
- ALMEIDA, G. P., DE SOUZA, V. L., SANO, S. S., SACCOL, M. F. & COHEN, M. 2012. Comparison of hip rotation range of motion in judo athletes with and without history of low back pain. *Man Ther*, 17, 231-5.
- ALLEN, J. & HOWELL, K. 2014. Microvascular imaging: techniques and opportunities for clinical physiological measurements. *Physiol Meas*, 35, R91-r141.
- AMMER, K. 1996. Occurrence of hyperthermia after ice massage. *Thermol Österr*, 17-20.
- AMMER, K. 2008. The Glamorgan Protocol for recording and evaluation of thermal images of the human body *Thermology International*, 18, 125-129.

- AMMER, K., ENGELBERT, B., HAMERLE-REITER, S. & KERN, E. 1999. Thermographische Veränderungen nach physikalischer Therapie bei Patienten mit Kniegelenkserguss, Algodystrophie oder generalisierter Fibromyalgie. *Thermology International*, 9, 100-105.
- ANDERSSON, H., KARLSEN, A., BLOMHOFF, R., RAASTAD, T. & KADI, F. 2010. Active recovery training does not affect the antioxidant response to soccer games in elite female players. *Br J Nutr*, 104, 1492-9.
- ANDERSSON, H., RAASTAD, T., NILSSON, J., PAULSEN, G., GARTHE, I. & KADI, F. 2008. Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. *Med Sci Sports Exerc*, 40, 372-80.
- ANDRZEJEWSKI, M., CHMURA, J., PLUTA, B., STRZELCZYK, R. & KASPRZAK, A. 2013. Analysis of sprinting activities of professional soccer players. *J Strength Cond Res*, 27, 2134-40.
- ARFAOUI, A., BERTUCCI, W. M., LETELLIER, T. & POLIDORI, G. 2014. *Thermoregulation during incremental exercise in masters cycling*.
- ARFAOUI, A., BOUZID, M. A., PRON, H., EACUTE, TAIAR, R. & POLIDORI, G. 2012a. Application of Infrared Thermography as a Diagnostic Tool of Knee Osteoarthritis. *Journal of Thermal Science and Technology*, 7, 227-235.
- ARFAOUI, A. & POLIDORI, G. 2012. La thermographie infrarouge se met au sport. *le mag*. Paris (France): GL events.
- ARFAOUI, A., POLIDORI, G., TAIAR, R. & POPA, C. 2012b. Infrared Thermography in Sports Activity. In: PRAKASH, R. V. (ed.) *Infrared Thermography*. InTech.
- ARNAIZ LASTRAS, J., FERNÁNDEZ CUEVAS, I., GÓMEZ CARMONA, P. M., SILLERO QUINTANA, M., GARCÍA DE LA CONCEPCIÓN, M. Á. & PIÑONOSA CANO, S. 2011. Pilot study to determinate thermal asymmetries in judokas. In: CABLE, N. T. & GEORGE, K., eds. 16th Annual Congress of the European College of Sport Sciences ECSS, 6th-9th july 2011 Liverpool, United Kingdom. ECSS, 107.
- ARORA, C. P. 2001. *Thermodynamics*, McGraw-Hill Education (India) Pvt Limited.
- ASCENSAO, A., LEITE, M., REBELO, A. N., MAGALHAES, S. & MAGALHAES, J. 2011. Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. *J Sports Sci*, 29, 217-25.
- ASCENSAO, A., REBELO, A., OLIVEIRA, E., MARQUES, F., PEREIRA, L. & MAGALHAES, J. 2008. Biochemical impact of a soccer match - analysis of oxidative stress and muscle damage markers throughout recovery. *Clin Biochem*, 41, 841-51.
- AZHARUDDIN, M., BERA, S. K., DATTA, H. & DASGUPTA, A. K. 2014. Thermal fluctuation based study of aqueous deficient dry eyes by non-invasive thermal imaging. *Exp Eye Res*, 120, 97-102.
- BABAULT, N., COMETTI, C., MAFFIULETTI, N. A. & DELEY, G. 2011. Does electrical stimulation enhance post-exercise performance recovery? *Eur J Appl Physiol*, 111, 2501-7.
- BADŽA, V., JOVANČEVIĆ, V., FRATRIĆ, F., ROGLIĆ, G. & SUDAROV, N. 2012. Possibilities of thermovision application in sport and sport rehabilitation. *Vojnosanit Pregl*, 69, 904-907.
- BAGAVATHIAPPAN, S., LAHIRI, B. B., SARAVANAN, T., PHILIP, J. & JAYAKUMAR, T. 2013. Infrared thermography for condition monitoring – A review. *Infrared Physics & Technology*, 60, 35-55.
- BAGAVATHIAPPAN, S., SARAVANAN, T., PHILIP, J., JAYAKUMAR, T., RAJ, B., KARUNANITHI, R., PANICKER, T. M., KORATH, M. P. & JAGADEESAN, K. 2009. Infrared thermal imaging for detection of peripheral vascular disorders. *J Med Phys*, 34, 43-7.
- BAILEY, D. M., ERITH, S. J., GRIFFIN, P. J., DOWSON, A., BREWER, D. S., GANT, N. & WILLIAMS, C. 2007. Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *J Sports Sci*, 25, 1163-70.
- BALAGEAS, D. L. Termografía infrarroja: una técnica multifacética para la Evaluación No Destructiva (END). In: ESTRUCTURALES, A. A. D. E. N. D. Y., ed. IV Conferencia Panamericana de Ensayos No Destructivos END, octubre 2007 2007 Buenos Aires. Asociación Argentina de Ensayos No Destructivos y Estructurales.

- BANDEIRA, F., MUNIZ DE MOURA, M. A., ABREU DE SOUZA, M., NOHAMA, P. & BORBA NEVES, E. 2012. Pode a termografia auxiliar no diagnóstico de lesões musculares em atletas de futebol? *Revista Brasileira de Medicina do Esporte*, 18, 234-239.
- BANDY, W. D. & IRION, J. M. 1994. The effect of time on static stretch on the flexibility of the hamstring muscles. *Phys Ther*, 74, 845-50; discussion 850-2.
- BANGSBO, J., MOHR, M. & KRUSTRUP, P. 2006. Physical and metabolic demands of training and match-play in the elite football player. *J Sports Sci*, 24, 665-74.
- BANISTER, E. W. 1991. *Modeling Elite Athletic Performance*, Champaign, Illinois: , Human Kinetics.
- BARBERO-ALVAREZ, J. C., BOULLOSA, D., NAKAMURA, F. Y., ANDRIN, G. & WESTON, M. 2014. Repeated Acceleration Ability (RAA): A New Concept with Reference to Top-Level Field and Assistant Soccer Referees. *Asian J Sports Med*, 5, 63-6.
- BARCELOS, E., CAMINHAS, W., RIBEIRO, E., PIMENTA, E. & PALHARES, R. 2014. A Combined Method for Segmentation and Registration for an Advanced and Progressive Evaluation of Thermal Images. *Sensors*, 14, 21950-21967.
- BARNES, C., ARCHER, D. T., HOGG, B., BUSH, M. & BRADLEY, P. S. 2014. The Evolution of Physical and Technical Performance Parameters in the English Premier League. *Int J Sports Med*.
- BARNES, R. B. 1963. Thermography of the Human Body. *Science*, 140, 870-877.
- BARTUZI, P., ROMAN-LIU, D. & WISNIEWSKI, T. 2012. The influence of fatigue on muscle temperature. *Int J Occup Saf Ergon*, 18, 233-43.
- BASTOS, F. N., VANDERLEI, L. C., NAKAMURA, F. Y., BERTOLLO, M., GODOY, M. F., HOSHI, R. A., JUNIOR, J. N. & PASTRE, C. M. 2012. Effects of cold water immersion and active recovery on post-exercise heart rate variability. *Int J Sports Med*, 33, 873-9.
- BEAULIEU, M. L., OH, Y. K., BEDI, A., ASHTON-MILLER, J. A. & WOJTYS, E. M. 2014. Does limited internal femoral rotation increase peak anterior cruciate ligament strain during a simulated pivot landing? *Am J Sports Med*, 42, 2955-63.
- BEDI, A., WARREN, R. F., WOJTYS, E. M., OH, Y. K., ASHTON-MILLER, J. A., OLTEAN, H. & KELLY, B. T. 2014. Restriction in hip internal rotation is associated with an increased risk of ACL injury. *Knee Surg Sports Traumatol Arthrosc*.
- BELENKY, G., WESENSTEN, N. J., THORNE, D. R., THOMAS, M. L., SING, H. C., REDMOND, D. P., RUSSO, M. B. & BALKIN, T. J. 2003. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *J Sleep Res*, 12, 1-12.
- BELIARD, S., CHAUVEAU, M., MOSCATIELLO, T., CROS, F., ECARNOT, F. & BECKER, F. 2015. Compression garments and exercise: no influence of pressure applied. *J Sports Sci Med*, 14, 75-83.
- BENELIYAHU, D. J. 1990. Infrared thermography in the diagnosis and management of sports injuries: a clinical study and literature review. *Chiropractic Sports Medicine*, 4, 46-53.
- BENTLEY, R. E. 1998. *Handbook of Temperature Measurement Vol. 3: The Theory and Practice of Thermoelectric Thermometry*, Springer.
- BERTUCCI, W., ARFAOUI, A., JANSON, L. & POLIDORI, G. 2013a. Relationship between the gross efficiency and muscular skin temperature of lower limb in cycling: a preliminary study. *Computer Methods in Biomechanics and Biomedical Engineering*, 16, 114-115.
- BERTUCCI, W., ARFAOUI, A., JANSON, L. & POLIDORI, G. 2013b. Relationship between the gross efficiency and muscular skin temperature of lower limb in cycling: a preliminary study. *Comput Methods Biomech Biomed Engin*, 16 Suppl 1, 114-5.
- BESIER, T. F., LLOYD, D. G. & ACKLAND, T. R. 2003. Muscle Activation Strategies at the Knee during Running and Cutting Maneuvers. *Medicine and science in sports and exercise*, 35, 119.
- BETTERIDGE, D. J. 2000. What is oxidative stress? *Metabolism*, 49, 3-8.
- BHARGAVA, A., CHANMUGAM, A. & HERMAN, C. 2014. Heat transfer model for deep tissue injury: a step towards an early thermographic diagnostic capability. *Diagn Pathol*, 9, 36.

- BHOWMIK, A., SINGH, R., REPAKA, R. & MISHRA, S. C. 2013. Conventional and newly developed bioheat transport models in vascularized tissues: A review. *Journal of Thermal Biology*, 38, 107-125.
- BINDER, A., PARR, G., THOMAS, P. P. & HAZLEMAN, B. 1983. A clinical and thermographic study of lateral epicondylitis. *Br J Rheumatol*, 22, 77-81.
- BISHOP, D., GIRARD, O. & MENDEZ-VILLANUEVA, A. 2011. Repeated-sprint ability - part II: recommendations for training. *Sports Med*, 41, 741-56.
- BLEAKLEY, C. M., BIEUZEN, F., DAVISON, G. W. & COSTELLO, J. T. 2014. Whole-body cryotherapy: empirical evidence and theoretical perspectives. *Open Access J Sports Med*, 5, 25-36.
- BLEAKLEY, C. M. & HOPKINS, J. T. 2010. Is it possible to achieve optimal levels of tissue cooling in cryotherapy? *Physical Therapy Reviews*, 15, 344-350.
- BOERNER, E., BAUER, J., RATAJCZAK, B., DEREN, E. & PODBIELSKA, H. 2015. Application of thermovision for analysis of superficial temperature distribution changes after physiotherapy. *Journal of Thermal Analysis and Calorimetry*, 120, 261-267.
- BOGDANIS, G. C., NEVILL, M. E., BOOBIS, L. H. & LAKOMY, H. K. 1996. Contribution of phosphocreatine and aerobic metabolism to energy supply during repeated sprint exercise. *J Appl Physiol* (1985), 80, 876-84.
- BOMPA, T. & BUZZICHELLI, C. 2015. *Periodization Training for Sports*, 3E, Human Kinetics Publishers.
- BONNETT, P., HARE, D. B., JONES, D. D., RING, E. F. J. & HARE, C. J. 2006. Some preliminary observations of the effects of sports massage on heat distribution of lower limb muscles during a graded exercise test. *Thermology International*, 16, 143-149.
- BORN, D. P., HOLMBERG, H. C., GOERNERT, F. & SPERLICH, B. 2014a. A novel compression garment with adhesive silicone stripes improves repeated sprint performance - a multi-experimental approach on the underlying mechanisms. *BMC Sports Sci Med Rehabil*, 6, 21.
- BORN, D. P., HOPPE, M. W., LINDNER, N., FREIWALD, J., HOLMBERG, H. C. & SPERLICH, B. 2014b. Adaptive mechanisms and behavioural recommendations: playing football in heat, cold and high altitude conditions. *Sportverletz Sportschaden*, 28, 17-23.
- BORRESEN, J. & LAMBERT, M. I. 2008. Quantifying training load: a comparison of subjective and objective methods. *Int J Sports Physiol Perform*, 3, 16-30.
- BORSA, P. A., LARKIN, K. A. & TRUE, J. M. 2013. Does phototherapy enhance skeletal muscle contractile function and postexercise recovery? A systematic review. *J Athl Train*, 48, 57-67.
- BOUZAS MARINS, J. C., ANDRADE FERNANDES, A. D., GOMES MOREIRA, D., SOUZA SILVA, F., MAGNO A. COSTA, C., PIMENTA, E. M. & SILLERO-QUINTANA, M. 2014. Thermographic profile of soccer players' lower limbs. *Revista Andaluza de Medicina del Deporte*, 7, 1-6.
- BOWTELL, J. L., LEESE, G. P., SMITH, K., WATT, P. W., NEVILL, A., ROOYACKERS, O., WAGENMAKERS, A. J. & RENNIE, M. J. 1998. Modulation of whole body protein metabolism, during and after exercise, by variation of dietary protein. *J Appl Physiol* (1985), 85, 1744-52.
- BRADLEY, P. S., DI MASCIIO, M., PEART, D., OLSEN, P. & SHELDON, B. 2010. High-intensity activity profiles of elite soccer players at different performance levels. *J Strength Cond Res*, 24, 2343-51.
- BRENGELMANN, G. L., JOHNSON, J. M., HERMANSEN, L. & ROWELL, L. B. 1977. Altered control of skin blood flow during exercise at high internal temperatures. *J Appl Physiol Respir Environ Exerc Physiol*, 43, 790-4.
- BRINK, M. S., NEDERHOF, E., VISSCHER, C., SCHMIKLI, S. L. & LEMMINK, K. A. 2010. Monitoring load, recovery, and performance in young elite soccer players. *J Strength Cond Res*, 24, 597-603.
- BUCKERIDGE, E. M., BULL, A. M. & MCGREGOR, A. H. 2014. Foot force production and asymmetries in elite rowers. *Sports Biomech*, 13, 47-61.

- BUCHHEIT, M., PEIFFER, J. J., ABBISS, C. R. & LAURSEN, P. B. 2009. Effect of cold water immersion on postexercise parasympathetic reactivation. *Am J Physiol Heart Circ Physiol*, 296, H421-7.
- BUCHHEIT, M., CHIVOT, A., PAROUTY, J., MERCIER, D., AL HADDAD, H., LAURSEN, P. B. & AHMAIDI, S. 2010. Monitoring endurance running performance using cardiac parasympathetic function. *Eur J Appl Physiol*, 108, 1153-67.
- BUCHHEIT, M. & LAURSEN, P. B. 2013a. High-intensity interval training, solutions to the programming puzzle. Part II: anaerobic energy, neuromuscular load and practical applications. *Sports Med*, 43, 927-54.
- BUCHHEIT, M. & LAURSEN, P. B. 2013b. High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. *Sports Med*, 43, 313-38.
- BUCHHEIT, M., RACINAIS, S., BILSBOROUGH, J., HOCKING, J., MENDEZ-VILLANUEVA, A., BOURDON, P. C., VOSS, S., LIVINGSTON, S., CHRISTIAN, R., PERIARD, J., CORDY, J. & COUTTS, A. J. 2013. Adding heat to the live-high train-low altitude model: a practical insight from professional football. *Br J Sports Med*, 47 Suppl 1, i59-69.
- BUSONI, F., ROMAGNOLI, C., BAGNOLESI, P. & GEMIGNANI, G. 1988. Imaging of enthesopathies of the ligamentum patellae in athletes. Echography and computerized telethermography. *Radiol Med*, 76, 44-7.
- CARLING, C., BLOOMFIELD, J., NELSEN, L. & REILLY, T. 2008. The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. *Sports Med*, 38, 839-62.
- CARLING, C., WILLIAMS, A. M. & REILLY, T. 2006. Handbook of Soccer Match Analysis: A Systematic Approach to Improving Performance. *Journal of Sports Science & Medicine*, 5, 171-171.
- CARMONA, P. M. G. 2012. *Influencia de la información termográfica infrarroja en el protocolo de prevención de lesiones de un equipo de fútbol profesional español.*, Universidad Politécnica de Madrid.
- CASAMICHANA, D. & CASTELLANO, J. 2010. Time-motion, heart rate, perceptual and motor behaviour demands in small-sides soccer games: effects of pitch size. *J Sports Sci*, 28, 1615-23.
- CASAMICHANA, D., CASTELLANO, J. & DELLAL, A. 2013. Influence of different training regimes on physical and physiological demands during small-sided soccer games: continuous vs. intermittent format. *J Strength Cond Res*, 27, 690-7.
- CIBULKA, M. T., SINACORE, D. R., CROMER, G. S. & DELITTO, A. 1998. Unilateral hip rotation range of motion asymmetry in patients with sacroiliac joint regional pain. *Spine (Phila Pa 1976)*, 23, 1009-15.
- CLARK, R. P., MULLAN, B. J. & PUGH, L. G. 1977. Skin temperature during running -a study using infra-red colour thermography. *J Physiol*, 267, 53-62.
- ČOH, M. & ŠIROK, B. 2007. Use of the thermovision method in sport training. *Physical Education and Sport.*, 5, 85-94.
- COMETTI, G., MAFFIULETTI, N. A., POUSSON, M., CHATARD, J. C. & MAFFULLI, N. 2001. Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. *Int J Sports Med*, 22, 45-51.
- COOK, G. 2010. *Movement: Functional Movement Systems: Screening, Assessment, Corrective Strategies*, On Target Publications.
- COSTELLO, J. T., DONNELLY, A. E., KARKI, A. & SELFE, J. 2014. Effects of whole body cryotherapy and cold water immersion on knee skin temperature. *Int J Sports Med*, 35, 35-40.
- COSTELLO, J. T., MCINERNEY, C. D., BLEAKLEY, C. M., SELFE, J. & DONNELLY, A. E. 2012a. The use of thermal imaging in assessing skin temperature following cryotherapy: a review. *Journal of Thermal Biology*, 37, 245-274.
- COSTELLO, J. T., MCINERNEY, C. D., BLEAKLEY, C. M., SELFE, J. & DONNELLY, A. E. 2012b. The use of thermal imaging in assessing skin temperature following cryotherapy: a review. *Journal of Thermal Biology*, 37, 103-110.

- COUTTS, A., REABURN, P., MURPHY, A., PINE, M., AND IMPELLIZZERI, F.M. 2003. Validity of the session-RPE method for determining training load in team sport athletes. *Journal of Science and Medicine in Sport*, 6, 525.
- COUTTS, A. J., RAMPININI, E., MARCORA, S. M., CASTAGNA, C. & IMPELLIZZERI, F. M. 2009. Heart rate and blood lactate correlates of perceived exertion during small-sided soccer games. *J Sci Med Sport*, 12, 79-84.
- COZA, A., DUNN, J. F., ANDERSON, B. & NIGG, B. M. 2012. Effects of compression on muscle tissue oxygenation at the onset of exercise. *J Strength Cond Res*, 26, 1631-7.
- CRANE, J. D., OGBORN, D. I., CUPIDO, C., MELOV, S., HUBBARD, A., BOURGEOIS, J. M. & TARNOPOLSKY, M. A. 2012. Massage Therapy Attenuates Inflammatory Signaling After Exercise-Induced Muscle Damage. *Science Translational Medicine*, 4, 119ra13-119ra13.
- CROISIER, J. L., GANTEAUME, S., BINET, J., GENTY, M. & FERRET, J. M. 2008. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. *Am J Sports Med*, 36, 1469-75.
- CUEVAS, I. F. 2012. *Efecto del entrenamiento de resistencia, velocidad y fuerza en la temperatura de la piel a través de la Termografía Infrarroja.*, Universidad Politécnica de Madrid.
- CUMMINS, C., ORR, R., O'CONNOR, H. & WEST, C. 2013. Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Med*, 43, 1025-42.
- CHAPMAN, R. F., LAYMON, A. S. & ARNOLD, T. 2014. Functional movement scores and longitudinal performance outcomes in elite track and field athletes. *Int J Sports Physiol Perform*, 9, 203-11.
- CHARKOUDIAN, N. 2003. Skin blood flow in adult human thermoregulation: how it works, when it does not, and why. *Mayo Clinic proceedings. Mayo Clinic*, 78, 603-612.
- CHARKOUDIAN, N. 2010. Mechanisms and modifiers of reflex induced cutaneous vasodilation and vasoconstriction in humans. *J Appl Physiol*, 109, 1221-8.
- CHERKAS, L. F., CARTER, L., SPECTOR, T. D., HOWELL, K. J., BLACK, C. M. & MACGREGOR, A. J. 2003. Use of thermographic criteria to identify Raynaud's phenomenon in a population setting. *The Journal of Rheumatology*, 30, 720-722.
- CHIANG, M. F., LIN, P. W., LIN, L. F., CHIOU, H. Y., CHIEN, C. W., CHU, S. F. & CHIU, W. T. 2008. Mass screening of suspected febrile patients with remote-sensing infrared thermography: alarm temperature and optimal distance. *J Formos Med Assoc*, 107, 937-44.
- CHOI, D., COLE, K. J., GOODPASTER, B. H., FINK, W. J. & COSTILL, D. L. 1994. Effect of passive and active recovery on the resynthesis of muscle glycogen. *Med Sci Sports Exerc*, 26, 992-6.
- CHOLEWKA, A., DRZAZGA, Z., MICHNIK, A., SIERON, A. & WISNIEWSKA, B. 2004. Temperature Effects of Whole Body Cryotherapy Determined By Thermography. *Thermology International*, 14, 57-63.
- CHOLEWKA, A., DRZAZGA, Z., SIERON, A. & STANEK, A. 2010. Thermovision diagnostics in chosen spine diseases treated by whole body cryotherapy. *Journal of Thermal Analysis & Calorimetry*, 102, 113-119.
- CHOLEWKA, A., STANEK, A., SIERON, A. & DRZAZGA, Z. 2012. Thermography study of skin response due to whole-body cryotherapy. *Skin Research and Technology*, 18, 180-187.
- CHORBA, R. S., CHORBA, D. J., BOUILLON, L. E., OVERMYER, C. A. & LANDIS, J. A. 2010. Use of a functional movement screening tool to determine injury risk in female collegiate athletes. *N Am J Sports Phys Ther*, 5, 47-54.
- CHUDECKA, M. & LUBKOWSKA, A. 2010. Temperature changes of selected body's surfaces of handball players in the course of training estimated by thermovision, and the study of the impact of physiological and morphological factors on the skin temperature. *Journal of Thermal Biology*, 35, 379-385.
- CHUDECKA, M. & LUBKOWSKA, A. 2012. The use of Thermal Imaging to evaluate Body Temperature changes of athletes during training and a study on the impact of physiological and morphological factors on skin temperature. *Human Movement*, 13, 33-39.

- CHUDECKA, M., LUBKOWSKA, A., LEZNICKA, K. & KRUPCEKI, K. 2015. The Use of Thermal Imaging in the Evaluation of the Symmetry of Muscle Activity in Various Types of Exercises (Symmetrical and Asymmetrical). *J Hum Kinet*, 49, 141-7.
- CHUDECKA, M., SZCZEPANOWSKA, E. & KEMPINSKA, A. 2008. Changes of thermoemission of upper extremities in female handball players - the preliminary study. *Medicina Sportiva*, 12, 99-102.
- DANESHJOO, A., RAHNAMA, N., MOKHTAR, A. H. & YUSOF, A. 2013. Bilateral and Unilateral Asymmetries of Isokinetic Strength and Flexibility in Male Young Professional Soccer Players. *Journal of Human Kinetics*, 36, 45-53.
- DAVIES, V., THOMPSON, K. G. & COOPER, S. M. 2009. The effects of compression garments on recovery. *J Strength Cond Res*, 23, 1786-94.
- DAWSON, B., COW, S., MODRA, S., BISHOP, D. & STEWART, G. 2005. Effects of immediate post-game recovery procedures on muscle soreness, power and flexibility levels over the next 48 hours. *J Sci Med Sport*, 8, 210-21.
- DE ALMEIDA, P., LOPES-MARTINS, R. A., DE MARCHI, T., TOMAZONI, S. S., ALBERTINI, R., CORREA, J. C., ROSSI, R. P., MACHADO, G. P., DA SILVA, D. P., BJORDAL, J. M. & LEAL JUNIOR, E. C. 2012. Red (660 nm) and infrared (830 nm) low-level laser therapy in skeletal muscle fatigue in humans: what is better? *Lasers Med Sci*, 27, 453-8.
- DE CESARIS, R., GRIMALDI, A., BALESTRAZZI, M., RANIERI, G., CHIARAPPA, R. & AVANTAGGIATO, F. 1985. Changes in blood pressure and thermographic values resulting from use of a beta-blocker plus diuretic and of an alpha-beta-blocker plus diuretic. *Drugs Exp Clin Res*, 11, 725-9.
- DE MARCHI, T., LEAL JUNIOR, E. C., BORTOLI, C., TOMAZONI, S. S., LOPES-MARTINS, R. A. & SALVADOR, M. 2012. Low-level laser therapy (LLLT) in human progressive-intensity running: effects on exercise performance, skeletal muscle status, and oxidative stress. *Lasers Med Sci*, 27, 231-6.
- DELEXTRAT, A., CALLEJA-GONZALEZ, J., HIPPOCRATE, A. & CLARKE, N. D. 2013. Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players. *J Sports Sci*, 31, 11-9.
- DELLAL, A., CHAMARI, K., WONG, D. P., AHMAIDI, S., KELLER, D., BARROS, R., BISCIOTTI, G. N. & CARLING, C. 2011. Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *European Journal of Sport Science*, 11, 51-59.
- DENOBLE, A. E., HALL, N., PIEPER, C. F. & KRAUS, V. B. 2010. Patellar skin surface temperature by thermography reflects knee osteoarthritis severity. *Clin Med Insights Arthritis Musculoskeletal Disord*, 3, 69-75.
- DI SALVO, V., BARON, R., TSCHAN, H., CALDERON MONTERO, F. J., BACHL, N. & PIGOZZI, F. 2007. Performance characteristics according to playing position in elite soccer. *Int J Sports Med*, 28, 222-7.
- DONATELLI, R., DIMOND, D. & HOLLAND, M. 2012. Sport-specific biomechanics of spinal injuries in the athlete (throwing athletes, rotational sports, and contact-collision sports). *Clin Sports Med*, 31, 381-96.
- DU BOIS, D. & DU BOIS, E. F. 1989. A formula to estimate the approximate surface area if height and weight be known. *Nutrition*, 5, 303-11; discussion 312-3.
- DUFFIELD, R., CANNON, J. & KING, M. 2010. The effects of compression garments on recovery of muscle performance following high-intensity sprint and plyometric exercise. *J Sci Med Sport*, 13, 136-40.
- DUFFIELD, R., EDGE, J., MERRELLS, R., HAWKE, E., BARNES, M., SIMCOCK, D. & GILL, N. 2008. The effects of compression garments on intermittent exercise performance and recovery on consecutive days. *Int J Sports Physiol Perform*, 3, 454-68.

- DUFFIELD, R. & PORTUS, M. 2007. Comparison of three types of full-body compression garments on throwing and repeat-sprint performance in cricket players. *Br J Sports Med*, 41, 409-14; discussion 414.
- EDWARDS, A. M. & NOAKES, T. D. 2009. Dehydration: cause of fatigue or sign of pacing in elite soccer? *Sports Med*, 39, 1-13.
- EDWARDS, S. 1993. *The heart rate monitor book*, New York, Polar Electro Oy.
- EKSTRAND, J., HAGGLUND, M. & WALDEN, M. 2011. Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med*, 39, 1226-32.
- ELIAS, G. P., VARLEY, M. C., WYCKELSMA, V. L., MCKENNA, M. J., MINAHAN, C. L. & AUGHEY, R. J. 2012. Effects of water immersion on posttraining recovery in Australian footballers. *Int J Sports Physiol Perform*, 7, 357-66.
- ELIAS, G. P., WYCKELSMA, V. L., VARLEY, M. C., MCKENNA, M. J. & AUGHEY, R. J. 2013. Effectiveness of water immersion on postmatch recovery in elite professional footballers. *Int J Sports Physiol Perform*, 8, 243-53.
- ELLENBECKER, T. S., ELLENBECKER, G. A., ROETERT, E. P., SILVA, R. T., KEUTER, G. & SPERLING, F. 2007. Descriptive profile of hip rotation range of motion in elite tennis players and professional baseball pitchers. *Am J Sports Med*, 35, 1371-6.
- ENISELER, N. 2005. Heart rate and blood lactate concentrations as predictors of physiological load on elite soccer players during various soccer training activities. *J Strength Cond Res*, 19, 799-804.
- ENWEMEKA, C. S., PARKER, J. C., DOWDY, D. S., HARKNESS, E. E., SANFORD, L. E. & WOODRUFF, L. D. 2004. The efficacy of low-power lasers in tissue repair and pain control: a meta-analysis study. *Photomed Laser Surg*, 22, 323-9.
- ESPOSITO, F., IMPELLIZZERI, F. M., MARGONATO, V., VANNI, R., PIZZINI, G. & VEICSTEINAS, A. 2004. Validity of heart rate as an indicator of aerobic demand during soccer activities in amateur soccer players. *Eur J Appl Physiol*, 93, 167-72.
- FAIRCHILD, T. J., ARMSTRONG, A. A., RAO, A., LIU, H., LAWRENCE, S. & FOURNIER, P. A. 2003. Glycogen synthesis in muscle fibers during active recovery from intense exercise. *Med Sci Sports Exerc*, 35, 595-602.
- FALK, B. & DOTAN, R. 2011. Temperature regulation and elite young athletes. *Med Sport Sci*, 56, 126-49.
- FARR, T., NOTTLE, C., NOSAKA, K. & SACCO, P. 2002. The effects of therapeutic massage on delayed onset muscle soreness and muscle function following downhill walking. *J Sci Med Sport*, 5, 297-306.
- FAULKNER, J. A., GLEADON, D., MCLAREN, J. & JAKEMAN, J. R. 2013. Effect of lower-limb compression clothing on 400-m sprint performance. *J Strength Cond Res*, 27, 669-76.
- FELDMAN, F. & NICKOLOFF, E. L. 1984. Normal thermographic standards for the cervical spine and upper extremities. *Skeletal Radiol*, 12, 235-49.
- FERNANDES ADE, A., AMORIM, P. R., BRITO, C. J., SILLERO-QUINTANA, M. & BOUZAS MARINS, J. C. 2016. Regional Skin Temperature Response to Moderate Aerobic Exercise Measured by Infrared Thermography. *Asian J Sports Med*, 7, e29243.
- FERNÁNDEZ-CUEVAS, I. 2012. *Effect of endurance, speed and strength training on skin temperature measured by Infrared Thermography*. PhD, Universidad Politécnica de Madrid.
- FERNÁNDEZ-CUEVAS, I., BOUZAS MARINS, J. C., ARNÁIZ LASTRAS, J., GÓMEZ CARMONA, P. M., PIÑONOSA CANO, S., GARCÍA-CONCEPCIÓN, M. Á. & SILLERO-QUINTANA, M. 2015a. Classification of factors influencing the use of infrared thermography in humans: A review. *Infrared Physics & Technology*, 71, 28-55.
- FERNÁNDEZ-CUEVAS, I., BOUZAS MARINS, J. C., ARNÁIZ LASTRAS, J., GÓMEZ CARMONA, P. M., PIÑONOSA CANO, S., GARCÍA-CONCEPCIÓN, M. Á. & SILLERO-QUINTANA, M. 2015b. Classification of factors influencing the use of infrared thermography in humans: A review. *Infrared Physics & Technology*, 71, 28-55.

- FERNÁNDEZ-CUEVAS, I., MARINS, J. C., GÓMEZ CARMONA, P. M., GARCÍA-CONCEPCIÓN, M. Á., ARNAIZ LASTRAS, J. & SILLERO QUINTANA, M. 2012. Reliability and reproducibility of skin temperature of overweight subjects by an infrared thermography software designed for human beings. *Thermology International*, 22, 130-137.
- FERNÁNDEZ CUEVAS, I., GÓMEZ CARMONA, P. M., SILLERO QUINTANA, M., NOYA SALCES, J., ARNAIZ LASTRAS, J. & PASTOR BARRÓN, A. Economic costs estimation of soccer injuries in first and second spanish division professional teams. In: ECSS, ed. 15th Annual Congress of the European College of Sport Sciences ECSS, 23th 26th june 2010 Antalya, Turkey. ECSS.
- FERRARESI, C., BELTRAME, T., FABRIZZI, F., NASCIMENTO, E. S., KARSTEN, M., FRANCISCO, C. O., BORGHI-SILVA, A., CATAI, A. M., CARDOSO, D. R., FERREIRA, A. G., HAMBLIN, M. R., BAGNATO, V. S. & PARIZOTTO, N. A. 2015. Muscular pre-conditioning using light-emitting diode therapy (LEDT) for high-intensity exercise: a randomized double-blind placebo-controlled trial with a single elite runner. *Physiother Theory Pract*, 1-8.
- FERREIRA, D. M., ZANGARO, R. A., VILLAYERDE, A. B., CURY, Y., FRIGO, L., PICOLO, G., LONGO, I. & BARBOSA, D. G. 2005. Analgesic effect of He-Ne (632.8 nm) low-level laser therapy on acute inflammatory pain. *Photomed Laser Surg*, 23, 177-81.
- FERREIRA, J. J., MENDONCA, L. C., NUNES, L. A., ANDRADE FILHO, A. C., REBELATTO, J. R. & SALVINI, T. F. 2008. Exercise-associated thermographic changes in young and elderly subjects. *Ann Biomed Eng*, 36, 1420-7.
- FORMENTI, D., LUDWIG, N., GARGANO, M., GONDOLA, M., DELLERMA, N., CAUMO, A. & ALBERTI, G. 2013. Thermal imaging of exercise-associated skin temperature changes in trained and untrained female subjects. *Ann Biomed Eng*, 41, 863-71.
- FOSTER, C. 1998. Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exerc*, 30, 1164-8.
- FOSTER, C., RODRIGUEZ-MARROYO, J. A. & DE KONING, J. J. 2017. Monitoring Training Loads: The Past, the Present, and the Future. *Int J Sports Physiol Perform*, 12, S22-s28.
- FOUSEKIS, K., TSEPIS, E., POULMEDIS, P., ATHANASOPOULOS, S. & VAGENAS, G. 2011. Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players. *Br J Sports Med*, 45, 709-14.
- FOUSEKIS, K., TSEPIS, E. & VAGENAS, G. 2010. Multivariate isokinetic strength asymmetries of the knee and ankle in professional soccer players. *J Sports Med Phys Fitness*, 50, 465-74.
- FREITAS, C. G., AOKI, M. S., FRANCISCON, C. A., ARRUDA, A. F., CARLING, C. & MOREIRA, A. 2014. Psychophysiological responses to overloading and tapering phases in elite young soccer players. *Pediatr Exerc Sci*, 26, 195-202.
- GABBETT, T. J. 2010. The development and application of an injury prediction model for noncontact, soft-tissue injuries in elite collision sport athletes. *J Strength Cond Res*, 24, 2593-603.
- GABBETT, T. J. & DOMROW, N. 2007. Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *J Sports Sci*, 25, 1507-19.
- GABBETT, T. J. & ULLAH, S. 2012. Relationship between running loads and soft-tissue injury in elite team sport athletes. *J Strength Cond Res*, 26, 953-60.
- GARAGIOLA, U. & GIANI, E. 1990. Use of telethermography in the management of sports injuries. *Sports Med*, 10, 267-72.
- GARCÍA-CONCEPCIÓN, M. A., PEINADO, A. B., PAREDES HERNÁNDEZ, V. & ALVERO-CRUZ, J. R. 2015. Efficacy of different recovery strategies in elite soccer players. *Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte*.
- GARRISON, M., WESTRICK, R., JOHNSON, M. R. & BENENSON, J. 2015. Association between the functional movement screen and injury development in college athletes. *Int J Sports Phys Ther*, 10, 21-8.
- GARZA, D., ROLSTON, B., JOHNSTON, T., SUNGAR, G., FERGUSON, J. & MATHESON, G. Heat-Loss Patterns in National Football League Players as Measured by Infrared Thermography. In: ITC, I. T. C., ed. *InfraMation*, 2008. Infrared Training Center ITC.

- GAUDINO, P., ALBERTI, G. & IAIA, F. M. 2014. Estimated metabolic and mechanical demands during different small-sided games in elite soccer players. *Hum Mov Sci*, 36, 123-33.
- GAUDINO, P., IAIA, F. M., STRUDWICK, A. J., HAWKINS, R. D., ALBERTI, G., ATKINSON, G. & GREGSON, W. 2015. Factors Influencing Perception of Effort (Session-RPE) During Elite Soccer Training. *Int J Sports Physiol Perform*.
- GAUSSORGUES, G. & CHOMET, S. 2012. *Infrared Thermography*, Springer Netherlands.
- GAVIN, J. P., MYERS, S. D. & WILLEMS, M. E. 2014. Neuromuscular responses to mild-muscle damaging eccentric exercise in a low glycogen state. *J Electromyogr Kinesiol*.
- GIL, S. M., GIL, J., RUIZ, F., IRAZUSTA, A. & IRAZUSTA, J. 2007. Physiological and anthropometric characteristics of young soccer players according to their playing position: relevance for the selection process. *J Strength Cond Res*, 21, 438-45.
- GIRARD, O., MENDEZ-VILLANUEVA, A. & BISHOP, D. 2011. Repeated-sprint ability - part I: factors contributing to fatigue. *Sports Med*, 41, 673-94.
- GLASGOW, P. D., FERRIS, R. & BLEAKLEY, C. M. 2014. Cold Water Immersion in the Management of Delayed-Onset Muscle Soreness: Is Dose Important? A Randomised Controlled Trial. *Physical Therapy in Sports*.
- GÓMEZ CARMONA, P. M. 2012. *Influencia de la información termográfica infrarroja en el protocolo de prevención de lesiones de un equipo de fútbol profesional español*. PhD, Universidad Politécnica de Madrid.
- GÓMEZ CARMONA, P. M., SILLERO QUINTANA, M., NOYA SALCES, J. & PASTRANO LEÓN, R. 2008. Infrared Thermography as an injury prevention method in soccer. *Archivos de Medicina del Deporte*, 25 (6), 490.
- GONZALEZ-ALONSO, J. 2012. Human thermoregulation and the cardiovascular system. *Exp Physiol*, 97, 340-6.
- GONZALEZ-ALONSO, J., MORTENSEN, S. P., JEPPESEN, T. D., ALI, L., BARKER, H., DAMSGAARD, R., SECHER, N. H., DAWSON, E. A. & DUFOUR, S. P. 2008. Haemodynamic responses to exercise, ATP infusion and thigh compression in humans: insight into the role of muscle mechanisms on cardiovascular function. *J Physiol*, 586, 2405-17.
- GONZALEZ-ALONSO, J., QUISTORFF, B., KRUSTRUP, P., BANGSBO, J. & SALTIN, B. 2000. Heat production in human skeletal muscle at the onset of intense dynamic exercise. *J Physiol*, 524 Pt 2, 603-15.
- GONZALO-SKOK, O., TOUS-FAJARDO, J., ARJOL-SERRANO, J. L. & MENDEZ-VILLANUEVA, A. 2014. Determinants, reliability, and usefulness of a bench press repeated power ability test in young basketball players. *J Strength Cond Res*, 28, 126-33.
- GRAMMER, K. & THORNHILL, R. 1994. *Human (Homo sapiens) facial attractiveness and sexual selection: The role of symmetry and averageness* [Online]. US: American Psychological Association. 108].
- GREGSON, W., BLACK, M. A., JONES, H., MILSON, J., MORTON, J., DAWSON, B., ATKINSON, G. & GREEN, D. J. 2011. Influence of cold water immersion on limb and cutaneous blood flow at rest. *Am J Sports Med*, 39, 1316-23.
- GUR, H., AKOVA, B., PUNDUK, Z. & KUCUKOGLU, S. 1999. Effects of age on the reciprocal peak torque ratios during knee muscle contractions in elite soccer players. *Scand J Med Sci Sports*, 9, 81-7.
- HADER, K., MENDEZ-VILLANUEVA, A., AHMAIDI, S., WILLIAMS, B. & BUCHHEIT, M. 2014. Changes of direction during high-intensity intermittent runs: neuromuscular and metabolic responses. *BMC Sports Sci Med Rehabil*, 6, 2.
- HÄGGLUND, M., WALDÉN, M., MAGNUSSON, H., KRISTENSON, K., BENGTSSON, H. & EKSTRAND, J. 2013. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. *British Journal of Sports Medicine*.

- HALOUANI, J., CHTOUROU, H., DELLAL, A., CHAOUACHI, A. & CHAMARI, K. 2014a. Physiological responses according to rules changes during 3 vs. 3 small-sided games in youth soccer players: stop-ball vs. small-goals rules. *J Sports Sci*, 32, 1485-90.
- HALOUANI, J., CHTOUROU, H., GABBETT, T., CHAOUACHI, A. & CHAMARI, K. 2014b. Small-sided games in team sports training: a brief review. *J Strength Cond Res*, 28, 3594-618.
- HALSON, S. L. 2014a. Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine*, 44, 139-147.
- HALSON, S. L. 2014b. Sleep in elite athletes and nutritional interventions to enhance sleep. *Sports Med*, 44 Suppl 1, S13-23.
- HARDAKER, N. J., MOSS, A. D., RICHARDS, J., SALLY JARVIS, J., MCEWAN, I. & SELFE, J. 2007. The relationship between skin surface temperature measured via Non-contact Thermal Imaging and intra-muscular temperature of the Rectus Femoris muscle. *Thermology International*, 17, 45-50.
- HEALEY, K. C., HATFIELD, D. L., BLANPIED, P., DORFMAN, L. R. & RIEBE, D. 2014. The effects of myofascial release with foam rolling on performance. *J Strength Cond Res*, 28, 61-8.
- HEMMINGS, B., SMITH, M., GRAYDON, J. & DYSON, R. 2000. Effects of massage on physiological restoration, perceived recovery, and repeated sports performance. *Br J Sports Med*, 34, 109-14; discussion 115.
- HERBERT, R. D., DE NORONHA, M. & KAMPER, S. J. 2011. Stretching to prevent or reduce muscle soreness after exercise. *Cochrane Database Syst Rev*, Cd004577.
- HERRERA, E., SANDOVAL, M. C., CAMARGO, D. M. & SALVINI, T. F. 2010. Motor and sensory nerve conduction are affected differently by ice pack, ice massage, and cold water immersion. *Phys Ther*, 90, 581-91.
- HIGHAM, D. G., PYNE, D. B., ANSON, J. M. & EDDY, A. 2012. Movement patterns in rugby sevens: effects of tournament level, fatigue and substitute players. *J Sci Med Sport*, 15, 277-82.
- HILDEBRANDT, C. & RASCHNER, C. 2009. An Intra-Examiner Reliability Study of Knee Temperature Patterns With Medical Infrared Thermal Imaging. *Thermology International*, 19, 73-76.
- HILDEBRANDT, C., RASCHNER, C. & AMMER, K. 2010. An overview of recent application of medical infrared thermography in sports medicine in Austria. *Sensors*, 10, 4700-4715.
- HILDEBRANDT, C., ZEILBERGER, K., RING, E. F. J. & RASCHNER, C. 2012. The application of medical Infrared Thermography in sports medicine. In: ZASLAV, K. R. (ed.) *An International Perspective on Topics in Sports Medicine and Sports Injury*. InTech.
- HILL-HAAS, S. V., DAWSON, B., IMPELLIZZERI, F. M. & COUTTS, A. J. 2011. Physiology of small-sided games training in football: a systematic review. *Sports Med*, 41, 199-220.
- HILL, J. A., HOWATSON, G., VAN SOMEREN, K. A., WALSHE, I. & PEDLAR, C. R. 2014. Influence of compression garments on recovery after marathon running. *J Strength Cond Res*, 28, 2228-35.
- HIRATA, K., NAGASAKA, T. & NODA, Y. 1989. Venous return from distal regions affects heat loss from the arms and legs during exercise-induced thermal loads. *Eur J Appl Physiol Occup Physiol*, 58, 865-72.
- HJORTSKOV, N., RISSEN, D., BLANGSTED, A. K., FALLENTIN, N., LUNDBERG, U. & SOGAARD, K. 2004. The effect of mental stress on heart rate variability and blood pressure during computer work. *Eur J Appl Physiol*, 92, 84-9.
- HOFF, J. & HELGERUD, J. 2004. Endurance and strength training for soccer players: physiological considerations. *Sports Med*, 34, 165-80.
- HOOPER, D. R., DULKIS, L. L., SECOLA, P. J., HOLTZUM, G., HARPER, S. P., KALKOWSKI, R. J., COMSTOCK, B. A., SZIVAK, T. K., FLANAGAN, S. D., LOONEY, D. P., DUPONT, W. H., MARESH, C. M., VOLEK, J. S., CULLEY, K. P. & KRAEMER, W. J. 2015. The Roles of an Upper Body Compression Garment on Athletic Performances. *J Strength Cond Res*.
- HUNOLD, S., MIETZSCH, E. & WERNER, J. 1992. Thermographic studies on patterns of skin temperature after exercise. *Eur J Appl Physiol Occup Physiol*, 65, 550-4.

- IHSAN, F. R. 2005. Low-level laser therapy accelerates collateral circulation and enhances microcirculation. *Photomed Laser Surg*, 23, 289-94.
- IMPELLIZZERI, F. M., RAMPININI, E., COUTTS, A. J., SASSI, A. & MARCORA, S. M. 2004. Use of RPE-based training load in soccer. *Med Sci Sports Exerc*, 36, 1042-7.
- INCROPERA, F. P. & DEWITT, D. P. 1999. *Fundamentos de transferencia de calor*, Pearson Educación.
- INGRAM, J., DAWSON, B., GOODMAN, C., WALLMAN, K. & BEILBY, J. 2009. Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *J Sci Med Sport*, 12, 417-21.
- ISPIRLIDIS, I., FATOUROS, I. G., JAMURTAS, A. Z., NIKOLAIDIS, M. G., MICHAILIDIS, I., DOUROUDOS, I., MARGONIS, K., CHATZINIKOLAOU, A., KALISTRATOS, E., KATRABASAS, I., ALEXIOU, V. & TAXILDARIS, K. 2008. Time-course of changes in inflammatory and performance responses following a soccer game. *Clin J Sport Med*, 18, 423-31.
- IVY, J. L. 2004. Regulation of Muscle Glycogen Repletion, Muscle Protein Synthesis and Repair Following Exercise. *Journal of Sports Science & Medicine*, 3, 131-138.
- IVY, J. L., KATZ, A. L., CUTLER, C. L., SHERMAN, W. M. & COYLE, E. F. 1988. Muscle glycogen synthesis after exercise: effect of time of carbohydrate ingestion. *J Appl Physiol* (1985), 64, 1480-5.
- JACKSON, A. S. & POLLOCK, M. L. 1978. Generalized equations for predicting body density of men. *Br J Nutr*, 40, 497-504.
- JENTJENS, R. & JEUKENDRUP, A. 2003. Determinants of post-exercise glycogen synthesis during short-term recovery. *Sports Med*, 33, 117-44.
- JONES, B. C., LITTLE, A. C., PENTON-VOAK, I. S., TIDDEMAN, B. P., BURT, D. M. & PERRETT, D. I. 2001. Facial symmetry and judgements of apparent health. *Evolution and Human Behavior*, 22, 417-429.
- JONES, B. F. & PLASSMANN, P. 2002. Digital infrared thermal imaging of human skin. *IEEE Eng Med Biol Mag*, 21, 41-8.
- KARKI, A., KARPPI, P., EKBERG, J. & SELFE, J. 2004. A thermographic investigation of skin temperature changes in response to a thermal washout of the knee in healthy young adults. *Thermology International*, 14, 137-141.
- KATZ, A. & WESTERBLAD, H. 2014. Regulation of glycogen breakdown and its consequences for skeletal muscle function after training. *Mamm Genome*, 25, 464-72.
- KENNET, J., HARDAKER, N., HOBBS, S. & SELFE, J. 2007. Cooling efficiency of 4 common cryotherapeutic agents. *J Athl Train*, 42, 343-8.
- KIESEL, K., PLISKY, P. J. & VOIGHT, M. L. 2007. Can Serious Injury in Professional Football be Predicted by a Preseason Functional Movement Screen? *North American Journal of Sports Physical Therapy : NAJSPT*, 2, 147-158.
- KIESEL, K. B., BUTLER, R. J. & PLISKY, P. J. 2014. Prediction of injury by limited and asymmetrical fundamental movement patterns in american football players. *J Sport Rehabil*, 23, 88-94.
- KIM, Y. H., BAEK, S. S., CHOI, K. S., LEE, S. G. & PARK, S. B. 2002. The effect of cold air application on intra-articular and skin temperatures in the knee. *Yonsei Med J*, 43, 621-6.
- KING, M. & DUFFIELD, R. 2009. The effects of recovery interventions on consecutive days of intermittent sprint exercise. *J Strength Cond Res*, 23, 1795-802.
- KINUGASA, T. & KILDING, A. E. 2009. A comparison of post-match recovery strategies in youth soccer players. *J Strength Cond Res*, 23, 1402-7.
- KLEBANOV, G. I., KREININA, M. V., POLTANOV, E. A., KHRISTOFOROVA, T. V. & VLADIMIROV, Y. A. 2001. Mechanism of therapeutic effect of low-intensity infrared laser radiation. *Bull Exp Biol Med*, 131, 239-41.
- KOKLU, Y., SERT, O., ALEMDAROGLU, U. & ARSLAN, Y. 2013. COMPARISON OF THE PHYSIOLOGICAL RESPONSES AND TIME MOTION CHARACTERISTICS OF YOUNG

- SOCCER PLAYERS IN SMALL SIDED GAMES: THE EFFECT OF GOALKEEPER. *J Strength Cond Res*.
- KONG, S. C. O. C. I. H. *Flir Systems Company Limited* [Online]. Available: <http://www.swedcham.com.hk/members/flir-systems-company-limited/>.
- KOPSA, H., CZECH, W., SCHMIDT, P., ZAZGORNIAK, J., PILS, P. & BALCKE, P. 1979. Use of thermography in kidney transplantation: two year follow up study in 75 cases. *Proc Eur Dial Transplant Assoc*, 16, 383-7.
- KOVACS, M. S. & BAKER, L. B. 2014. Recovery interventions and strategies for improved tennis performance. *Br J Sports Med*, 48 Suppl 1, i18-21.
- KRAEMER, W. J., FLANAGAN, S. D., COMSTOCK, B. A., FRAGALA, M. S., EARP, J. E., DUNN-LEWIS, C., HO, J. Y., THOMAS, G. A., SOLOMON-HILL, G., PENWELL, Z. R., POWELL, M. D., WOLF, M. R., VOLEK, J. S., DENEGAR, C. R. & MARESH, C. M. 2010. Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. *J Strength Cond Res*, 24, 804-14.
- KYROLAINEN, H., AVELA, J. & KOMI, P. V. 2005. Changes in muscle activity with increasing running speed. *J Sports Sci*, 23, 1101-9.
- LAAKSO, E. L. & CABOT, P. J. 2005. Nociceptive scores and endorphin-containing cells reduced by low-level laser therapy (LLLT) in inflamed paws of Wistar rat. *Photomed Laser Surg*, 23, 32-5.
- LAGO-PENAS, C. 2012. The Role of Situational Variables in Analysing Physical Performance in Soccer. *Journal of Human Kinetics*, 35, 89-95.
- LAHIRI, B. B., BAGAVATHIAPPAN, S., JAYAKUMAR, T. & PHILIP, J. 2012. Medical Applications of Infrared Thermography: A Review. *Infrared Physics & Technology*, 55, 221-235.
- LARK, S. D. & MCCARTHY, P. W. 2007. Cervical range of motion and proprioception in rugby players versus non-rugby players. *J Sports Sci*, 25, 887-94.
- LASTELLA, M., ROACH, G. D., HALSON, S. L. & SARGENT, C. 2015. Sleep/wake behaviours of elite athletes from individual and team sports. *Eur J Sport Sci*, 15, 94-100.
- LATHROP-LAMBACH, R. L., ASAY, J. L., JAMISON, S. T., PAN, X., SCHMITT, L. C., BLAZEK, K., SISTON, R. A., ANDRIACCHI, T. P. & CHAUDHARI, A. M. 2014. Evidence for joint moment asymmetry in healthy populations during gait. *Gait Posture*, 40, 526-31.
- LEAL JUNIOR, E. C., DE GODOI, V., MANCALOSSO, J. L., ROSSI, R. P., DE MARCHI, T., PARENTE, M., GROSSELLI, D., GENEROSI, R. A., BASSO, M., FRIGO, L., TOMAZONI, S. S., BJORDAL, J. M. & LOPES-MARTINS, R. A. 2011. Comparison between cold water immersion therapy (CWIT) and light emitting diode therapy (LEDT) in short-term skeletal muscle recovery after high-intensity exercise in athletes--preliminary results. *Lasers Med Sci*, 26, 493-501.
- LEAL JUNIOR, E. C., LOPES-MARTINS, R. A., BARONI, B. M., DE MARCHI, T., TAUFER, D., MANFRO, D. S., RECH, M., DANNA, V., GROSSELLI, D., GENEROSI, R. A., MARCOS, R. L., RAMOS, L. & BJORDAL, J. M. 2009a. Effect of 830 nm low-level laser therapy applied before high-intensity exercises on skeletal muscle recovery in athletes. *Lasers Med Sci*, 24, 857-63.
- LEAL JUNIOR, E. C., LOPES-MARTINS, R. A., ROSSI, R. P., DE MARCHI, T., BARONI, B. M., DE GODOI, V., MARCOS, R. L., RAMOS, L. & BJORDAL, J. M. 2009b. Effect of cluster multi-diode light emitting diode therapy (LEDT) on exercise-induced skeletal muscle fatigue and skeletal muscle recovery in humans. *Lasers Surg Med*, 41, 572-7.
- LEE, M. H. M. & COHEN, J. M. 2008. *Rehabilitation medicine and thermography*, Wilsonville, OR, Impress Publications.
- LIU, Y., MIMURA, K., WANG, L. & IKUDA, K. 2003. Physiological benefits of 24-style Taijiquan exercise in middle-aged women. *J Physiol Anthropol Appl Human Sci*, 22, 219-25.
- LUCIA, A., HOYOS, J., SANTALLA, A., EARNEST, C. & CHICHARRO, J. L. 2003. Tour de France versus Vuelta a Espana: which is harder? *Med Sci Sports Exerc*, 35, 872-8.
- MACDONALD, G. Z., BUTTON, D. C., DRINKWATER, E. J. & BEHM, D. G. 2014. Foam rolling as a recovery tool after an intense bout of physical activity. *Med Sci Sports Exerc*, 46, 131-42.

- MACDONALD, G. Z., PENNEY, M. D., MULLALEY, M. E., CUCONATO, A. L., DRAKE, C. D., BEHM, D. G. & BUTTON, D. C. 2013. An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *J Strength Cond Res*, 27, 812-21.
- MACRAE, B. A., COTTER, J. D. & LAING, R. M. 2011. Compression garments and exercise: garment considerations, physiology and performance. *Sports Med*, 41, 815-43.
- MACRUM, E., BELL, D. R., BOLING, M., LEWEK, M. & PADUA, D. 2012. Effect of limiting ankle-dorsiflexion range of motion on lower extremity kinematics and muscle-activation patterns during a squat. *J Sport Rehabil*, 21, 144-50.
- MAGALHAES, J., OLIVEIRA, J., ASCENSAO, A. & SOARES, J. 2004. Concentric quadriceps and hamstrings isokinetic strength in volleyball and soccer players. *J Sports Med Phys Fitness*, 44, 119-25.
- MALDAGUE, X. 2001. *Theory and practice of infrared technology for nondestructive testing*, New York, Wiley.
- MALKINSON, T. J. Calf skin temperature during ergometer exercise: effect of intensity. Engineering in Medicine and Biology, 2002. 24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society EMBS/BMES Conference, 2002. Proceedings of the Second Joint, 2002 2002. 1297-1298 vol.2.
- MALLIARAS, P., HOGAN, A., NAWROCKI, A., CROSSLEY, K. & SCHACHE, A. 2009. Hip flexibility and strength measures: reliability and association with athletic groin pain. *Br J Sports Med*, 43, 739-44.
- MANN, T. N., LAMBERTS, R. P. & LAMBERT, M. I. 2014. High responders and low responders: factors associated with individual variation in response to standardized training. *Sports Med*, 44, 1113-24.
- MANNING, J. T. & PICKUP, L. J. 1998. Symmetry and performance in middle distance runners. *Int J Sports Med*, 19, 205-9.
- MANSFIELD, C. M., FARRELL, C. & ASBELL, S. O. 1970. The use of thermography in the detection of metastatic liver disease. *Radiology*, 95, 696-8.
- MANZI, V., IELLAMO, F., IMPELLIZZERI, F., D'OTTAVIO, S. & CASTAGNA, C. 2009. Relation between individualized training impulses and performance in distance runners. *Med Sci Sports Exerc*, 41, 2090-6.
- MARINO, F. E. 2008. The evolutionary basis of thermoregulation and exercise performance. *Med Sport Sci*, 53, 1-13.
- MARINS, J. C. B., FERNANDES, A. A., CANO, S. P., MOREIRA, D. G., DA SILVA, F. S., COSTA, C. M. A., FERNANDEZ-CUEVAS, I. & SILLERO-QUINTANA, M. 2014a. Thermal body patterns for healthy Brazilian adults (male and female). *Journal of Thermal Biology*.
- MARINS, J. C. B., FERNANDES, A. A., MOREIRA, D. G., DA SILVA, F. S., COSTA, C. M. A., PIMENTA, E. & SILLERO-QUINTANA, M. 2014b. Thermographic profile of soccer players' lower limb. *Revista Andaluza de Medicina del Deporte*, 7, 1-6.
- MARINS, J. C. B., MOREIRA, D. G., CANO, S. P., QUINTANA, M. S., SOARES, D. D., FERNANDES, A. D. A., SILVA, F. S. D., COSTA, C. M. A. & AMORIM, P. R. D. S. 2014c. Time required to stabilize thermographic images at rest. *Infrared Physics & Technology*.
- MARINS, J. C. B. F.-C., I.; ARNAIZ-LASTRAS, J.; FERNANDES, A.A. Y SILLERO-QUINTANA, M. 2015. Aplicaciones de la termografía infrarroja en el deporte. Una revisión. *Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte*.
- MARTINENT, G., DECRET, J. C., ISOARD-GAUTHEUR, S., FILAIRE, E. & FERRAND, C. 2014. Evaluations of the psychometric properties of the Recovery-Stress Questionnaire for Athletes among a sample of young French table tennis players. *Psychol Rep*, 114, 326-40.
- MAUGHAN, R. J., WATSON, P., EVANS, G. H., BROAD, N. & SHIRREFFS, S. M. 2007. Water balance and salt losses in competitive football. *Int J Sport Nutr Exerc Metab*, 17, 583-94.

- MCCARTNEY, N., SPRIET, L. L., HEIGENHAUSER, G. J., KOWALCHUK, J. M., SUTTON, J. R. & JONES, N. L. 1986. Muscle power and metabolism in maximal intermittent exercise. *J Appl Physiol* (1985), 60, 1164-9.
- MCDANIEL, G. W. & ROBINSON, D. Z. 1962. Thermal Imaging by Means of the Evaporograph. *Applied Optics*, 1, 311-324.
- MCDONOUGH, A. & FUNK, L. 2014. Can glenohumeral joint isokinetic strength and range of movement predict injury in professional rugby league. *Phys Ther Sport*, 15, 91-6.
- MCGILL, S., FROST, D., ANDERSEN, J., CROSBY, I. & GARDINER, D. 2013. Movement quality and links to measures of fitness in firefighters. *Work*, 45, 357-66.
- MCGILL, S. M., ANDERSEN, J. T. & HORNE, A. D. 2012. Predicting performance and injury resilience from movement quality and fitness scores in a basketball team over 2 years. *J Strength Cond Res*, 26, 1731-9.
- MCHUGH, M. P., MAGNUSSON, S. P., GLEIM, G. W. & NICHOLAS, J. A. 1992. Viscoelastic stress relaxation in human skeletal muscle. *Med Sci Sports Exerc*, 24, 1375-82.
- MENDIGUCHIA, J., SAMOZINO, P., MARTINEZ-RUIZ, E., BRUGHELLI, M., SCHMIKLI, S., MORIN, J. B. & MENDEZ-VILLANUEVA, A. 2014. Progression of Mechanical Properties during On-field Sprint Running after Returning to Sports from a Hamstring Muscle Injury in Soccer Players. *Int J Sports Med*.
- MERLA, A., DIDONATO, L. & ROMANI, G. L. Infrared functional imaging: analysis of skin temperature during exercise. Engineering in Medicine and Biology, 2002. 24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society EMBS/BMES Conference, 2002. Proceedings of the Second Joint, 2002 2002. 1141-1142 vol.2.
- MERLA, A., IODICE, P., TANGHERLINI, A., DE MICHELE, G., DI ROMUALDO, S., SAGGINI, R. & ROMANI, G. 2005. Monitoring skin temperature in trained and untrained subjects throughout thermal video. *Conf Proc IEEE Eng Med Biol Soc*, 2, 1684-1686.
- MERLA, A., MATTEI, P. A., DI DONATO, L. & ROMANI, G. L. 2010. Thermal imaging of cutaneous temperature modifications in runners during graded exercise. *Ann Biomed Eng*, 38, 158-63.
- MICKLEWRIGHT, D., GRIFFIN, M., GLADWELL, V. & BENEKE, R. 2005. Mood State Response to Massage and Subsequent Exercise Performance. *The Sport Psychologist*, 19, 234-250.
- MINETT, G. M. & DUFFIELD, R. 2014. Is recovery driven by central or peripheral factors? A role for the brain in recovery following intermittent-sprint exercise. *Front Physiol*, 5, 24.
- MIYAMOTO, N. & KAWAKAMI, Y. 2014. Effect of pressure intensity of compression short-tight on fatigue of thigh muscles. *Med Sci Sports Exerc*, 46, 2168-74.
- MIYAMOTO, N. & KAWAKAMI, Y. 2015. No graduated pressure profile in compression stockings still reduces muscle fatigue. *Int J Sports Med*, 36, 220-5.
- MOHR, M., KRUSTRUP, P. & BANGSBO, J. 2003a. Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences*, 21, 519-528.
- MOHR, M., KRUSTRUP, P. & BANGSBO, J. 2003b. Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci*, 21, 519-28.
- MOHR, M., KRUSTRUP, P. & BANGSBO, J. 2005. Fatigue in soccer: a brief review. *J Sports Sci*, 23, 593-9.
- MORESIDE, J. M. & MCGILL, S. M. 2013. Improvements in hip flexibility do not transfer to mobility in functional movement patterns. *J Strength Cond Res*, 27, 2635-43.
- MORGAN, W. P., BROWN, D. R., RAGLIN, J. S., O'CONNOR, P. J. & ELLICKSON, K. A. 1987. Psychological monitoring of overtraining and staleness. *Br J Sports Med*, 21, 107-14.
- MORTON, R. H., FITZ-CLARKE, J. R. & BANISTER, E. W. 1990. Modeling human performance in running. *J Appl Physiol* (1985), 69, 1171-7.
- MULLER, M. D., KIM, C. H., SEO, Y., RYAN, E. J. & GLICKMAN, E. L. 2012. Hemodynamic and thermoregulatory responses to lower body water immersion. *Aviat Space Environ Med*, 83, 935-41.

- MURRAY, A. M., JONES, T. W., HOROBEANU, C., TURNER, A. P. & SPROULE, J. 2016. Sixty seconds of foam rolling does not affect functional flexibility or change muscle temperature in adolescent athletes. *International Journal of Sports Physical Therapy*, 11, 765-776.
- NAKAYAMA, T., OHNUKI, Y. & KANOSUE, K. 1981. Fall in skin temperature during exercise observed by thermography. *Jpn J Physiol*, 31, 757-62.
- 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, 997-1015.
- NEDELEC, M., MCCALL, A., CARLING, C., LEGALL, F., BERTHOIN, S. & DUPONT, G. 2013. Recovery in soccer : part ii-recovery strategies. *Sports Med*, 43, 9-22.
- NEDELEC, M., MCCALL, A., CARLING, C., LEGALL, F., BERTHOIN, S. & DUPONT, G. 2014. The influence of soccer playing actions on the recovery kinetics after a soccer match. *J Strength Cond Res*, 28, 1517-23.
- NERIC, F. B., BEAM, W. C., BROWN, L. E. & WIERSMA, L. D. 2009. Comparison of swim recovery and muscle stimulation on lactate removal after sprint swimming. *J Strength Cond Res*, 23, 2560-7.
- NG, E. Y. K. 2009. A review of thermography as promising non-invasive detection modality for breast tumor. *International Journal of Thermal Sciences*, 48, 849-859.
- NGO, J. K., TSUI, M. C., SMITH, A. W., CARLING, C., CHAN, G. S. & WONG DEL, P. 2012. The effects of man-marking on work intensity in small-sided soccer games. *J Sports Sci Med*, 11, 109-14.
- NIU, H. H., LUI, P. W., HU, J. S., TING, C. K., YIN, Y. C., LO, Y. L., LIU, L. & LEE, T. Y. 2001. Thermal symmetry of skin temperature: normative data of normal subjects in Taiwan. *Zhonghua Yi Xue Za Zhi (Taipei)*, 64, 459-68.
- NO, M. & KWAK, H. B. 2016. Effects of environmental temperature on physiological responses during submaximal and maximal exercises in soccer players. *Integr Med Res*, 5, 216-222.
- NOYA, J. & SILLERO, M. 2012. Incidencia lesional en el fútbol profesional español a lo largo de una temporada: días de baja por lesión. *Apunts. Medicina de l'Esport*, 47, 115-123.
- NOYA SALCES, J., GOMEZ-CARMONA, P. M., GRACIA-MARCO, L., MOLINER-URDIALES, D. & SILLERO-QUINTANA, M. 2014. Epidemiology of injuries in First Division Spanish football. *J Sports Sci*, 32, 1263-70.
- NOYA SALCES, J. & SILLERO QUINTANA, M. 2012. Epidemiología de las lesiones en el fútbol profesional español en la temporada 2008-2009. *Archivos de Medicina del Deporte*, XXIX, 750-766.
- OKAMOTO, T., MASUHARA, M. & IKUTA, K. 2014. Acute effects of self-myofascial release using a foam roller on arterial function. *J Strength Cond Res*, 28, 69-73.
- OOSTERVELD, F. G., RASKER, J. J., JACOBS, J. W. & OVERMARS, H. J. 1992. The effect of local heat and cold therapy on the intraarticular and skin surface temperature of the knee. *Arthritis Rheum*, 35, 146-51.
- PAPACOSTA, E. & NASSIS, G. P. 2011. Saliva as a tool for monitoring steroid, peptide and immune markers in sport and exercise science. *J Sci Med Sport*, 14, 424-34.
- PARCHMANN, C. J. & MCBRIDE, J. M. 2011. Relationship between functional movement screen and athletic performance. *J Strength Cond Res*, 25, 3378-84.
- PAROLIN, M. L., CHESLEY, A., MATSOS, M. P., SPRIET, L. L., JONES, N. L. & HEIGENHAUSER, G. J. 1999. Regulation of skeletal muscle glycogen phosphorylase and PDH during maximal intermittent exercise. *Am J Physiol*, 277, E890-900.
- PASCOE, D. D., SKELTON, M., SMITH, E. W., KREMER, D. & PUROHIT, R. C. 1992. Infrared thermography pattern of the back of human subjects during exercise: 921. *Medicine & Science in Sports & Exercise*, 24(5), S154.

- PASIAKOS, S. M., LIEBERMAN, H. R. & MCLELLAN, T. M. 2014. Effects of protein supplements on muscle damage, soreness and recovery of muscle function and physical performance: a systematic review. *Sports Med*, 44, 655-70.
- PAUL, D. J., NASSIS, G. P., WHITELEY, R., MARQUES, J. B., KENNEALLY, D. & CHALABI, H. 2014. Acute responses of soccer match play on hip strength and flexibility measures: potential measure of injury risk. *J Sports Sci*, 32, 1318-23.
- PEARCEY, G. E., BRADBURY-SQUIRES, D. J., KAWAMOTO, J. E., DRINKWATER, E. J., BEHM, D. G. & BUTTON, D. C. 2015. Foam rolling for delayed-onset muscle soreness and recovery of dynamic performance measures. *J Athl Train*, 50, 5-13.
- PETIT, J. M., BURLET-GODINOT, S., MAGISTRETTI, P. J. & ALLAMAN, I. 2015. Glycogen metabolism and the homeostatic regulation of sleep. *Metab Brain Dis*, 30, 263-79.
- PLANCK, M. 2013. *Treatise on Thermodynamics*, Dover Publications.
- PLEWS, D. J., LAURSEN, P. B., KILDING, A. E. & BUCHHEIT, M. 2014. Heart-rate variability and training-intensity distribution in elite rowers. *Int J Sports Physiol Perform*, 9, 1026-32.
- POPPENDIECK, W., FAUDE, O., WEGMANN, M. & MEYER, T. 2013. Cooling and performance recovery of trained athletes: a meta-analytical review. *Int J Sports Physiol Perform*, 8, 227-42.
- PRETORIUS, T., LIX, L. & GIESBRECHT, G. 2011. Shivering heat production and body fat protect the core from cooling during body immersion, but not during head submersion: a structural equation model. *Comput Biol Med*, 41, 154-8.
- PRIEGO QUESADA, J. I., CARPES, F. P., BINI, R. R., SALVADOR PALMER, R., PEREZ-SORIANO, P. & CIBRIAN ORTIZ DE ANDA, R. M. 2015. Relationship between skin temperature and muscle activation during incremental cycle exercise. *J Therm Biol*, 48, 28-35.
- PRIEGO QUESADA, J. I., CARPES, F. P., SALVADOR PALMER, R., PÉREZ-SORIANO, P. & CIBRIÁN ORTIZ DE ANDA, R. M. 2016. Effect of saddle height on skin temperature measured in different days of cycling. *SpringerPlus*, 5, 205.
- PURVIS, A. & TUNSTALL, H. 2004. Effects of sock type on foot skin temperature and thermal demand during exercise. *Ergonomics*, 47, 1657-1668.
- RA, S.-G., MAEDA, S., HIGASHINO, R., IMAI, T. & MIYAKAWA, S. 2014. Metabolomics of salivary fatigue markers in soccer players after consecutive games. *Applied Physiology, Nutrition, and Metabolism*, 39, 1120-1126.
- RAGO, V. L., ITALO, PIZZUTO, FEDERICO; COSTA, JÚLIO; ANGEICCHIO, GIANLUCA; TAFURI, DOMENICO; RAIOLA, GAETANO 2016. Variation of Oxidative Stress of Elite Football Players during Pre-Season and In-Season. *Journal of Physical Education and Sport*, 16.
- RAHNAMA, N., LEES, A. & BAMBAECICHI, E. 2005. Comparison of muscle strength and flexibility between the preferred and non-preferred leg in English soccer players. *Ergonomics*, 48, 1568-75.
- RAMPININI, E., IMPELLIZZERI, F. M., CASTAGNA, C., COUTTS, A. J. & WISLOFF, U. 2009. Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *J Sci Med Sport*, 12, 227-33.
- RANDERS, M. B., ROSTGAARD, T. & KRUSTRUP, P. 2007. Physical match performance and yo-yo IR2 test results of successful and unsuccessful football teams In the Danish premier league. *Journal of Sports Science & Medicine*, 6, [np].
- RASMUSSEN, L. K. & MERCER, J. B. 2004. A comparison of thermal responses in hands and feet of young and elderly subjects in response to local cooling as determined by infrared imaging. *Thermology International*, 14, 71-76.
- REILLY, T. 2005. An ergonomics model of the soccer training process. *J Sports Sci*, 23, 561-72.
- REILLY, T. & EKBLOM, B. 2005. The use of recovery methods post-exercise. *J Sports Sci*, 23, 619-27.
- REILLY, T. & PIERCY, M. 1994. The effect of partial sleep deprivation on weight-lifting performance. *Ergonomics*, 37, 107-15.

- RENKIELSKA, A., KACZMAREK, M., NOWAKOWSKI, A., GRUDZINSKI, J., CZAPIEWSKI, P., KRAJEWSKI, A. & GROBELNY, I. 2014. Active dynamic infrared thermal imaging in burn depth evaluation. *J Burn Care Res*, 35, e294-303.
- REY, E., LAGO-PÉÑAS, C., LAGO-BALLESTEROS, J. & CASAIS, L. 2010. The effect of cumulative fatigue on activity profiles of professional soccer players during a congested fixture period. *Biology of Sport*.
- REY, E., LAGO-PÉÑAS, C., CASAIS, L. & LAGO-BALLESTEROS, J. 2012. The Effect of Immediate Post-Training Active and Passive Recovery Interventions on Anaerobic Performance and Lower Limb Flexibility in Professional Soccer Players. *Journal of Human Kinetics*, 31, 121-129.
- RHODES, G. & ZEBROWITZ, L. A. 2002. *Facial Attractiveness: Evolutionary, Cognitive, and Social Perspectives*, Ablex.
- RIERA, F., HERR, R., XU, X., MELIN, B., REGNARD, J. & BOURDON, L. 2014. Thermal and metabolic responses of military divers during a 6-hour static dive in cold water. *Aviat Space Environ Med*, 85, 509-17.
- RING, E. & AMMER, K. 2000. The Technique of Infra red Imaging in Medicine. *Thermology International*, 10, 7-14.
- RING, E., JONES, C., AMMER, K., PLASSMANN, P. & BOLA, T. 2004a. Cooling effects of Deep Freeze Cold gel applied to the skin, with and without rubbing, to the lumbar region of the back. *Thermology International*, 14, 64-70.
- RING, E., JONES, C., AMMER, K., PLASSMANN, P. & BOLA, T. 2004b. Cooling effects of Deep Freeze Cold Gel compared to that of an ice pack applied to the skin. *Thermology International*, 14, 93-98.
- RING, E. F. 1990. Quantitative thermal imaging. *Clin Phys Physiol Meas*, 11 Suppl A, 87-95.
- RING, E. F. 2006. The historical development of thermometry and thermal imaging in medicine. *J Med Eng Technol*, 30, 192-8.
- RING, E. F. & AMMER, K. 2012. Infrared thermal imaging in medicine. *Physiol Meas*, 33, R33-46.
- RING, F. J. 2014. Pioneering progress in infrared imaging in medicine. *Quantitative InfraRed Thermography Journal*, 11, 57-65.
- ROACH, S. M., JUAN, J. G., SUPRAK, D. N., LYDA, M., BIES, A. J. & BOYDSTON, C. R. 2015. Passive hip range of motion is reduced in active subjects with chronic low back pain compared to controls. *Int J Sports Phys Ther*, 10, 13-20.
- ROBSON-ANSLEY, P. J., GLEESON, M. & ANSLEY, L. 2009. Fatigue management in the preparation of Olympic athletes. *J Sports Sci*, 27, 1409-20.
- RODAS, G. 2008. Variabilidad de la frecuencia cardíaca: Concepto, medidas y relación con aspectos clínicos (I). *Archivos de Medicina del Deporte*, XXV, 41-47.
- ROGALSKI, A. 2012. History of infrared detectors. *Opto-Electronics Review*, 20, 279-308.
- ROLLE, K. C. 1999. *Thermodynamics and Heat Power*, Prentice Hall.
- ROSSIGNOLI, I., FERNÁNDEZ-CUEVAS, I., BENITO, P. J. & HERRERO, A. J. 2016. Relationship between shoulder pain and skin temperature measured by infrared thermography in a wheelchair propulsion test. *Infrared Physics & Technology*, 76, 251-258.
- ROWSELL, G. J., COUTTS, A. J., REABURN, P. & HILL-HAAS, S. 2009. Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *J Sports Sci*, 27, 565-73.
- ROWSELL, G. J., COUTTS, A. J., REABURN, P. & HILL-HAAS, S. 2011. Effect of post-match cold-water immersion on subsequent match running performance in junior soccer players during tournament play. *J Sports Sci*, 29, 1-6.
- RUMPF, M. C., CRONIN, J. B., MOHAMAD, I. N., MOHAMAD, S., OLIVER, J. L. & HUGHES, M. G. 2014. Kinetic asymmetries during running in male youth. *Phys Ther Sport*, 15, 53-7.

- RUSSELL, M. & KINGSLEY, M. 2014. The efficacy of acute nutritional interventions on soccer skill performance. *Sports Med*, 44, 957-70.
- RUSSELL, M., NORTHEAST, J., ATKINSON, G., SHEARER, D. A., SPARKES, W., COOK, C. J. & KILDUFF, L. 2015. The between-match variability of peak power output and Creatine Kinase responses to soccer match-play. *J Strength Cond Res*.
- SAINZ, J. M. 2013. *La preparación (física) para el fútbol basada en el juego*, Fútbol de Libro.
- SAIRYO, K., IKATA, T., TAKAI, H. & IWANAGA, K. 1993. Effect of active recovery on intracellular pH following muscle contraction, a ³¹P-MRS study. *Ann Physiol Anthropol*, 12, 173-9.
- SAIRYO, K., IWANAGA, K., YOSHIDA, N., MISHIRO, T., TERA, T., SASA, T. & IKATA, T. 2003. Effects of active recovery under a decreasing work load following intense muscular exercise on intramuscular energy metabolism. *Int J Sports Med*, 24, 179-82.
- SAMPEDRO, J., PIÑONOSA CANO, S. & FERNÁNDEZ-CUEVAS, I. 2012. Thermography as a new assessment tool in basketball. Pilot study carried out with a professional player in the ACB. *Cuadernos de Psicología del Deporte*, 12, 51-56.
- SANCHIS-SANCHEZ, E., SALVADOR-PALMER, R., CODONER-FRANCH, P., MARTIN, J., VERGARA-HERNANDEZ, C., BLASCO, J., BALLESTER, E., SANCHIS, E., GONZALEZ-PENA, R. & CIBRIAN, R. 2014a. Infrared thermography is useful for ruling out fractures in paediatric emergencies. *Eur J Pediatr*.
- SANCHIS-SANCHEZ, E., VERGARA-HERNANDEZ, C., CIBRIAN, R. M., SALVADOR, R., SANCHIS, E. & CODONER-FRANCH, P. 2014b. Infrared thermal imaging in the diagnosis of musculoskeletal injuries: a systematic review and meta-analysis. *AJR Am J Roentgenol*, 203, 875-82.
- SANDS, W. A., MCNEAL, J. R. & STONE, M. 2011. Thermal imaging and gymnastics injuries: a means of screening and injury identification. *Science of Gymnastics Journal*, 3, 5-12.
- SAVIC, M., FONDA, B. & SARABON, N. 2013. Actual temperature during and thermal response after whole-body cryotherapy in cryo-cabin. *Journal of Thermal Biology*, 38, 186-191.
- SCOTT, B. R., LOCKIE, R. G., KNIGHT, T. J., CLARK, A. C. & JANSE DE JONGE, X. A. 2013. A comparison of methods to quantify the in-season training load of professional soccer players. *Int J Sports Physiol Perform*, 8, 195-202.
- SCHILTZ, M., LEHANCE, C., MAQUET, D., BURY, T., CRIELAARD, J. M. & CROISIER, J. L. 2009. Explosive strength imbalances in professional basketball players. *J Athl Train*, 44, 39-47.
- SCHMERMUND, A., RODERMANN, J. & ERBEL, R. 2003. Intracoronary thermography. *Herz*, 28, 505-12.
- SELFE, J., HARDAKER, N., WHITAKER, J. & HAYES, C. 2007. Thermal imaging of an ice burn over the patella following clinically relevant cryotherapy application during a clinical research study. *Physical Therapy in Sport*, 8, 153-158.
- SEMINATI, E., NARDELLO, F., ZAMPARO, P., ARDIGO, L. P., FACCIOLI, N. & MINETTI, A. E. 2013. Anatomically asymmetrical runners move more asymmetrically at the same metabolic cost. *PLoS One*, 8, e74134.
- SERWAY & BEICHNER 2002. *Física*, Mexico, McGraw Hill.
- SHOEMAKER, J. K., TIIDUS, P. M. & MADER, R. 1997. Failure of manual massage to alter limb blood flow: measures by Doppler ultrasound. *Med Sci Sports Exerc*, 29, 610-4.
- SILVA, J. R., REBELO, A., MARQUES, F., PEREIRA, L., SEABRA, A., ASCENSAO, A. & MAGALHAES, J. 2014. Biochemical impact of soccer: an analysis of hormonal, muscle damage, and redox markers during the season. *Appl Physiol Nutr Metab*, 39, 432-8.
- SILLERO-QUINTANA, M. & FERNÁNDEZ-CUEVAS, I. Infrared Thermography as a means to quantify the effects of the training load. In: NOWAKOWSKI, A. & MERCER, J., eds. 132nd ICB Seminar. Advances of Infra-red Thermal Imaging in Medicine, 30th June 3rd July 2013 Warsaw, Poland. International Center of Biocybernetics, 85-91.

- SILLERO-QUINTANA, M., FERNÁNDEZ-JAÉN, T., FERNÁNDEZ-CUEVAS, I., GÓMEZ-CARMONA, P. M., ARNAIZ-LASTRAS, J., PÉREZ, M.-D. & GUILLÉN, P. 2015. Infrared Thermography as a Support Tool for Screening and Early Diagnosis in Emergencies. *Journal of Medical Imaging and Health Informatics*, 5, 1223-1228.
- SILLERO QUINTANA, M., GÓMEZ CARMONA, P. M., NOYA SALCES, J., NÚÑEZ, F. J. & FERNÁNDEZ RODRÍGUEZ, I. Comparison of infrared thermography with tensiomyography as injury prevention method in professional soccer players. In: FRANCIS, T., ed. BASES, 1st to 3rd september 2009 2009 Leeds. Taylor & Francis, S174.
- SIVANANDAM, S., ANBURAJAN, M., VENKATRAMAN, B., MENAKA, M. & SHARATH, D. 2012. Medical thermography: a diagnostic approach for type 2 diabetes based on non-contact infrared thermal imaging. *Endocrine*.
- SLOTH, M., SLOTH, D., OVERGAARD, K. & DALGAS, U. 2013. Effects of sprint interval training on VO₂max and aerobic exercise performance: A systematic review and meta-analysis. *Scand J Med Sci Sports*, 23, e341-52.
- SMALL, K., MCNAUGHTON, L. R., GREIG, M., LOHKAMP, M. & LOVELL, R. 2009. Soccer fatigue, sprinting and hamstring injury risk. *Int J Sports Med*, 30, 573-8.
- SMITH, C. J. & HAVENITH, G. 2011. Body mapping of sweating patterns in male athletes in mild exercise-induced hyperthermia. *Eur J Appl Physiol*, 111, 1391-404.
- SPORIS, G., JUKIC, I., OSTOJIC, S. M. & MILANOVIC, D. 2009. Fitness profiling in soccer: physical and physiologic characteristics of elite players. *J Strength Cond Res*, 23, 1947-53.
- STOLEN, T., CHAMARI, K., CASTAGNA, C. & WISLOFF, U. 2005. Physiology of soccer: an update. *Sports Med*, 35, 501-36.
- STROYER, J., HANSEN, L. & KLAUSEN, K. 2004. Physiological profile and activity pattern of young soccer players during match play. *Med Sci Sports Exerc*, 36, 168-74.
- STRUDWICK, T. & REILLY, T. 2001. Work-rate profiles of elite Premier League football players. *Insight*, 2, 28-29.
- SUAREZ-ARRONES, L., ARENAS, C., LOPEZ, G., REQUENA, B., TERRILL, O. & MENDEZ-VILLANUEVA, A. 2014a. Positional differences in match running performance and physical collisions in men rugby sevens. *Int J Sports Physiol Perform*, 9, 316-23.
- SUAREZ-ARRONES, L., TORRENO, N., REQUENA, B., SAEZ DE VILLARREAL, E., CASAMICHANA, D., BARBERO-ALVAREZ, J. C. & MUNGUÍA-IZQUIERDO, D. 2014b. Match-play activity profile in professional soccer players during official games and the relationship between external and internal load. *J Sports Med Phys Fitness*.
- SUDHAKAR, S., KAYSHAP, B. & SRIDHAR REDDY, P. 2011. Thermography in dentistry-revisited. *International Journal of Biological and Medical Research*, 2, 461-465.
- TAMARIT, X. & GIMENO, X. T. 2007. *¿Qué es la Periodización Táctica?*, Moreno y Conde Sports, S.L.
- TAYLOR, C. J., PIZZARI, T., AMES, N., ORCHARD, J. W., GABBE, B. J. & COOK, J. L. 2011. Groin pain and hip range of motion is different in Indigenous compared to non-indigenous young Australian football players. *J Sci Med Sport*, 14, 283-6.
- TESSITORE, A., MEEUSEN, R., CORTIS, C. & CAPRANICA, L. 2007. Effects of different recovery interventions on anaerobic performances following preseason soccer training. *J Strength Cond Res*, 21, 745-50.
- TESSITORE, A., MEEUSEN, R., PAGANO, R., BENVENUTI, C., TIBERI, M. & CAPRANICA, L. 2008. Effectiveness of active versus passive recovery strategies after futsal games. *J Strength Cond Res*, 22, 1402-12.
- TEUNISSEN, L. P. & DAANEN, H. A. 2011. Infrared thermal imaging of the inner canthus of the eye as an estimator of body core temperature. *J Med Eng Technol*, 35, 134-8.
- THORPE, R. & SUNDERLAND, C. 2012. Muscle damage, endocrine, and immune marker response to a soccer match. *J Strength Cond Res*, 26, 2783-90.

- THORPE, R. T., STRUDWICK, A. J., 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*.
- THUN, E., BJORVATN, B., FLO, E., HARRIS, A. & PALLESEN, S. 2014. Sleep, circadian rhythms, and athletic performance. *Sleep Med Rev*, 23c, 1-9.
- TIIDUS, P. M. & SHOEMAKER, J. K. 1995. Effleurage massage, muscle blood flow and long-term post-exercise strength recovery. *Int J Sports Med*, 16, 478-83.
- TIKTINSKII, O. L., MEL'NIKOVA, V. P., MOSHKALOV, A. A. & NOVIKOV, I. F. 1989. The role of thermography in the diagnosis of testicular diseases. *Urol Nefrol (Mosk)*, 23-6.
- TIMMINS, R. G., OPAR, D. A., WILLIAMS, M. D., SCHACHE, A. G., DEAR, N. M. & SHIELD, A. J. 2014. Reduced biceps femoris myoelectrical activity influences eccentric knee flexor weakness after repeat sprint running. *Scand J Med Sci Sports*.
- TIPTON, K. D. & WOLFE, R. R. 2001. Exercise, protein metabolism, and muscle growth. *Int J Sport Nutr Exerc Metab*, 11, 109-32.
- TKACOVA, M., HUDAK, R., FOFFOVA, P. & ZIVCAK, J. 2010. An importance of camera - subject distance and angle in musculoskeletal application of medical thermography. *Acta Electrotechnica et Informatica*, 10, 57-60.
- TOMKINSON, G. R. & OLDS, T. S. 2000. Physiological correlates of bilateral symmetry in humans. *Int J Sports Med*, 21, 545-50.
- TOMKINSON, G. R., POPOVIC, N. & MARTIN, M. 2003. Bilateral symmetry and the competitive standard attained in elite and sub-elite sport. *J Sports Sci*, 21, 201-11.
- TORII, M., YAMASAKI, M. & SASAKI, T. 1987. [Skin surface temperatures during submaximal cycling observed by color thermography]. *Ann Physiol Anthropol*, 6, 21-4.
- TORII, M., YAMASAKI, M., SASAKI, T. & NAKAYAMA, H. 1992. Fall in skin temperature of exercising man. *Br J Sports Med*, 26, 29-32.
- TSAI, L.-C., SIGWARD, S. M., POLLARD, C. D. & FLETCHER, M. J. 2009. Effects of fatigue and recovery on knee mechanics during side-step cutting. *Medicine and science in sports and exercise*, 41, 1952-1957.
- UEMATSU, S. 1985. Symmetric of skin temperature comparing one side of the body to the other. *Thermology*, 1, 4-7.
- UEMATSU, S., EDWIN, D. H., JANKEL, W. R., KOZIKOWSKI, J. & TRATTNER, M. 1988a. Quantification of thermal asymmetry. Part 1: Normal values and reproducibility. *J Neurosurg*, 69, 552-5.
- UEMATSU, S., EDWIN, D. H., JANKEL, W. R., KOZIKOWSKI, J. & TRATTNER, R. T. 1988b. Quantification of thermal asymmetry, Part I: Normal values and reproducibility. *J Neurosurg*, 69, 552-555.
- VAILE, J., HALSON, S., GILL, N. & DAWSON, B. 2008. Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. *J Sports Sci*, 26, 431-40.
- VAINER, B. G. 2005. FPA-based infrared thermography as applied to the study of cutaneous perspiration and stimulated vascular response in humans. *Physics in Medicine and Biology*, 50, R63.
- VALDERRABANO, V., NIGG, B. M., HINTERMANN, B., GOEPFERT, B., DICK, W., FRANK, C. B., HERZOG, W. & VON TSCHARNER, V. 2007. Muscular lower leg asymmetry in middle-aged people. *Foot Ankle Int*, 28, 242-9.
- VAN BEIJSTERVELDT, A. M., VAN DE PORT, I. G., VEREIJKEN, A. J. & BACKX, F. J. 2013. Risk factors for hamstring injuries in male soccer players: a systematic review of prospective studies. *Scand J Med Sci Sports*, 23, 253-62.
- VANDERTHOMMEN, M., SOLTANI, K., MAQUET, D., CRIELAARD, J. M. & CROISIER, J. L. 2007. Does neuromuscular electrical stimulation influence muscle recovery after maximal isokinetic exercise? *Isokinetics and Exercise Science*, 15, 143-149.

- VARDASCA, R. & MENDES, J. G. 2017. *Innovative Research in Thermal Imaging for Biology and Medicine*, MEDICAL INFOR SCIENCE IGI.
- VARDASCA, R., RING, E. F. J., PLASSMANN, P. & JONES, C. D. 2012. Thermal symmetry of the upper and lower extremities in healthy subjects. *Thermology International*, 22, 53-60.
- VEGHTE, J. H., ADAMS, W. C. & BERNAUER, E. M. 1979. Temperature changes during exercise measured by thermography. *Aviat Space Environ Med*, 50, 708-13.
- VGONTZAS, A. N., ZOUMAKIS, E., BIXLER, E. O., LIN, H. M., FOLLETT, H., KALES, A. & CHROUSOS, G. P. 2004. Adverse effects of modest sleep restriction on sleepiness, performance, and inflammatory cytokines. *J Clin Endocrinol Metab*, 89, 2119-26.
- VIGNE, G., DELLAL, A., GAUDINO, C., CHAMARI, K., ROGOWSKI, I., ALLOATTI, G., WONG, P. D., OWEN, A. & HAUTIER, C. 2013. Physical outcome in a successful Italian Serie A soccer team over three consecutive seasons. *J Strength Cond Res*, 27, 1400-6.
- WADE, C. E. & VEGHTE, J. H. 1977. Thermographic evaluation of the relative heat loss by area in man after swimming. *Aviat Space Environ Med*, 48, 16-8.
- WALLACE, L. K., SLATTERY, K. M. & COUTTS, A. J. 2009. The ecological validity and application of the session-RPE method for quantifying training loads in swimming. *J Strength Cond Res*, 23, 33-8.
- WANG, J.-G. & TOH, H. L. Visualizing skin temperature before, during and after exercise for dynamic area telethermometry. Engineering in Medicine and Biology Society, 2001. Proceedings of the 23rd Annual International Conference of the IEEE, 2001 2001. 2831-2835 vol.3.
- WARREN, M., SMITH, C. A. & CHIMERA, N. J. 2014. Association of Functional Movement Screen With Injuries in Division I Athletes. *J Sport Rehabil*.
- WASNER, G., SCHATTSCHEIDER, J. & BARON, R. 2002. Skin temperature side differences--a diagnostic tool for CRPS? *Pain*, 98, 19-26.
- WEGMANN, M., FAUDE, O., POPPENDIECK, W., HECKSTEDEN, A., FROHLICH, M. & MEYER, T. 2012. Pre-cooling and sports performance: a meta-analytical review. *Sports Med*, 42, 545-64.
- WILCOCK, I. M., CRONIN, J. B. & HING, W. A. 2006. Physiological response to water immersion: a method for sport recovery? *Sports Med*, 36, 747-65.
- WILKIE, D. R. 1968. Heat work and phosphorylcreatine break-down in muscle. *J Physiol*, 195, 157-83.
- WILMORE, J. H. & COSTILL, D. L. 2007. *Fisiología del esfuerzo y del deporte*, Barcelona, Paidotribo.
- WILMORE, J. H., COSTILL, D. L. & KENNEY, W. L. 2008. *Physiology of Sport and Exercise*, Human Kinetics.
- WILTSHIRE, E. V., POITRAS, V., PAK, M., HONG, T., RAYNER, J. & TSCHAKOVSKY, M. E. 2010. Massage impairs postexercise muscle blood flow and "lactic acid" removal. *Med Sci Sports Exerc*, 42, 1062-71.
- WILLIAMS, J. R. 2008. The Declaration of Helsinki and public health. *Bull World Health Organ*, 86, 650-2.
- WOLFE, R. R. 2001. Effects of amino acid intake on anabolic processes. *Can J Appl Physiol*, 26 Suppl, S220-7.
- WONG, P. L., CHAMARI, K., DELLAL, A. & WISLOFF, U. 2009. Relationship between anthropometric and physiological characteristics in youth soccer players. *J Strength Cond Res*, 23, 1204-10.
- YOUNG, A. J., SAWKA, M. N., NEUFER, P. D., MUZA, S. R., ASKEW, E. W. & PANDOLF, K. B. 1989. Thermoregulation during cold water immersion is unimpaired by low muscle glycogen levels. *J Appl Physiol* (1985), 66, 1809-16.
- YU, B., QUEEN, R. M., ABBEY, A. N., LIU, Y., MOORMAN, C. T. & GARRETT, W. E. 2008. Hamstring muscle kinematics and activation during overground sprinting. *Journal of Biomechanics*, 41, 3121-3126.

- ZAIÏDI, H., TAIAR, R., FOHANNO, S. & POLIDORI, G. 2007. The influence of swimming type on the skin-temperature maps of a competitive swimmer from infrared thermography. *Acta Bioeng Biomech*, 9, 47-51.
- ZAINUDDIN, Z., NEWTON, M., SACCO, P. & NOSAKA, K. 2005. Effects of massage on delayed-onset muscle soreness, swelling, and recovery of muscle function. *J Athl Train*, 40, 174-80.
- ZAKAS, A. 2006. Bilateral isokinetic peak torque of quadriceps and hamstring muscles in professional soccer players with dominance on one or both two sides. *J Sports Med Phys Fitness*, 46, 28-35.
- ZALEWSKA, A. & WIECEK, B. 2005. Dermatological applications of thermal imaging. *Thermology International*, 15, 49-56.
- ZHU, W. P. & XIN, X. R. 1999. Study on the distribution pattern of skin temperature in normal Chinese and detection of the depth of early burn wound by infrared thermography. *Ann N Y Acad Sci*, 888, 300-13.
- ZIFCHOCK, R. A., DAVIS, I., HIGGINSON, J., MCCAW, S. & ROYER, T. 2008. Side-to-side differences in overuse running injury susceptibility: a retrospective study. *Hum Mov Sci*, 27, 888-902.
- ZONTAK, A., SIDEMAN, S., VERBITSKY, O. & BEYAR, R. 1998. Dynamic thermography: analysis of hand temperature during exercise. *Ann Biomed Eng*, 26, 988-93.
- ZVIJAC, J. E., TORISCELLI, T. A., MERRICK, S. & KIEBZAK, G. M. 2013. Isokinetic concentric quadriceps and hamstring strength variables from the NFL Scouting Combine are not predictive of hamstring injury in first-year professional football players. *Am J Sports Med*, 41, 1511-8.