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Training Load and Performance Monitoring, Recovery, Wellbeing, Illness and Injury Prevention

Edited by

Filipe Clemente, Daniel Castillo and Asier Los Arcos

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About the Editors

Filipe Clemente

Filipe Manuel Batista Clemente has been a university professor since the 2012/2013 academic year and is currently an assistant professor at Escola Superior de Desporto e Lazer de Melgaço (IPVC, Portugal). Filipe holds a Ph.D. in Sports Sciences –Sports Training from the University of Coimbra; his dissertation entitled "Towards a new approach to match analysis: understanding football players'synchronization using tactical metrics"involved observation and match analysis in soccer.

As scientific merit, Filipe has had 264 articles published and/or accepted by journals indexed with an impact factor (JCR), as well as over 105 scientific articles that have been peer-reviewed indexed in other indexes. In addition to scientific publications in journals and congresses, he is also the author of six international books and seven national books in the areas of sports training and football. He has also edited various special editions subordinate to sports training in football in journals with an impact factor and/or indexed in SCImago. Additionally, he is a frequent reviewer for impact factor journals in quartiles 1 and 2 of the JCR.

Although he started producing research in 2011, he was included in the restricted list of the world's most-cited researchers in the world (where only eight other Portuguese researchers in sports sciences appear), which was published in the journal Plos Biology in 2020. In 2021, the list was updated, with Filipe Manuel Clemente being again included in the top 2% of the world researchers, in which was positioned in the second place in six Portugueses included in the area of sports sciences. Filipe M. Clemente's SCOPUS h-index is 24 (with a total of 2605 citations), and his Google h-index is 35 (5305 citations). In a list promoted by independent website Expert Escape, he was ranked 40th of 14,875 researchers of football (soccer) in 2020 and in 19th of 15,949 in 2021.

Daniel Castillo

Currently, Daniel Castillo has been full-time lecturer and research in the Faculty of Education of Soria belonged to University of Valladolid since 2021. Previous, he has taught and researched in University Isabel I from 2017 and in University of Basque Country from 2014. He also works at other universities as a visiting professor in masters.

In respect to research merits, he has published more than 100 articles published in peer-review scientific journal (90 of them indexed in the Journal Citation Report). Additionally, he is editor of 2 books and coauthor of 6 book chapters (in SCI impact factor editorials) and more than 30 contributions to international conferences, which all have given rise to derivative publications. In addition, he counts with a great international activity, with important collaborations with high standard researches from all over the world, which have resulted in multiple publications in high impact journals of the JCR. Likewise, he has participated in 10 regional, national, and international scientific projects.

Regarding academic merits, he was a Ph.D. in physical activity and sport sciences from 2017 obtaining the qualification of *Cum Laude* unanimously for the jury and the extraordinary award. Also, he got the bachelor's degree in physical activity and sport sciences (University of Basque Country), the master's degree in physical activity and sports sciences research (University of Basque Country), the master's degree in high performance in team sports (F. C. Barcelona e Institut Nacional d'Educació Física. Barcelona) and the master's degree in teacher teaching in physical education (University of Basque Country).

Asier Los Arcos

Currently, Asier Los Arcos Larumbe is professor and senior researcher in the Faculty of Education and Sport of Vitoria-Gasteiz belonged to University of Basque Country (UPV/EHU) from 2017. He got the bachelor's degree in physical activity and sport sciences (University of Basque Country, UPV/EHU) and the master's degree in physical activity and sports sciences research (University of Basque Country, UPV/EHU). He was a Ph.D. in physical activity and sport sciences from 2014 obtaining the qualification of Cum Laude unanimously for the jury. He has published more than 80 articles published in peer-review scientific journals (Source: Web of Science). Additionally, he is editor of two Special Issues in Journal Citation Report journals, and coauthor of 7 book chapters (in SCI impact factor editorials) and more than 30 contributions to international conferences. He is member of the research group of the Society, Sports and Physical Exercise Research Group (GIKAFIT), University of the Basque Country (UPV/EHU). In addition, he worked as strength and physical conditioning specialist of the reserve soccer team of the CA Osasuna during 7 full seasons.

Preface to "Training Load and Performance Monitoring, Recovery, Wellbeing, Illness and Injury Prevention"

A growing body of literature demonstrates the importance of establishing a well-implemented player monitoring cycle in order to optimize training processes and improve performance. Such tools enable coaches and sport scientists to track the development of players and athletes across the season; help minimize injuries, risk factors and illnesses; and increase player readiness for competitive events. Naturally, the multifactorial dimension of performance requires a holistic point of view to establish a well-connected relationship between the training process and the associated load, the impact on the player's recovery, and the consequences of acute and chronic responses. Moreover, it is also important to determine how the physical status of a player may interfere with the recovery and management of load. Despite an important understanding of how those factors interact, commonly, the research splits the analysis, not allowing a multivariate interpretation of how load, recovery, and physical status contribute to performance or, on the other side, to explain possible illness or injuries. Thus, it is important to enact additional epidemiological studies to identify the determinants of injuries and illness in athletes. Such studies would both increase performance opportunities and reduce the possibility of alarming symptoms, decreased performance, or long hiatuses in performance due to injuries/illness. Many athletes and players are amateurs or play recreationally without oversight by sport science departments or coaches; therefore, it is necessary to monitor their training in order to minimize the risk factors which lead to injuries and illness as a matter of public health.

Considering that more research should be carried out and published on such important topics, the aim of this Special Issue on "Training Load and Performance Monitoring, Recovery, Wellbeing, Illness and Injury Prevention"was to publish high-quality original investigations, narrative, and systematic reviews in the field of training processes, dose–response relationships, training load monitoring, recovery strategies, illness, and injuries.

Filipe Clemente, Daniel Castillo, Asier Los Arcos
Editors

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Article

Functional and Anthropometrical Screening Test among High Performance Female Football Players: A Descriptive Study with Injury Incidence Analysis, the Basque Female Football Cohort (BFFC) Study

Marta Álvarez-Zafra [1], Javier Yanci [2,*], Ibai García-Tabar [2], Eder Bikandi [3], Saioa Etxaleku [4], Mikel Izquierdo [3], Tron Krosshaug [5], Uxue Fernandez-Lasa [2] and Igor Setuain [3,4]

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Abstract: The main objectives of the present study were to describe the injury incidence and to analyze the anthropometric and physical characteristics of players from three high-level women's football teams. The present study involved 54 female football players (21.9 ± 4.9 years old) from three different teams competing in the Spanish Reto Iberdrola-Segunda División PRO league. A battery of tests was carried out to determine the anthropometric and physical performance characteristics of the players along with an injury incidence record during a full competitive season. The obtained results showed that there was a high incidence of injury, as 38% of the players suffered some type of injury during the season (range 1–5; 1.75 ± 1.02 injuries per player). Injuries occurred in both matches and during training at a similar percentage (48.6 vs. 51.4%), and the majority of the registered episodes were graded as moderate or severe injury types (60%). Players suffering from an injury accumulated a total of 1587 chronological days off work due to injury during the season, with a recurrence rate of 55%. Considering the high incidence of injury, and the injury burden and the reinjure rate observed in this research, it seems necessary to apply the most efficient prevention and recovery measures possible in these female football teams. These descriptive data could serve athletic trainers and medical staff of female football teams to better understand their own screening procedure-derived data.

Keywords: soccer; women; team sports; elite; performance; injury

1. Introduction

Football is one of the most popular sports around the world [1–3]. Despite the greater impact that male football has in the media, female football has experienced a significant rise in worldwide popularity and support in recent years [3,4]. In this sense, several studies [1,4,5] have referred to the increasing number of United European Football Associations (UEFA) licenses for female football players. Several authors [4,6] have highlighted the need for more research targeting injury incidence [5,7] as well as descriptive physical conditioning and anthropometric data among female football players [4,5]. However, despite this increase in women's participation in football, research on elite football remains more predominant among their male counterparts [3,5].

Football has been described as a demanding sport from the neuromuscular [1,8] and physiological [9] perspectives leading to female athletes having a high injury risk with subsequent time off from competition [2] and an inevitable impact on the player's physical and physiological health [10]. Injuries among female football players have been reported to range from 9.1 to 24 injuries per 1000 h of exposure [11], which is less than males in terms of incidence, but with a greater associated injury burden due to the more severe nature of the resulting injuries, especially ACL ruptures [1]. Several risk factors have been proposed with regard to this issue, such as neuromuscular, hormonal and/or biomechanical factors [4]. More specifically, some authors [1] have linked poor neuromuscular control at the trunk, hip, knee, and ankle joints to a greater injury risk for quadriceps, lateral ankle ligaments, and ACL injuries. Other researchers have also linked the observed greater injury risk to poor abdomino-lumbopelvic stability [12]. Several investigations have identified knee valgus, knee abduction moment, and increased vertical ground reaction forces during landings as potential risk factors for ACL injury.

Other analyzed risk factors have focused on body composition and anthropometrics [10] as well as physical conditioning-related factors [13] in an attempt to explain the sex-dependent differences among football players. Nilstad et al. [14] found a significant correlation between body mass index and knee injury incidence among Norwegian female soccer league players. On the other hand, other studies have found a significant association between injury incidence and either knee joint laxity [15] or knee joint laxity, poor balance scores, and generalized joint laxity [16] among Swedish female football players. Furthermore, even peak lower limb strength has been proven to not be a reliable risk factor for ACL injuries among female handball and football players [16]. Regarding biomechanical and functional evaluations and injury risk among female football players, some controversy seems to exist. While Nilstad et al. [14] found a significant correlation between knee joint valgus during the landing phase and ankle injuries, Nilstad et al. [17] reported poor combined specificity and sensitivity of medial knee displacement as a screening tool for ACL injury risk.

The increasing popularity that female football has experienced in recent years, along with the high injury burden linked to the reported injury incidence, could make it suitable to increase the body of knowledge regarding female football players' anthropometric and functional testing-related data with implications for injury risk. Some investigations have addressed injury incidence [1,18,19] as well as anthropometric and physical characteristics [20]. However, normative data from high-level national league players [11,21] dealing with a wide range of anthropometrics and physical conditioning-related variables [16,22] remain scarce in the scientific literature. Understanding the physical characteristics and anthropometric profile of high-performance female football players could provide club medical staff and athletic trainers with valuable data to interpret their own recordings from their functional screening procedures.

Hence, the objectives of the present study were to report normative data with respect to anthropometrics and physical characteristics such as lower limb range of motion (ROM), core strength in stability demanding positions, lower limb strength and vertical and horizontal jump performance. In addition, we aimed to report the injury incidence among high-performance female football players.

2. Materials and Methods

2.1. Participants

In the present study, 62 female soccer players (21.9 ± 4.9 years, range = 17–25 years) were included from three different competing teams in the Spanish Reto Iberdrola-Second Division PRO league. All the players had a valid federation license issued by the Royal Spanish Football Federation (RFEF). Before participating in the study, all involved players, their parents, or legal tutors in the case of underage players, were informed of the research procedures and signed the corresponding consent. In the same way, before starting the investigation, the express consent was obtained from the Sports Management department of the football clubs which the players belonged to. The study followed the guidelines set out in the Declaration of Helsinki (2013) and was approved by the Research Ethics Committee of the Public University of Navarra (code PI-001/19). From a total of 62 players, 54 players were evaluated at the pre-season screening process.

2.2. Data Collection

The results of the present study were obtained during an entire competitive season (from August 2018 to June 2019). At the beginning of the preseason (first week of the preseason, month of August) all the players participating in the study carried out a battery of tests in order to study anthropometric characteristics, hip, knee, and ankle joints range of motion (ROM), isometric strength of lower limb and trunk muscle groups, and vertically and horizontally oriented jumping ability. This battery of tests was carried out in a single session. In all tests, 2 attempts were recorded, the mean of the two being chosen for statistical analysis. Before conducting the tests, a 10-min warm-up was carried out consisting of low intensity running exercises, lateral and frontal lunges, and vertical and horizontal counter movement jumps.

Additionally, throughout the entire competitive season, both the injury incidence and its characteristics (type, location, severity, time loss) were recorded.

2.2.1. Anthropometrics

Basic anthropometric items were measured following the guidelines established by the International Society Advancement Kinanthropometry (ISAK) [23]. The anthropometric variables that were measured for each participant were height (cm), body mass (kg) and skinfolds thickness (mm). Height and body mass were measured with a height rod and a scale (Stadiometer Barys Electra, Pontevedra, Spain). Body mass index (BMI) was calculated from body mass and height ($kg \cdot m^{-2}$). The 6 skinfolds (subscapular, tricipital, iliac crest, abdominal, femoral, triceps surae) were measured with a caliper (John Bull British Indicators LTD, UK) according to the considerations made by Grazioli et al. [24]. Subsequently, the sum of the 6 skinfolds was calculated [25]. The percentage of body fat was calculated using the Jackson and Pollok formula [26]. The right leg tibia and femur bony segments length and the sum of both (TL + FL) were measured. Pelvic width was also measured (Idass BMI tape-measure, Beijing, China). Lastly, anterior-posterior knee laxity measures of the tibia respect to the femur were performed according to the protocol used by Setuain et al. [27], both right (KT1000R) and left (KT1000L) legs using an arthrometer (KT1000, MEDmetric Corporation, San Diego, CA, USA). The bilateral ratio (KT1000 LSI) was calculated subsequently.

2.2.2. Range of Motion (ROM) Measurements

For the hip extension and flexion ROM, the Tomas Test and the Passive Straight Leg Raise test (PSLR test) were used, respectively [28]. Knee flexion ROM was measured with the Modified Tomas Test [29] and knee extension with the Active Knee Extension test (AKE Test) [28]. Joint angles were registered using a goniometer (W50195, 3B Scientific, Spain) following the established protocol of Barret et al. [3,4]. Measurements were performed independently on both extremities. Subsequently, the bilateral ratio (LSI) of each test was calculated. The ankle dorsiflexion test was performed according to the protocol established by Konor et al. [30]. This test was performed in a standing position, with the heel in contact with the ground, the knee in line with the second toe, and the big toe 10 cm from the wall. Participants were asked to drop forward, directing their knees toward the wall (in line with the second toe) until their knees touched the wall. Once the knee touched the wall, the foot progressed in smaller increments towards the wall until the knee made contact with the wall and the heel contacted the ground. Here the distance (cm) from the big toe to the wall is registered.

2.2.3. Hand-Held Dynamometry (HHD)

Hamstring isometric strength on a prone position was measured with a hand-held dynamometer (Hoggan Scientific, MicroFET3, Salt Lake City, UT, USA) according to a previously validated protocol [31]. Participants were lying in prone position, with the knee flexed 15° (Hamstring Prone 15°) and with the hip and contralateral limb fixed to avoid compensation during the assessment. The examiner placed the dynamometer on the heel of the executing leg (both right and left leg) and instructed the player to do a maximal isometric contraction for 3 s trying to flex the knee.

Hamstring isometric strength was also measured in the AKE test position (Hamstring AKE R and L). Participants were placed in a lying supine, with 90° hip flexion and 30° knee flexion. They had to actively produce knee flexion strength from that position for 3 s, avoiding elevating the pelvis from the bench.

For the isometric knee extension strength (Quadriceps 90°, both right and left), the test previously described by Toonstra et al. [32] was utilized. Participants sat on a bench and quadriceps isometric strength was assessed using a resistive cinch tied 2–3 cm proximal to the ankle joint line to maintain 90° knee flexion angle and holding the dynamometer. The contralateral limb was fixed to avoid compensation during the evaluation. The examiner instructed the players to perform a maximum isometric contraction for 3 s, trying to extend their knee.

2.2.4. Core Musculature Functional Evaluation

Lastly, to determine the force production and stabilization capacity of the abdominal-lumbo-pelvic complex (CORE), isometric strength of the gluteal muscles at two different CORE-challenging positions was registered. The device used to carry out the measurement was a hand-held dynamometer also.

The Prone Plank Isometric Test was performed according to the protocol established by Etxaleku et al. [33]. The participants were placed in the prone position with the ankles placed at neutral dorsiflexion (0°). They were instructed to keep the pelvis in a parallel position, aligned with the trunk and supporting leg, and the executing leg was placed as initial position at 20° of hip extension and abduction, maintaining the knee extended. The tester was placed ipsilateral to the execution leg and the dynamometer was placed superior to the external malleolus. Once in the initial position, the participants exerted a maximum isometric contraction towards hip extension and abduction for 3 s. Pelvic compensation was not allowed during the execution of the test.

The Side Bridge Isometric Test was also performed according to the protocol established by Etxaleku et al. [33]. The participants were placed in a side lying position, resting the body on the supporting leg's knee and the flexed ipsilateral elbow. The examiner was positioned in front of the executing upper leg and the dynamometer was positioned superior to the external malleolus. The participants had to perform a hip extension and abduction force for 3 s.

The results of all the tests are shown in absolute values (N) and in values relative to the body mass ($N \cdot kg^{-1}$). In all cases, the symmetry index between right and left leg (LSI) was calculated.

2.2.5. Jumping Biomechanics Assessment

For the vertical jumping biomechanics assessment, participants performed the drop jump (DJ) maneuver, both bilateral and unilaterally [34,35]. Participants started from a 50 cm height box for the bilateral jump and 20 cm height for the unilateral jump. Keeping the hands on their hips during the whole maneuver, then they had to drop down and perform a maximum vertical jump with a correct final landing stabilization. Kinetic variables were obtained from an inertial measurement unit sensor (IMU, MTx, 3DOF Human Orientation Tracker, Xsens, Shanghai, China) fixed at L3-L4 level with a strap, near where the body center of mass is located. The IMU estimated the flight time, the vertical ground reaction force (VGRF) of the first (VF1) and final (VF2) landing when the foot initially contacted with the floor, the propulsive vertical force in the concentric phase of the jump (PF), and the mechanical power output (MP) both in absolute values and relative to body mass. In addition, kinematic recording was performed for the VBDJ. The reflective body markers were placed on different anatomical points. For the frontal view, markers were in the anterior superior iliac spine, patellar tendon, mid-thigh, quadriceps tendon, intermalleolar line, and tibial tuberosity. On the lateral view, the markers were in the lateral mid-thigh, femoral greater trochanter, external femoral condyle, head of fibula, external malleolus, and toe (between the second and third metatarsals). Jumps were recorded with two standard 60 Hz video cameras (Nikon, D3200, Tokyo, Japan) that captured frontal and sagittal plane views of the jump. The bony segments angles were analyzed using the Kinovea software (version 0.8.15, a free and open-source software program) [36]. The moments of foot-floor initial contact and maximum triple-flexion were selected to evaluate the knee dynamic valgus in the frontal plane during the landing phase.

For horizontal jumping biomechanics assessment, participants performed the Cross-Over Hop for Distance (COHD) test [34]. The kinetic data, such as the VGRF in the initial contact phase (VF) of each step and the produced horizontal force (HF) during each propulsive phase, were registered. The COHD was performed independently with both limbs (right and left leg). For the maneuver, the participants were instructed to keep their hands on their hips during the execution of each trial. They started in a single-limb stance position, then performed three cross-over hops outside two lanes separated by a 15-cm-wide tape attached on the floor, trying to land as far as possible while maintaining their balance for 1 s at the final landing. The first jumping step was interiorly directed. A practice trial was performed to ensure the participant's comfort and safety and was followed by two further test trials interspersed with 30 s of rest. Total jump length was recorded (TJL) [35]. Kinetic data was registered using the IMU technology described above and based on a previously validated methodology [37].

2.3. Injury Surveillance Assessment

Injuries were registered using a standardized questionnaire from the Oslo Sports Injury Research Center (OSTRC) [38]. The definition of injury refers to that which occurred during a training session or a scheduled match that caused the absence of the next training session or match [39]. The injury record was made both during matches and training sessions. As established by Fuller et al. [40], injuries are grouped according to the days of absence of the player: negligible (0 days of absence), minimal (from 1 to 3 days of absence), mild (from 4 to 7 days off), moderate (from 8 to 28 days off), severe (more than 28 days off), and career ending (abandoning soccer practice due to this condition). For this study, a player's recovery from injury was considered to occur when the medical staff indicated that the athlete could fully return to training or competition. The time from the injury to discharge was considered time loss.

2.4. Statistical Analysis

Descriptive data are presented as mean ± standard deviation (SD) and frequencies or percentages. Data analysis was performed with the JASP program (JASP for Windows, version 0.13, Amsterdam, The Netherlands).

3. Results

3.1. Anthropometrics

The anthropometric data and KT1000 values (knee AP laxity) of the measured players are shown in Table 1.

Table 1. Anthropometric characteristics and AP knee.

	Mean	SD	Min.	Max.
Age	21.9	4.9	15.3	36.6
Body mass (kg)	60.4	8.1	45.0	78.7
Height (cm)	163.8	6.7	152.0	183.0
BMI (kg·m^{-2})	22.7	2.2	18.9	29.6
TL (cm)	35.4	2.4	30.3	41.5
FL (cm)	36.4	3.2	29.6	44.8
TL + FL (cm)	71.7	4.8	59.8	85.8
Pelvis with (cm)	23.7	2.6	19.0	29.5
Skinfold's thickness				
Subscapularis (mm)	11.2	3.4	6.8	19.7
Triceps (mm)	15.5	4.2	8.3	25.5
Iliac Crest (mm)	14.0	6.4	6.0	32.6
Abdominal (mm)	19.3	7.7	7.5	37.5
Vastus Cruralis (mm)	26.9	7.2	15.2	41.4
Gastrocnemius (mm)	12.8	5.8	4.0	31.0
Σ skinfolds (mm)	99.6	29.6	55.4	170.5
% Body fat	19.8	5.1	6.0	30.0
Antero-Posterior Knee Laxity				
KT1000 D (mm)	4.6	1.8	1.0	9.0
KT1000 I (mm)	5.3	1.8	2.0	9.5
KT1000 LSI	0.7	0.7	−5.0	4.0

SD: Standard deviation; Min.: Minimum; Max.: Maximum; BMI: Body Mass Index TL: Tibia Length; FL: Femur Length; KT100 D: knee laxity right; KT1000 I: knee laxity left; KT1000 LSI: Knee laxity lower symmetry index.

3.2. ROM Measurements

Figure 1 depicts the ROM measurements for hip, knee, and ankle joints for both the right and left leg.

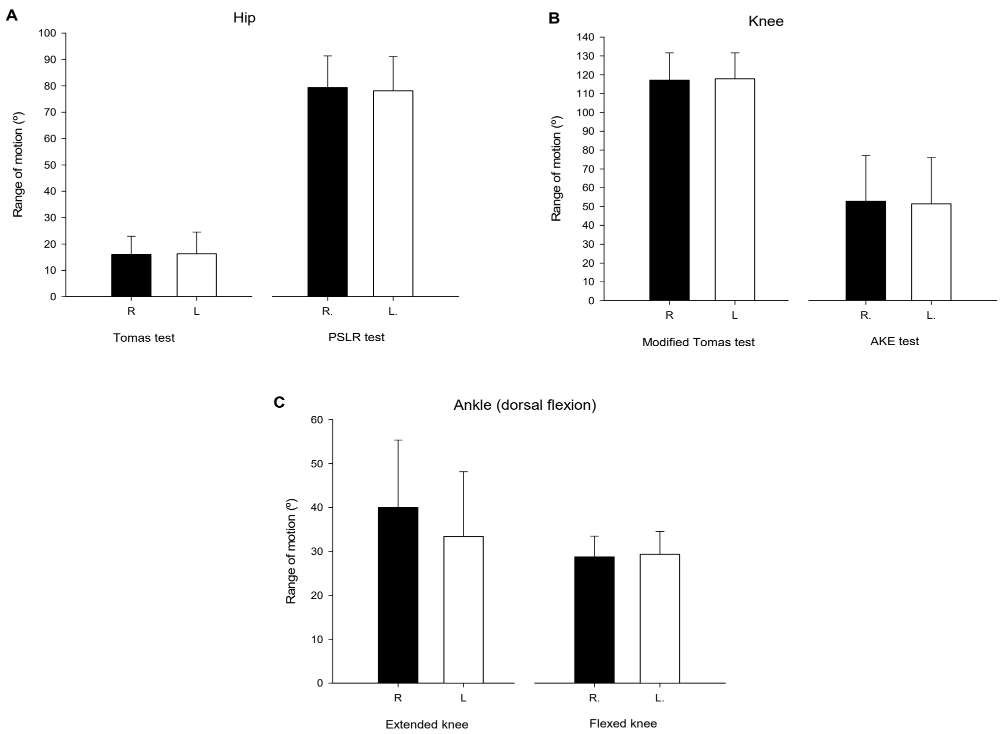


Figure 1. Range of motion (ROM) results for hip (**A**), knee (**B**) and ankle (**C**) joints for both right (R) and left (L) leg.

3.3. HHD Strength Evaluations

Figure 2 shows the reported values of force in N from the Hamstring (Figure 2A), Quadriceps (Figure 2B), and core (Figure 2C) muscles for both the right and left leg.

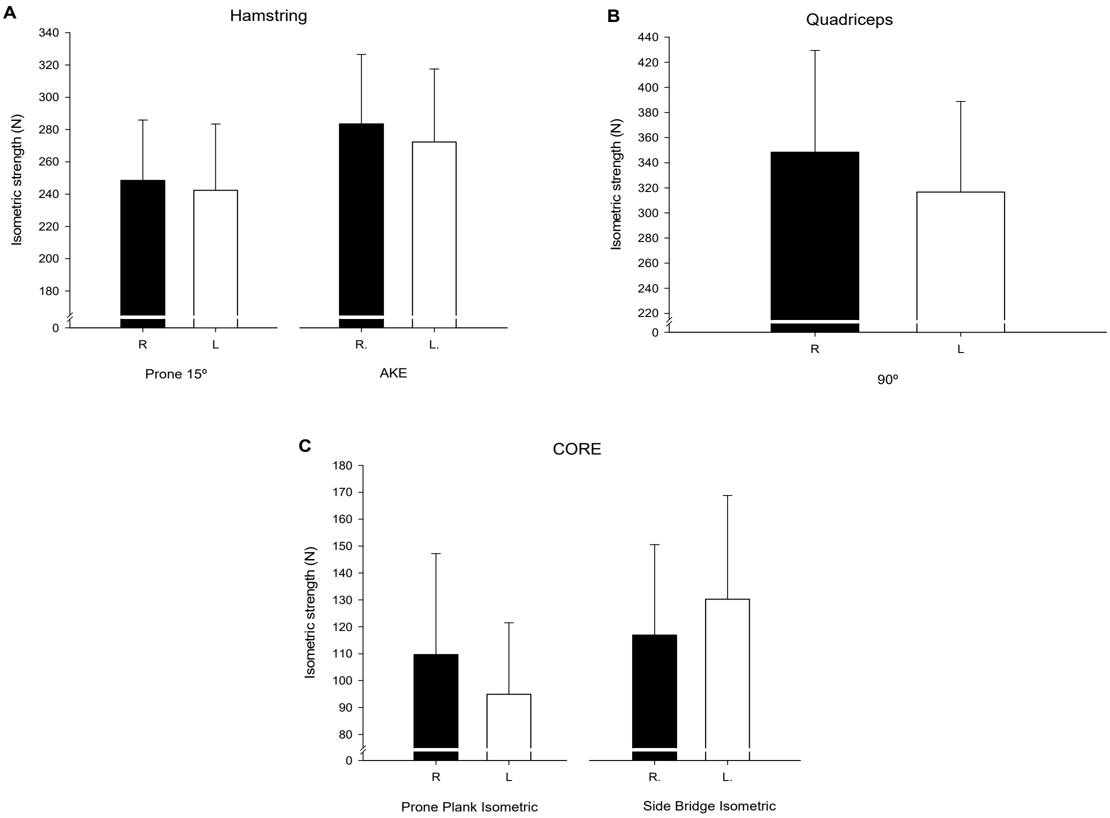


Figure 2. Results of Quadriceps (**A**), Hamstring (**B**) and core (**C**) muscles forces for both right (R) and left (L) leg.

3.4. Jumping Biomechanics

3.4.1. Vertical Bilateral Drop Jump (VBDJ) & Vertical Unilateral Drop Jump (VUDJ)

The biomechanical (kinetic) descriptive data reported from the vertical drop jump evaluations performed (Bilateral and Unilateral) are shown in Table 2.

The biomechanical (kinematic) descriptive data reported from the vertical drop jump evaluations performed (Bilateral and Unilateral) are shown in Table 3.

3.4.2. Cross over Hop for Distance (COHD)

The biomechanical (kinetic) descriptive data reported from the Cross Over Hop for Distance jump performed are reported in Table 4.

Table 2. Drop Jump Test (bilateral and unilateral) related biomechanical kinetic descriptive values.

	Mean	**SD**	**Min.**	**Max.**
Bilateral				
Height (cm)	48	3	41	54
Vf1 (N)	3370.5	1442.0	1441.3	7630.0
Vf2 (N)	2644.5	1670.2	544.8	7194.0
Vip (Ns)	1342.1	695.1	522.5	4093.6
Vf1 ($N{\cdot}kg^{-1}$)	5.5	1.9	2.5	10.0
Vf2 ($N{\cdot}kg^{-1}$)	4.3	2.7	9.8	11.0
Vip ($N{\cdot}kg^{-1}$)	2.3	1.2	9.6	6.8

Table 2. *Cont.*

	Mean	SD	Min.	Max.
Unilateral				
Height R (cm)	17.6	2.4	12.3	23.0
Height L (cm)	18.2	2.7	13.0	28.0
Vf1 R (N)	1796.3	780.4	831.4	4073.5
Vf1 L (N)	1740.3	781.0	710.1	3723.7
Vf1 R (N·BW^{-1})	2.9	11.0	1.5	5.6
Vf1 L (N·BW^{-1})	2.8	11.5	10.4	62.6
Vf2 R (N)	2675.0	1030.3	1142.8	6623.6
Vf2 L (N)	2574.4	1051.4	818.3	6438.9
Vf2 R (N·BW^{-1})	4.4	1.5	1.8	9.0
Vf 2 L (N·BW^{-1})	4.2	1.4	14.2	8.8
Vpi R (Ns·BW^{-1})	1.7	0.2	1.3	2.1
Vpi L (Ns·BW^{-1})	1.7	0.2	1.2	2.2
Mech power D (W·kg^{-1})	14.3	2.8	7.9	22.2
Mech power I (W·kg^{-1})	14.7	2.7	9.4	22.3

SD: Standard Deviation; Min.: Minimum; Max.: Maximum; Vf1: Initial contact ground reaction force Vf2: Final contact vertical ground reaction force; Vpi: Vertical propulsive impulse; BW: Body weight; R: Right; I: Left; Mech Power: Mechanical Power output.

Table 3. Drop Jump Test (bilateral and unilateral) related biomechanical kinematic descriptive values.

Vertical Bilateral Drop Jump	**Mean**	**SD**	**Min.**	**Max.**
Frontal plane				
I.C trunk lateral flexion (°)	−0.7	4.2	−13.0	7.0
I.C Knee valgus R (°)	0.1	5.0	−12.5	10.0
I.C Knee valgus L (°)	−0.6	5.5	−18.0	10.0
Max Flex trunk lateral flexion (°)	−0.1	4.3	−13.0	7.5
Max Flex valgus R (°)	−7.8	17.4	−53.0	21.5
Max Flex valgus L (°)	−6.5	14.6	−48.0	27.5
Sagittal plane				
C.I trunk Flexion (°)	42.7	10.2	24	67
C.I knee Flexion (°)	47.0	12.0	20.5	73
Max Flex. Trunk Flexion (°)	102.0	9.7	67.5	127.5
Max Flex. Knee Flexion (°)	102.7	20.6	61.5	176

SD: Standard deviation; Min.: Minimum; Max.: Maximum; I.C: Initial Contact; Max Flex: Maximal flexion.

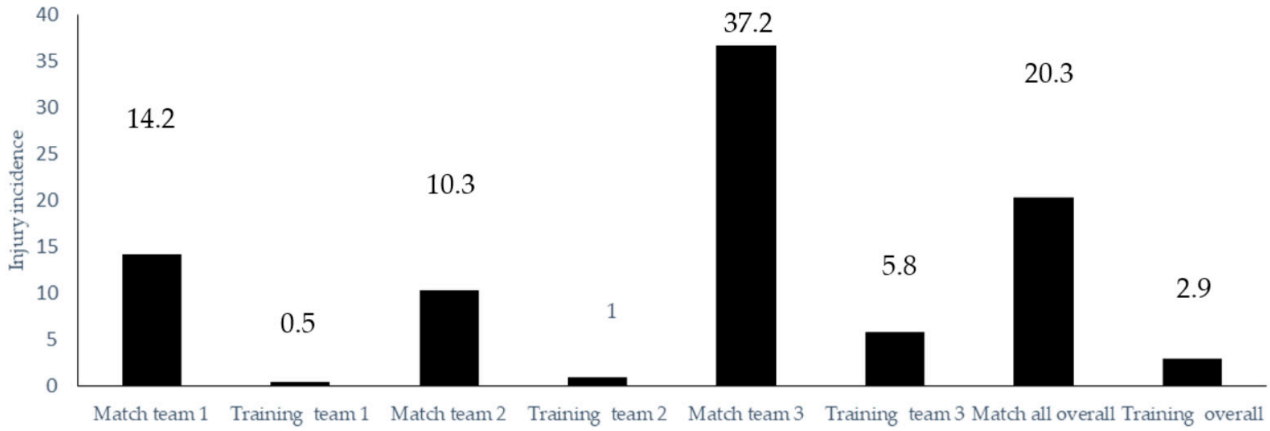
Table 4. CHOD Kinetic descriptive data.

	Mean	SD	Min.	Max.
Vf R (N)	3207.2	1280.2	1379.6	8007.2
Vf L (N)	3221.1	1141.7	1091.4	6287.6
Vf R (N·BW^{-1})	5.3	18.2	2.7	10.9
Vf L (N·BW^{-1})	5.3	1.7	2.3	9.4
Hf R (N)	184.0	49.4	105.9	306.5
Hf L (N)	188.7	53.5	97.7	335.1
Hf R (N·BW^{-1})	3.0	0.7	1.9	5.5
Hf L (N·BW^{-1})	3.1	0.8	1.9	5.4
Distance R (cm)	357.0	44.4	235.0	468.5
Distance L (cm)	349.7	54.4	154.0	432.0

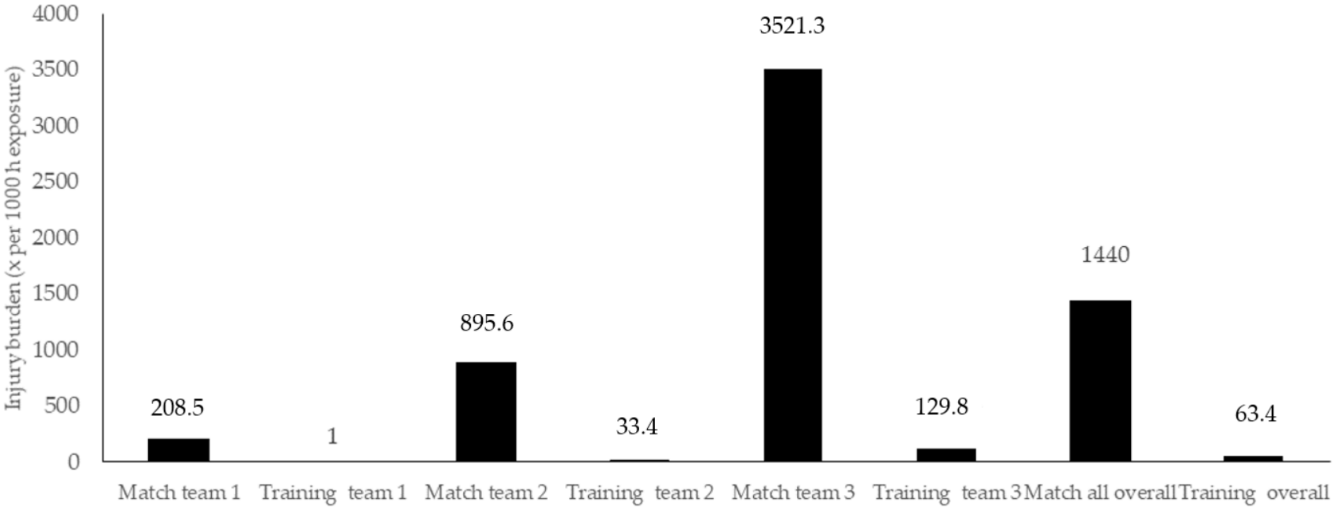
SD: Standard deviation; Min.: Minimum; Max.: Maximum; R: Right; L: Left, Vf: Vertical ground reaction force, initial contact; Hf: Horizontal ground reaction force propulsive phase.

3.5. Injury Surveillance Assessment

At 1-year follow up, 28 (45.2%) players were injured registering a total of 54 injuries during the 2018–2019 season. Fifty-one percent of the injuries were sustained during practice sessions whereas 49.0% were reproduced during matches. The injury incidence and burden distribution among match and training practices (expressed x per 1000 h exposure) are depicted in the Figure 3A,B, respectively.



(**A**)



(**B**)

Figure 3. Injury incidence (**A**) and burden (**B**) distribution among match and training practices (expressed x per 1000 h exposure).

The severity of the reported injuries was distributed as follows: six slight (11.8%), eight mild (15.7%), 23 moderate (45.1%), and 14 severe (27.5%). From the 28 injured players, three (5.9%) suffered from a reinjury episode.

4. Discussion

The main objectives of the present study were to describe the injury incidence and to analyze the anthropometric and physical characteristics of players from three high-level women's football teams. The present study involved 54 female football players

(21.9 ± 4.9 years old) from three different teams competing in the Spanish Reto Iberdrola, Segunda División PRO league. The testing battery included anthropometric measurements (fat skinfolds and osseous segment length), hip, knee, and ankle ROM measurements, quadriceps and hamstring dynamometry, and descriptions of vertical and horizontal jump biomechanics. Indeed, injury incidence and the associated burden were also reported. Some previous studies have focused on the physical characterization of female football players [20] in an attempt to shed light on their performance [41] and provide an explanation for their injury risk profile [42,43].

As previously demonstrated in male football players [44], female football players also tend to display different anthropometric profiles depending on the athlete´s competition level. The data obtained in the present study reflect the reality of the players and the teams analysed. Due to coaching staff decisions, some of the players participating in the study trained and competed at this level even though they were U18 and there are also older players (e.g., 36 years of age). This aspect has been able to condition the high variability of results found in some anthropometric variables. Nevertheless, regarding body fat-related measures, the present study showed similar results to those previously reported among Norwegian [17], Brazilian [45], or Greek [46] elite female football players. With reference to these data, it seems that elite female football players range from 19% to 21% body fat [17,20,45,47] and have a BMI near 21–22 $kg{\cdot}m^{-2}$ [11,17,45]. Knowledge of the body fat profile among female football players could be relevant when associated with players' cardiorespiratory fitness [48]. Monitoring these two variables could also explain in part how the playing performance requirements fluctuate over the years along with evolution of the specific sport.

ROM assessment of the lower limb joints has been previously investigated with regard to injury risk factor identification [49]. The hip and ankle ROM values reported in the present study are in agreement with those previously reported among female football professional players [42], establishing hip extension and ankle dorsiflexion with knee extended mobility at 15° and 36° (16.1 ± 7.6° and 39.7 ± 15.0° in the present study), respectively. Knee flexion flexibility values were slightly lower in the present study than those previously reported by Lopez Valenciano et al. [42] (117.5 ± 14.1 vs. 130°). Considering that both the mean age (20 vs. 22 years old) and competition level (professional football) were similar between cohorts, the reported knee flexion flexibility difference may have arisen from methodological issues (i.e., timing of the evaluation or previous training load). Other investigations have reported greater ROM values among younger female football players [49], indicating that age and competitive level [50] may influence the ROM profile of athletes. Another interesting result from the present investigation came from the absence of significant limb-to-limb differences, suggesting that ROM asymmetries were not present on lower limb flexibility among the evaluated players. These results are in line with previous research addressing lower limb joint flexibility among female football players [42,51]. This fact could be interesting from an injury prevention perspective, as ROM asymmetries have been previously associated with greater injury risk [52].

Lower limb isometric force evaluations have been widely analyzed in relation to both performance and injury prevention among female football players [53,54]. Lumbopelvic complex and lower limb muscle strength imbalances have been proposed as risk factors for articular or muscular injuries in these players [52]. The quadriceps and hamstring HHD values reported in this research were shown to be greater than those previously reported among elite Cypriot [55] and North American adolescent female football players [54]. Similarly, Farley et al. [50] also reported lower hamstring and slightly decreased isometric peak force values among elite female Australian rules football players. In the latest study, they also demonstrated that a competition-level effect on isometric quadriceps and hamstring strength seemed to exist [50]. These results could indicate that both age (sport participation experience) and level of competition could influence the physical fitness-related variables observed in female football athletes. The description of the lower limb strength profile among these types of athletes with regard to their playing experience, age, and competition level could aid athletic trainers and team physicians to optimize and individualize performance and injury prevention training routines to each player. Maintaining balanced and adequate muscle strength levels in the lower limb muscles may help to reduce the overall injury risk in female football players [56].

Regarding vertical jump functional evaluations, previous research found similar performance values on both VBDJ and VUDJ maneuvers among Spanish first division female football players [57]. Furthermore, these data were lower than those reported from North American NCAA Division I female players, suggesting that this may be influenced by differences in playing style across countries and that competitions could also determine the key performance aptitude of the players. In this sense, Mugica et al. [58] reported that vertical jumping performance, agility, and intermittent anaerobic capacity could be key performance determinants for Spanish senior and junior female football players. Mok et al. [59] reported lower raw vertical ground reaction forces in their female elite handball and football athlete cohort when analyzing the VBDJ from a 30 cm box. In the present study, the VBDJ was performed from a 50 cm box, making direct comparisons across the two cohorts difficult.

Regarding horizontal jumping tasks, some studies analyzing the horizontal component of the ground reaction force and its implications for performance in male but not female football players have been published [60,61]. Specifically, to the best of the authors´ knowledge, there is only one study with female football players to compare with the results of the present investigation. In that study, Bishop et al. [62] reported similar COHD jumping performance among British female football players compared with the present investigation, which establishes the athletes´ performance in this task between 3.2 and 3.6 m. Based on the available scientific literature, it seems that more descriptive studies addressing not only jumping performance, but also biomechanics are needed to better understand the association of these two variables in the functional profile description of the female football player in both vertical and horizontal jumping tasks.

On the other hand, the biomechanical jumping profile description by means of the use of an ISU was, to the best of the authors´ knowledge, reported for the first time among female football players. The ISU-based jumping biomechanical evaluation methodology has been validated elsewhere [34]. This procedure would enable team medical staff and athletic trainers to better understand the mechanical efficiency of the players, as they could analyze the jumping performance obtained in both vertical and horizontal maneuvers in relation to the mechanical penalization in terms of the magnitude of the ground reaction forces borne in the landing phases of the analyzed tasks. Furthermore, as the ISU is placed on the subject´s center of mass location at the lumbar spine, no conditioned foot placement is needed, preserving the ecological environment of the player keeping her closer to a real-game situation. Previous research has demonstrated lower mechanical efficiency ratios among male and female [37] handball players with previous ACL reconstruction in comparison to age-, sex-, and competition level-matched controls in horizontal jumping maneuvers.

Currently, there is a growing body of knowledge with respect to injury incidence descriptions among female football players [2,5,63,64]. It is known that female players suffer from a lower injury incidence but a greater injury burden due to their increased risk for severe articular injuries such as anterior cruciate ligament (ACL) rupture [1]. In fact, 72.6% of the registered injuries in the present research were classified as moderate or severe injury types. These data are in accordance with Faude et al. [11], who reported injury epidemiology among German national league female football players. This greater injury severity observed among female football players in comparison to competitive level-matched male counterparts remain a cornerstone for team physicians and clinical researchers. Exploring the interrelation of the high physiological and neuromuscular demands required in competitive football [1,9] and the physical fitness level demonstrated in female athletes [65] could shed light on the physical and functional determination of the high risk of injury based on female player profiles.

The injury incidence and injury burden expressed as n per 1000 h of exposure found in the present investigation were 2.9 and 20.3 for training and match exposure, respectively. These data are in agreement with those previously published in the scientific literature. A recently published systematic review and meta-analysis reported injury incidences during training and matches of 3.1 and 19.5 per 1000 h, respectively [66]. Another study performed among female first division female football players reported a similar match injury incidence (19.0 per 1000 h) but a slightly lower number of injuries during training exposures (1.7 per 1000 h) [10]. Regarding injury burden, the results in the present research are partially in accordance with those previously reported in the literature by Sprouse et al. [63]. While the authors reported injury burdens of 538.1 and 69.6 days of absence due to injury per 1000 h exposure to matches and training, respectively, among senior English international female football players, we found in the present investigation similar training (63.4 vs. 69.6) but greater match injury burden recordings (1440 vs. 538.1). There is some caution required when interpreting female football epidemiological data, as some data heterogeneity exists among the different clubs and discrepancies among medical staff own-injury recording procedures [66]. In this sense, articles reporting injury incidence among different competition levels and ages with a standardized injury incidence reporting methodology would help to enhance the statistical validity of these data. Injury prevention training programs should be incorporated into the planification of the teams´ training routines as it has been previously demonstrated that they can effectively reduce the injury incidence, and by doing so enhance the performance level of the squad during both regular and regular and K.O competitions.

The present study has several limitations. First, the study sample and the follow-up period could be considered limited, and data should be cautiously interpreted. This study cohort remains active such that nearly 300 players are being evaluated and injury incidence is being collected. In the future, we could use this information to better understand the physical, functional, and biomechanical interrelation with injury incidence among female football players. Second, this study was a descriptive investigation to provide athletic trainers and team medical staff with normative anthropological and physical fitness data as well as injury incidence reporting. Further statistical analysis should be performed to elucidate the correlations between these variables and injury risk. It seems plausible that more comprehensive statistical designs could be employed, including training load-induced fatigue and its influence on lower limb biomechanics throughout the competitive season, to better determine what the influence of motor control quality is with respect to injury risk among female football players.

5. Conclusions

The present study provides descriptive data in relation to physical conditioning, biomechanical behavior and anthropometric data along with injury incidence reports of a cohort of 54 elite female football players. It has been observed that female athletes seem to suffer from more severe injuries than their male counterparts.

The results of the present investigation could aid athletic trainers and medical staff of female clubs in better interpreting and categorizing the results obtained from their own functional screening procedures. The implementation of ISU-based technologies could also provide further information with regard to the mechanical efficiency ratios of the players to better determine the mechanical proficiency of the athletes. This fact could aid in reducing aberrant motor patterns that are well known to contribute to a higher injury risk.

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Article

Static and Dynamic Strength Indicators in Paralympic Power-Lifters with and without Spinal Cord Injury

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Abstract: Background: In Paralympic powerlifting (PP), athletes with and without spinal cord injury (SCI) compete in the same category. Athletes with SCI may be at a disadvantage in relation to the production of muscle strength and the execution of motor techniques. Objective: To analyze the indicators force, dynamic and static, at different intensities, on performance in athletes with and without SCI. Methods: The sample was composed of two groups of PP athletes: SCI (30.57 ± 4.20 years) and other deficiencies (OD; 25.67 ± 4.52 years). Athletes performed a test of maximum isometric force (MIF), time to MIF (Time), rate of force development (RFD), impulse, variability and fatigue index (FI), dynamic tests Mean Propulsive Velocity (MPV), Maximum Velocity (Vmax) and Power. Results: There were differences in the SCI in relation to OD, 50% 1RM ($p < 0.05$), in relation to MPV and Vmax. There were no differences in the static force indicators. Regarding EMG, there were differences between the SCI triceps in relation to the previous deltoid ($p = 0.012$). Conclusion: We concluded that the static and dynamic strength indicators are similar in Paralympic powerlifting athletes with spinal cord injury and other disabilities.

Keywords: spinal cord injury; para-athletes; muscle strength; disabled persons; athletic performance

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1. Introduction

Spinal cord injury (SCI) is a condition that tends to be debilitating, and annually around half a million people are affected worldwide [1]. These injuries are traumatic (car accident and falls) or non-traumatic (myelomengiocele, spinal stenosis, transverse myelitis and tumor) [1,2]. SCI usually presents physical disability and impaired quality of life in several aspects, such as physical, social and environmental [3]. Most of the people with SCI are male and under 30 years of age [4]. The forms of rehabilitation are of paramount importance, where physical exercises tend to represent a very important strategy [1]. The practice of physical and sports activities has shown great importance, not only in physical health but also in general well-being [5]. Sports practice increases the sense of belonging, promoting social interaction and emotional support [6]. As a result, encouraging sports practice, as well as participation in competitions, can be an important aspect of total rehabilitation. To facilitate this, understanding the challenges presented by people with disabilities becomes important [7].

In the context of parasports, it is necessary to take into account that SCI tends to provide secondary complications, notably in relation to the damage of the autonomic nervous system (ANS) [3]. This is because the ANS serves as a control that interferes with the regulation of many physiological functions, blood pressure (BP), heart rate (HR), respiratory rate, urination and intestinal motility, among others. In this sense, physical performance depends on a coordinated and broadly functioning ANS [8]. SCI tends to compromise athletic performance, influencing the difficulty of maintaining strength, power, velocity, endurance and specific and important neuromotor skills required for the sport. In addition, performance tends to be impaired due to premature fatigue, resulting from the interaction that involves multiple physiological systems and mechanisms [9]. Therefore, the loss or decrease in autonomic control, which tends to be impaired in people with SCI, tends to impair athletic performance across a range of potential severities, ranging from low performance caused by fatigue to serious risks, including death [10].

When assessing sports practice, Paralympic powerlifting (PP) appears to be an excellent mode of sports practice for the disabled, being a sport characterized by the manifestation of strength, and only has the bench press adapted from conventional powerlifting (CP) [11]. Men and women with physical disabilities, especially in the lower limbs, may be eligible for the PP dispute [11]. The main difference in relation to CP is that the Paralympic sport is performed on the bench press with the lower limbs on the bench, with the athletes being fixed to the bench through bands [11].

The number of athletes in the sport has increased, and the results have been increasingly prominent [12,13]. Studies have focused more on the issue of health in relation to the etiology and prevention of injuries [14], recovery methods [15], warm-up [16], or even the width of the catch in sport [17]. On the other hand, when evaluating the PP, where the legs are extended on the bench, the SCI tends to reduce the transfer of strength for lifting in the adapted bench press [18]. Additionally, in the SCI, the transfer would be more impaired, given the inability to maintain strength, power, speed, and, consequently, the performance of sport-specific neuromotor skills in relation to other disabilities [9].

It is noteworthy that in other Paralympic sports, such as swimming, athletics and bocce ball, the athletes undergo analysis carried out by health professionals; the analyses will classify the athletes functionally and allocate them in subcategories [11]. For example, in the Paralympic Bocce, there are Categories BC2 and BC3. BC2 is characterized by athletes who have cerebral palsy and who are able to move the wheelchair and perform moves without the aid of an external person or additional equipment to perform the throwing of bochas [11]. BC3 is composed of athletes who have various disabilities; however, they do not have the ability to move the wheelchair without assistance from another person, and they do not have enough muscle strength to perform the throwing of the balls. Therefore, they use external equipment to perform the launch [11].

As exemplified, the subcategories of functional classification enable a fair competition among Paralympic athletes; however, this functional classification does not occur in PP [11]. In PP, the classification is purely binary, where the subject is classified as eligible (i.e., having an injury that impairs lower limbs) or ineligible [11]. Thus, a stratified functional classification is necessary to enable a fair competition between athletes in the PP. When evaluating the PP, where the legs are extended on the bench (an adapted bench press), the transfer of force could be impaired, making it difficult to maintain strength, power and speed, with decreased neuromotor abilities [11,18]. In this sense, we raised the hypothesis that athletes with SCI would present different patterns of strength and activation in relation to other deficiencies eligible for the sport [11].

The aim of this study was to analyze mechanical, dynamic and static indicators of strength, at different intensities, on performance in athletes with Spinal Cord Injury and other deficiencies of Paralympic powerlifting.

2. Materials and Methods

2.1. Sample

The sample consisted of 19 male Paralympic powerlifting athletes: 9 with spinal cord injuries and 10 with other deficiencies (OD). The participants were classified competitors, eligible to compete in the sport [11], with at least 12 months of experience and training. Among the deficiencies in the SCI group, eight had spinal cord injury by accident and one due to injury caused by the parasite Schistosoma Mansoni in the spinal cord, all with spinal cord injury below the eighth thoracic vertebra. In the other deficiencies group (OD), four subjects suffered from amputation, three with arthrogryposis, two with lower limb disability due to traumatic brain injury and one due to nerve damage to the right lower limb. The athletes participated in the study on a voluntary basis and signed a free and informed consent form, in accordance with resolution 466/2012 of the National Research Ethics Commission (CONEP), of the National Health Council, and the ethical principles expressed in Helsinki Declaration (1964, reformulated in 2013), by the World Medical Association. This study was approved by the Research Ethics Committee of the Federal University of Sergipe, CAAE: 2.637.882 (date of approval: 7 May 2018). The sample characterization is shown in Table 1.

Table 1. Sample characterization.

Characteristics	Spinal Cord Injury	Other Deficiencies	*p*	ICC	CV	α
Age (years)	30.57 ± 4.20	25.67 ± 4.52	0.232	0.308	5.04	0.302
Body mass (kg)	81.29 ± 21.68	73.89 ± 17.56	0.400	0.375	0.16	0.371
Experience (years)	3.07 ± 0.82	2.23 ± 0.86	0.023 #	0.095	15.23	0.151
1RM bench press test (kg)	122.29 ± 25.88 *	106.40 ± 31.17	0.701	0.251	10.19	0.278
1RM/weight	1.54 ± 0.32 **	1.48 ± 0.37 **	0.701	0.308	6.77	0.302

# $p < 0.05$ (independent "t" test). * All athletes with loads that keep them in the top 10 of their categories nationwide. ** Values above 1.4 in the bench press would be considered elite athletes, according to Ball and Weidman [19]. ICC: Intraclass Correlation Coefficient; CV: Variation Coefficient.

The sampling power was calculated a priori using the open source software G*Power® (Version 3.0; Berlin, Germany), choosing a "F family statistics (ANOVA)" considering a standard $\alpha < 0.05$, $\beta = 0, 80$ and the effect size of 1.33 found for the Rate of Force Development (RFD) in Paralympic powerlifting athletes in the study by Sampaio et al. [13]. Thus, it was possible to estimate a sample power of 0.80 ($F_{(2.0)}$: 4.73) for a minimum sample of eight subjects per group, suggesting that the sample size of the present study has statistical strength to respond to the research approach.

This study followed a static and dynamic force test, we analyzed the effects of two different classifications of disabilities (i.e., SCI and OD; see Table 1) on the performance of Paralympic powerlifting athletes at the national level. The study lasted three weeks. The first week aimed at familiarization with the tests of 1 Maximum Repetition (1RM) and 72-h later with the dynamic and static tests. At week 2, the 1RM and static tests were performed with a 72-h interval. Records in these sessions included maximum isometric force (MIF), time to MIF (Time), rate of force development (RFD), impulse, variability and fatigue index (FI). Finally, in week 3, the two sessions comprised dynamic tests at 40 to 60% 1-RM and, 72-h later, at 70 to 90% 1-RM. In both sessions, measurements included mean propulsive velocity (MPV), maximum velocity (Vmax) and power and Surface Electromiography (sEMG). All tests were performed on different days at the same time (between 9:00 a.m. and 12:00 p.m.) at temperatures ranging between 23 °C and 25 °C with a relative humidity of ~60%. All tests were performed on an adapted bench press in the supine position. The study was carried out at the Federal University of Sergipe.

2.2. Instruments

The body mass of the athletes was measured with the subjects in a sitting position using an appropriate Michetti digital electronic scale, Model Mic Welchair (Michetti, São Paulo, SP, Brazil). An official 210 cm long straight bench and a 220 cm long 20 lg bar were used herein (Eleiko Sport AB, Halmstad, Sweden), both pieces of equipment were approved by the International Paralympic Committee (IPC) [11].

2.3. Determination of Load

The athletes started the testing with a self-selected load estimated to be the maximal load. Weight was then added until the maximum load was attained. If the participant overestimated the initial load, 2.5% of the load was subtracted before a new attempt [20]. A rest period of 3 to 5 min was provided between attempts, according to the participants' perception of recovery [13,15,16]. The coefficient of variation between the two measures was at least 94%.

2.4. Warm Up

The participants performed a standardized warm-up for the upper limbs, using three exercises (abduction of the shoulders with dumbbells, military press with dumbbells, and medial and lateral rotation of the arm to warm up the rotator cuff with dumbbells) as described elsewhere [15], for approximately 15 min.

2.5. Dynamic Evaluation

The athletes were evaluated during the competitive phase of the season and were familiar with the testing procedures due to their constant training and testing routines. To measure the velocity of movement, a valid and reliable linear position transducer [21], Chronojump (Chronojump, BoscoSystem, Barcelona, Spain), was attached to the bar. The MPV and VMax were collected for analysis purposes with loads of 100% 1RM [13,16,22–24].

2.6. Isometric Force Measurements

The measures of muscle strength, RFD ($N \cdot s^{-1}$), MIF (N), FI (%) and time to MIF (s), were determined by a Chronojump force sensor (Chronojump, BoscoSystem, Barcelona, Spain) as described in detail elsewhere [16]. The perpendicular distance between the force sensor and the center of the joint was determined and used to calculate joint torques and FI [13,15,16,25]. MIF was measured by the maximum isometric force generated by the muscles of the upper limbs. The MIF, the FI and the RFD were calculated, as explained elsewhere [16,26].

2.7. Surface Electromyography

The electromyographic signals were captured on the dominant side, using double electrodes Meditrace (Tyco/Kendall, Mansfield, MA, USA), positioned parallel to the muscle fibers, 2.0 cm from the center at the point of greatest muscle area of the following muscles: brachial triceps (long head), anterior deltoid and in the sternal and clavicular portions of the pectoralis major, on both sides of the body. The ground electrode was positioned over the olecranon. The skin area where the electrodes were placed was previously shaved and cleaned with 70% alcohol solution. The electrodes (11.0 mm contact diameter and a 2.0 cm center-to-center distance) were placed along the presumed direction of the underlying muscle fiber according to the recommendations by SENIAM [27]. For data acquisition, one set was used with one repetition and a maximum load of 100% 1RM. The marker function was used to define the data intervals for each height in the sticking region. The electrodes were placed on the muscle belly along the estimated direction of the muscle fiber. Before placing the electrode, the skin was scraped, sanded and washed with alcohol according to the recommendations of SENIAM [27]. The electrodes were placed in four locations: the pectoral clavicular portion (~4 cm medial to the axillary crease, in the second intercostal space under the midpoint of the clavicle), the pectoral scapular portion (~6 cm medial to the axillary crease, and between the third and fourth intercostal space under the point proximal to the Sternum), anterior deltoid (1.5 cm distal and anterior to the acromion) and brachial triceps (long head, ~3 cm medial and 50% on the line between the acromion and the olecranon) [28].

The equipment used was an electromyographic MIOTEC® (MIOTEC, Porto Alegre, RS, Brasil), with eight channels. The data were filtered (second-order Butterworth band-pass filter of 20–500 Hz; notch of 60 Hz). The signal amplitude was calculated through the mean square root (MSR), which was normalized by the percentage of the maximum voluntary isometric contraction (MVIC). MVIC acquisition occurred before the test was performed, and a lift was carried out that remained in an isometric state for 5 s. CVMI values were recorded by the equipment and used for normalization. The equipment program issues a report with the values after normalization that were used for analysis in this study, adapted from Golas et al. [29].

2.8. Statistics

Descriptive statistics were performed using measures of central tendency, mean (X) $\pm$ Standard Deviation (SD) and 95% confidence interval (95% CI). To verify the normality of the variables, the Shapiro–Wilk test was used. The data for all variables were homogeneous and normally distributed. To compare the conditions of exercise and moments of measurement (40% $\times$ 50% $\times$ 60% $\times$ 70% $\times$ 80% $\times$ 90% of 1RM), the ANOVA (Two Way) test was performed with Bonferroni's Post Hoc. To check the effect size, the partial Eta squared ($\eta 2p$) was used, adopting values of low effect ($\leq$0.05), medium effect (0.05 to 0.25), high effect (0.25 to 0.50) and very high effect (>0.50) [30]. In comparisons between groups (SCI $\times$ OD), a Student's t-test was used. For the t-test, an effect size (Cohen's d) was calculated, adopting values of low effect ($\leq$0.20), medium effect (0.20 to 0.80), high effect (0.80 to 1.20) and very high effect (>1.20) [31,32]. The variation coefficient (CV%) was calculated by the formula: CV% = (standard deviation (SD)/mean) $\times$ 100. In addition, we calculated the intraclass correlation coefficient (ICC), whose magnitudes were determined as [29]: absence: <0; bad: 0–0.19; weak: 0.20–0.39; moderate: 0.30–0.59; substantial: 0.60–0.79; almost complete: $\geq$0.80. Statistical analyses were performed using the Statistical Package for the Social Science (SPSS) version 22.0 software (IBM, North Castle, New York, NY, USA). The level of significance was set at $p < 0.05$.

3. Results

The presented results were found in MPV ($m \cdot s^{-1}$; Figure 1) and Vmax ($m \cdot s^{-1}$; Figure 2) in subjects SCI and OD, in the percentages of 40% to 90% of 1 RM.

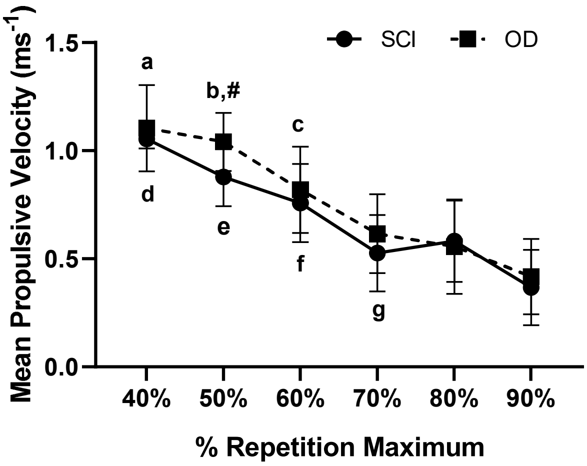

Figure 1. Analysis of dynamic force indicators, mean propulsive velocity (m s^{-1}) measured from 40% to 90% of 1RM in sLM and OD groups. SCI: Spinal Cord Injury; OD: Other Disability.

Mean Propulsive Velocity (m·s^{-1}) measured from 40% to 90% of 1RM in SCI and OD subjects. a: Indicates difference in SCI between 40% in relation to 70% (p = 0.002), 80% (p = 0.005) and 90% 1RM (p < 0.001); b: Indicates differences in SCI between 50% in relation to 70 and 90% (p < 0.001) and 80% 1RM (p < 0.024); c: Indicates differences in SCI between 60% in relation and 90% 1RM (p = 0.014); d: Indicates differences in SCI between 40% compared to 60% (p = 0.025), 70% (p = 0.008) and 90% 1RM (p = 0.002); e: Indicates differences in OD between 50% in relation to 70% (p = 0.007), 80% (p = 0.002) and 90% of 1RM (p < 0.001); f: Indicates difference in OD between 60% in relation to 80% (p = 0.001) and 90% of 1RM (p < 0.001); g: Indicates differences in OD between 80% in relation to 90% 1RM (p = 0.004); #: Indicates differences in the SCI in relation to OD 50% 1RM (p = 0.003). The effect was very high intra group η2p = 0.936 (very high effect), and inter group, small effect η2p = 0.173 (Medium effect).

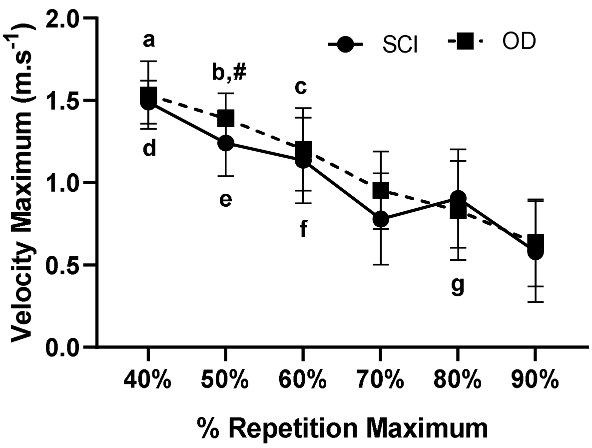

Figure 2. Analysis of dynamic force indicators maximum velocity (m·s^{-1}) measured from 40% to 90% of 1RM in LM and OD groups. SCI: Spinal Cord Injury; OD: Other Disability.

Maximum Velocity (m s^{-1}) measured from 40 to 90% of 1RM in SCI and OD subjects. a: Indicates difference in SCI between 40% in relation to 70% (p = 0.006) and 90% 1RM (p = 0.002). b: Indicates differences in the SCI between 50% in relation to 70% (p = 0.001) and 90% 1RM (p = 0.002). c: Indicates differences in SCI between 60% in relation and 90% 1RM (p = 0.023). d: Indicates differences in OD between 40% in relation to 70% (p = 0.008), 70% (p = 0.016) and 90% 1RM (p = 0.003). e: Indicates differences in OD between 50% in relation to 70% (p = 0.016), 80% (p = 0.022) and 90% of 1RM (p = 0.004). f: Indicates difference in OD between 60% in relation to 80% (p = 0.011) and 90% of 1RM (p = 0.002). g:

Indicates differences in OD between 80% in relation to 90% 1RM (p = 0.001). #: Indicates differences in SCI in relation to OD 50% 1RM (p = 0.049). The effect was very high intra group η2p = 0.910 (very high effect), and inter group, small effect η2p = 0.177 (Medium effect).

The results found in the Power (W) of the subjects SCI and OD, in the percentages of 40% to 90% of 1 RM, are shown in Figure 3.

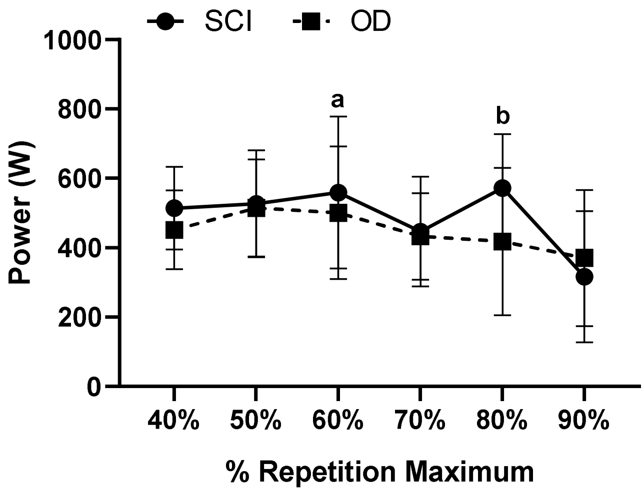

Figure 3. Power (W) measured from 40% to 90% of 1RM in subjects LM and OD. SCI: Spinal Cord Injury; OD: Other Disability.

Power (W) measured from 40% to 90% of 1RM in subjects SCI and OD; a: Indicates differences in OD 60% compared to 90% 1RM (p = 0.011); b: Indicates differences in OD 80% compared to 90% 1RM (p = 0.008); The effect was very medium intra Group η2p = 0.529 (very high effect), and inter Group small effect η2p = 0.144 (medium effect).

The results found in the dynamic mechanical variables (VMP, Vmax, Pot and 1RM) and isometric (FIM, Time, RFD, Impulse, Variability, FI) of the subjects SCI and OD are shown in Table 2.

Table 2. Indicators of dynamic and isometric force with 100% of 1RM (mean ± standard deviation) in spinal cord injured and other disabled individuals.

Force Indicators	SCI	OD	p	Cohen's d
MPV ($m \cdot s^{-1}$)	0.17 ± 0.13	0.20 ± 0.08	0.668	0.33 [b]
Vmax ($m \cdot s^{-1}$)	0.32 ± 0.19	0.34 ± 0.08	0.742	0.39 [b]
Power (w)	178.86 ± 111.10	194.89 ± 82.16	0.952	0.86 [c]
1RM (kg)	122.29 ± 25.88	106.44 ± 31.17	0.179	0.96 [c]
MIF (N)	867.84 ± 172.08	856.74 ± 167.84	0.945	0.24 [b]
Time (μs)	2651.73 ± 1478.78	2359.73 ± 1338.24	0.601	0.75 [b]
RFD ($N \cdot s^{-1}$)	2362.11 ± 1078.38	2397.57 ± 867.79	0.561	0.05 [a]
Impulse (N·s)	4011.52 ± 815.44	3828.39 ± 819.33	0.776	0.44 [b]
Variability (N)	44.12 ± 26.44	37.37 ± 11.83	0.308	0.34 [b]
FI (%)	8.04 ± 2.44	10.84 ± 5.59	0.213	0.67 [b]

[a]: Small Effect (≤0.20), [b]: Medium Effect (0.20 to 0.80), [c]: High Effect (0.80 to 1.20), [d]: Very High Effect (>1.20); MPV: Mean Propulsive Velocity; Vmax: Maximum Velocity; 1RM: 1 Repetition Maximum, MIF: Maximum Isometric Force; Time: Time to MIF; RFD: Rate of Force Development; FI: fatigue index, SCI: Spinal cord injury; OD: Other Deficiencies.

The results found in the surface electromyography at the intensities of 40% to 90% of 1 RM, are shown in Table 3. There was greater activation of the triceps in the OD group in relation to the anterior deltoid muscle of the SCI, indicating a pattern of muscular activation differentiated between the groups.

Table 3. Surface Electromyography in the different muscle groups in SCI and OD subjects (X ± SD and 95% CI).

Group	Pectoral Sternal (X ± SD) 95% CI	Pectoral Clavicular (X ± SD) 95% CI	Deltoide Anterior (X ± SD) 95% CI	Triceps (X ± SD) 95% CI	p	η2p
SCI	115.41 ± 104.57 27.99 − 202.83	95.81 ± 52.48 51.94 − 139.69	34.03 ± 23.38 * 14.48 − 53.58	109.56 ± 43.53 * 73.16 − 145.95	0.012	0.368 [b]
OD	141.80 ± 108.49 51.10 − 232.50	152.45 ± 86.94 33.83 − 308.73	121.96 ± 113.45 27.11 − 216.81	240.56 ± 166.75 101.15 − 379.97	0.116	0.241 [a]

* $p < 0.05$ (two-way ANOVA, and Bonferroni's Post Hoc). [a]: medium effect (0.05 to 0.25), and [b]: high effect (0.25 to 0.50); SCI: Spinal cord injury; OD: Other Deficiencies; mean (X) ± Standard Deviation (SD) and 95% confidence interval (95% CI).

4. Discussion

The aim of this study was to analyze mechanical, dynamic and static indicators of performance in Paralympic powerlifting athletes with and without spinal cord injury. The main findings were: (i) For intragroup propulsive velocity, the higher the 1RM load, the lower the propulsive velocity; (ii) In the comparison between propulsive velocity in both groups, there was a 50% difference between SCI and OD; (iii) There was a difference in the maximum velocity in relation to the 40% to 90% percentages of 1RM intra groups for SCI and OD; (iv) There was a difference in power for the OD at 60% of 1RM compared to 90% of 1RM; (v) There was a difference in the activation of the triceps brachii in the SCI group in relation to the activation of the anterior deltoid in the OD.

The present study found that the greater the load of 1RM, the lower the propulsive velocity of athletes of Paralympic powerlifting. This is to be expected and is in line with the force–velocity relationship. García-Ramos et al. [23] found that the bench press postures (i.e., arched or flat) can influence the velocity in powerlifting. Elliott et al. [33] concluded that a more arched posture allows a more vertical displacement of the bar. It can lead to an improvement in the force exerted in terms of transfer [34]. Given these perspectives, athletes with SCI can be harmed, since they are unable to make a good bow, and due to injury, they point out difficulties in transferring the strength from the lower limbs to the upper limbs. In view of the inability to maintain the position, in addition to the damage to strength, power, velocity, and, consequently, the performance of sport-specific neuromotor skills in relation to athletes who have other disabilities [9].

In the specific case of the sample herein, Paralympic powerlifters are unable to move their lower limbs and depend on their upper limbs for their activities, such as pushing wheelchairs, among others. Theisen [35] found that these restrictions result in interfering with performance, as upper limb exercise causes a reduced cardiovascular response when compared to lower limb exercise. Theisen [34] also found that when cycling with upper limbs, the maximum power and VO2peak of people without SCI were reduced by approximately 40% and 25%, respectively, when compared to cycling with lower limbs. On the other hand, a study that compared neuromuscular response when bench pressing at loads of 60% to 100% 1RM found differences in the anterior deltoid, triceps, and pectoralis major activation between disabled and non-disabled athletes [36]. Thus, in general, with the change in support, especially with athletes with greater disabilities, higher loads tend to promote an increase in muscle activity [37], and these changes tend to be related to muscle control [38]. This could help to explain the different activation herein between SCI and OD athletes. Moreover, when assessing whether there would be differences between the normal position vs. with the chest arched, it was found that there were no significant differences in total load, bar trajectory and average bar speed; indicating that greater support, as allowed in competitions with the use of a belt, may enable a greater stability for athletes [39].

In Paralympic powerlifting, where the legs must be extended on the bench, this position tends to reduce the transfer of force for lifting in the adapted bench press [18]. This fact was not observed in the present study, with similar results in both groups recorded. However, in the present study, when maximum velocity was analyzed, a difference was found only within the group. On the other hand, higher velocities were observed for less trained subjects than for more trained ones [22], where the velocity in more trained subjects was lower than in less trained subjects. Loturco et al. [24] found, in a study with Paralympic athletes, that certain segments had extremely low execution velocity in the adapted bench press. However, our study found no differences between groups. Perhaps this is explained by the adaptations not mentioned in other studies, where athletes with disabilities tend to produce better performance in terms of the production of strength in the upper limbs [36–38]. This fact needs to be better explored, but it may have some relation as to the fact that they use the upper limbs as a form of locomotion when using wheelchairs or crutches [40].

Regarding power, differences were found only in OD at an intensity of 90% in relation to 60% and 80% 1RM. There is no difference in SCI and between groups. It is possible that diaphragm fatigue induced by exercise is the justification in relation to the power in the spinal cord injury group. The diaphragm contracts and expands the rib cage during inspiration, at the same time that it opposes the mechanical forces transmitted by the thorax. This added to the lying position in dorsal decubitus could affect the breathing dynamics and hinder the manifestation of force in spinal cord injury [41,42].

In the dynamic and isometric mechanical variables, there were no differences between the groups analyzed by the present research. This may be due to the fact that Paralympic powerlifting athletes are better able to apply force against heavier loads and, consequently, at lower velocities, this would be a consequence of training with higher loads, which tends to generate specific adaptations [43]. Therefore, this could also justify the non-statistical differences between the groups in the parameters of static strength since this would be a constant in training aimed at maximum strength, in this case, the Paralympic powerlifting [44].

Regarding EMG, greater activation was observed between the triceps in the SCI in relation to the anterior deltoid of the OD. In this sense, changes in EMG activity between able-bodied and disabled athletes during bench press movements are most likely linked to tonic muscle function. Brennecke et al. [45] recommend alternate concepts of muscle stimulation during the same and incremental loads that have not yet been specifically clarified. The first theory applies to low energy consumption. The second principle is based on the interpretation of external forces, such as gravity, while the third principle consists of muscle synergy between different parts of the body. In the case of a low limb disability athlete with restricted kinesthetic awareness and proprioception in this region, deficits can be offset by improved coordination of the motor units and increased engagement of specific muscle groups during the bench press.

The SCI athletes had a larger training experience compared with OD. However, the level of performance, as shown by the absolute and relative bench press 1-RM, was not significantly higher. Moreover, a study that aimed to compare the reliability and magnitude of the speed variables between three variants of the bench press exercise in individuals with and without training experience, concluded that regardless of the type of bench press variant, no significant differences in execution speed were observed between experienced and non-experienced participants [46]. Therefore, we may suggest that the larger experience in SCI group did not play a significant role herein.

However, despite the relevance of the results, the present study has a limitation that the small sample size limits the generalizability of these results. Larger trials utilizing a large sample are required to enhance the applicability of these findings. Another limitation of the study was that it comprised only male athletes of national level. In addition, the evaluations were performed only with the adapted bench press and cannot be extrapolated to other muscle groups or other movements related to activities of daily living. In addition, there was a difference in training experience between the two groups herein.

It is suggested that further studies be carried out to verify the effect of training time on elite athletes. Other studies could also evaluate the activities of daily living and relating other muscle groups in PP athletes.

5. Conclusions

It was concluded that the indicators of static and dynamic strength for the bench press Paralympic powerlifting are similar for athletes with SCI and with other disabilities. It is suggested that sports training may supply part of the expected loss of strength in subjects with SCI.

In view of the results herein, we endorse the current rules of functional classification, with a single classification for Paralympic powerlifting (eligible or not eligible).

Finally, coaches can give more emphasis to the muscles most demanded according to the deficiency, where the triceps tend to be more activated in the SCI and the deltoids in the OD condition. In addition, it appears that athletes with SCI tend to produce more speed and power at higher loads (i.e., 80% of 1RM), and this should be accounted for when using movement speed to control training load.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Research Ethics Committee of the Federal University of Sergipe, CAAE: 2.637.882 (date of approval: 7 May 2018).

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

Data Availability Statement: The data used in the study can be obtained from Group of Studies and Research of Performance, Sport, Health and Paralympic Sports (GEPEPS), Federal University of Sergipe (UFS), São Cristovão, Sergipe 49100-000, Brazil; fjaidar@academico.ufs.br (F.J.A.).

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Review

A Meta-Analytical Comparison of the Effects of Small-Sided Games vs. Running-Based High-Intensity Interval Training on Soccer Players' Repeated-Sprint Ability

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Abstract: This systematic review with a meta-analysis was conducted to compare the effects of small-sided games (SSGs)-based interventions with the effects of running-based high-intensity interval training (HIIT) interventions on soccer players' repeated sprint ability (RSA). The data sources utilized were Web of Science, Scopus, SPORTDiscus, and PubMed. The study eligibility criteria were: (i) parallel studies (SSG-based programs vs. running-based HIIT) conducted in soccer players with no restrictions on age, sex, or competitive level; (ii) isolated intervention programs (i.e., only SSG vs. only running-based HIIT as individual forms) with no restrictions on duration; (iii) a pre–post outcome for RSA; (iv) original, full-text, peer-reviewed articles written in English. An electronic search yielded 513 articles, four of which were included in the present study. There was no significant difference between the effects of SSG-based and HIIT-based training interventions on RSA (effect size (ES) = 0.30; p = 0.181). The within-group analysis revealed no significant effect of SSG-based training interventions (ES = −0.23; p = 0.697) or HIIT-based training interventions (ES = 0.08; p = 0.899) on RSA. The meta-comparison revealed that neither SSGs nor HIIT-based interventions were effective in improving RSA in soccer players, and no differences were found between the two types of training. This suggests that complementary training may be performed to improve the effects of SSGs and HIIT. It also suggests that different forms of HIIT can be used because of the range of opportunities that such training affords.

Keywords: football; athletic performance; drill-based games; interval training; repeated sprint

1. Introduction

Small-sided games (SSGs) are adjusted formats of play that are often used in soccer training to develop a specific tactical/technical attribute [1] while intensifying some load parameters [2,3]. Typically, SSGs are designed according to different task constraints, which act concurrently to promote changes in the tactical/technical, physiological/physical, and psychological dimensions of players [3–5]. Naturally, the changes promoted by these games are influenced by how the constraints interact with each other [1]. Such constraints include the format of play (i.e., the number of players involved and the numerical relationships), pitch configuration (i.e., pitch size and shape), scoring method (e.g., with or without goalkeeper, goals or no goals), action restrictions (e.g., limited number of ball touches, limited movements), and tactical/strategical instructions (e.g., type of defensive marking, type of attack) [6,7]. These constraints are related to the structure of the game. However, another important constraint is related to the training regimen (e.g., work duration, recovery duration, work-to-rest ratio) [3].

Usually, SSGs are prescribed with regimens similar to those recommended for long-interval high-intensity interval training (HIIT) sessions [8]. The internal load demands imposed by SSGs and running-based long-interval HIIT are also similar, and this has been considered one of the reasons for using SSG as a replacement for running-based HIIT; SSGs also have the advantage of developing tactical/technical issues [2,9]. In a meta-comparison between SSGs and conventional endurance training (in which running-based HIIT was included), the effects on aerobic performance were similar between both types of training (trivial differences), and within-group analyses of both revealed beneficial effects [10]. However, aerobic performance is just one of the many physical qualities that players must develop to support the demands of the game.

Soccer is characterized by its intermittent nature, in which low-to-moderate intensity activities are interspaced with highly demanding activities in which explosive actions and repeated high exertion occur based on the context of the game [11]. Among other factors, repeated sprint ability (RSA) is a determinant physical component since the capacity to sustain repeated high-intensity efforts is often needed for different periods of a match and is associated with overall match performance [12]. Due to the complexity of RSA, it has several limiting factors (e.g., muscular factors, neural factors) [12]. Naturally, the training process is one of the variables that may alter RSA, especially considering energy supply, hydrogen accumulation, and muscle activation [13]. The training approaches that are implemented to develop RSA include repeated sprint training, sprint training, SSGs, and resistance training [13].

In soccer, the optimization of the training time is crucial. Therefore, it is important to understand whether drill-based exercises (e.g., SSGs) can develop RSA to a similar extent as other forms of exercise (e.g., running-based HIIT) and whether they are significantly beneficial for soccer players. Such an understanding (SSG vs. running-based HIIT) will help define a practical application for the soccer field.

Additionally, a systematic review and meta-analysis will help summarize the main training protocols and parallel studies that have compared SSGs and running-based HIIT, with a focus on their effects on RSA. Although two meta-analyses of SSGs have been carried out recently [10,14], one did not consider RSA [10], and the other only included young players and did not objectively compare running-based HIIT with SSGs [14]. Thus, the need remains for a systematic review and meta-analysis that consolidates evidence about the effects of these forms of training on the RSA of soccer players. The purpose of this systematic review and meta-analysis was to compare the effects of SSG-based interventions vs. the effects of running-based HIIT interventions on soccer players' RSA.

2. Materials and Methods

This study followed the Cochrane Collaboration guidelines [15] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [16]. The protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols with the number INPLASY202080129.

2.1. Information Sources

A comprehensive computerized search of the following electronic databases was performed: (i) Web of Science; (ii) Scopus; (iii) SPORTDiscus; (iv) PubMed. The searching process for relevant publications had no restriction regarding the year of publication and included articles retrieved until 1 September 2020. The following search strings were employed: ("soccer" OR "football") AND ("small-sided games" OR "drill-based games" OR "sided-games" OR "SSG" OR "conditioned games" OR "small-sided and conditioned games" OR "reduced games" OR "play formats") AND ("sprint").

The following inclusion criteria were established: (i) parallel randomized studies (SSG-based programs vs. running-based HIIT) conducted in soccer players with no restriction of age, sex, or competitive level; (ii) isolated intervention programs (i.e., only SSG vs. only running-based HIIT as discrete forms) with no restrictions on duration; (iii) a pre–post outcome for RSA; (iv) original, peer-reviewed articles written in English that provided the full text.

Studies were excluded on the basis that they (i) were observational analytic designs; (ii) included other sports; (iii) used SSG or running-based HIIT combined with other training methods or between them (e.g., SSG + running based-HIIT); (iv) were conducted in recreational soccer (e.g., healthy population but not soccer players) or physical education contexts; (iv) were review articles, letters to the editor, errata, invited commentaries, or conference abstracts.

2.2. Data Extraction

An Excel spreadsheet was designed (Microsoft Corporation, Redmond, WA, USA) to process the data extraction [17]. Two of the authors performed the data extraction (F.M.C. and H.S.). Disagreements about study eligibility were solved in discussions between the authors. Full-text articles that were excluded were recorded with reasons for exclusion. All of the records were stored in the spreadsheet.

2.3. Data Items

The outcomes chosen for this systematic review and meta-analysis included RSA measured through field-based tests. The RSA was collected based on the mean time (s), mean power (W), or total time (s) in a series of multiple sprints. Additionally, the following information was extracted from the included studies: (i) the number of participants (n), age (years), competitive level (if available), and sex; (ii) the SSGs format and pitch size (if available); (iii) the period of intervention (number of weeks) and number of sessions per week (n/w); (iv) the regimen of intervention (work duration, work intensity, modality, relief duration, relief intensity, repetitions and series, and between-set recovery).

2.4. Assessment of Methodological Quality

To assess the methodological quality of the included articles, the methodological index for non-randomized studies (MINORS) was used [18]. Twelve items were analyzed, in which there were 0 represented cases of no report, 1 case reported but inadequate, and 2 cases reported and adequate. Two of the authors (F.M.C. and H.S.) independently scored the articles. Any disagreements were resolved through discussion. The inter-observer analysis was conducted using a Kappa correlation test. An agreement level of k = 0.91 was obtained.

2.5. Summary Measures

The analysis and interpretation of results in this systematic review and meta-analysis were conducted only in the case that at least three study groups provided baseline and follow-up data for RSA [19–21]. Means and standard deviations for RSA were converted to Hedges' *g* effect size (ES). The inverse-variance random-effects model for meta-analyses was used because it allocates a proportionate weight to trials based on the size of their individual standard errors [22] and enables analysis while accounting for heterogeneity across studies [23]. The ESs were presented alongside 95% confidence intervals (CIs) and were interpreted using the following thresholds [24]: <0.2, trivial; 0.2–0.6, small; >0.6–1.2, moderate; >1.2–2.0, large; >2.0–4.0, very large; >4.0, extremely large. All analyses were carried out using the Comprehensive Meta-Analysis program (version 2; Biostat, Englewood, NJ, USA).

2.6. Synthesis of Results

To estimate the degree of heterogeneity between the included studies, the percentage of total variation across the studies due to heterogeneity was used to calculate the I^2 statistic [25]. Low, moderate, and high levels of heterogeneity correspond to I^2 values of <25%, 25–75%, and >75%, respectively [25,26].

2.7. Risk of Bias Across Studies

The extended Egger's test [27] was used to assess the risk of bias across the studies. In the case of bias, Duval and Tweedie's trim and fill method was conducted.

3. Results

3.1. Study Identification and Selection

The searching of databases identified a total of 513 titles. These studies were then exported to the reference manager software EndNote™ X9 (Clarivate Analytics, Philadelphia, PA, USA). Duplicates (249) were subsequently removed, either automatically or manually. The remaining 264 articles were screened for their relevance based on titles and abstracts, resulting in the removal of a further 242 studies. The full texts of the remaining 22 articles were examined diligently. After reading the full texts, a further 18 studies were excluded due to a number of reasons (Figure 1). The four studies included in the meta-analysis provided the mean and standard deviation of pre- and post-intervention data for the main outcome.

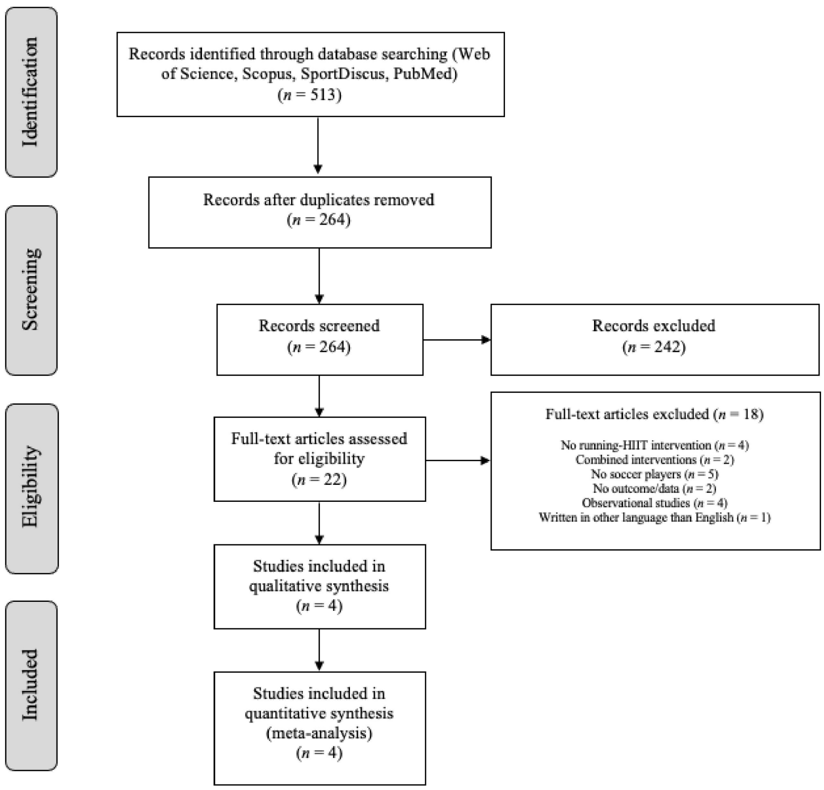

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram highlighting the selection process for the studies included in the systematic review and meta-analysis. HIIT: high-intensity interval training

3.2. Study Characteristics

The characteristics of the four studies included in the systematic review and meta-analysis can be found in Table 1.

Table 1. Characteristics of the included studies and outcomes extracted.

Study	Mean Age (Yo)	Sex	CL	Design	Tests Used in the Original Studies	Measure Extracted from the Tests in the Original Studies
Arslan et al. [28]	14.2	Men	Y	Parallel	6 × (2 × 15-m)/20 s recovery	RSA total (sum of all sprints)
Eniseler et al. [29]	16.9	Men	Y	Parallel	6 × (2 × 20-m)/20 s recovery	RSA mean time (mean of all sprints)
Mohr and Krustrup [30]	19	Men	U	Parallel	5 × 30-m/25 s recovery	RSA mean time (mean of all sprints)
Safania et al. [31]	15.7	Men	Y	Parallel	6 × 35-m/25 s recovery	Average power (mean of all sprints)

Yo: years old; CL: competitive level; Y: youth; U: university-level; s: seconds; m: meters; RSA: repeated-sprint ability

Additionally, the details of the SSG-based and running-based HIIT programs can be found in Table 2. The included parallel studies involved 8 individual groups (4 SSG-based groups and 4 running-based HIIT groups) and 77 participants (n = 39 in SSG-based groups; n = 38 in running-based HIIT groups). Among the included studies, the smaller intervention lasted 4 weeks [30] and the longer 6 weeks [29,31]. Three of the interventions had two sessions per week [28–30], while one [31] had three sessions per week. The total number of sessions ranged between a minimum of 8 [30] and a maximum of 18 [31].

Table 2. Characteristics of small-sided game (SSG)-based programs in the included studies.

Study	Intervention	Duration (w)	d/w	Total Sessions	SSG Formats	SSG Pitch Dimension(Length × Width)	SSG Area per Player (m^2)	Sets	Reps	Recovery between Sets (Duration)	Recovery between Sets (Intensity)	Work Duration	Work Intensity	Between Reps Duration	Relief Intensity
Arslan et al. [28]	SSG	5	2	10	2 vs. 2	20 × 15-m	75 m^2	2	2	2 min	-	2.5–4.5 min	NR	-	Passive
Eniseler et al. [29]	SSG	6	2	12	3 vs. 3	18 × 30-m	90 m^2	4	-	4 min	-	3 min	90–95% HRmax	-	Passive
Mohr and Krustrup [30]	SSG	4	2	8	2 vs. 2	20 × 20-m	100 m^2	8–10	-	45 s	-	45 s	NR	-	NR
Safania et al. [31]	SSG	6	3	18	2 vs. 2 to 4 vs. 4	10 × 15 to 40 × 50-m	NR	4	-	3 min	-	4 min	NR	-	NR
Arslan et al. [28]	HIIT	5	2	10	-	-	-	2	12–20	NR	NR	15 s	90–95% V_{IFT}	15 s	Passive
Eniseler et al. [29]	HIIT	6	2	12	-	-	-	3	6	4 min	NR	40-m	All-out	20 s	Passive
Mohr & Krustrup [30]	HIIT	4	2	8	-	-	-	-	8–10	-	-	30 s	All-out	150 s	NR
Safania et al. [31]	HIIT	6	3	18	-	-	-	-	4	-	-	4 min	70–95% HRmax	3 min	NR

w: weeks; d/w: days per week; NR: not reported; m: meters; s: seconds; min: minutes; V_{IFT}: maximal velocity at 30–15 Intermittent Fitness Test; IAT: individual anaerobic threshold; HRmax: maximal heart rate; Passive: passive recovery.

3.3. Methodological Quality

All the included studies were classified with 18 points (Table 3).

Table 3. Methodological index for non-randomized studies (MINORS).

Study	N.º1 *	N.º2	N.º3	N.º4	N.º5	N.º6	N.º7	N.º8	N.º9	N.º10	N.º11	N.12	Total **
Arslan et al. [28]	2	1	2	2	0	2	2	0	1	2	2	2	18
Eniseler et al. [29]	2	1	2	2	0	2	2	0	1	2	2	2	18
Mohr and Krustrup [30]	2	1	2	2	0	2	2	0	1	2	2	2	18
Safania et al. [31]	2	1	2	2	0	2	2	0	1	2	2	2	18

*: MINORS scale items number; N.º1: A clear study aim; N.º2: Inclusion of consecutive patients; N.º3: Prospective collection of data; N.º4: Endpoints appropriate to the aim of the study; N.º5: Unbiased assessment of the study endpoint; N.º6: Follow-up period appropriate to the aim of the study; N.º7: Loss to follow-up less than 5%; N.º8: Prospective calculation of the study size; N.º9: An adequate control group; N.º10: Contemporary groups; N.º11: Baseline equivalence of groups; N.º12: Adequate statistical analyses; **: the total number of points from a possible maximal of 24.

3.4. SSG vs. Running-Based HIIT Interventions on Repeated-Sprint Ability

A summary of the included studies and results of RSA reported before and after SSG-based and running-based HIIT interventions are provided in Table 4.

Table 4. Summary of the included studies and results of repeated sprint ability before and after SSG-based and running-based high-intensity interval training (HIIT) intervention.

Study	Intervention	*n*	Before Mean ± SD	After Mean ± SD	Before−After (Δ%)
Arslan et al. [28]	SSG	10	37.8 ± 1.5	35.6 ± 1.2	−5.8
Eniseler et al. [29]	SSG	10	7.12 ± 0.17	7.22 ± 0.20	1.4
Mohr and Krustrup [30]	SSG	9	4.41 ± 0.07	4.35 ± 0.22	−1.4
Safania et al. [31]	SSG	10	309.0 ± 39.0	220.0 ± 24.0	−28.8
Arslan et al. [28]	HIIT	10	38.2 ± 1.7	34.9 ± 1.5	−8.6
Eniseler et al. [29]	HIIT	9	7.13 ± 0.17	7.13 ± 0.21	0.0
Mohr and Krustrup [30]	HIIT	9	4.45 ± 0.05	4.36 ± 0.14	−2.0
Safania et al. [31]	HIIT	10	291.0 ± 38.0	207.0 ± 29.0	−28.9

n: number of participants per group; SD: standard deviation; SSG: small-sided game; HIIT: high-intensity interval training

Four studies provided data for RSA, involving four SSG-based and four HIIT-based groups (pooled n = 77). There was no significant difference between SSG-based compared to HIIT-based training interventions on the effect over RSA (ES = 0.30; 95% CI = −0.14 to 0.73; p = 0.181; I^2 = 0.0%; Egger's test p = 0.332; Figure 2). The relative weight of each study in the analysis ranged from 24.2% to 26.5% (the size of the plotted squares reflects the statistical weight of each study).

Study name	Hedges' g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Arslan et al. (2020)	0.776	0.446	0.198	−0.098	1.649	1.741	0.082
Eniseler et al. (2017)	0.466	0.445	0.198	−0.406	1.339	1.047	0.295
Mohr and Krustrup (2016)	0.155	0.450	0.202	−0.726	1.036	0.345	0.730
Safania et al. (2011)	−0.180	0.429	0.184	−1.021	0.661	−0.419	0.675
	0.296	0.221	0.049	−0.138	0.729	1.338	0.181

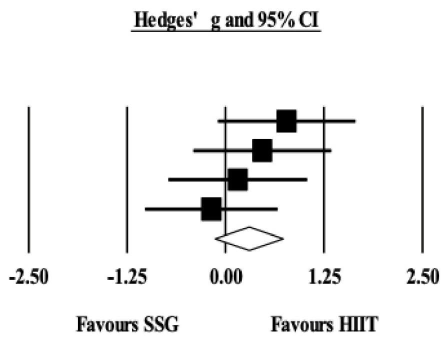

Figure 2. Forest plot of between-mode effect sizes (Hedges' *g*) with 95% confidence intervals (CIs) in repeated sprint ability.

The within-group analysis revealed no significant effect of SSG-based training interventions on RSA (ES = −0.23; 95% CI = −1.40 to 0.94; p = 0.697; I^2 = 93.8%; Egger's test p = 0.695; Figure 3). The relative weight of each study in the analysis ranged from 23.4% to 25.9%.

The within-group analysis revealed no significant effect of HIIT-based training interventions on RSA (ES = 0.08; 95% CI = −1.17 to 1.33; p = 0.899; I^2 = 94.0%; Egger's test p = 0.801; Figure 4). The relative weight of each study in the analysis ranged from 23.9% to 26.0%.

Study name	Hedges' g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Arslan et al. (2020)	1.440	0.335	0.112	0.783	2.098	4.296	0.000
Eniseler et al. (2017)	−0.485	0.239	0.057	−0.954	−0.016	−2.029	0.042
Mohr and Krustrup (2016)	0.236	0.237	0.056	−0.229	0.700	0.994	0.320
Safania et al. (2011)	−2.247	0.449	0.202	−3.128	−1.367	−5.004	0.000
	−0.232	0.598	0.357	−1.404	0.939	−0.389	0.697

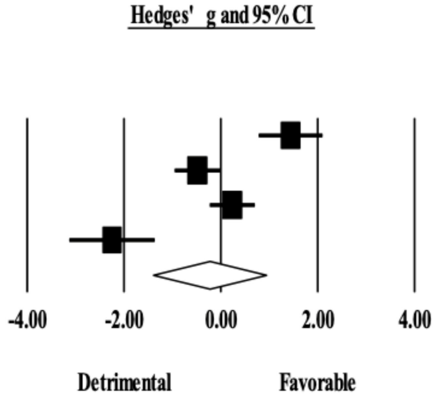

Figure 3. Forest plot of within-mode (SSG) effect sizes (Hedges' *g*) with 95% confidence intervals (CIs) in repeated sprint ability.

Study name	Hedges' g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Arslan et al. (2020)	1.865	0.393	0.155	1.095	2.636	4.745	0.000
Eniseler et al. (2017)	0.000	0.233	0.054	−0.457	0.457	0.000	1.000
Mohr and Krustrup (2016)	0.568	0.255	0.065	0.068	1.068	2.225	0.026
Safania et al. (2011)	−2.184	0.440	0.193	−3.045	−1.322	−4.968	0.000
	0.081	0.637	0.406	−1.168	1.330	0.127	0.899

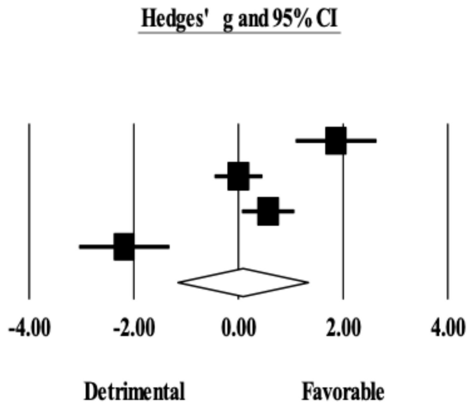

Figure 4. Forest plot of within-mode (HIIT) effect sizes (Hedges' *g*) with 95% confidence intervals (CIs) in repeated sprint ability.

3.5. Adverse Effects

Among the included studies, none reported soreness, pain, fatigue, injury, damage, or adverse effects related to the SSG-based and running-based HIIT interventions.

4. Discussion

The purpose of this meta-analysis was to compare the effects of SSGs and HIIT-based interventions on soccer players' RSA. In short, despite the small number of included studies, the results revealed no significant differences between the two types of training; neither type of training was found to significantly affect RSA.

SSGs are drill-based activities that fall within the scope of running-based HIIT training. The difference between SSGs and running-based HIIT is that SSGs are performed using the dynamics of the game (two teams and one ball). In a well-known pair of published articles [8,32], HIIT training was classified (based on training regimen) into several types: short-interval, long-interval, repeated sprint training, sprint interval training, and game-based training (which includes SSGs) [8].

Typically, SSGs are prescribed as a part of long-interval regimens (2–4 min of high-intensity, non-maximal-intensity exercise). Among the studies included in this meta-analysis, SSG duration varied between 45 s [30] and 4 min [29], with the number of sets ranging between 2 and 10 (2 sets in longer-duration cases and 10 sets in minimum-duration cases). Additionally, formats of play varied between two vs. two [28,30] and four vs. four [31] games, played on a minimum field size of 75 m^2 [28] and a maximum field size of 100 m^2 [30] per player (field lengths ranged between 18 and 50 m). However, smaller formats of play and pitch sizes imply restricted high-intensity running demands (e.g., high-speed running and sprinting) [33,34], as well as high variability in the stimuli [35,36]. Therefore, this would be expected to promote the favorable effects of running-based HIIT on RSA. However, no significant differences were found between SSG and running-based HIIT.

The absence of significant differences between groups might be related to the range of running-based HIIT. Among the training regimens, one involved short intervals (15 s–15 s work–rest) [28], one involved long intervals (4 min–4 min work–rest) [31], one involved repeated sprint training (40 m all-out, interspaced by 20 s rest) [29], and one involved sprint interval training (30 s all-out interspaced by 150 s rest) [30]. In 50% of the included articles, RSA was improved by HIIT more significantly than by SSG [28,30]. Of these two articles, one involved similar regimens of training for the HIIT and SSG groups [28], while the other applied different regimens (one regimen of speed production with a 1:5 work-to-rest ratio favoring the running-based HIIT and one of speed maintenance with a 1:1 ratio favoring SSG) [30]. Therefore, it is difficult to compare the effects of the two training types. In a recent systematic review with meta-analysis about HIIT in soccer [37], it was also observed that different HIIT training regimens did not vary in their ability to improve RSA, although there were greater expectations that sprint interval training or repeated sprint training would be more appropriate to benefit RSA.

Interestingly, the within-group changes also revealed no significant effects of training interventions in RSA. This was somewhat unexpected, mainly in the running-based HIIT group. The particularly detrimental results obtained in a long-interval HIIT intervention [31] could explain these results (Figure 4). However, considering that RSA depends on several other factors (e.g., energy supply, hydrogen accumulation, and muscle activation) [13], interventions made alone (e.g., short intervals and long intervals) may not be as effective as when they are combined with other methods (e.g., resistance training, sprinting training). Concurrent training might be worth exploring since RSA benefits from lower-limb power for change-of-direction and maximal speed as well as a good energy supply. For example, a study comparing concurrent training (eccentric overload and HIIT) with HIIT by itself in soccer players showed benefits in players who underwent concurrent training [38].

One of the limitations of the current systematic review and meta-analysis is that only English articles from the Web of Science, Scopus, SPORTDiscus, and PubMed were included, thus potentially overlooking other relevant publications. Another limitation is the reduced number of included articles. However, this serves to highlight the need for more research on this topic. For instance, the absence of research on women and professional players was apparent. The results might change based on such moderators or other factors, such as baseline levels or even the volume of training completed beyond the interventions. Future research on this topic should apply the same training regimen to SSGs and running-based HIIT to homogenize the methodological process. Future research should also account for the responding profile of players to determine which type of profile is more responsive to the interventions.

As for practical applications, this meta-analysis highlights the importance of including complementary training methods that may help to develop RSA. Among other training regimens, combining SSG with running-based HIIT [39,40] or with strength/power training [41] might promote neuromuscular stimuli support improvements in RSA. Such research is worthwhile since previous findings have consistently revealed the beneficial effects of SSGs and running-based HIIT in aerobic performance [10,42].

5. Conclusions

The current meta-analytical comparison revealed no significant changes in the effects of SSG-based and running-based HIIT interventions on soccer players' RSA. Additionally, among the included parallel studies, the within-group analysis revealed no significant improvements after SSG or running-based HIIT interventions. Despite the limited number of studies included in the present analysis, the findings should be carefully considered as practical applications. Specifically, the results indicate that complementary training methods (e.g., strength/power training, combined interventions) could help to improve RSA due to their multifactor-dependent quality. Finally, more research comparing SSG and running-based HIIT is needed; no studies on women or professional players were found in the present analysis.

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Article

A Longitudinal Exploration of Match Running Performance during a Football Match in the Spanish La Liga: A Four-Season Study †

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Abstract: This study aimed to analyze and compare the match running performance during official matches across four seasons (2015/2016–2018/2019) in the top two professional leagues of Spanish football. Match running performance data were collected from all matches in the First Spanish Division (Santander; n = 1520) and Second Spanish Division (Smartbank; n = 1848), using the Mediacoach® System. Total distance and distances of 14–21 km·h^{-1}, 21–24 km·h^{-1}, and more than 24 km·h^{-1}, and the number of sprints between 21 and 24 km·h^{-1} and more than 24 km·h^{-1} were analyzed. The results showed higher total distances in the First Spanish Division than in the Second Spanish Division (p < 0.001) in all the variables analyzed. Regarding the evolution of both leagues, physical demands decreased more in the First Spanish Division than in the Second Spanish Division. The results showed a decrease in total distance and an increase in the high-intensity distances and number of sprints performed, although a clearer trend is perceived in the First Spanish Division (p < 0.001; p < 0.01, respectively). Knowledge about the evolution of match running performance allows practitioners to manage the training load according to the competition demands to improve players' performances and reduce the injury rate.

Keywords: longitudinal study; match running performance; professional soccer leagues; sports performance; external load

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1. Introduction

The external load of soccer matches has been studied in depth over the last two decades, which has improved knowledge on its evolution and trends [1]. Thus, different variables have been analyzed, usually related to the distance covered by the players at different intensities [2], and it should be noted that soccer match running performance has evolved, with significant increases in high-intensity actions [3]. Match physical demands can vary depending on the tactical planning, the opposite team's playing style or the tactical–technical demands [4]. Research has also shown that these changes could be related to differences between soccer leagues [5]. However, to the best of our knowledge, there are no updated studies on how efforts have evolved in professional leagues' full seasons. In addition, we found no studies of the analysis and comparison of match running performance from several seasons between two professional soccer leagues to update our knowledge about physical differences at the competitive level and in the evolution of football.

Regarding the comparison of match running performance between professional soccer leagues, a previous study analyzed the external load of the top three leagues in English soccer: the FA Premier League, Championship, and League One [5]. This study concluded that the players in the Premier League, compared to players in the lower leagues such as the Championship and League One, covered less total distance and had fewer high-intensity running distances ($p < 0.01$). A related study collected physical demand data over four seasons (2006–2010) in two top leagues of English soccer, with similar external load data [6]. Players of the Championship League (2nd) covered more total distance than players of the Premier League (1st). In addition, Championship players covered more high-intensity running distance and performed more sprinting-intensity actions than Premiership players. However, recent research has found the opposite results in this area of study. In this way, authors described and compared the match running performance of the teams of the Spanish First and Second Division leagues during the 2015–2016 season, showing that the Spanish First Division teams covered more total distance than the Spanish Second Division teams [7]. There were differences in the distance covered at high intensity and very high intensity, where teams from the First Division covered more meters at these intensities. In this line, similar results were reported in the analysis of the match running performance of three professional soccer leagues in Norwegian football [8]. They found a higher total distance in the Norwegian first league teams, but differences were nonsignificant. Concerning high-intensity running distances, Norway's first league teams covered higher sprinting distances than Norway's second and fourth league teams ($p < 0.05$). Thus, the most recent studies agree on the presence of higher match physical demands (total and at high intensity) in the top professional soccer leagues.

On the other hand, research of the evolution of external load has shown that total distances have been stable over the period from 1967 to 2012 [9]. However, it has also demonstrated that total distance has increased by 2% in the English Premier League over seven consecutive seasons (2006/2007–2012/2013), whereas high-intensity running and sprint distances have increased by 30–50% [3]. Moreover, a longitudinal study of the World Cup final soccer games reported that the soccer game trend evolved towards shorter, higher intensity play periods because players covered a higher sprint distance and they performed sprints more frequently [10]. Although the evolution of match running performance has also been analyzed by ranking tiers, similar trends have been found for all tiers. In this sense, one study reported that, during seven consecutive seasons in the English Premier League, there was an increase in high-intensity running distance (40%) and leading (15%) and explosive (25%) sprints for all tiers, although the average distance covered per sprint decreased [11]. Thus, changes have been observed in the external load of soccer competitions over the last few years. It is difficult to attribute these findings to a single factor. These changes could be explained through the increases in the competition levels of the leagues, the evolution of movement patterns, training specificity based on match physical demand data or a new approach to training [12]. It also could be related to the playing formation or, possibly, the recruitment of players with more explosive characteristics [1,7,11,13].

There are few studies on the evolution of external load over several years. Most of them are outdated and only analyzed the English Premier League. In addition, even if some works compare leagues or analyze the evolution of external load, there are no studies comparing the evolution of leagues of different levels over several years. Therefore, the aim of this study was to analyze and compare the evolution of match running performance between LaLiga Santander (LL1) and LaLiga Smartbank (LL2) across four seasons (2015/2016–2018/2019).

Based on the aforementioned studies [3,7,11], the authors established the following hypotheses. Concerning the match running performance comparison, we expected that the total distances, the distances covered at high intensity, and the number of very high-intensity running efforts would be higher in LL1 than in LL2.

On the other hand, we expected that the total distance, the distances covered at high intensity, and the number of very high-intensity running efforts would increase in both professional soccer leagues across the four seasons analyzed.

2. Materials and Methods

2.1. Participants

The sample included observations of all the matches played over four seasons in LL1 and LL2 (2015/2016, 2016/2017, 2017/2018, and 2018/2019). Two observations were made by match, and one by team. In LL1, 752 team match observations were included in the 2015/2016 season; 744 team match observations were included in the 2016/2017 season; 723 observations were included in the 2017/2018 season and, finally, 731 observations were included in the 2018/2019 season. Similarly, in LL2, 700 team match observations were included in the 2015/2016 season; 744 team match observations were included in the 2016/2017 season; 870 observations were included in the 2017/2018 season and, finally, 731 observations were included in the 2018/2019 season. In addition, 784 observations were excluded due to technical problems in the data collecting system or adverse weather conditions during the match, leading to a total of 5952 team match observations.

2.2. Design and Procedures

Match running performance data were collected by a multicamera tracking system called Mediacoach®. This system assesses the distance covered in meters by teams and the number of high-intensity sprints (LaLiga™, Madrid, Spain). It consists of a series of super 4K-High Dynamic Range cameras based on a positioning system (Tracab—ChyronHego VTS) that records and analyzes X and Y positions for each player from several angles, thus providing real-time three-dimensional tracking (tracking data are recorded at 25 Hz). Mediacoach® has been proven to be both reliable and valid and has been used in previous studies [14–16]. Data were provided to the authors by LaLiga™, and the study received ethical approval from the University of Extremadura, Vice-Rectorate of Research, Transfer and Innovation—Delegation of the Bioethics and Biosafety Commission (Protocol number: 153/2017).

2.3. Study Variables

Similarly to previous studies [17–19], the physical demand variables were recorded for each match: (1) total distance covered by soccer teams in meters (TD); (2) distance covered between 14 and 21 km·h^{-1} (i.e., High-Intensity Running Distance = HIRD); (3) distance covered between 21 and 24 km·h^{-1} (i.e., Very High-Intensity Running Distance = VHIRD); (4) distance covered at more than 24 km·h^{-1} (i.e., Sprinting Distance = SpD). These variables were shown and analyzed by matches and separated by halves (first and second half). In addition, the number of sprints performed was registered, as well as (5) the number of very high-intensity running sprints at 21–24 km·h^{-1} (i.e., SpVHIR), and (6) the number of sprints at more than 24 km·h^{-1} (i.e., SP). All efforts that implied a minimum movement of one meter, which was maintained for a 1 s minimum, were recorded. Any recording at a speed of over 80% of the value of that category (i.e., >24 km·h^{-1}) was considered as a single register. All these variables show total team values (i.e., all players who participated in matches, starters, nonstarters and substitutes).

2.4. Data Analysis

The statistical program SPSS 25.0 was used (Armonk, NY: IBM Corp, 2017) to analyze and treat the data. Firstly, a two-way Analysis of Variance (ANOVA) was used to explore the main differences between the two professional soccer leagues for external load variables (i.e., variables related to distances covered and the number of sprints) across matches and halves. Subsequently, a 2 × 4 Multivariate Analysis of Variance (MANOVA) was used to examine the differences between the two professional soccer leagues across four seasons in different subsets of dependent variables. A split file, where data were separated by seasons, was used to carry out a posthoc comparison between the professional soccer leagues, using Bonferroni posthoc analyses. Thus, MANOVA investigated the evolution of the external load variables, where season and league (LL1 or LL2) were independent variables. Statistical significance was set at $p < 0.05$, $p < 0.01$, and $p < 0.001$.

3. Results

Table 1 shows the mean match running performance comparison between LL1 and LL2 across the four league seasons. We observed a higher TD in LL1 than in LL2 ($p < 0.001$). In the analysis of TD by halves, in LL1, TD decreased over the match, as TD was higher in the first half than in the second half, whereas this trend was the opposite in LL2. Similarly, HIRD was higher in LL1 than in LL2 ($p < 0.001$). Concerning the analysis of the HIRD by halves, this variable was higher in the first half than in the second half in both leagues. VHIRD and SpD were also higher in LL1 than in LL2 ($p < 0.001$). These two variables were higher in the second halves for these two leagues. Finally, SpVHIR and SP were higher in LL1 ($p < 0.001$).

Table 1. Differences between both professional soccer leagues in match running performance.

	LL1		LL2		F	*p*
	M (%)	SD	M (%)	SD		
TD (m)	109,135	4355	107,895	4110	126	0.00 (***)
TD 1st Half (m)	54,826 (50.24%)	2390	53,935 (49.99%)	2386	205	0.00 (***)
TD 2nd Half (m)	54,309 (49.76%)	2664	53,960 (50.01%)	2570	26	0.00 (***)
HIRD 14–21 km·h^{-1} (m)	22,436 (20.56%)	2182	21,727 (20.14%)	2005	169	0.00 (***)
HIRD 1st Half (m)	11,395 (10.44%)	1222	10,971 (10.17%)	1129	191	0.00 (***)
HIRD 2nd Half (m)	11,041 (10.12%)	1186	10,756 (9.97%)	1129	89	0.00 (***)
VHIRD 21–24 km·h^{-1} (m)	3019 (2.77%)	385	2838 (2.63%)	378	331	0.00 (***)
VHIRD 1st Half (m)	1504 (1.38%)	230	1409 (1.31%)	223	255	0.00 (***)
VHIRD 2nd Half (m)	1515 (1.39%)	234	1429 (1.32%)	231	202	0.00 (***)
SpD > 24 km·h^{-1} (m)	2905 (2.66%)	490	2687 (2.49%)	481	296	0.00 (***)
SpD 1st Half (m)	1437 (1.32%)	291	1329 (1.23%)	279	209	0.00 (***)
SpD 2nd Half (m)	1467 (1.34%)	304	1357 (1.26%)	299	196	0.00 (***)
SpVHIR 21–24 km·h^{-1}	264 (62.12%)	30	249 (62.41%)	30	354	0.00 (***)
SP > 24 km·h^{-1}	161 (37.88%)	23	150 (37.59%)	22	287	0.00 (***)

Note: *** $p < 0.001$; TD = Total distance, HIRD = High-intensity running distances, VHIRD = Very high-intensity running distances, SpD = Sprinting distance, SpVHIR = Sprints at very high-intensity running, and SP = Sprints at more than 24 km/h; LL1: LaLiga Santander; LL2: LaLiga Smartbank; % = percentage of the total distance covered. The percentage of SpVHIR and SP takes into account the sum of both variables.

Table 2 shows the evolution of TD and HIRD in LL1 and LL2 over these four seasons. We can observe a progressive decrease in TD, especially in LL1. Furthermore, during the second half, TD decreased more in LL2 than in LL1, where it remained more stable. HIRD showed a slight increase in LL1 and a slight decrease in LL2. Concretely, during the first half, HIRD increased slightly in both professional soccer leagues over the four seasons. However, during the second half, HIRD increased in LL1, whereas in LL2, there was a decrease.

Table 2. Multivariate Analysis of Variance (MANOVA) to compare TD and HIRD between seasons and professional soccer leagues.

		LL1		*p*	LL2		*p*	F	Sig.	Eta	Power
Variables	**Season**	**M**	**SD**		**M**	**SD**					
TD (m)	15/16	109,368	4376	d	108,176	3973	bd	1.53	0.20	0.001	0.41
	16/17	109,241	4319	d	107,581	4082	ac				
	17/18	109,321	4189	d	108,205	4238	bd				
	18/19	108,603	4495	abc	107,530	4062	ac				
TD 1st Half (m)	15/16	55,009	2387	d	53,974	2244		3.04	0.03	0.002	0.72
	16/17	54,900	2381	d	53,775	2230	c				
	17/18	54,861	2395	d	54,206	2520	bd				
	18/19	54,526	2374	abc	53,707	2500	c				
TD 2nd Half (m)	15/16	54,358	2660		54,201	2609	bd	1.67	0.17	0.001	0.44
	16/17	54,340	2604		53,806	2618	a				
	17/18	54,460	2546	d	53,999	2578					
	18/19	54,077	2827	c	53,822	2434	a				
HIRD 14–21 km·h^{-1} (m)	15/16	22,304	2050	c	21,743	1987	bc	1.68	0.17	.001	0.44
	16/17	22,267	2112	c	21,383	2022	acd				
	17/18	22,709	2322	ab	22,044	2023	abd				
	18/19	22,472	2217		21,688	1910	bc				
HIRD 1st Half (m)	15/16	11,335	1167	c	10,922	1103	c	1.50	0.21	0.001	0.40
	16/17	11,307	1189	c	10,810	1123	c				
	17/18	11,515	1293	ab	11,174	1154	abd				
	18/19	11,427	1230		10,939	1087	c				
HIRD 2nd Half (m)	15/16	10,969	1135	c	10,821	1160	b	2.85	0.04	0.001	0.69
	16/17	10,960	1140	c	10,573	1142	acd				
	17/18	11,194	1259	ab	10,869	1120	b				
	18/19	11,044	119		10,749	1062	b				

Note: TD = total distance and HIRD = high-intensity running distances; LL1: LaLiga Santander; LL2: LaLiga Smartbank. Posthoc comparisons: a = significant differences compared with 2015/2016 season; b = significant differences compared with 2016/2017 season; c = significant differences compared with 2017/2018 season; d = significant differences compared with 2018/2019 season.

The main difference in the evolution of these professional soccer leagues was the distance covered at very high intensity and sprinting, as shown in Table 3. VHIRD and SpD increased across these four seasons, especially in LL1 ($p < 0.001$ and $p < 0.001$, respectively). During the first half, VHIRD increased significantly in both leagues. Likewise, VHIRD also increased during the second half over the four seasons and in LL1 this increase was significant. In addition, VHIRD was higher in LL1 than in LL2 ($p < 0.001$). For SpD, significant increases were obtained in both leagues ($p < 0.001$). Concretely, in both halves, SpD increased significantly over the four seasons, but it was higher in LL1 than in LL2 ($p < 0.01$).

Finally, Table 4 shows the evolution of SpVHIR and SP across the four seasons and the comparison between the two professional soccer leagues. For SpVHIR, significant increases were found in both leagues ($p < 0.001$). Moreover, SpVHIR was higher in LL1 than in LL2 ($p < 0.001$). On the other hand, SP increased over the four seasons and, in LL2, this increase was significant. SP was also higher in LL1 ($p < 0.001$) than in LL2.

Table 3. MANOVA to compare VHIRD and SpD between seasons and professional soccer leagues.

Variables	Season	LL1 M	LL1 SD	p	LL2 M	LL2 SD	p	F	Sig.	Eta	Power
VHIRD 21–24 km·h^{-1} (m)	2015/2016	3020	375		2817	47	c	7.19	0.00	0.004	0.98
	2016/2017	2988	385	d	2782	47	cd				
	2017/2018	3013	384		2907	49	abd				
	2018/2019	3056	396	b	2836	50	bc				
VHIRD 1st Half (m)	2015/2016	1515	233		1392	358	c	9.65	0.00	0.004	0.99
	2016/2017	1485	230	d	1383	362	c				
	2017/2018	1492	222		1448	392	abd				
	2018/2019	1523	235	b	1406	385	c				
VHIRD 2nd Half (m)	2015/2016	1504	225	d	1424	210	c	2.86	0.04	0.005	0.69
	2016/2017	1503	225		1399	217	c				
	2017/2018	1521	244		1459	232	ab				
	2018/2019	1533	241	a	1429	225					
SpD > 24 km·h^{-1} (m)	2015/2016	2873	468	d	2630	28	c	3.99	0.01	0.003	0.84
	2016/2017	2860	502	cd	2636	29	c				
	2017/2018	2930	486	b	2777	31	abd				
	2018/2019	2959	500	ab	2689	30	c				
SpD 1st Half (m)	2015/2016	1432	286		1299	491	c	5.73	0.00	0.002	0.95
	2016/2017	1413	303	d	1293	466	cd				
	2017/2018	1440	284		1382	477	abd				
	2018/2019	1464	289	b	1335	475	bc				
SpD 2nd Half (m)	2015/2016	1441	285	cd	1331	281	c	1.56	0.20	0.003	0.41
	2016/2017	1447	295	cd	1342	270	c				
	2017/2018	1489	316	ab	1394	285	ab				
	2018/2019	1495	317	ab	1354	267					

Note. VHIRD = very high-intensity running distances, SpD = sprinting distance; LL1: LaLiga Santander; LL2: LaLiga Smartbank. Posthoc comparisons: a = significant differences compared with 2015/2016 season; b = significant differences compared with 2016/2017 season; c = significant differences compared with 2017/2018 season; d = significant differences compared with 2018/2019 season.

Table 4. MANOVA to compare number of sprints at different speed levels between seasons and professional soccer leagues.

Variables	Season	LL1 M	LL1 SD	p	LL2 M	LL2 SD	p	F	Sig.	Eta	Power
No. SpVHIR 21–24 km·h^{-1}	2015/2016	263	29	d	247	224	c	6.85	0.00	0.001	0.98
	2016/2017	262	31	d	245	226	c				
	2017/2018	264	30		255	241	abd				
	2018/2019	268	32	ab	249	228	c				
No. SP > 24 km·h^{-1}	2015/2016	160	22		148	291	c	4.93	0.00	0.001	0.91
	2016/2017	160	23		148	300	c				
	2017/2018	161	22		155	303	abd				
	2018/2019	162	23		150	297	c				

Note. SpVHIR = sprints at very high-intensity running and SP = sprints at more than 24 km·h^{-1}; LL1: LaLiga Santander; LL2: LaLiga Smartbank. Posthoc comparisons: a = significant differences compared with 2015/2016 season; b = significant differences compared with 2016/2017 season; c = significant differences compared with 2017/2018 season; d = significant differences compared with 2018/2019 season.

4. Discussion

This study aimed to analyze and compare the evolution of the match running performance between the top two professional Spanish leagues (LL1 and LL2) across four seasons: 2015/2016–2018/2019. The main findings of the study showed that TD, VHIRD, and SpD were higher in LL1 than in LL2. Concerning the comparison between the first and second halves, we found that high-intensity efforts increased in the second half, especially in LL1. The match running performance evolved during these seasons, showing different changes between the two leagues. Specifically, TD decreased significantly in LL1, whereas VHIRD and SpD increased progressively in both leagues. SpVHIR also increased significantly in both leagues, whereas SP increased significantly only in LL2.

Firstly, concerning the match running performance comparison, we expected that all the physical variables analyzed in the present study would be higher in LL1 than in LL2. The results showed that external load was higher in LL1 than in LL2. In particular, the distances covered at high intensity and the number of high-intensity efforts were significantly higher in LL1. These results showed that the league at the higher competitive level had higher physical demands during matches. Our findings agree with previous studies [7,8,20], which compared the top two Spanish and Norwegian professional soccer leagues, finding that the top-tiered leagues were more physically demanding. Several explanations could be used to interpret our results. One reason could be the physical capacity of the players of these teams, such that the LL1 clubs contributed to improving the match running performance of their players [11]. Another reason could be related to the playing formation used by LL1 teams, as certain playing formations imply higher external loads, and LL1 teams may use these more demanding playing formations [13]. Concerning the differences between halves of the matches, it can be observed that the first half of LL1 is more demanding than the second half.

Secondly, with respect to the evolution of match running performance during these four seasons, we expected an increase in total distance, the distances covered at high intensity, and the number of very high-intensity running efforts. On the contrary, the changes showed significant decreases in TD in both professional soccer leagues. A possible cause of this may be the playing style used by teams of LaLiga [21] because, in recent years, there has been a gradual increase in teams that prioritized ball possession, confirming that in ball control plays with few transitions players covered less total running distances, although greater distances were covered at high intensity [22]. In addition, the introduction of Video Assistant Referee (VAR) has led to a decrease in effective game time, which has contributed to the decrease in TD [23,24].

In agreement with our hypothesis, where we expected an increase in the distances covered at high intensity and the number of very high-intensity running efforts, the results showed that significant increases in distances covered and efforts performed at high intensity were obtained during the four seasons. In this sense, the significant increases in HIRD and VHIRD are indicators of the evolution and changes occurring in soccer, where players are now trained to perform more high-intensity actions. This has probably been caused by the current training perspective, which increases the presence of high-intensity stimuli according to the competition demands and it decreases the rate of injuries, as achieving optimal player performance while minimizing the risk of injury is the main objective [12,25,26]. These types of efforts are keys to achieving high performances in soccer [27,28] and they are important in decisive situations in professional football. They are the most dominant actions when scoring goals [29]. In this sense, in the 2018/2019 season, VAR was added, which promoted longer recovery times, where high-intensity efforts predominate [24]. Another possible reason could be the tactical evolution of football. Today's models and playstyles tend to advance defensive pressure lines, resulting in larger spaces and more actions performed at high intensity to take advantage of these spaces.

When examining the match running performance separated by halves, TD decreased in LL1 across the second half, contrary to the results shown in LL2, where TD increased. In addition, in LL1, the decrease in TD in the second half was less than in the first halves of the matches. These results could be explained by the high equality between the teams in LL1 and LL2, where the matches are usually decided in the second half. The decrease in TD in LL1 is further supported by the fact that LL1 teams performed a large number of high-intensity efforts compared to LL2 during the first half, which could cause a decrease in TD during the second half [30].

Finally, concerning the comparison of the evolution between the two professional soccer leagues, we found that in LL1 there is a trend toward a progressive increase in VHIRD and SpD, especially in the second half, whereas in LL2, the trend is not clear. On the other hand, VHIRD and SpD increased during the second halves in both professional soccer leagues, contrary to the results reported in previous studies [31]. A possible reason for these results is the higher TD and high-intensity efforts performed by the substitutes during the second halves [32]. Although we stated that the equality between teams was higher in LL2, another possible explanation is the increase in the effect of match status during the second halves. In both leagues, time pressure is higher in the second half. For example, it is not the same to be losing 1–0 at half-time as at 80 min. The effects of time pressure and match status probably increase high-intensity actions [17,33].

4.1. Limitations and Future Perspectives

Taking into account the characteristics of the present study and the novelty of this topic, we considered some limitations with a view to future research. In the 2018/2019 season, VAR was added, which has promoted longer recovery times. In future investigations, we should analyze the differences in the external load before and after the implementation of VAR. In addition, we did not analyze other physical variables such as accelerations and decelerations, which are part of the external load of soccer matches [34]. Thus, these types of physical variables must be analyzed to obtain more information about the match running performance of the competition. Finally, another possible study would be about the different evolution of each team across these seasons (e.g., according to classification or playing style).

4.2. Practical Applications

Based on the results obtained, some practical applications can be extracted. Firstly, the paradigm of match running performance has changed across the seasons. Thus, it is also necessary for physical training in soccer to evolve in keeping with current match physical demands to optimize the training process. In this sense, knowledge about the match running performance allows coaches to design soccer training with the correct stimuli to optimize players' performances. In this regard, this type of stimuli constitutes a methodology for injury prevention and could reduce the injury rate of soccer players. In addition, the evolution of high-intensity efforts is very important in designing specific training tasks that reproduce competition demands. Finally, it was found that the Spanish LL1 is more demanding than LL2, and this information is very important to practitioners who are training in each professional soccer league, since it allows them to discern the different external loads in both the first and second divisions.

5. Conclusions

The present research describes and compares the differences in match running performances between the top two Spanish professional soccer leagues across four seasons. Firstly, the results showed higher external loads in LL1 than in LL2. Concretely, the distances covered at high intensity are higher in LL1 than in LL2. Secondly, the decrease in total distance and the increase in distance covered and efforts performed at high intensity are the main changes in the external load of soccer in both leagues. Finally, VHIRD and SpD increased during the second halves in both professional soccer leagues. In summary, we must take into account the evolution of the match running performance in training and the teams' playing styles to ensure that players are trained to perform more high-intensity efforts during the matches.

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Article

Short-Term Core Strengthening Program Improves Functional Movement Score in Untrained College Students

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Abstract: Functional movement is an important part of developing athletes' but also untrained individuals' performance. Its monitoring also proved useful in identifying functional limitations and asymmetries, and also in determining the intervention effects. The quasi-experimental pre-test post-test study investigated the effects of core stability training program on the Functional Movement Screen (FMS) score in untrained students after six weeks. The intervention (INT) and control (CG) groups included 73 and 65 male students, respectively. Functional movement patterns were evaluated using the FMS including seven components scores representing seven basic functional patterns. Both groups significantly improved almost all FMS components scores, but the INT increased the mean performance of the hurdle step (partial $\eta^2 \times 100 = 4\%$, $p = 0.02$), in-line lunge (partial $\eta^2 \times 100 = 3\%$, $p = 0.05$), rotatory stability (partial $\eta^2 \times 100 = 4\%$, $p = 0.02$) and total FMS (partial $\eta^2 \times 100 = 3\%$, $p = 0.04$) significantly more than the CG. This justifies that core strengthening can improve FMS in untrained individuals even with the short duration programs.

Keywords: functional movement screen; injury prevention; core strength; stability training; students

1. Introduction

There is a clear evidence that a sedentary lifestyle, low physical fitness and levels of physical activity represent risk factors for musculoskeletal injuries [1]. Health benefits of physical activities mainly depend on engagement at recommended levels [2]. Accordingly, there are great number of activity-induced injuries among young adults [3,4].

Despite possible limitations in determining the risk factors for injuries, some screening measures have demonstrated promise in various populations [5]. Traditional tests for evaluation of strength or range of motion cannot detect fundamental changes in motor control [6]. However, the Functional Movement Screen (FMS) aims to identify imbalances in mobility and stability during seven fundamental movement patterns [7]. Although the FMS is primarily designed to screen active adults for future injury, determining a baseline of movement competence could allow comparisons after treatment or rehabilitation [5].

Previous studies have examined the effects of various training interventions on the FMS in different groups of participants where short-term functional movement training was not enough to improve the FMS performance in adolescents [8]. Additionally, individually based specific mobility and neuromuscular control training did not elicit positive changes in the FMS scores in firefighters after 12 weeks [9]. However, the improvements in the FMS scores were shown after a six-weeks training program in children [10], a yoga program [11], and a six-week functional training program [12]. At higher competitive levels in professional American football players, the improvements in the FMS scores were also collected after a seven-week corrective exercise program [6].

Core stability has been considered as a decisive factor in foundation for movement of the extremities, for supporting loads, and for the protection of the spinal cord and nerve roots [13]. It has also been speculated that inadequate static core stability may compromise the dynamic stability of the extremities, which could lead to increased stress on the soft tissue [14,15], and the appearance of repetitive strain injuries [16].

Improved postural stability and increased core endurance has been shown in university students following an eight-week thoracic spine stabilization exercise program [17]. It has been stated that core training emphasizes strength and conditioning of the local and global muscles that work together to stabilize the spine [16]. Accordingly, a significant improvement was found in the back-endurance tests after a 10-week stability ball core training program [18]. Similarly, positive effects from a spinal stability exercise protocol using Swiss balls was winkled out in sedentary people [19].

The benefits of FMS in injury prediction have been documented [5]. However, injuries are not just characteristic of athletes. Therefore, identifying weaknesses in healthy adults and then trying to improve it could play a significant role for lifelong physical activity and movement [20]. Moreover, it was demonstrated recently that FMS performance has a strong association with key health markers [21]. Therefore, the aim of the present study was to investigate the effects of core stability training program on the FMS scores in young untrained adults. It was hypothesized that core strengthening training would improve the FMS of students.

2. Materials and Methods

A quasi-experimental, pre-test/post-test control group design was used in this study. University students from Novi Sad, Serbia volunteered to participate and were placed into one of two groups: intervention and control group. The intervention consisted of the implementation of a core exercise program three times per week. The FMS scores were examined before and after a six-week training intervention. Participants were tested for changes in basic patterns of movement that were measured by Cook's FMS [7]. All participants were asked to continue their standard obligations at the faculty and to refrain from making any changes to their physical activity habits for the six-week period.

2.1. Participants

A total of 138 males were divided into two groups, intervention (INT) (mean ± SD: n = 73, age 20 ± 0.5 years, height 180 ± 5.20 cm, body mass 76 ± 9.4 kg), and control (CG) (n = 65, age 20 ± 0.7 years, height 181 ± 8.10 cm, body mass 78.6 ± 4.7 kg). We included healthy subjects who were not engaged in any systematic training in the last two years, but they had systematically practiced a sport for at least three years. Participants were free of any musculoskeletal injury or illness. University ethics board approved the study (ref. no. 20/2018), and all the participants gave their informed consent before any data collection. Testing procedures were performed following the ethical standards laid down in the Declaration of Helsinki. Figure 1 presents flow diagram for study participants.

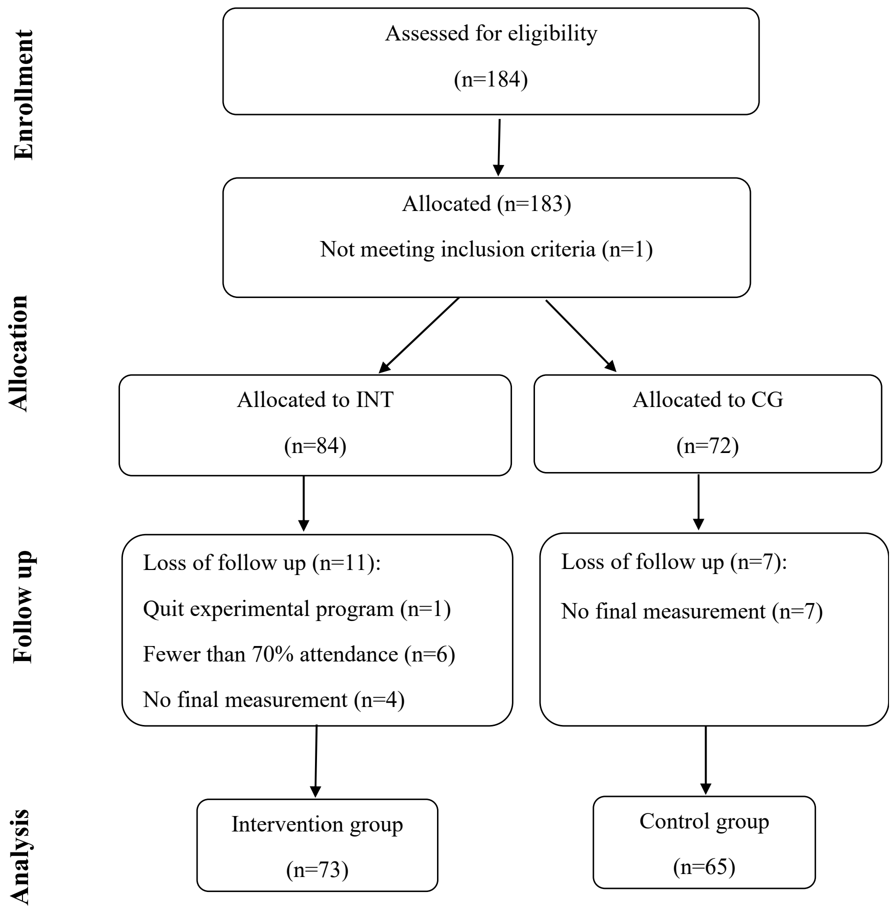

Figure 1. Flow diagram of participant enrolment, group allocation and final analysis.

2.2. Testing Procedures

Functional movement patterns were evaluated using the FMS [22]. The FMS identifies limits in seven basic functional patterns: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raises, trunk stability push-up and rotary stability. Reliability of FMS was confirmed in previous studies [23,24].

Testing was performed using a model of score from 0–3 [22]. The zero score was given to the respondents who felt pain during the tests. In cases when they felt pain, regardless if the task had been executed or not, they did not pass the test. Score one was given to the respondents who did not do the test by following given instructions. Score two indicated that the respondent could carry out the given movement, but there was a lower degree of limitation or compensation for the movement. Score three was given to the respondents who performed the movement in the described way, without any compensation. The overall score of the screening represented the sum of individual assessments of each test, totaling 21. Five of seven tests were bilaterally tested, meaning both for the left and right body side individually. In the case of bilateral tests, when the respondent received a lower score for one body side, that score was taken as an overall score for that specific test.

Initial testing was conducted in October and the final testing was conducted in December. All subjects were tested during the semester, with subject testing occurring at the start of the day, just before the lessons. A familiarization day supervised by a certified strength and conditioning specialist was implemented a week prior to conducting the baseline tests to ensure that the participants understood the testing procedures and to demonstrate reliability in testing measures.

The FMS was recorded using two video cameras (Panasonic, NV-GS400, Panasonic Corp., Osaka, Japan) placed in the frontal and sagittal planes and scored later. Two raters, both of whom had two years of experience using the FMS in clinical practice, scored participant performance on the movement tasks. A subgroup analysis showed good interrater reliability between the raters for composite scoring (intraclass correlation coefficient, 0.897).

2.3. Program

Participants were required to take part in a six-week program which included supervised sessions three times per week with sessions lasting 30 min each. Core strengthening program involved an isometric exercise program, sustained contraction against an immovable load or resistance with no or minimal change in length of the involved muscle group [10] and was implemented in the first and second week. The exercises were focused on the weakest and asymmetrical scores, with primary focus on mobility patterns and secondary focus onto stability patterns. Most of the exercises included activities where the upper extremity and the lower extremity were active at the same time while holding a neutral abdominal posture. Exercises of anti-flexion, anti-extension and anti-rotation were used to stabilize the spine. The treatment included exercises for increasing the mobility and strength of the neck, shoulders, pelvis and hips. In the first two weeks, participants did various durability exercises (all position planks, plank walk, plank jacks, forearm to pushup plank, etc.). The third and fourth week included similar exercises reinforced with additional movements and rotations (alternating arm and leg plank hold, superman plank hold, front plank plate switches, etc.). During the fifth and sixth week, the exercises were performed on unstable surfaces (Table 1). The McGill curl up [25], performed by flexing torso in the supine position with elbows on the floor, was performed during every treatment for all six weeks.

Table 1. Core strengthening program.

Week	Exercises	Sets, Reps, Time
1–2	All position planks (pushup, forearm, side, reverse) Plank walk Plank jacks Forearm to pushup plank Feet elevated side plank 3-point plank Bird dog	Hold (average) 50 s
3–4	Alternating arm plank hold Alternating leg plank hold Superman plank hold Side plank star hold Alligator plank walk Plank barrel roll Bird dog	20–30 reps
5–6	Plank down dog to toe tap Plank with single arm fly, feet on ball Feet elevated side plank Side plank hip adduction circle Front plank plate switches Side plank raises on ball Swiss-ball stir the pot Bird dog	20–30 reps
1–6	McGill curl up	20 reps

Both groups were not involved in any systematic exercise training except a regular program at the Faculty of Sports. The program represents a group of activities carried out at the Faculty of Sports during the second year. The sports activities represented in the regular classes were football, handball and rhythmic gymnastics. Respondents learned only techniques in the listed sports.

2.4. Statistical Analysis

Data were analyzed using SPSS (version 20.0, IBM Corp., Armonk, NY, USA). Mean and standard deviations for the pre- and post-test FMS scores were calculated for each group. Log-transformed data were analyzed if a Kolmogorov-Smirnov test rejected normality but original data were reported for the sake of clarity. The Levene's and Box's tests failed to reject homogeneity of variances and covariance matrices, respectively.

A 2 (INT vs. CG) × 2 (baseline and after six weeks) mixed-model ANOVA evaluated the intervention effects on the FMS test outcomes, and a group-by-time interaction effect (a 2 × 2 interaction effects) was the hypothesis of primary interest. We analyzed the simple main effects of time to show the mean changes in the FMS scores after six weeks for each group, and the six-week-induced changes are reported as percentage of change (% Δ). Partial eta squared (partial η^2) is reported as a measure of an effect size for the interaction effects, and defined as small (0.01), medium (0.06), and large (0.14) [26]. Bonferroni adjusted p-values for multiple comparisons, and the level of significance was set at $p \leq 0.05$.

3. Results

After six weeks, the INT and CG mean performance significantly improved in six and five FMS component tests, respectively. Both groups also enhanced total FMS score after six weeks. However, the INT increased the mean performance of the hurdle step, in-line lunge, rotatory stability, and total FMS to a significantly greater extent as compared to the CG. For detailed results of the 2 × 2 mixed-design ANOVA model, see Table 2.

Table 2. The Functional Movement Screen (FMS) scores at pre- and post-test for the intervention and control group.

Outcome	Pre-Test	Post-Test	% Δ	A Group-by-Time Interaction Effect			
Group	Mean ± SD	Mean ± SD		$F_{(1, 136)}$	p	Partial η^2	1-β
Deep Squat (score)							
INT	2.32 ± 0.57	2.52 ± 0.50	+8.6 **	0.51	0.48	0.00	0.11
CG	2.32 ± 0.64	2.51 ± 0.59	+8.2 *				
Hurdle Step (score)							
INT	2.05 ± 0.28	2.32 ± 0.50	+13.2 **	5.48	0.02	0.04	0.64
CG	2.08 ± 0.32	2.15 ± 0.40	+3.4				
In-line Lunge (score)							
INT	2.18 ± 0.54	2.56 ± 0.53	+17.4 **	3.77	0.05	0.03	0.49
CG	2.22 ± 0.57	2.40 ± 0.58	+8.1 *				
Shoulder Mobility (score)							
INT	2.84 ± 0.37	2.89 ± 0.31	+1.8	2.27	0.14	0.02	0.32
CG	2.48 ± 0.64	2.63 ± 0.51	+5.7 **				
Active Straight Leg Raise (score)							
INT	2.49 ± 0.60	2.68 ± 0.49	+7.6 *	1.29	0.23	0.01	0.20
CG	2.51 ± 0.64	2.80 ± 0.40	+10.4 **				
Trunk Stability Push Up (score)							
INT	2.63 ± 0.49	2.89 ± 0.32	+9.9 **	3.25	0.07	0.02	0.43
CG	2.71 ± 0.49	2.83 ± 0.38	+4.4 *				
Rotatory Stability (score)							
INT	1.96 ± 0.20	2.15±0.36	+9.7 **	6.13	0.02	0.04	0.69
CG	1.98 ± 0.33	2.03 ± 0.17	+2.5				
Total FMS (score)							
INT	16.45 ± 1.27	18.01 ± 1.57	+9.5 **	4.18	0.04	0.03	0.53
CG	16.31 ± 1.51	17.43 ± 1.47	+6.9 **				

Values are Mean ± SD; Abbreviations: INT intervention group; CG control group; % Δ percentage of change from pre- to post-test; F(dffactor, dferror) = F-statistic; p probability value; partial η^2 partial eta squared; ** significant changes after six weeks at $p < 0.001$; * significant changes after six weeks at $p \leq 0.05$.

4. Discussion

There is currently very little evidence of the ability to change scores on the FMS following a core strength training program. Accordingly, this study aimed to examine the effects of core strength training on FMS scores in university students. The results of this study showed that both groups improved significantly in the overall score on FMS. Previous research indicates that the average FMS scores are highest within the 20–39 age group (mean: 15.08), and lowest for those who were age 65 years (12.68) [20]. At pre-test, participants in our study had higher values for the total FMS score (mean ± SD: intervention group 16.49 ± 1.28, control group 16.29 ± 1.52) compared to those norms. Therefore, it can be speculated that improvements would be even better with lower initial values for FMS.

Individually analyzing variables, the positive effects of the intervention are visible in the tests: hurdle step (η_p^2 = 0.04), in-line lunge (η_p^2 = 0.03), rotatory stability (η_p^2 = 0.04), total FMS (η_p^2 = 0.03). Core stability is of great importance in all three individual tests. In the hurdle step and in-line lunge tests, the support is on the standing leg while the movements are performed at the hip, knee and ankle. On that occasion, the fixators play an important role in order to stay upright without losing balance. It is similar when performing the rotator stability test. The FMS is used to evaluate performance with fundamental movements and to find deficits in the body during dynamic movements [7,22]. Accordingly, the core becomes activated before gross body movements as part of the postural control system [16,27]. The current study used a variety of core-stabilization training methods that included muscle endurance exercises, exercise using unstable surfaces, and performing some exercises in a weightbearing position, which may be the reason why scores in the FMS improved.

In summary, the main idea was to develop core stability throughout core muscle isometric strengthening, because ideal quality of core stabilization is a foundation for any proper movement, and then progress to dynamic stability exercises by incorporating limb movements and changing positions [16]. In general, the core stability affects the effective use of the strength and endurance required [28].

This study supports the use of exercise interventions in university students for the improvement in the FMS score. There is sufficient evidence for the effectiveness of core stability training in untrained individuals. Functional movement screen test results showed greater change for the exercise group compared with the control group. This result justifies the hypothesis that core strengthening can improve FMS in college students even with short duration programs. Similar results were obtained by applying a periodized functional strength training program to the total FMS score in college students of physical education [29].

We had some limitations, of which the most important could be listed as the nonexistence of randomization. The study did not include effects on other motor skills. High baseline values also significantly contributed to a smaller effect size in our study.

5. Conclusions

Relative to research findings, it is safe to infer that FMS could be used for the assessment of changes in movement pattern induced by six-week core-stabilization-training. Isometric core strengthening with an exercise program involving multiplane movements has plausible benefits to functional movement patterns. Practitioners working in this population should consider the specific changes in the intervention group in this study. It would be interesting for future studies to consider the long-term effects of core strengthening program, as well as the application of programs for people with existing pain syndromes.

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Effect of a Simulated Match on Lower Limb Neuromuscular Performance in Youth Footballers—A Two Year Longitudinal Study

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Abstract: The aim of this study was to explore the effects of simulated soccer match play on neuromuscular performance in adolescent players longitudinally over a two-year period. Eleven players completed all measurements in both years of the study (1st year: age 16.0 ± 0.4 y; stature 178.8 ± 6.4 cm; mass 67.5 ± 7.8 kg; maturity-offset 2.24 ± 0.71 y). There was a significant reduction in hamstring strength after simulated match by the soccer-specific aerobic field test (SAFT^{90}), with four out of eight parameters compromised in U16s (4.7–7.8% decrease) and six in the U17s (3.1–15.4%). In the U17s all of the concentric quadriceps strength parameters were decreased (3.7–8.6%) as well as the vastus lateralis and semitendinosus firing frequency (26.9–35.4%). In both ages leg stiffness decreased (9.2–10.2%) and reactive strength increased pre to post simulated match (U16 8.0%; U17 2.5%). A comparison of changes between age groups did not show any differences. This study demonstrates a decrease in neuromuscular performance post simulated match play in both ages but observed changes were not age dependent.

Keywords: simulated match-play; leg stiffness; reactive strength; EMG; isokinetic

1. Introduction

During soccer match-play a significant amount of sudden accelerations and decelerations, jumping and landing tasks, and rapid unanticipated changes of directions are performed [1–3]. These high-intensity movements may be associated with increased predisposition to injury risk in youth players [4], especially when fatigue is likely present at the end of both the first and the second halves of match-play [5]. The most common injuries in both adult and youth soccer are reported in lower limbs, specifically the hamstrings, knee joint, and ankle [6–10]. A recent systematic review on youth players concluded that the injury incidence in young soccer players has increased, with values exceeding those of professional soccer players, mainly in muscle injuries [6,9]. It has been well documented that local fatigue is one of the main etiological factors which contributes to lower limb noncontact injuries in soccer [11]. Local fatigue, both as a result of acute load or its long-term application, increases the risk of injury, alters muscular activation and coactivation, lower limb kinematics, reactive strength, muscle stiffness and other factors associated with injuries and soccer performance [12–16].

The muscle antagonist force production capacity is considered an essential factor for joint stability during intensive movements [17–20], where ipsilateral knee flexors (hamstrings, H) and extensors (quadriceps, Q) strength imbalance and fatigue are included in ACL injuries [18,19,21–23] and hamstring strain injuries [18,24–26]. Although there is a lack of evidence on the predictive value of H/Q ratios for ACL injuries, it was demonstrated that soccer players with isokinetic strength imbalance were 4.66 more likely to sustain hamstring strain injury [27]. The cause of hamstrings injuries is often related to altered neuromuscular coordination running patterns induced by fatigue [28]. Adult studies have reported that submaximal muscular fatigue increases anterior tibial translation along with hamstring latency, which influence knee joint stability by ligament and tendon interactions [29,30]. Available studies of soccer-specific fatigue on neuromuscular function predominantly point to the reduction in muscle strength after physical load, where soccer sprints and deceleration ability correlates with the H and Q concentric and eccentric strength at different speeds [31,32]. In some studies, reduction of the H strength when fatigue is present [11,33] and decrease in the H/Q have been observed [11,25,34–36]. However, conflicting data are available as other studies on youth soccer players have shown no significant decrease in the H/Q, but leg stiffness and RSI were compromised [37–39]. Activity of muscles which help to stabilize the knee joint may be assessed by means of surface electromyography (EMG). Research has identified that well-timed activation of the H muscles can protect the ACL from mechanical strain by stabilising the tibia and reducing anterior tibial translation and that the speed of this activation is vital for the subsequent joint stability [40]. It is also accepted that analysis of EMG signal by mean frequency is a feasible method of assessing changes in muscle activation due to fatigue [41,42]. Only two studies appear to have explored changes in neuromuscular function, using EMG, in young soccer players following simulated match-play [37,38] and their findings point to fatigue induced changes in activation in knee flexors and extensors of players. In one study [43], the effects of competitive match-play on the neuromuscular function was explored in adolescent soccer players and no effects of match play on muscle activation were evident both for knee flexors and extensors.

Leg stiffness, incorporating muscle, tendon, and joint stiffness, is also based on neuromuscular feed-forward mechanism, acting as a protective mechanisms against injury to counteract the external forces placed on the tibiofemoral joint, particularly during dynamic movements to improve joint stability [19,44]. Greater levels of leg stiffness leads to a reduction in the probability of excessive load of the knee passive structures such as the ACL [19]. There are only a few studies examining the influence of simulated match-play on leg stiffness in adolescent soccer players showing both a decrease [38,45] and no change [46]. Reactive strength, assessed by means of the reactive strength index (RSI), has been suggested as a reliable measure of stretch-shortening cycle (SSC) capability in youth athletes [47]. RSI has been developed as a tool to monitor stress on the muscle-tendon complex during plyometric exercise and is described as the ability of transition from eccentric to concentric muscle actions [48,49]. Low values of RSI are considered a potential risk factor in ACL injury [39,50]. Likewise in the case of stiffness, there is minimal research on changes of RSI after soccer specific fatigue in youth male soccer players; however, most studies have indicated negative fatigue related effects on reactive strength [38,45,46].

It is well recognized that the risk of injury affects both male and female athletes of all ages, however, this risk increases during growth and maturation [6,51,52] and is linked to periods of rapid growth (Peak height velocity) [53] typically in 13–15 year-olds [54]. Other predisposed ages are 16–18 and 9–12 year-olds [54,55]. In footballers of this age group, 70% of all leg injuries are in the lower extremities [54]. In a recent study De Ste Croix et al. [56] reported a reduction in peak torque (PT) after a simulated match by the soccer-specific aerobic field test ($SAFT^{90}$) in all female youth players irrespective of age, but this resulted in only a small effect of fatigue on neuromuscular function determined by changes in muscle activation and electromechanical delay. However, in a similarly focused study on female youth soccer players (13–15 y), the change of the H/Q_{FUNC} after the $SAFT^{90}$ was observed with age related differences [57]. Further, significantly longer electromechanical delay was observed in children compared with adults [58] and developmental changes were observed in a study on female youth players [56]. This suggests that children and adolescents are an at risk group in terms of injury but also highlights the lack of data on male youth players [59].

There is lack of research regarding how acute post exercise fatigue influences physiological mechanisms in youth populations, including adolescent soccer players, and no studies appear to have examined the acute effects of simulated soccer match play during growth using longitudinal data. As changes in neuromuscular function, which has been associated with injury risk, are modifiable, it is important to understand the age-related effects of fatigue on neuromuscular mechanisms. This knowledge enables coaches to better prepare players by applying intervention training programs to improve fatigue resistance and at the same time positively influence performance capacity of players. Therefore, the aim of this study was to explore the effects of simulated soccer match play on the neuromuscular performance in adolescent players and examine if changes differ in male adolescent soccer players within a one year time period.

2. Materials and Methods

2.1. Participants

A group of eleven elite youth footballers, playing the highest Czech league in their category, were measured in the 1st and 2nd year of the study (19 recruited, 8 dropped, 11 remained). The 11 players were under 16 years of age (U16) during the 1st year and under 17 years (U17) in the second year (Table 1). The training age of the players was 8–9 y. The players played one competitive match and trained five times per week (7–8 h) during both seasons. Training consisted of typical age-related training for youth athletes: i.e., physical fitness training (mainly strength and power, speed and agility with and without ball, repeated sprint ability with and without ball), skill-oriented training (technical-tactical training, game-like training), and recovery training.

Table 1. Physical characteristics of participants (n = 11).

Variable	Age (y)	PHV Offset (y)	Stature (cm)	Body Mass (kg)
U16 year 1	16.0 ± 0.4	+2.24 ± 0.71	178.8 ± 6.4	67.5 ± 7.8
U17 year 2	17.0 ± 0.4	+3.31 ± 0.57	180.9 ± 5.7	71.4 ± 6.6

PHV—age from peak height velocity, U16 = first year of testing when the group was under 16 years of calendar age, U17 = second year of testing when the group was under 17 years of calendar age.

Only healthy players who had not sustained a serious musculoskeletal lower-extremity injury (in this study defined as an injury which caused an interruption of the regular training process for more than two weeks) in the previous six months were included in the study. Goalkeepers were not included in the study. The kicking leg was determined by kicking preference and subsequently the other limb was determined as the stance leg. Players and their parents were fully informed about the aim of the study and the testing procedures. The study protocol and written informed consent was approved by the Palacky University institution's ethical committee is in accordance with Declaration of Helsinki 2013. Written informed consent to the testing procedures and the use of the data for further research was obtained from the players' parents and written informed assent from children. The day before testing, the players were not exposed to any high intensity exercises. All players were on time maturing after the peak height velocity (PHV). Biological maturity was calculated as offset from PHV using the Mirwald et al. [60] equation.

2.2. Procedures

The players were longitudinally tested using a repeated-measures design towards the end of the competitive season (Figure 1A). % start a new page

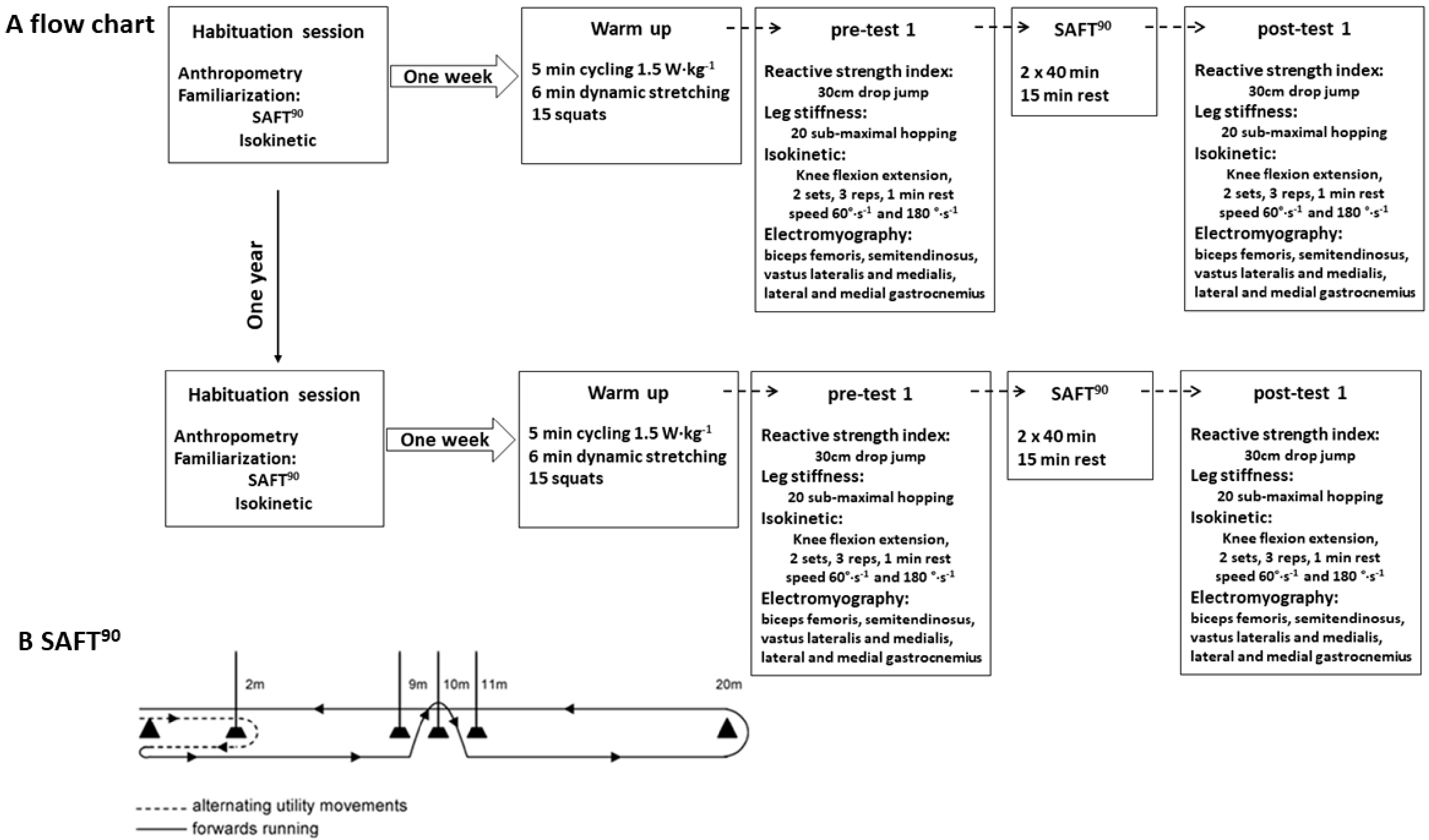

Figure 1. (**A**) Flow chart of performed procedures. (**B**) Diagram of the SAFT^{90} (adopted from Small, McNaughton, Greig, & Lovell, 2010). SAFT^{90} = soccer-specific protocol to induce fatigue.

A habituation session took place a week before testing, where players were familiarised to the soccer specific protocol (SAFT^{90}, Figure 1B), isokinetic dynamometry and anthropometric measures, including leg length, tibia length, and sitting height for the purpose of PHV offset calculation, were taken. During the first and second session, the players completed a warm-up consisting of 5 min cycling at 1.5 W·kg^{-1}, 6 min of dynamic stretching of the lower limbs, and fifteen squats. The main testing consisted of measuring the leg stiffness, RSI, and isokinetic dynamometry with integrated EMG. These tests were consistently undertaken in the above-mentioned order pre and post the SAFT^{90}. Both sessions were conducted at the university research laboratory by experienced researchers and research assistants.

2.3. Isokinetic Dynamometry

The isokinetic strength of the kicking leg and stance leg was measured using an dynamometer (IsoMed 2000; D. & R. Ferstl GmbH, Hemau, Germany) with high reproducibility in sporting populations [61] for concentric and eccentric actions and with gravitational correction for the mass of the measured lower limb. Participants were placed in a seated position with a hip flexion angle of 100° with strapping placed over the pelvis, shoulders, and thigh of the tested leg. The lever arm of the dynamometer was aligned with the lateral epicondyle of the knee and with the distal part fixed to the shin ≈ 2 cm above the medial malleolus.

The testing protocol included concentric and eccentric single actions of knee flexors and in concentric single actions of knee extensors at 60°·s^{-1} and 180°·s^{-1} in the 10–90° range of knee flexion (0° = full voluntary extension). The protocol included two sets of 3 maximum repetitions at each velocity with 1 min rest. Visual feedback was provided by participants observing the strength curve, accompanied by strong verbal encouragement. For the assessment of changes and differences in isokinetic strength, peak torque normalized for body weight (relative PT; Nm·kg^{-1}) was used. To calculate the functional hamstring: quadriceps ratio (hamstring eccentric to the quadriceps concentric; H/Q_{FUNC}) and conventional hamstring: quadriceps ratio (hamstring concentric to the quadriceps concentric; H/Q_{CONV}) absolute peak torque (PT; Nm) was used. The reliability of H/Q ratios has been reported as being medium to high (H/Q_{CONV}: ICC = 0.73; H/Q_{FUNC}: ICC = 0.62) [62].

2.4. EMG

Surface EMG data were obtained using an 8-channel polyelectromyography (Noraxon-Myosystem 1400A, Scottsdale, AZ, USA) during the isokinetic task described above. The within-session reliability of EMG during isokinetic knee actions has been reported as high (ICC = 0.86) with the between-session reliability lower (ICC = 0.65) [63]. We used Kendall-ARBO silver chlorid electrodes with a solid hydrogel with a diameter of 24 mm. The signal was captured eight manifolds with a 1000 Hz frequency. The resistance of the poly-EMG device was >10 MΩ (24 mm). Prior to application of the electrodes, the skin in the area was cleaned with water and dried. Surface electrodes were placed on the muscle belly in parallel with the process of muscle fibres with 1 cm distance between electrodes, with a ground electrode located on the tibial tuberosity. For the second measurement if the electrode was dislodged due to sweating during the fatigue protocol then a new electrode was used to reduce impedance and improve the electrode contact with the skin [64]. Electrodes were placed on the kicking leg on the biceps femoris (BF), semitendinosus (ST), vastus lateralis (VL), vastus medialis (VM), lateral gastrocnemius (LG), and medial gastrocnemius (MG). EMG data were analysed in the MyoResearch XP Master Version 1.03.05 Noraxon software (Noraxon-Myoresearch, Scottsdale, AZ, USA), where the raw EMG signal was full wave rectified and smoothed. Data for each movement velocity and muscle were split into the resting phase and muscle action phase and the mean frequency value (Hz) was determined for each phase. For normalization of the signal, retained ratio between the value of the mean frequency in the resting phase and the value of the phase of muscle activity was used.

2.5. Measurements of Reactive Strength Index

The RSI was measured using a 30 cm drop jump test with hands positioned on the hips using an Opto-jump Next system (Microgate, Bolzano, Italy) with 0.001 s accuracy. Participants were instructed to perform a maximal jump utilizing as short a take-off phase as possible [65]. The greatest value from three trials was used for further analysis, and RSI was calculated as the ratio between jump height and contact time [47,52]. This method has been shown to be valid and reliable in youth athletes [47].

2.6. Leg Stiffness

Leg stiffness was calculated from contact time data obtained during a 20 submaximal bilateral hopping test with a coefficient of variation in youth soccer players of 8.2% [66]. Participants performed three sets of consecutive hops on force platform PS-2142 (Pasco, Roseville, CA, USA) at a hopping frequency of 2.5 Hz [47] determined by a quartz Wittner metronome (WITTNER, Isny, Germany).

Participants were instructed to jump and land on the same spot, to keep hands on the hips, land with legs fully extended, and to look forward at a fixed posture. The first 4 hops were discounted and the 10 hops closest to the hopping frequency were used in subsequent analysis. Absolute leg stiffness ($kN \cdot m^{-1}$) was calculated by using the Dalleau et al. [65] equation and divided by body mass to determine relative leg stiffness [47,66]. This method has been shown to be valid and reliable in youth athletes [47,66].

2.7. Fatigue Protocol

The $SAFT^{90}$ which incorporates frequent acceleration and deceleration typical of match-play was used [35]. The $SAFT^{90}$ was created according to data from English Championship matches (Prozone®) and was validated to replicate the fatigue response of soccer match play [35]. The $SAFT^{90}$ duration was 2×40 min with 15 min rest and intensity and type of activity during the test were maintained by prerecorded 15-min verbal signals from MP3 player.

2.8. Statistical Analysis

Descriptive statistic and t test were performed using Statistica, version 12 (StatSoft, Inc., Tulsa, OK, USA) and changes in pre to post match data were interpreted using a magnitude-based decision method (MBD) [67], according to current recommendation by Greenland [68]. Analyses were performed using the spreadsheet available online ([67], https://www.sportsci.org/2019/) for the analysis of post-only control trials with adjustment for a predictor [69], which also permits analysis of data consisting of repeated measurements of subjects in one group [70].

The data and magnitudes of the effects were log-transformed and standard deviations of mean change scores were back-transformed to percent units as 0.2, 0.6, 1.2, and 2.0 for small, moderate, large, and very large effect respectively. Uncertainty was expressed as 90% confidence limits and as probabilities that value of the effect was beneficial, harmful, or trivial. These probabilities were presented as clinical inferences [69]. Unclear effects were identified as odds ratio of benefit to harm <66. Clinically clear effects were 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely. Wilcoxon pair-tests was used to examine whether changes in the variables differed between age groups. The effect sizes were determined by the r coefficient and evaluated as small ($r = 0.1$), medium ($r = 0.3$), and large ($r = 0.5$) [71].

3. Results

The pre- and post- $SAFT^{90}$ values for all measured variables for groups over the two testing occasions and the results of magnitude-based decision statistics are reported in Supplementary file 1 (Tables S1–S6) and Supplementary file 2 (dataset). For technical reasons, EMG data was not obtained from two players in the second year of measurement and isokinetic data from one player in the first year of measurement.

The SAFT^{90} protocol decreased H strength in both groups U16 and U17. Four out of eight H strength parameters were decreased in U16 and six out of eight in U17 age groups. All of the concentric Q strength parameters were decreased in U17 and none in U16 (while one Q strength value was increased in the U16 group) (Figures 2 and 3).

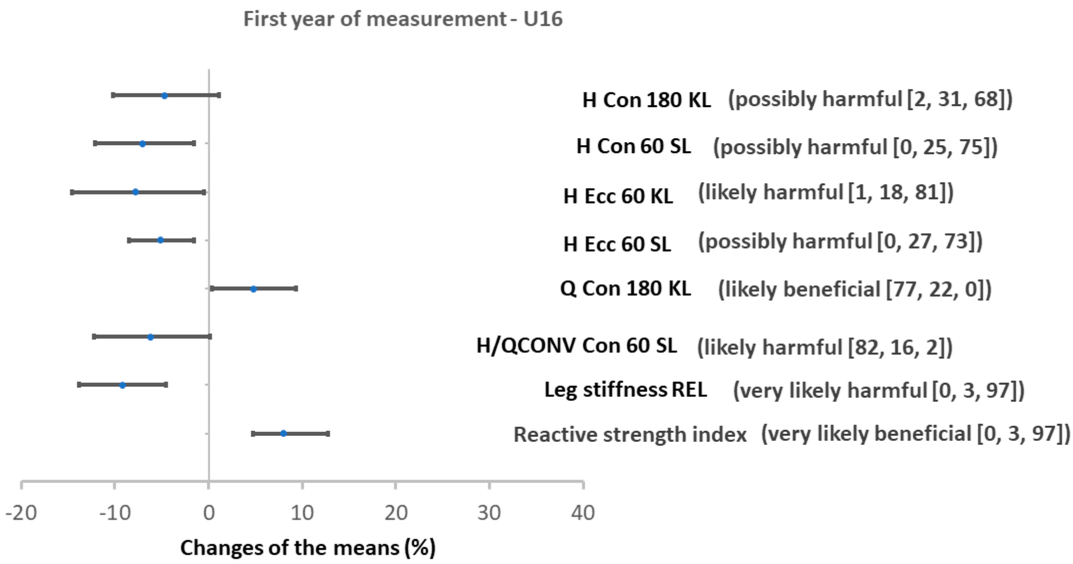

Figure 2. Percentage changes in strength measurement after SAFT^{90} protocol in U16. Values are changes in means with confidence intervals (as %), bracket = (effect [odds ratios]), H = hamstrings, Q = quadriceps, Strength is described by the peak torque, H/Q_{CONV} = conventional ratio of H and Q, SL = stance nondominant lower limb, KL = kicking dominant lower limb.

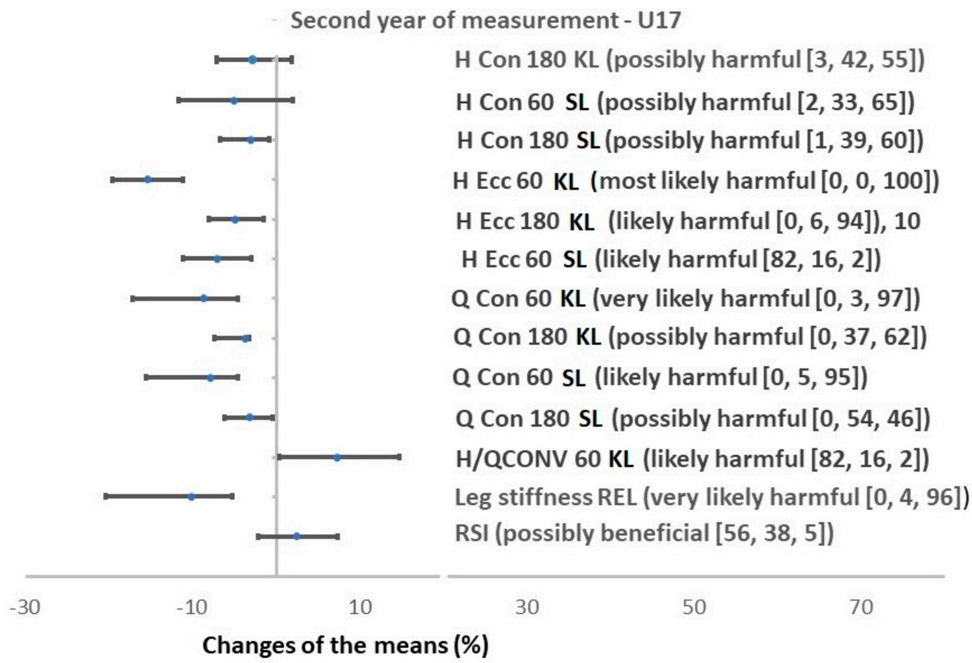

Figure 3. Percentage changes in strength measurement after SAFT^{90} protocol in U17. Values are changes in means with confidence intervals (%), bracket = (effect [odds ratios]), Strength is described by the peak torque, H = hamstrings, Q = quadriceps, H/Q_{CONV} = conventional ratio of H and Q, SL = stance nondominant lower limb, KL = kicking dominant lower limb.

Specifically, the SAFT^{90} induced a reduction in concentric H strength at 180°·s^{-1} in the kicking leg, at 60°·s^{-1} in the stance leg and in eccentric H strength at 60°·s^{-1} in both limbs in the U16 group.

The effect ranged from possibly harmful to likely harmful. Q concentric strength at 180°·s^{-1} in the stance leg significantly increased (likely beneficial) but no change in all other Q strength parameters were observed in the U16 group. Consequently, the H/Q$_{CONV}$ at 60°·s^{-1} in the stance leg decreased in the U16 group post-SAFT^{90} (likely harmful effect). After the SAFT^{90}, a significant decrease in the concentric H strength in stance leg at both velocities, in eccentric H strength at 60°·s^{-1} in both limbs and at 180°·s^{-1} in the kicking leg (the effect ranged from most likely harmful to very likely harmful) was observed in the U17 age group. Concentric Q strength decreased at both velocities and in both limbs. The effect ranged from most likely harmful to very likely harmful. After the SAFT^{90}, an increase in the H/Q$_{CONV}$ at 60°·s^{-1} for the kicking leg was also observed in the U17 age group.

In both the U16 and U17 groups leg stiffness decreased and RSI increased (Figures 2 and 3) after the SAFT^{90}. For both groups, the magnitude of the effect was very likely harmful for both absolute and relative leg stiffness. Changes in RSI were very likely beneficial in the U16s and possibly beneficial in U17s.

Increased muscle activation of the ST during concentric knee flexion at 60°·s^{-1} and at 180°·s^{-1} (the effect was likely beneficial in both cases) and increased activation of the BF during concentric knee flexion at 60°·s^{-1} (the effect was very likely beneficial) (Figure 4) was observed in the U16 group after the SAFT^{90}.

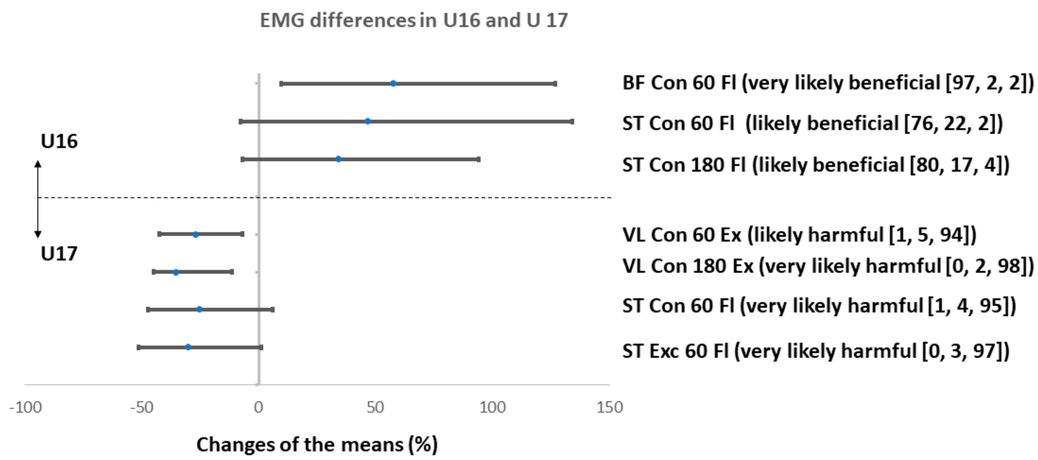

Figure 4. Percentage change in thigh muscle EMG mean frequency after SAFT90 protocol in U16 and U17. Values are changes of means with confidence intervals (as %), bracket = (effect [odds ratios]), BF = biceps femoris, ST = semitendinosus, VL = vastus lateralis quadriceps, Fl = flexion.

Muscle activation of the plantar flexors demonstrated a decrease in LG at 60°·s^{-1} during eccentric knee flexion actions (very likely harmful effect) and at 60°·s^{-1} in both concentric and eccentric knee flexion action (both possibly harmful effect). In the U17 a decreased muscle activation of the ST during concentric and eccentric knee flexion at 60°·s^{-1} (the effect was very likely harmful), and a decrease in the VL during concentric knee extension at 60°·s^{-1} and 180°·s^{-1} (the effect was likely harmful and very likely harmful) (Figure 4) was observed after the SAFT^{90}. Moreover, muscle activation of the plantar flexors during eccentric knee flexion at 60°·s^{-1} and 180°·s^{-1} decreased following fatigue exercise (Supplementary file 1, Table S5). The effect was likely harmful and most likely harmful for LG and likely harmful in both the cases in MG.

A comparison of the differences in the changes of the observed variables in the pre and post-test values between both age groups confirmed significant differences only in H eccentric PT at 180°·s^{-1} for the stance leg (p = 0.026; r = 0.473), Q concentric PT at 180°·s^{-1} for the stance leg (p = 0.016; r = 0.512), H/Q$_{CONV}$ at a velocity of 180°·s^{-1} (kicking leg: p = 0.032; r = 0.454; SL: p = 0.032; r = 0.454), and muscle activation in the case of BF (p = 0.022; r = 0.530).

4. Discussion

The aim of this study was to explore the effects of simulated soccer match play on the neuromuscular performance in adolescent players longitudinally over a two-year period. The finding of this study indicates that simulated soccer match play induces a significant decrease in HPT and leg stiffness and increase in reactive strength, irrespective of participants age. However, greater changes/effects in neuromuscular function and performance were found in U17 compared to U16 age. The U17 also demonstrated significantly greater reductions in firing frequency of motor units in VL and BF, compared to the U16. These results do not indicate a positive influence of age on fatigue resistance in observed youth soccer players.

4.1. Changes in Torque Production in Hamstrings

Local muscular fatigue is a factor associated with injury which can explain the greater risk of injury in the second half of a soccer game and towards the end of each half [72]. In the case of muscle strength, in this study fatigue produced by the SAFT^{90} was defined as a reduction in relative PT production by muscle group. Changes in muscle strength resulted in a reduction (likely or very likely harmful, except for H eccentric PT at 180°·s^{-1} for the stance leg) of PT production of knee flexors (hamstrings) in particular during eccentric actions in the U17 (Figure 3) and partly in U16 groups (likely harmful in H eccentric PT at 60°·s^{-1} in both legs) (Figure 2). The decline in H strength (both eccentric and concentric) may be explained by the efforts of the H in the control of running activities and for stabilizing the knee joint during foot contact with the ground [25]. The reduction of hamstrings PT production in eccentric action has an implication in practice because H strain occurs predominantly during the latter part of the swing phase of sprinting when H work eccentrically and their tension is maximal to stabilize the knee [73]. This result could also indicate that after simulated soccer, susceptibility to ACL injury increases in players due to loss of H muscle strength and consequently deterioration of their stabilization function [74]. This capacity for muscular knee joint stabilization is progressively augmented at gradually more extended knee joint positions and increasing angular velocity.

These changes are consonant with findings in a recent study [35], where only H PT during eccentric actions were reduced significantly (16.8%) at a velocity of 120°·s^{-1} in youth soccer players after a fatigue protocol. In addition, in a study on female youth soccer players, a reduction in PT was evident after the SAFT^{90} irrespective of age (concentric PT 17% and eccentric PT 26%, respectively [56].

A significant difference, with a medium effect size, in changes of PT in the H between both age groups was observed only for H eccentric PT at 180°·s^{-1} for the stance leg (p = 0.026, r = 0.473), with a nonsignificant increase of PT (p = 0.657, r = 0.090) in the younger age group and a nonsignificant decrease (p = 0.286, r = 0.208) in the older age group. Although a different direction of change was observed in this case, other results suggest that chronological age does not influence the ability of the H to resist fatigue after simulated match-play.

4.2. Changes in Torque Production in Quadriceps

Knee extensor (quadriceps) strength during concentric muscle actions is compromised significantly in older players (in younger players, a decrease in only one strength parameter was observed) with the effects of the reductions observed ranging from possibly harmful to very likely harmful (Figure 3). Due to the stabilization function of the Q during contact phase, this tendency, together with the significant changes in strength in both age groups could point to an impairment in the ability of these muscles to help stabilise joints after simulated soccer in youth players. The reduction of torque production in both Q and could be attributed to peripheral fatigue caused in particular by depletion of muscle glycogen stores, creatine phosphate concentration, dehydration, and decreased ability to recruit muscle fibres [25]. However, to what extent peripheral or central fatigue contributed to this reduction, could not be assessed in this study.

A comparison of the differences in changes of PT in Q strength between age groups indicated that differences were significant only in the VL at 180°·s^{-1} (p = 0.016, r = 0.512), with a significant decrease of PT (p = 0.032, r = 0.456) in the U17 group and nonsignificant increase (p = 0.248, r = 0.235) of PT in the U16 group. This indicates that the change in Q strength is not age dependent.

4.3. Changes in H/Q Ratios

Acute fatigue changes in H/Q ratios resulted only in a likely harmful decrease of the H/Q_{CONV} at 60°·s^{-1} stance leg in the U16 group and likely beneficial increase in the H/Q_{CONV} at 60°·s^{-1} in the kicking leg in the U17. However, from the point of view of injury risk, we do not consider the increase in the U17 as beneficial since it was achieved by a decrease of Q strength and not an increase in H strength. These results do not indicate impairment of muscular control postfatigue in observed players of both age groups. This suggestion is also supported by the results of H/Q_{FUNC}, where the average value in both measurements was around and/or above 0.7. Findings of the latest review by Baroni et al. [75] support reference value close to 80% for isokinetic H/Q_{FUNC} ratio at slow angular velocities up to 60°·s^{-1} as an indicator of injury risk in professional male soccer players. These results support the results of a previous study by Lehnert et al. [38] on male soccer players aged U15, where no fatigue related decrease in the H/Q_{FUNC} at angular velocities of 60°·s^{-1}, 180°·s^{-1}, and 360°·s^{-1} were observed after the SAFT^{90}. On the contrary, these results contradict the results of studies in adult soccer players which indicated decline in H/Q ratios after simulated soccer match play [25,76]. In one study [76], both H/Q_{CONV} and H/Q_{FUNC} were significantly reduced after exercise only in a group of players with balanced H/Q ratio (>0.60). However, differences in the results in previous studies on youth players and adult players could be explained by the differences in the exercise used to induce fatigue as well as the participants investigated.

As far as a comparison of differences in changes of H/Q ratios in pre and post-test values (before and after SAFT^{90}) between both age groups is concerned, significant differences were found only in H/Q_{CONV} at a velocity of 180°·s^{-1} with a medium effect size (kicking leg: p = 0.032, r = 0.454; stance leg: p = 0.032, r = 0.454), with a nonsignificant decrease observed in both age groups (U16, kicking leg: p = 0.308, r = 0.208; stance leg: p = 0.328, r = 0.199; U17, kicking leg: p = 0.722, r = 0.075; stance leg: p = 0.859; r = 0.037). These results support the findings of the changes in PTs in the current study and do not indicate an influence of age on fatigue resistance in observed players.

4.4. Changes in EMG

The EMG data demonstrates a significant decrease in muscle activation after the SAFT^{90} compared to the nonfatigued state, especially in the older age group (U17). There were significant reductions at a velocity of 60°·s^{-1} in knee flexors (ST: very likely harmful, concentric and eccentric muscle action) and extensors (VL: very likely or likely harmful, concentric muscle action during knee extension) and also in plantar flexors (LG: most likely harmful, eccentric muscle action during knee flexion). This data suggests that toward the end of match play, youth players' ability to effectively utilize neuromuscular mechanisms to control joint movement and reduce load on ligaments is reduced and injury risk is increased. In U16 players acute fatigue changes in muscle activity resulted only in a very likely harmful decrease in LG (eccentric muscle action during knee flexion) at a velocity of 60°·s^{-1} and 180°·s^{-1}. In contrast, we observed very likely beneficial changes in BF (concentric flexion; 60°·s^{-1}) and likely beneficial changes in ST concentric flexion; 60°·s^{-1} and 180°·s^{-1}).

The findings in the U17 are to some extent in agreement with one previous pediatric study that demonstrated a significant increase in electromechanical delay following the SAFT90 in female youth soccer players [56]. However, in our study a significant decrease of mean frequency values was localised in different muscle groups and was observed in more muscle groups. This fatigue related effect in knee flexors (ST, concentric flexion) and also extensors (VL, concentric extension) at the U17 supports the findings of a previous study on youth footballers aged U15 [38], where the authors reported significantly compromised muscle activity in ST at 60°·s^{-1}, 120°·s^{-1} and nonsignificant decrease at

$180^{\circ}{\cdot}s^{-1}$. In the BF there was a trend of a reduction; however, this was nonsignificant. Surprisingly, in the most recent study by De Ste Croix et al. [43], which explored the effects of competitive soccer match-play on neuromuscular performance and muscle damage in 13-16y players (further split into PHV group and post PHV group based on maturity off-set), no significant changes in muscle activation of H and Q muscles were observed. Considering all the above-mentioned studies in which elite youth soccer players were observed, the differences in changes of muscle activity could be, in our opinion, explained by differences in the applied fatigue exercise (soccer-specific fatigue protocol and competitive match-play, respectively). However, this is only speculation; the workload was not monitored in any of these studies.

An increase in injury risk of the lower limbs after the $SAFT^{90}$ in the older age group (U17) may be also due to a significant decrease in mean frequency in the VL (at both velocities). VL and MV act as agonists (extension of knee joint) and also as antagonists (control position of patella). Based on the reduction in the VL, we could assume that the MV is weaker in players and thus VL replaces its function, which can affect the position of the patella laterally. Furthermore, we have seen a significant decrease in the mean frequency value of LG during eccentric muscle actions of the knee flexors in both age groups (at 16 y the reduction was at $60^{\circ}{\cdot}s^{-1}$ while at 17 y at both measured velocities). Despite the fact that the function of LG for stability of the knee joint is secondary, a decrease in LG activity may have negative consequences for injury risk during landing, cutting, and running.

The between group differences in changes of muscle activation were found for both the knee flexors and extensors. The $SAFT^{90}$ increased the knee flexors (ST and BF) muscle activation in the younger age group and decreased knee flexors (only ST) muscle activation in the older age group. However, the change was statistically significant only in the case of BF ($p = 0.022$; $r = 0.530$). Furthermore, the $SAFT^{90}$ decreased muscle activation of VL during concentric knee extension at both velocities in the U17s and resulted in no change in U16s; however, the difference in changes was not significant. The explanation of the higher (although mostly nonsignificant) decrease of muscle activation and compromised state of most of the other observed injury risk indicators after the $SAFT^{90}$ in the older age is difficult. However, one of the reasons could be the difference in anthropometric characteristics, especially a lower body mass. It could also be related to the difference in the training and competition load in recent training cycles and higher level of fatigue. Nevertheless, the players were not exposed to a high intensity training load the day before testing in both years. Unfortunately, the current level of fatigue was not monitored in players. In this context, interesting results are presented in the already mentioned study on youth soccer players aged 13–16 y by De Ste Croix et al. [43]. The authors reported that the influence of competitive match-play on neuromuscular function evaluated by muscle activity recorded using surface polyelectromyography and RSI was found to be similar in male youth around the time of peak height velocity and those post peak height velocity. The authors suggested that these results indicate that other factors must contribute to the heightened injury risk around PHV.

4.5. Changes in Leg Stiffness

Both U16 and U17 groups demonstrated a very likely harmful decrease in absolute and relative leg stiffness after the $SAFT^{90}$. Compromised stiffness when fatigue is present may indicate fatigue-induced changes in muscle-tendon complex activation and consequently reduced ability to produce muscle strength and resist against deformities (absorb energy) originated during SSC [12]. The potential consequence of such reductions could be an increase in shear force absorption directly by the knee joint, which would have negative permeations for ACL injury risk [77]. Moreover, decreased leg stiffness negatively influences jump and speed performance [78]. From a neuromuscular perspective, it is likely that fatigue will have induced a change in the activation of the musculotendon unit, leading to a reduction in preactivation prior to ground contact (feed-forward control) and an increase in cocontraction after ground contact (feedback control). Up to 97% of the variance in leg stiffness has been explained by the contribution of preactivation and stretch-reflex response of lower limb extensor muscles [59]; therefore, changes in stiffness are likely to reflect changes in these control mechanisms.

Mechanically, a reduction in leg stiffness would typically be characterized by an increased yielding action, greater ground contact times, greater centre of mass displacement, and less efficient movement when the limb comes into contact with the ground [79]. The potential consequence of such fatigue-induced reductions in ground reaction forces (and overall leg stiffness) could be an increase in shear force absorption directly by the knee joint, which would have negative permeations for ACL injury risk [77]. A reduction in leg stiffness in the measured age groups may place an individual at increased risk of lower limb injury due to a reduction in dynamic stabilization of the knee.

Only a small number of studies appear to examine changes of leg stiffness after specific fatigue protocol and/or a competitive soccer game. Our findings are in agreement with one newer study on 14-year-old players [38] where a significant reduction in both absolute and relative stiffness was reported after the SAFT^{90}. In addition, in a study on 15-year-old players [45], absolute leg stiffness deteriorated nonsignificantly after soccer-specific fatigue protocol. The authors, however, point out that in half of players the stiffness increased and in the other half it was reduced. In contrast, in the study by De Ste Croix et al. (2019) on 13–16 y old soccer players, the authors observed no significant fatigue-related change in absolute and relative leg stiffness both in a PHV group and a post-PHV group. The authors also state that their findings support some of the previous literature in youth players that have also identified that acute changes in leg stiffness appear to be very individualized. Surprisingly, an increase in the relative leg stiffness was recorded after a soccer-specific exercise in 16-year-old female youth players [66].

Comparison of differences in changes of leg stiffness between both age categories showed that differences were not age dependent (p = 0.094 and r = 0.075). In both the groups, the decreased values after the SAFT^{90} indicate that due to the fatigue state, neural control in knee was reduced and ACL injury risk increased [80,81].

4.6. Changes in RSI

After the SAFT^{90}, RSI demonstrated very likely beneficial changes in U16 and possibly beneficial changes in U17. As RSI represents the strain placed on the muscle-tendon unit, our findings indicate that tolerance to the eccentric loading placed on the muscle-tendon unit was not compromised [49]. It would seem strange that we found reduction in stiffness but not RSI when they both represent SSC capability. However, the study by [81] indicated that RSI has a limited amount of common variance with leg stiffness in children. The findings of the current study are not in agreement with a recent study [46] which shows a reduction in RSI immediately post competitive match in soccer players in U14 and U16 players. In addition, other previously mentioned studies on male youth soccer players [38,45] showed a significant reduction in RSI after a competitive soccer game and simulated match-play respectively. Likewise, in the case of leg stiffness, a comparison of differences in the change in RSI between age categories did not demonstrate any age related effects (p = 0.130, r = 0.322).

4.7. Limitations

One limitation of this study is that observed indicators were not measured during half time and during other parts of the soccer season, and we did not have the data to explore the reliability of measured outcomes. Moreover, our study actually included players with regular maturation [82,83] and not early maturation typical for elite players. Since it has been shown that maturation status influences the players' body composition, which is probably the factor influencing the level of fatigue in SAFT [37,84,85], this might highly influence the results. Another limitation could be that the execution of changes of direction during the SAFT^{90} was done by the individual players preferentially and therefore workload on kicking and stance leg could have been different.

5. Conclusions

The results of a two-year study on youth male soccer players showed that a simulated soccer protocol (SAFT^{90}) induced a significant decrease in most of the observed neuromuscular performance indicators at both ages. Greater changes were found in the older age group (U17); however, most of these differences did not reach statistical significance so we cannot confirm that the effects of a soccer related fatigue protocol on indicators of neuromuscular functions associated with noncontact ACL and H injuries is age dependent. This may be due to the fact that there was only a one-year difference between measurements of the players and that they were post PHV at the first test occasion. With respect to incidence and consequences of ACL and H injuries in soccer, this type of diagnostics has the potential for being effective in developing training strategies to affect neuromuscular mechanisms important for joint stability and reduce injuries in youth soccer, in particular if the results are reflective in flexible planning of the training cycles, especially in competitive microcycle with higher competitive match-play demands and/or cycles with higher level of training and/or competitive demands on players.

Supplementary Materials: The following are available online at http://www.mdpi.com/1660-4601/17/22/8579/s1, Table S1: Descriptive statistics for isokinetic parameters pre and post SAFT90, and magnitude-based inferences for the percent changes of the means in U16, Table S2: Descriptive statistics for muscle activation for kicking leg pre and post SAFT90, and magnitude-based inferences for the percent changes of the means in U16, Table S3: Descriptive statistics (Mean ± SD) for Leg stiffness and RSI parameters pre and post $SAFT^{90}$, and magnitude-based inferences for the changes of the means in U16, Table S4: Descriptive statistics for isokinetic parameters pre and post $SAFT^{90}$, and magnitude-based inferences for the percent changes of the means in U17, Table S5: Descriptive statistics for muscle activation for kicking leg pre and post SAFT90, and magnitude-based inferences for the percent changes of the means in U17, Table S6: Descriptive statistics (Mean ± SD) for Leg stiffness and RSI parameters pre and post SAFT90, and magnitude-based inferences for the changes of the means in U17.

Author Contributions: Conceptualization, M.L., M.D.S.C., A.Z., and P.S.; methodology, M.L., M.D.S.C., A.Z., P.L., and P.S.; validation, M.L. and P.S.; formal analysis, P.L. and P.S.; investigation, M.L., A.Z., and P.S.; data curation, M.L., A.Z., and P.S.; writing—original draft preparation, M.L., M.D.S.C., A.Z., P.L., and P.S.; writing—review and editing, M.L., M.D.S.C., A.Z., P.L., and P.S.; visualization, P.S., and A.Z.; project administration, M.L., M.D.S.C., A.Z.; funding acquisition, M.L., M.D.S.C., and A.Z. All authors have read and agreed to the published version of the manuscript.

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Prediction of Somatotype from Bioimpedance Analysis in Elite Youth Soccer Players

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Abstract: The accurate body composition assessment comprises several variables, causing it to be a time consuming evaluation as well as requiring different and sometimes costly measurement instruments. The aim of this study was to develop new equations for the somatotype prediction, reducing the number of normal measurements required by the Heath and Carter approach. A group of 173 male soccer players (age, 13.6 ± 2.2 years, mean ± standard deviation; body mass index, BMI, 19.9 ± 2.5 kg/m^2), members of the academy of a professional Italian soccer team participating in the first division (Serie A), participated in this study. Bioelectrical impedance analysis (BIA) was performed using the single frequency of 50 kHz and fat-free mass (FFM) was calculated using a BIA specific, impedance based equation. Somatotype components were estimated according to the Heath-Carter method. The participants were randomly split into development (n = 117) and validation groups (n = 56). New anthropometric and BIA based models were developed (endomorphy = −1.953 − 0.011 × stature^2/resistance + 0.135 × BMI + 0.232 × triceps skinfold, R^2 = 0.86, SEE = 0.28; mesomorphy = 6.848 + 0.138 × phase angle + 0.232 × contracted arm circumference + 0.166 × calf circumference − 0.093 × stature, R^2 = 0.87, SEE = 0.40; ectomorphy = −5.592 − 38.237 × FFM/stature + 0.123 × stature, R^2 = 0.86, SEE = 0.37). Cross validation revealed R^2 of 0.84, 0.80, and 0.87 for endomorphy, mesomorphy, and ectomorphy, respectively. The new proposed equations allow for the integration of the somatotype assessment into BIA, reducing the number of collected measurements, the instruments used, and the time normally required to obtain a complete body composition analysis.

Keywords: anthropometry; BIA; body composition; football; predictive equation

1. Introduction

Young soccer players are one of the most studied populations in sports science. In fact, there is a tremendous number of studies focusing on the search for talent and on the development of new techniques for evaluating physical features and their improvement in order to achieve high level performance [1,2]. Variables among the most informative and associated with physical performance are those related to body composition (BC). One of the most used techniques to evaluate BC in soccer players is bioelectrical impedance analysis (BIA) [2–4]. BIA uses bioelectrical properties of tissues to estimate BC variables such as total body water (TBW) and the respective intra and extracellular compartment (ICW and ECW) [5], fat mass (FM), fat-free mass (FFM) [6], and lean soft tissue (LST) [7]. This allows for the evaluation of a wide range of BC variables in not only a short time, but also easily and with high reliability and reproducibility [8]. Furthermore, its high use in athletes has meant that in recent years, several equations were proposed and validated against the four-compartment model (4C), the gold standard for the BC assessment at the molecular level [5–7].

In addition to the molecular level of the BC, other parameters are also frequently scrutinized in sports. In particular, these parameters include the morphological characteristics which belong to the whole body level, the fifth organizational level of BC proposed by Wang and collaborators [9]. In this regard, endomorphy, mesomorphy, and ectomorphy represent the three morphological components of the somatotype and their different combinations allow for the classification of the athlete's body shape into one of 13 different categories. The evaluation of the somatotype in addition to other variables of BC allows for a complete and highly informative examination of the physical profile of the athletes. In fact, the morphological characteristics are related to physical performance [1,10], as well as discriminating for the player position/role and competitive level. In particular, a dominance of the endomorphic component was associated with a worse ability in performing repeated sprints with change of direction and with a low quality in functional movement patterns [10]. Additionally, significant differences in endomorphic values were observed between elite and sub-elite soccer players [1,10]. Furthermore, Víctor Cárdenas-Fernández et al. [11], in a recent study, showed that the dominant somatotype of soccer players was meso-endomorphic in goalkeepers, central for external defenders, balanced ectomorph in central defenders, balanced mesomorph in the case of midfielders, and meso-ectomorph in forwards/extremes.

However, the evaluation of the somatotype according to the Heath and Carter method requires the measurement of 10 specific anthropometric dimensions by a qualified anthropometrist and dependence on the measurement instruments, including possible technical errors that mitigate the accuracy of the evaluations [12]. In fact, these measurements include four skinfold thickness (triceps, subscapular, supraspinal, and medial calf), two circumferences (contracted arm and calf), and two diameters (humerus and femur), for which three different measuring instruments are required [13]. Unfortunately, when measuring a large sample of athletes, time constraints limit the amount of measurements that can be taken using different tools and therefore, the best decision may be to conduct quick but precise evaluations that allow for the measurement of a sufficient number of variables. Reducing the number of instruments used and the measurements collected for the evaluation of the somatotype would permit the integration of the analysis of morphological characteristics to BIA, thus allowing the analysis of a large number of variables belonging to different levels of BC in a practical way and in a short amount of time. Therefore, the aim of this study is to generate new predictive models for the somatotype assessment in youth elite soccer players, including bioelectrical and their BC-derived parameters, and to reduce the number of anthropometric measurements already required by the Heath and Carter method.

2. Materials and Methods

2.1. Participants

173 soccer players (age, 13.6 ± 2.2 years, mean ± standard deviation; body mass index, BMI, 19.9 ± 2.5 kg/m^2), from the under 10 to under 17 age categories, registered in a professional Italian soccer team participating in the first division (Serie A), were selected to participate in the study. The players voluntarily decided to participate and their parents provided informed consent after a detailed description of the study procedures. The project was conducted according to the Declaration of Helsinki and was approved by the Bioethics Committee of the University of Bologna (Approval Code: 25027).

2.2. Procedures

All anthropometric measurements were profiled by an accredited anthropometrist (S.T.). Height was measured to the nearest 0.1 cm using an anthropometer (GPM, DKSH, Zurich, Switzerland). Body weight was measured to the nearest 0.1 kg using a calibrated electronic scale. BMI was calculated as body mass in kilograms divided by the square of height in meters. Somatotype components were calculated according to the Heath-Carter method [13], for which girth was taken to the nearest 0.1 cm using a tape measure, breadth was measured to the nearest 0.1 cm using a sliding caliper, and skinfold thicknesses at four sites (triceps, subscapular, supraspinal, and medial calf) were measured to the nearest 0.1 mm using a Lange skinfold caliper. The raw impedance parameters, resistance (R), and reactance (Xc) were obtained with a bioimpedance analyzer (BIA 101 Anniversary; Akern Srl, Florence, Italy) at a frequency of 50 kHz, according to the standard procedures [14,15]. Phase angle (PhA) was calculated as the arctangent of $Xc/R \times 180°/\pi$ and FFM using a specific equation [6]:

$$FFM = -\ 2.261 + 0.327{*}stature^2/R + 0.525{*}body\ weight + 5.462{*}1,$$

2.3. Statistical Analysis

Descriptive statistics were performed to characterize the sample. All variables were checked for normality, using the Kolmogorov-Smirnov test. Stratified random assignment based on age categories was used to assign participants to either a development group (n = 117) or a cross validation group (n = 56). Stepwise regression analysis was used to evaluate the ability of variables (R, Xc, PhA, FFM, FFM/stature, chronological age, stature, weight, BMI, skinfold thickness, circumferences, stature^2/resistance, and stature^2/reactance) to predict endomorphy, mesomorphy, and ectomorphy in the development group. During model development, normality of residuals and homogeneity of variance were tested. The criterion for inclusion of a predictor was significant at $p \leq 0.05$. If more than one variable remained in the model, a variance inflation factor (VIF) for each independent variable was calculated and values below five were considered as not having multicollinearity [16]. To cross validate the developed models, the resulting equations were applied to the cross validation group according to the statistics method described elsewhere [16]. A paired sample t-test was used to compare the mean values obtained from the reference technique and from the new method. To assess the accuracy of the new predictive models, validation parameters included the analysis of the coefficient of determination and the pure error. The pure error was assessed using the following equation $(\sum(\ddot{Y} - Y)^2/n^{1/2}$, where $\ddot{Y}$ is the predicted variable, Y is the observed variable, and n is the number of participants [17]. Additionally, the concordance correlation coefficient (CCC) using the Lin approach [18] calculated with MedCalc Statistical Software v.11.1.1.0, 2009 (MedCalc, Mariakerke, Belgium) was performed. The CCC contains a measurement of precision and accuracy ($\rho_c = \rho\ C_b$): where ρ is the Pearson correlation coefficient, which measures how far each observation deviates from the line of best-fit and is a measure of precision, and C_b is a bias correction factor that measures how far the best fit line deviates from the 45° line through the origin and is a measure of accuracy. Finally, agreement between the developed models and the reference procedure was assessed using the Bland-Altman method [19], including the analysis of the correlation between the mean and the difference of the methods and an estimate of the limits of agreement. Data were analyzed with IBM SPSS Statistics, version 24.0 (IBM Corp., Armonk, NY, USA).

3. Results

The participants' characteristics for the development and cross validation groups are presented in Table 1.

Table 1. Descriptive Characteristics of the Development and Cross validation Groups.

	Development Group (n = 117)	Cross Validation Group (n = 56)
	Mean ± standard deviation	Mean ± standard deviation
Age (years)	13.5 ± 2.1	13.5 ± 2.3
Weight (kg)	53.5 ± 14.9	54.0 ± 14.9
Stature (cm)	162.3 ± 15.2	162.2 ± 16.7
Body mass index (kg/m^2)	20.0 ± 2.5	19.9 ± 2.5
Resistance (ohm)	555.4 ± 89.7	537.9 ± 73.3
Reactance (ohm)	64.4 ± 6.9	62.1 ± 9.9
Phase angle (degree)	6.7 ± 0.9	6.7 ± 1.1
Fat free mass (kg)	47.6 ± 12.6	48.3 ± 12.5
Triceps skinfold (mm)	8.1 ± 2.6	7.6 ± 2.3
Subscapular skinfold (mm)	6.6 ± 2.1	6.3 ± 1.7
Supraspinal skinfold (mm)	5.8 ± 2.6	5.4 ± 1.9
Medial calf skinfold (mm)	6.9 ± 2.5	6.6 ± 2.4
Contracted arm circumference (cm)	25.5 ± 4.1	25.9 ± 3.6
Calf circumference (cm)	33.3 ± 4.8	33.8 ± 3.5
Humerus width (cm)	6.3 ± 0.6	6.3 ± 0.7
Femur width (cm)	9.1 ± 0.7	9.2 ± 0.7
Endomorphy	2.1 ± 0.7	1.9 ± 0.5
Mesomorphy	4.1 ± 1.1	4.3 ± 0.9
Ectomorphy	3.3 ± 1.0	3.1 ± 1.1

3.1. Models Developments

Only variables contributing as significant predictors using a backward stepwise approach were used in the models' developments. The final prediction models are shown in Table 2.

Table 2. Prediction Models for Endomorphy, Mesomorphy, and Ecthomorphy Based on Anthropometrics and Bioimpedance-Derived Variables.

	Predictors	R	R^2	SEE	VIF	Prediction Equation
Endomorphy	S^2/R BMI Triceps skinfold	0.92	0.86	0.28	4.22 3.61 1.55	$y = -1.953 - 0.011 \times S^2/R + 0.135 \times BMI + 0.232 \times$ triceps skinfold
Mesomorphy	PhA CAC CC Stature	0.93	0.87	0.40	1.49 2.34 1.84 2.68	$y = 6.848 + 0.138 \times PhA + 0.232 \times CAC + 0.166 \times CC - 0.093 \times$ stature
Ectomorphy	FFM/S Stature	0.93	0.86	0.37	4.75 4.75	$y = -5.592 - 38.237 \times FFM/S + 0.123 \times$ Stature

Abbreviations: R = multiple correlation coefficient; R^2 = multiple coefficient of determination; SEE = standard error of estimate; VIF = variation inflation factor; S^2/R = stature^2/resistance; BMI = body mass index; PhA = phase angle; CAC = contracted arm circumference; CC = calf circumference; FFM/S = fat-free mass/stature.

3.2. Cross Validation of Derived Prediction Models

A cross validation was performed and the results of the regression parameters, CCC, and agreement analyses between the somatotype components estimated from the new developed models and the reference procedure are presented in Table 3 (cross validation panel).

Table 3. Cross Validation of the Somatotype's Predictive Models and the Reference Procedure.

	Regression Analysis		CCC Analysis			Agreement Analysis		
	R^2	PE	CCC	ρ	C_b	Bias	95% LoA	Trend
Cross Validation								
Endomorphy	0.84	0.222	0.92	0.9158	0.9954	−0.004	−0.246; 0.239	r = 0.232 (p = 0.086)
Mesomorphy	0.80	0.422	0.89	0.8920	0.9932	0.034	−0.034; 0.452	r = −0.238 (p = 0.077)
Ectomorphy	0.87	0.389	0.93	0.9335	0.9987	−0.029	−0.415; 0.357	r = −0.117 (p = 0.390)

Abbreviations: R^2, coefficient of determination; PE, pure error; CCC, concordance correlation coefficient; ρ, precision; C_b, accuracy; LoA, limits of agreement.

Regarding the paired sample t-test, no differences between methods were observed for any of the calculated somatotypes estimation ($p > 0.05$). Concerning the regression analysis, the methods were highly correlated ($R^2 \geq 0.80$; $p < 0.001$). The predictive models developed in phase I for the three somatotypes explained 84%, 80%, and 87% of the variability observed in the values of the reference methods for endomoorphy, mesomorphy, and ectomorphy, respectively. The precision and accuracy of the methods was higher than 0.89 and 0.99, respectively, with a CCC between the new method and the reference procedure superior to 0.89 (Table 3, Figure 1). From the agreement analysis, we observed no trend between the mean and the differences of the methods for any of the somatotypes and small limits of agreements (Figure 2).

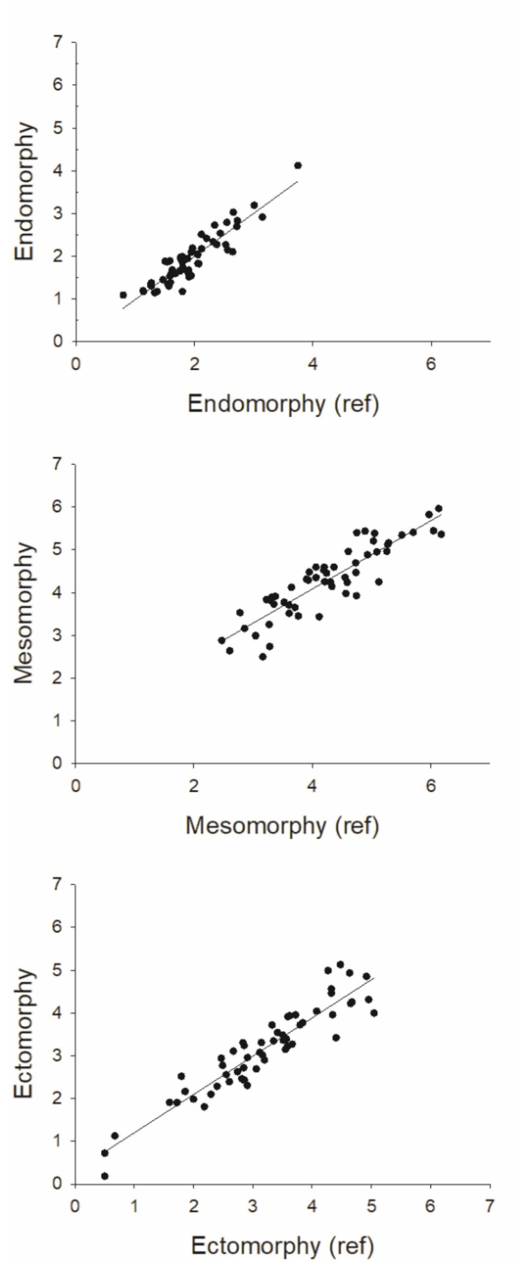

Figure 1. Scatterplot of the relationship between the somatotype components obtained by the reference method and the new formulas.

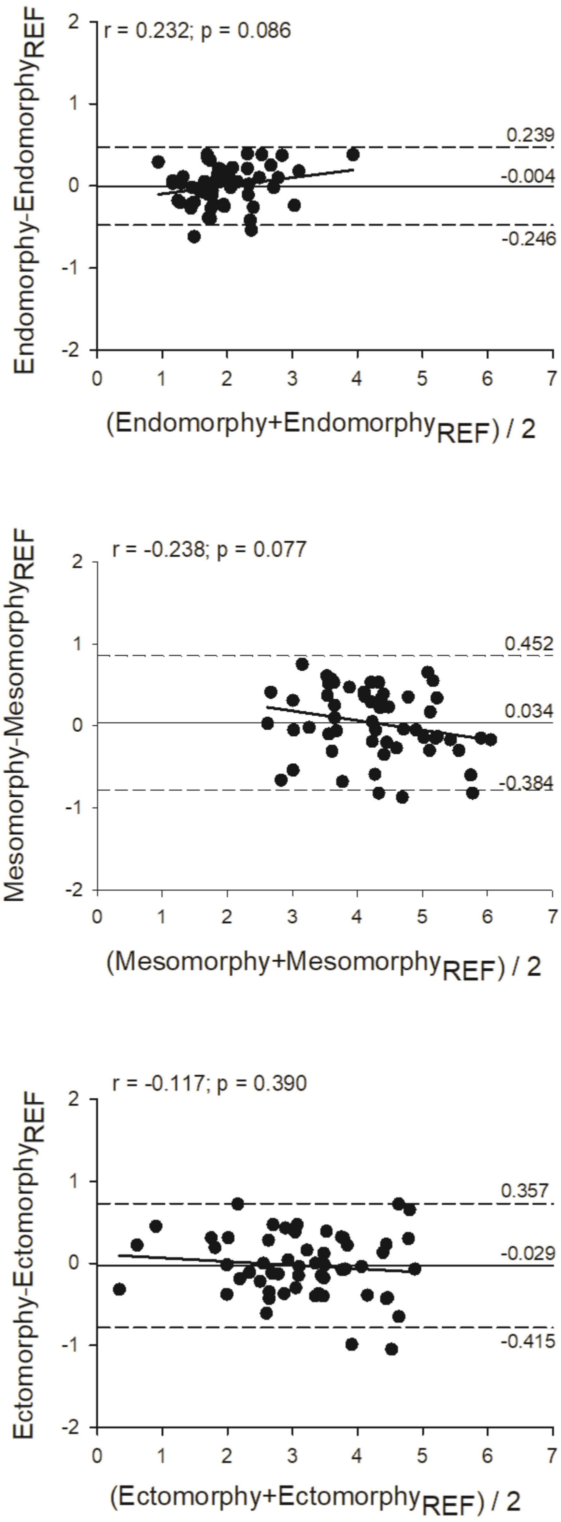

Figure 2. Bland-Altman analysis of the agreement between methods for the somatotype's components estimation. The middle solid line represents the mean differences between the values obtained by the new equations and the reference method (Ref) and was predicted by the equations. The upper and lower dashed line represents the 95% limits of agreement (± 1.96 SD). The trend line represents the degree of association between the differences of the methods and the mean of both methods, as illustrated by the coefficient of correlation (r).

4. Discussion

The purpose of this study was to propose a new strategy for the somatotype assessment, which would allow one to reduce the time and number of measurements, as well as instruments used in the traditional Heath and Carter method. The new proposed equations have been developed considering anthropometric characteristics and bioimpedance parameters in order to be able to use these two techniques to obtain a large number of BC parameters in a short period of time. All the measures necessary for calculating the somatotype according to Heath and Carter have been inserted into the predictive equations' development procedures of this study; nevertheless, only triceps skinfold thickness and the contracted arm and calf circumferences, as well as BMI and the impedance derived parameters were predictors of somatotype in youth soccer players.

Recently, Rudnevet al. [20] proposed a BIA based equation to estimate the three components of the somatotype in the general population. The same research group had already proposed two other equations, one for children and adolescents and the other for the elderly [21]. However, these studies only have a development group and not a validation group, so the accuracy of the models is not completely certain. Additionally, these equations may not be suitable for the sports population as they represent a special population. On the contrary, a cross validation was performed in this study and a very strong correlation was observed between the developed equations and the reference method ($R^2 \geq 0.80$). Moreover, precision and accuracy between the new predictive equations and the reference procedure were analyzed with concordance correlation coefficient analysis. In this regard, a moderate strength of agreement [22] between the methods was observed in estimating endomorphy and ectomorphy (CCC = 0.91 and 0.93, respectively), while for the mesomorphy, a weaker agreement was observed between the methods (CCC = 0.88). Furthermore, the magnitude of the differences between the new predictive model and the reference method was examined according to the Bland-Altman method [19]. Therefore, at an individual level, no bias between the mean and the differences of the methods for any of the somatotypes were observed and small limits of agreements are presented.

In addition to the classical BIA approach, the vector variant (BIVA) has also proved useful for the evaluation of the somatotype. Indeed, recent studies [23–25] have shown how raw bioimpedence parameters (R, Xc, and PhA) are able to discriminate the different somatotypes and are associated with the morphological components. In particular, Campa et al. [23] have shown that PhA and mesomorphy are positively correlated, while PhA and ectomorphy show an inverse association. This is because PhA accurately represents the ICW/ECW ratio [26,27] and this is superior in subjects with a marked muscularity typical of the mesomorphic constitution [28]; in fact, PhA fell into the predictive model of mesomorphy in this study.

The somatotype assessment represents a highly informative analysis for the BC of athletes. Mesomorphic component is linked to individual sports that require muscle strength, such as ball games [29], while ectomorphy is predominant in runners, especially those involved in long distance running [30]. Then, anthropometry and morphological features play a crucial role in determining potential success in sports [31]. Furthermore, being that soccer players vary in morphology according to the player's position [1,11], somatotype assessment in young athletes can prove useful in game choices and talent prediction.

A strong point of this work is represented by the fact that in these new equations, the measurements required for the calculation of the somatotype are reduced, eliminating three adipose skinfold thicknesses (subscapular, supraspinal, and medial calf) out of four and two diameters (humerus and femur), thus avoiding the use of the bone caliper for their measurement. In this regard, although the evaluation of morphology is an important aspect, it is not often integrated into routine evaluations due to the numerous measurements and tools required, which can involve a high operator dependent error as well as long processing times [12].

Some limitations inherent in this study need to be mentioned. First of all, despite being a large sample, the new equations were developed and validated on a sample of young male soccer players, so the results of this study are not extendable to all young athletes, adults, or female athletes. Furthermore, BIA was performed using a single frequency and this does not guarantee the reproducibility of the results with different impedance devices [32]. On the other hand, a strength of the study is its novelty, considering the lack of research on the relationship of somatotype and BIA in young male soccer players. The findings would be of great practical importance for coaches and fitness trainers working with soccer players in terms of talent identification and players' selection, also taking into account the somatic maturation of the athletes. In addition, since body composition is a major component of sport related physical fitness [33], our data might be used for training monitoring.

5. Conclusions

BIA is widely used and often favored over other assessment methods in sports because it provides a wide range of BC parameters in an easy, fast, and low operator dependent manner. On the contrary, the evaluation of the morphological characteristics according to the Heath and Carter approach requires the use of different tools and the collection of many measurements that are often time consuming. The new proposed equations make it easier to integrate the somatotype assessment with BIA, thus obtaining a complete analysis of the BC in youth elite soccer players.

Author Contributions: Conceptualization, F.C., C.N.M., J.T., and S.T.; data curation, F.C. and C.P.M.; formal analysis, F.C. and C.N.M.; investigation, F.C. and S.T.; methodology, C.N.M. and H.L.; supervision, H.L., P.T.N., and S.T.; visualization, P.T.N. and H.L.; writing—original draft, F.C., P.T.N., and C.N.M.; writing—review and editing, F.C., C.N.M., P.T.N., J.T., H.L., and S.T. All authors have read and agreed to the published version of the manuscript.

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Review

Injury Profile of Male and Female Senior and Youth Handball Players: A Systematic Review

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Abstract: Handball is a team sport in which players are exposed to high physical conditioning requirements and several contacts and collisions, so they must face various musculoskeletal injuries throughout their career. The aim of this study was to summarize the characteristics of handball injuries both in training and in competition contexts, differentiating by gender and age. A systematic review was conducted and a total of 15 studies (33 cohorts) met the inclusion criteria. Higher injury incidence was reported during matches compared to training sessions in all groups (i.e., male and female senior and youth players), with male senior players presenting the greatest values. Lower extremities were more frequently injured, being contusions and sprains the most common type of injuries. Females reported more serious injuries than males, who presented a higher percentage of acute injuries caused by direct contact, while in female players these injuries were not caused by direct contact actions. Wings and backs presented the highest injury incidence; additionally, players registered higher match incidence during international championships compared to national leagues. Due to the differences in the injury profile of handball players, specific preventive strategies should be implemented for each group to optimize the injury prevention process.

Keywords: incidence; risk factors; team sport

1. Introduction

Handball is a team sport founded in 1946 and included in the Olympic Games list for the first time in 1972 [1]. The popularity of this sport has increased in recent years, and currently, there are an estimated 25 million players worldwide [2], including male, female, senior, and youth players [3]. Despite the multiple beneficial effects derived from handball practice, such as improvements in cardiovascular, metabolic, muscular and psychosocial health [4–6], this team sport presents a high injury risk [7], mainly due to its high-intensity specific demands (i.e., rapid changes of direction, jumps with abrupt landings and repetitive throws, as well as frequent physical contact among players [8,9]). Likewise, low physical fitness, incorrect technique, lack of flexibility, and also inadequate rehabilitation treatment of injuries have been reported as risk factors related to the occurrence of injuries [10,11]. Additionally, the high training volumes and intensities that youth players undertake to achieve sporting excellence seem to contribute to the increase of the injury incidence [10]. In this regard, injuries are associated with negative consequences, such as a reduction of team success [12], an increment of costs related to treatments [13], and the risk of suffering new injuries [14]. In addition, injuries might also have long-term health consequences influencing handball players' quality of life and career [15]. Therefore, reducing the injury incidence can have a key positive impact for both players' and teams' performance.

To comprehensively address this issue, it seems necessary to apply a structured injury prevention approach [16]. In this sense, Van Mechelen et al. [17] established that epidemiological analysis must be the first step in developing effective injury prevention strategies, incorporating not only information about injury incidence (i.e., likelihood), but also burden and availability (i.e., consequence) values [18]. Regarding this, several studies have analyzed handball players' injury profile, showing an overall incidence of 4.1–12.4 injuries/1000 h overall exposure [19–21]. Likewise, training incidence in handball players is established between 0.6 and 4.6 injuries/1000 h training [3,19,22], and match incidence is set at 10.8–73.6 injuries/1000 h [1,3,19], confirming that match incidence is significantly higher than training incidence. Additionally, the lower extremities seem to be the body area where most injuries are sustained, affecting mainly the ankle, knee and head, with ligament sprains and muscle strains being the most frequent type of injuries [19,20,23]. Despite the great number of epidemiological studies focused on handball players, there is a discrepancy of definitions addressing injuries and data collection procedures, which suggests a need to perform a detailed study of the injury profile in handball with the aim of expanding and clarifying the current knowledge regarding handball injuries.

Injuries are considered a complex phenomenon [24] produced by the interaction of multiple risk factors [14], where players' characteristics (e.g., gender or age) are the most influential ones [25]. In this sense, previous studies have reported that injury risk increases with age or according to the gender of the players (i.e., higher injury risk for male players) [26], which may be explained by different game behaviors and physical contact among players [21,27]. Additionally, training load performed by the players during matches and training sessions should be taken into account when injury risk factors are analyzed [14]. Regarding this, previous studies have shown that training and match loads in terms of distance covered at high intensities are greater in male players compared to female ones [28] and between senior and youth [29] handball players; thus, these variables should be investigated within the analysis of the injury profile in cohort studies. In this sense, several epidemiological studies have focused on senior male and female players [3,19,22,30], and others on youth male and female handball players [3,20,21,31]. However, despite the key effect of gender and age on injuries in team sports [32–35], to date, no systematic reviews have been carried out to expand the knowledge about the injury profile (considering injury incidence, location, severity and type) in handball players.

Despite the increased interest in injuries associated with handball practice, no definitive evidence currently exists, and it is necessary to conduct a systematic review to generate robust conclusions about the injuries that take place in this sport and consequently facilitate their prevention process. Therefore, the objective of this systematic review is to summarize the characteristics of handball injuries in both training and competition, differentiating between gender and age.

2. Materials and Methods

The present review was carried out following the recommendations and criteria established in the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement guidelines [36].

2.1. Search Strategy

For this systematic review, potential studies were identified in PubMed/MEDLINE, SPORTDiscus, and Web of Science (including all Web of Science Core Collection: Citation Indexes) databases. The search syntax included the following keywords coupled with Boolean operators: "handball" AND ("injury" OR "injuries" OR "epidemiology" OR "prevalence" OR "incidence"). A year restriction was applied for this search (i.e., studies published between 2000 and 2019). Additionally, a secondary search was performed based on the screening of the reference lists these studies and the studies that cited the included studies through Google Scholar. Two authors (JRG and DC) independently screened the title and abstract of each reference to locate potentially relevant studies and reviewed them in detail to identify articles that met the inclusion criteria. Any discrepancies between the authors in the selection process were solved in consultation with a third reviewer (FMC).

2.2. Inclusion Criteria

The studies included in the present review had to fulfil the following inclusion criteria: (1) the sample must be composed only of handball players, (2) studies that analyzed the injury profile of different groups must report the data in a differentiated way (i.e., specific data of each group), (3) studies must report injury incidence or provide sufficient data to calculate it through standardized equations, (4) studies that reported values of time-loss injuries or allow the possibility to calculate it, and (5) studies had to be the full-text published in a peer-reviewed journal. In addition, conference abstracts, letters to the editor, errata, narrative reviews, systematic reviews, meta-analyses or invited commentaries and studies that were not written in English were also excluded.

2.3. Study Coding and Data Extraction

The following moderator variables were extracted from the included studies: (a) authors, year of publication and study design, (b) sample characteristics (including sample size, age, region and status), (c) follow-up duration, and (d) epidemiological data (including incidence, exposure, severity, burden, type of injury, location, and playing position).

2.4. Methodological Quality Assessment

The methodological quality of the included studies was assessed using a risk of-bias quality form of 15 items validated and adjusted for the specific context of epidemiological research [37], to provide guidance to facilitate a critical appraisal and interpretation of the results. Each question was answered with yes if the criteria were satisfied (2 points), with don't know (1 point), or with a no if the criteria were not satisfied (0 points). All 15 quality criteria are presented online as Supplementary material (i.e., Table S1). Based on this procedure, the studies were classified as follows: low methodological quality (≤50% of total points); good methodological quality (51–75% of total points); and excellent methodological quality (>75% of total points).

Data extraction and methodological quality assessment were performed independently by two authors (JRG and DC) and discrepancies between the authors were resolved in consultation with a third reviewer (FMC). To assess the reliability of the process, intraclass correlation coefficient (ICC) and the Cohen's κ coefficient were calculated showing an ICC of 0.94 (0.84–1.0) and a κ coefficient of 0.92 (0.83–1.0).

3. Results

3.1. Search Results

Figure 1 shows the evolution of the studies published on this topic for every 5-year period along the last 20 years, while the flow diagram of the study retrieval process performed in this research is reported in Figure 2.

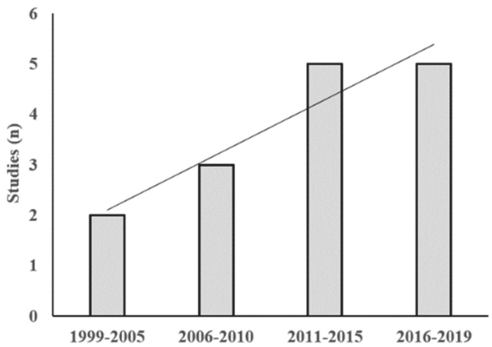

Figure 1. Date of publication of the selected studies.

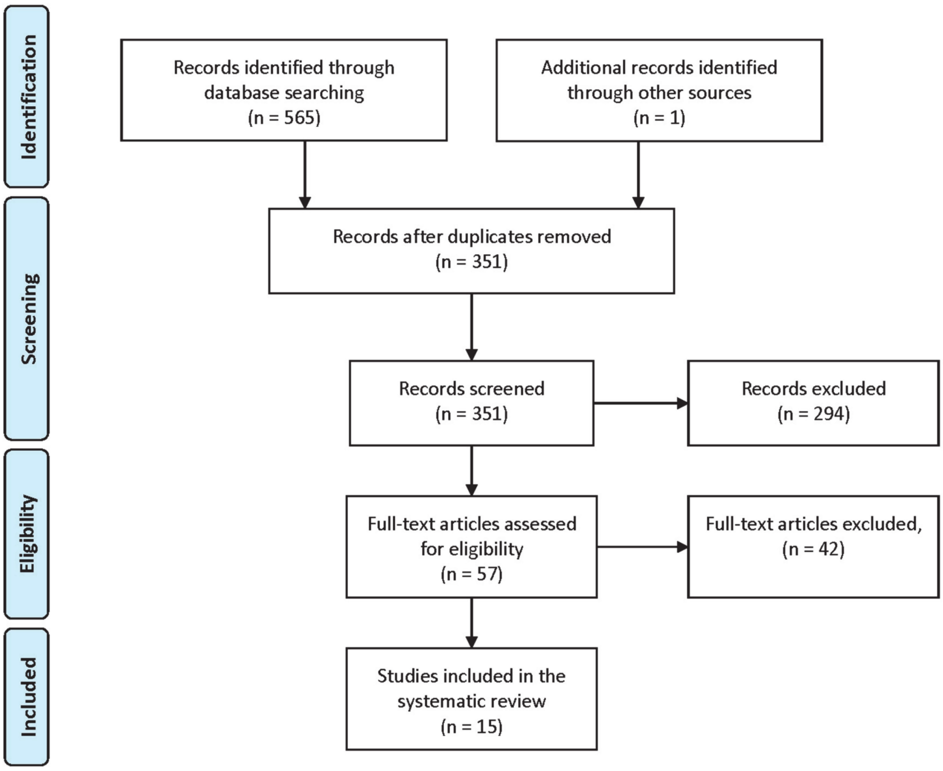

Figure 2. Flow diagram of the study retrieval process.

3.2. Descriptive Characteristics of the Studies

The included studies are summarized in Tables 1–4. The selected 15 studies resulted in 33 cohorts, as nine studies had more than one group. Eleven studies were carried out with senior male handball players [1,3,19,20,22,23,30,38–41], five with senior female handball players [3,22,30,39,42], five with youth male handball players [3,20,21,31,40], and four with youth female handball players [3,21,31,43]. These studies were carried out between 1999 and 2019 and comprised a total of 12,687 participants, divided as follows: 3516 senior male handball players, 952 senior female handball players, 4330 youth male handball players and 3889 youth female handball players. In addition, 12 studies [3,19–23,30,38–40,42,43] used a prospective cohort design, while the remaining three studies [1,31,41] used a retrospective cohort design. Finally, the identified studies had a duration between one month and six seasons.

Table 1. Group and intervention characteristics in senior male handball players.

Study	Study Design	Age Range	Number of Participants (N)	Region	Status	Duration
Bere et al. (2015) [19]	Prospective cohort study	N/D	384	International	Elite	World championship
Giroto et al. (2015) [22]	Prospective cohort study	24.1 y	156	Brazil	Elite	One season
Junge et al. (2006) [43]	Prospective cohort study	N/D	168	International	Elite	Olympic games
Langevoort et al. (2006) [30]	Prospective cohort study	N/D	384	International	Elite	World championship
Langevoort et al. (2006) [30]	Prospective cohort study	N/D	384	International	Elite	World championship
Luig et al. (2018) [1]	Retrospective cohort study	25.8 y	549	Germany	Elite	Three seasons (First division)

Table 1. *Cont.*

Study	Study Design	Age Range	Number of Participants (N)	Region	Status	Duration
Luig et al. (2018) [1]	Retrospective cohort study	24.8 y	828	Germany	Elite	Three seasons (Second division)
Moller et al. (2012) [3]	Prospective cohort study	24.9 y	56	Denmark	National level	31 weeks
Mónaco et al. (2013) [38]	Prospective cohort study	28.3 y	89	Spain	National level (First team)	Three seasons
Mónaco et al. (2013) [38]	Prospective cohort study	20.1 y	79	Spain	National level (Second team)	Three seasons
Mónaco et al. (2019) [20]	Prospective cohort study	20.4 y	31	Spain	National level (Second team)	Two seasons
Piry et al. (2011) [40]	Retrospective cohort study	N/D	40	Asia	Asian level	One year
Rafnsson et al. (2017) [23]	Prospective cohort study	23.6	109	Iceland	National level	One season
Tabben et al. (2019) [41]	Prospective cohort study	N/D	387	International	Elite	World championship

N/D: non data reported; y: years.

Table 2. Group and intervention characteristics in senior female handball players.

Study	Study Design	Age Range	Number of Participants (N)	Region	Status	Duration
Giroto et al. (2015) [22]	Prospective cohort study	22.8 y	183	Brazil	Elite	One season
Junge et al. (2006) [43]	Prospective cohort study	N/D	168	International	Elite	Olympic games
Langevoort et al. (2006) [30]	Prospective cohort study	N/D	384	International	Elite	World championship
Langevoort et al. (2006) [30]	Prospective cohort study	N/D	256	Europe	Elite	Europe Cup
Moller et al. (2012) [3]	Prospective cohort study	23.2	75	Denmark	National level	31 weeks
Petersen et al. (2005) [39]	Prospective cohort study	N/D	142	Germany	National level	One season

y: years; N/D: non data reported.

Table 3. Group and intervention characteristics in youth male handball players.

Study	Study Design	Age Range	Number of Participants (N)	Region	Status	Duration
Asai et al. (2019) [31]	Retrospective cohort study	13–14 y	3780	Japan	National level	Six seasons
Moller et al. (2012) [3]	Prospective cohort study	17.6 y (U18)	41	Denmark	National level	31 weeks
Moller et al. (2012) [3]	Prospective cohort study	15.7 y (U16)	28	Denmark	National level	31 weeks
Mónaco et al. (2013) [38]	Prospective cohort study	16.1 (U17)	85	Spain	National level	Three seasons
Mónaco et al. (2013) [38]	Prospective cohort study	14.7 y (U15)	87	Spain	National level	Three seasons
Mónaco et al. (2013) [38]	Prospective cohort study	12.7 y (U13)	69	Spain	National level	Three seasons
Mónaco et al. (2019) [20]	Prospective cohort study	14.4 y (U15)	133	Spain	National level	Two seasons
Olsen et al. (2006) [21]	Prospective cohort study	U17	107	Norway	National level	Seven months

y: years; U: under.

Table 4. Group and intervention characteristics in youth female handball players.

Study	Study Design	Age Range	Number of Participants (N)	Region	Status	Duration
Asai et al. (2019) [31]	Retrospective cohort study	13–14 y	3300	Japan	National level	Six seasons
Moller et al. (2012) [3]	Prospective cohort study	17.5 y (U18)	53	Denmark	National level	31 weeks
Moller et al. (2012) [3]	Prospective cohort study	15.7 y (U16)	89	Denmark	National level	31 weeks
Olsen et al. (2006) [21]	Prospective cohort study	U17	321	Norway	National level	Seven months
Wedderkopp et al. (1999) [42]	Prospective cohort study	16–18 y	126	Europe	Elite	One season

y: years; U: under.

3.2.1. Injury Incidence: Overall, Training and Match

Eleven studies (24 cohorts) reported information about the overall injury incidence [1,3,19–23,40–43], while fifteen studies (27 cohorts) reported match injury incidence [1,3,19–23,30,31,38,39,41,43], and nine studies (18 cohorts) reported training injury incidence [1,3,19,20,22,23,41,43].

According to the senior groups, eight studies reported overall incidence [1,3,19,20,22,23,40,41], ten reported match incidence [1,3,19,20,22,23,30,38,39,41], and six reported training incidence [1,3,19,22,23,38] in male handball players, while three studies reported overall incidence [3,22,42], four reported match incidence [3,22,30,39] and two reported training incidence [3,22] in female handball players. With regard to youth groups, four studies reported overall incidence [3,20,21,40], four reported match incidence [3,20,21,31], and three reported training incidence [3,20,21] in male handball players; and three studies reported overall incidence [3,21,43], four reported match incidence [3,21,31,43], and three reported training incidence [3,21,43] in female handball players.

3.2.2. Location and Type of Injuries

Injury location was reported in eight studies (14 cohorts) [1,19,22,23,30,31,38,43] distributed as follow: six studies in senior male handball players [1,19,22,23,30,38], two studies in senior female handball players [22,30], one study in youth male handball players [31], and two studies in youth female handball players [31,43].

Regarding the type of injuries, five studies (11 cohorts) reported this information [1,22,30,31,44], four studies in senior male handball players [1,19,22,30], three studies in senior female handball players [22,30,42], one study in youth male handball players [31], and one study in youth female handball players [31].

3.2.3. Severity and Mechanism

Nine studies (19 cohorts) reported the severity of injuries. As regards to this matter, eight studies reported the severity in senior male handball players [1,19,22,23,30,39–41], three studies in senior female handball players [22,30,39], one study in youth male handball players [40], and one study in youth female handball players [43].

Injury mechanism was reported in seven studies (13 cohorts) [19,21–23,30,39,41] such as: six studies in senior male handball players [19,22,23,30,39,41], three studies in senior female handball players [22,30,39], one study in youth male handball players [21], and one study in youth female handball players [21].

3.2.4. Playing Position and Competition

A total of eight studies (11 cohorts) reported information of injuries differentiating between playing positions (i.e., goalkeeper, back, wing and line) [19,20,22,23,31,38,41,43]. In this regard, six studies reported the severity in senior male handball players [19,20,22,23,38,41], one study in senior female handball players [22], two studies in youth male handball players [20,31], and two studies in youth female handball players [31,43].

Attending to the competition type, eleven studies (25 cohorts) were performed during national leagues while four studies (8 cohorts) reported injury information related to international championships (i.e., Olympic games, World championship and Europe championship).

3.3. Methodological Quality Assessment

Table S1 shows the individual scores for the quality assessment. Values ranged from 22 to 28 points, with an average score of 25 points. Regarding the individual quality assessment, thirteen studies were categorized as excellent, while the two remaining studies were categorized as being of good quality.

4. Discussion

The aim of this systematic review was to analyze the injuries derived from handball practice in both training sessions and matches, differentiating by gender and age. Despite the growing interest in injures in handball [23], this is the first systematic review that summarizes the injury profile of handball players according to gender (i.e., male and female) and age (i.e., senior and youth). This knowledge could provide valuable information for detecting possible factors associated with injuries in different groups of handball players, aiming to facilitate the implementation of specific preventive strategies.

4.1. Injury Incidence: Overall, Training and Match

A key variable for understanding the impact of injuries on athletes is the incidence (i.e., number of injuries/1000 h exposure) [45]. In this sense, the handball players included in our systematic review presented values ranging between 1.7 and 7.8 injuries/1000 h exposure. Specifically, senior male handball players showed the highest value (i.e., near to 7.8 injuries/h exposure), while lower incidences were observed in female senior players (i.e., 6.2 injuries/h exposure), in male youth players (i.e., 6.9 injuries/h exposure), and in female youth players (i.e., 6.8 injuries/h exposure). These differences could be due in part to high-intensity and faster play speed reported during male senior handball practice [3,21]. According to this, differences between categories are accentuated when match incidence is analyzed. In this sense, senior male players match incidence range from 15 to 73.6 injuries/h match exposure, which are the greatest values compared to female senior players (i.e., 13–36 injuries/h exposure), male youth players (i.e., 14.9–32.7 injuries/h exposure) and female youth players (i.e., 10.8–23.8 injuries/h exposure). Although higher match incidence was highlighted for senior male players, similar training incidence was observed in all categories (i.e., between 0.96 and 4.1 injuries/1000 h training exposure). These reported values show that training incidence is substantially lower in comparison to match incidence in all groups, in line with those studies focuses on other team sports (e.g., soccer [32] or basketball [35]). These differences may be associated with several factors, for instance, the higher physical and physiological demands performed by players during matches compared to training sessions [46], the variability and uncertainly of the game, as well as the neuromuscular and mental fatigue generated during matches [47], or because of different training load quantification and periodization strategies [48]. Therefore, strength and conditioning coaches should focus on recreating the physical, technical, tactical, and psychological demands of competition during the training sessions, as well as implementing specific recovery strategies to reduce the negative impact of the matches (e.g., accumulated fatigue) on the handball players (e.g., excessive fatigue or uncertainly), and consequently, to reduce the injury risk [46].

4.2. Location and Type of Injuries

From a practical point of view, it is crucial to understand the injury locations to make effective decisions during the injury prevention process (Figure 3). In this regard, an overall analysis of the studies included in this systematic review revealed that the most common injured areas in handball players (considering all categories) were the lower limbs, representing between 40% and 77% of the total injuries [1,19,22,23,30,31,38,43]. This could be explained by the changes in game rules during recent years, which have made the rules regarding contact between players more restrictive (e.g., trunk use instead the body to block the opponent or prohibition of dangerous elbow use both as a starting position and when in motion). This fact has led to a reduction in high-intensity bumps, contacts and collisions that would previously have resulted in more frequent upper limb injuries [19]. Specifically, the knee and the ankle seem to be the most damaged areas (i.e., near to 20% in each of the two locations), due to the implication of these joints in specific patterns of the most common actions in handball (e.g., jumps, decelerations or landings). Nevertheless, some authors [22] have shown a great incidence of overuse injuries in the shoulders (44%), caused by the repetitive throwing gesture imposed in this sport. Likewise, low back overuse injuries presented a high injury incidence (39%), possibly due to the extreme actions related to collisions and landings [49]. With respect to gender-related differences, Giroto et al. [22] observed a greater number of knee injuries in female senior handball players compared to their male partners (i.e., 38 vs. 14 injuries) during one season follow-up. This could be based on the reported gender differences in knee anatomy [50] and in proximal control and kinematics variables during common handball tasks, such as running or landing [51,52]. These differences in knee injuries have not been reported in youth handball players, since maturational changes take place at these ages [53]. However, male youth players showed a higher incidence in head/face and shoulder injuries in comparison with their youth female counterparts (35 vs. 18), possibly due to the more aggressive behavior and more frequent contact between players observed in this population [21,27]. It could be interesting to perform future research studying the relationship between playing positions and injury location.

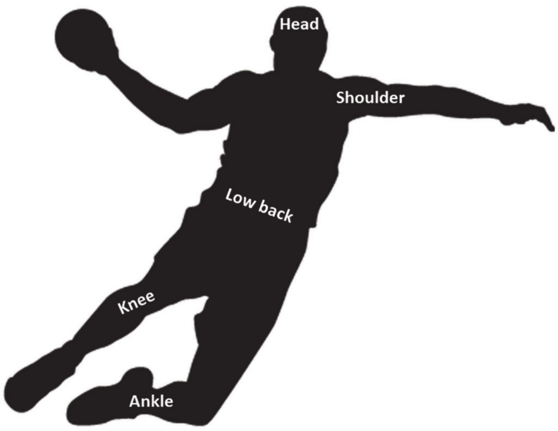

Figure 3. Locations with increased risk of injury.

With respect to the type of injury, similar patterns were observed between male and female senior handball players, with contusions and sprains being the most common. Nonetheless, studies referring to earlier championships (i.e., 2001–2003) [30] observed a higher prevalence of contusion injuries (i.e., near to 50%), possibly due to the rules changes mentioned above not having been implemented in those championships. On the other hand, Giroto et al. [22] reported that strains were the most common type of injury in male senior handball players (32.4%), perhaps influenced by the high physical demands during handball practice [28]. Additionally, in this study, also training injuries were analyzed, a fact that could underpin these results. Attending to youth populations, Asai et al. [31] showed a higher incidence in sprain injuries (128 injuries), with very high values compared to contusions (80 injuries). These differences with senior players could be due to youth players still not having a fully developed musculoskeletal system [54]. However, this finding should be taken with caution because of the lack of studies reporting injury type in youth handball players [31]. In this sense, further research investigating youth handball players, including information about injury location and type, is necessary to understand injury etiology and, subsequently, to propose specific preventive protocols for these populations.

4.3. Severity and Mechanism

Although injury incidence has been used as a quantitative parameter to analyze the impact of injuries [55], consequences of injuries should be assessed through the severity parameter to better understand their real impact [18]. In this sense, injuries with a duration of less than 7 days (i.e., 1–7 absence days) are the most commons in this systematic review. However, this evidence is relatively weak, because not all studies used the same criteria to classify injuries according to their severity. Specifically, in male handball players, including senior and youth, injuries of 1–7 absence days were reported as the most common, presenting values near to 65% of overall injuries [1,22,40]. Nevertheless, when international championships were analyzed (i.e., only values of match injuries are reported during congested periods) most injuries (near to 50%) resulted in 1–3 days of absence [19,30,39]. Despite male and female players showing similar results, a tendency to suffer more serious injuries (i.e., 7–28 absence days) was observed in senior and youth female handball players [22,43]. These findings seem to be imprecise, due to the aforementioned discrepancy with the severity classification; thus, it would be appropriate to present the value of burden (i.e., number of absence days/1000 h exposure) [18]. Regrettably, these studies only report incidence and severity, with the average number of absence days not being considered, so it was not possible to calculate the burden. Additionally, the availability (i.e., Σ of player match opportunities (number of team matches x squad size) —Σ of player match absences due to injury) is considered to be a new key indicator in sports injury research [12], although no data have been included in the selected studies. Therefore, further research assessing injuries through three different prisms (i.e., incidence, burden and availability) is necessary to help coaches to understand the meaningfulness of injury episodes in handball players across all ages, and thus to optimize the application of preventive programs.

Regarding injury mechanisms, acute injuries (i.e., those resulting from a specific and identifiable event) seem to be the most common in all the analyzed categories compared to overuse injuries (i.e., those caused by repeated micro-trauma without a single, identifiable event responsible for the injury), presenting values 55% to 85% of overall injuries [19,22,23,30,39]. These values are similar when comparing male and female handball players, although a higher percentage of acute injuries caused for a direct contact (e.g., collisions) were reported in male players, while female players suffer more acute injuries by no direct contact actions (e.g., landings) [22]. On the other hand, Piry et al. [41] reported specific mechanisms and observed that the most risky actions for these male senior handball players were plants and cuttings (28.57%), following of blocking (22.22%), shooting (20.63%), and turning (19.05%). With respect to youth handball players, only one study was included in our systematic review [21]. These authors reported similar values in male and female youth players, which were in line with values observed in senior players, with the acute injuries as the most common (75–80% of overall injuries). Even though acute injuries are difficult to prevent since they are mainly caused by collisions with teammates or opponents, instead it has been shown that neuromuscular training can reduce the incidence of overuse and non-contact injuries, as well as the burden derived from them [49].

4.4. Playing Position and Competition

The heterogeneity of criteria observed when classifying handball players according to playing position makes the comparison among studies difficult. In this regard, some authors only differentiated between goalkeepers and outfield players [31], other authors divided the players into goalkeepers, first line (i.e., backs and center backs) and second line (i.e., wing and line players) [20], while most studies classified players by specific playing positions (i.e., goalkeeper, backs, wing, and line) [19,22,23,38,41,43]. In spite of this limitation, the results observed in the included studies indicate that outfield players reported more injuries than goalkeepers in all the analyzed categories, ranging from 88% to 95%. Specifically, back [38] and wing [19,43] were the playing positions which presented the highest injury incidence, since each handball position is characterized by different tasks during practice [8]. However, this data must be taken with caution, because the majority of the studies reported the injuries in absolute values (i.e., percentage of total injuries); to clarify this point it is necessary to know the injury incidence (i.e., number of injuries/1000 h exposure) and the burden (i.e., number of absence days/1000 h exposure) to understand the magnitude of the injury pattern for each playing position. With respect to the type of exposure, Mónaco et al. [20] reported in male senior and youth handball players that first line players suffered a higher incidence during training, while the injury incidence during matches was greater in second line players. Although further studies focused on the injury incidence of each playing position are necessary, this information provides a novel knowledge to improve the implementation of specific preventive programs in handball players.

Handball competitions present different characteristics (e.g., play-off, congested schedule or use of players of the reserve team) that can influence the injury incidence of the players [56]. Therefore, it seems pertinent to analyze whether there are differences in the incidence during matches when the national league or international championships are played. In this regard, studies based on international championships showed higher injury incidence (from 30.9 to 50.5 injuries/1000 h match) in comparison to national leagues (from 15 to 31.7 injuries/1000 h match). These differences suggest the necessity of implementing specific injury prevention, load monitoring and recovery strategies to try to reduce the injury risk during international championships. Additionally, future studies should be performed in order to know the training incidence during the international championships to optimize the injury prevention process.

4.5. Limitations

This study is not exempt of limitations. Firstly, differences in classification of several variables such as severity or playing position complicate the comparisons among studies. In addition, none of the included studies reported injury incidence related to all variables, instead, they presented absolute and percentage values. Secondly, available literature related to youth handball players is scarce, especially for some variables such as injury mechanism, severity and playing positions. Finally, none of the included studies reported information regarding burden, absence days and availability, information that would improve the strength of this systematic review. On the other hand, the main value of this study is that allows to establish for the first time an overall evidence of incidence in handball, differentiating by age and gender, which are factors associated with injuries. This review is a key step forward for the development of specific preventive programs with handball players.

4.6. Practical Applications

In a practical approach, the findings observed in the present systematic review will make it possible to perform specific preventive programs attending to age and gender in handball players. In this respect, preventive programs should focus mainly on the riskiest locations and in the most prevalent type of injury for each group. Additionally, these programs should attend to the needs of each playing position and try to reproduce the most frequent injury mechanisms. Finally, due to the higher match incidence in all groups, training sessions should recreate the physical, technical, tactical, and psychological demands of competition in order to reduce the injury risk.

5. Conclusions

Handball players presented a higher injury incidence during matches than during training, with the male senior players having the highest overall values of training and match incidence. The lower extremities were the most commonly injured areas, with particular emphasis on the ankle and the knee for male players, and especially knee injuries in female players. Contusions and sprains were the most common type of injuries in senior female and youth handball players, while strains had a great incidence in male handball players. Injuries lasting fewer than 7 days were the most common in all the analyzed groups, although female players reported more serious injuries (i.e., 7–28 absence days). Acute injuries were more frequent than overuse ones, even though male players suffered a higher percentage of acute injuries caused by direct contact, while female players reported more acute injuries without contact. Regarding the playing position, wings and backs presented the highest percentages of injuries among playing positions. Finally, match injury incidence was higher during international championships compared to national leagues. All the included studies were categorized as having a good or excellent methodological quality, which therefore strengthens the conclusions of this systematic review.

Supplementary Materials: The following is available online at http://www.mdpi.com/1660-4601/17/11/3925/s1, Table S1: Methodologic quality of the included studies for handball players.

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Effect of HIIT with Tabata Protocol on Serum Irisin, Physical Performance, and Body Composition in Men

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Abstract: High-intensity interval training (HIIT) is frequently utilized as a method to reduce body mass. Its intensity of work results in a number of beneficial adaptive changes in a relatively short period of time. Irisin is a myokine and adipokine secreted to the blood during exercise and it takes part in the regulation of energy metabolism. It is a vital issue from the prophylaxis point of view as well as treatment through exercise of different diseases (e.g., obesity, type-2 diabetes). The aim of this study was to evaluate changes in irisin concentration, body composition, and aerobic and anaerobic performance in men after HIIT. Eight weeks of HIIT following the Tabata protocol was applied in the training group (HT) (n = 15), while a sedentary group (SED) (n = 10) did not participate in fitness activities within the same time period. Changes of irisin, body composition, and aerobic and anaerobic performance were evaluated after graded exercise test (GXT) and Wingate anaerobic test (WAnT) before and after eight weeks of training. Training resulted in an increased of blood irisin concentration (by 29.7%) $p < 0.05$), VO_{2max} increase (PRE: 44.86 ± 5.74 mL·kg^{-1}·min^{-1}; POST: 50.16 ± 5.80 mL kg^{-1}·min^{-1}; $p < 0.05$), reduction in percent body fat (PRE: 14.44 ± 3.33%; POST: 13.61 ± 3.16%; $p < 0.05$), and increase of WAnT parameters ($p < 0.05$) in the HT group. No changes were observed in the SED group. HIIT resulted in beneficial effects in the increase in blood irisin concentration, physical performance, and reduced fat content. The HIIT may indicate an acceleration of base metabolism. This effect can be utilized in the prevention or treatment of obesity.

Keywords: HIIT; power output; fat reduction; fitness; lean body mass; irisin; health; basal metabolism

1. Introduction

High-intensity interval training (HIIT) is a popular form of training among athletes that is used to further improve their level of physical activity from its already elevated state. However, HIIT has also aroused considerable interest among amateurs [1,2]. The basis of HIIT is to perform repeated maximum efforts with alternating rest breaks [3,4]. According to Kimm et al. [5], one of the main advantages of this form of training is its short duration and the variety of exercises, which prevents the sessions from becoming monotonous. Bartlett et al. [1] and Jung et al. [6] suggest that HIIT workouts can be a more enjoyable and attractive form of training compared to moderate-intensity continuous workouts utilized for weight reduction. As reported by Gibala et al. [7] and Gillen et al. [8], this training results in adaptive effects similar to low intensity endurance training along with increase of power and anaerobic capacity. Skally et al. [9] and Siahkouhian et al. [10] confirmed that HIIT training can be an alternative to traditional endurance training to bring beneficial physiological and biochemical changes in both healthy and diseased populations. Boutcher [11] and Shehata [12] reported that HIIT can be used as a weight reduction method, while others have reported improvements in blood lipid concentrations and cardiometabolic profiles among obese individuals [13,14]. Gillen et al. [8], Hood et al. [15], and Hoshino et al. [16] observed an increase in the oxidative potential of skeletal muscles after HIIT training. Rakobowchuk et al. [17] found after HIIT a greater glycogen content at rest, lower lactate (LA) production during the effort, improved lipid oxidation, and increased oxygen uptake. According to Stenman et al. [18], HIIT training also stimulates cognitive processes.

Recent evidence suggests that HIIT can be a time-efficient strategy to promote health in sedentary overweight/obese individuals. This may be contrary to the belief held by some health professionals that training programs at high intensity are not appropriate for optimizing fat oxidation and inducing weight loss in this population [19]. Alkahtani [20] observed improved fat oxidation rate in obese individuals after HIIT training. Other authors have reported an improvement in insulin sensitivity in sedentary patients [21] and increased glucose transporter-4 (GLUT-4) expression in individuals with diabetes [22] or reduction in body mass index (BMI) among obese and overweight individuals [23].

The rising popularity of high intensity training [24] including HIIT among athletes and amateurs is confirmed by the number of training programs available. Among these, the most popular training program is the Tabata protocol [25]. In its original version, the protocol consists of a 4 min workout, involving 10 s of rest for every 20 s of work. In this study, the improvement of aerobic and anaerobic performance was recorded. Authors recorded that the 6-weeks of training using high-intensity intermittent exhaustive exercise improved VO_{2max} by 7 $mL \cdot kg^{-1} \cdot min^{-1}$ and the anaerobic capacity by 28%. The spread of HIIT protocols has led to the emergence of various training modifications available on the fitness market [26].

During exercise, skeletal muscles secrete many different biologically active substances called myokines; among them is irisin, a fibronectin type III domain-containing protein 5 (FNDC5). Irisin is a relatively recently discovered myokine called an 'exercise hormone' [27] as well as an adipokine released by white adipose tissue [28]. Irisin is a protein consisting of 112 amino acids, released into the bloodstream under the influence of peroxisome proliferator-activated receptor gamma coactivator 1-alpha (PGC-1α) expression after proteolytic separation from FNDC5 [29]. Irisin expression has been primarily reported in skeletal muscles and adipocytes, and has also been expressed in the liver and kidneys [30]. Irisin alters the color of white adipocytes to brown and enhances fat combustion, which suggests that irisin increase may be useful for obesity therapy [31]. In adipose tissue cells, irisin stimulates the expression of uncoupling protein-1 (UCP-1) with PGC-1α and numerous genes of brown fat tissue adipocytes [32]. As a consequence, it contributes to an increase in energy expenditure and thermogenesis, which may result in an improved metabolic profile, increased sensitivity of cells to insulin, and intensified glucose and fat oxidation, especially in people with type 2 diabetes [33]. It also seems that irisin exerts an anti-atherosclerotic and neuroprotective effect [34].

In the literature, contradictory results have been reported related to changes in irisin levels in response to exercise programs. More specifically, changes in irisin concentration were not observed after 45 min of running [35] after 12-weeks of endurance training [36], or after 21-weeks of intensive endurance training [37]. However, these oppose the findings from Kraemer et al. [38] and Huh et al. [39] who reported transient elevations in irisin levels after prolonged moderate aerobic exercise, and after a week training with a sprints series, respectively. It has been also been reported that irisin levels increased significantly after one session of HIIT [40]. Additionally, Archundia et al. [41] observed an increase in irisin level after one HIIT session without changes after aerobic capacity. Given this evidence, we hypothesized that irisin level would increase in response to HIIT training.

Therefore, the aim of this study was to clarify whether 8-week HIIT according to the Tabata protocol would affect irisin secretion, aerobic and anaerobic physical capacity, and body composition in men with low physical activity who participated in recreational activities at a fitness club.

2. Material and Methods

2.1. Participants

The study involved 25 men randomly classified into two groups. The study group (HT) consisted of men (n = 15) with low physical activity who voluntarily participated in HIIT at a fitness club (age: 32.39 ± 6.63 years, weight: 81.01 ± 12.44 kg, height: 176.70 ± 7.44 cm, BMI: 25.75 ± 2.94 kg/m^2). Taking into account the average % FAT in this group, they were classified into normal weight men [42]. Prior to the study, they reported taking up physical activity only occasionally. For the duration of the 8-week experiment, they limited their physical activity solely to the exercises resulting from participation in HIIT. The initial number of participants in the HT group was twenty, however, within 8-weeks, five of them did not qualify. Two withdrew their participation during the training period because of the too high rigor and intensity, and the next three were excluded because of an absence above 10%. The sedentary group (SED) was comprised of men (n = 10) who did not undertake physical activity during the entire study period (age: 25.35 ± 3.28 years, weight: 79.05 ± 9.19 kg, height: 179.83 ± 4.08 cm, BMI: 24.16 ± 2.19 kg/m^2). Similar to the HT group, the sedentary group did not engage in regular physical activity prior to participation in this study. Exclusion criteria included: smoking cigarettes, diabetes mellitus, thyroid diseases, hypertension, joint pain, and musculoskeletal injuries. All participants declared a very good health status, which was confirmed by medical examination. Study participants were approved to engage in HIIT exercise after written agreement with a physician. On becoming familiar with all the conditions of the study, they provided their written consent to take part in the experiment and were informed that they could withdraw from the study at any stage. The study was approved by and performed in accordance with the recommendation of the Bioethics Committee of the University School of Physical Education in Wroclaw, Poland (date of approval 25/11/15). The studies were conducted in accordance with the Declaration of Helsinki.

2.2. Methods

At baseline and after the 8-week training, the participants' body composition was measured, fasting serum irisin concentration was determined first; on the second day, the anaerobic capacity was established; and on the last day, aerobic power was indicated on the basis of maximal oxygen uptake (VO_{2max}) in the order of actions presented in Figure 1.

Body composition analysis was performed in the morning between 8:00 am and 10:00 am, with the use of a BodyMetrix BX 2000 device (IntelaMatrix, Brendwood, CA, USA), in accordance with the manufacturer's instructions. Prior to testing, participants were instructed to maintain normal hydration, to abstain from the consumption of food and drink 4-h prior to testing, and exercise 12-h before testing. The following body composition parameters were measured: fat content (FAT/kg, % FAT) and lean body mass (LBM). Additionally, the LBM/FAT index was calculated. Each participant's body mass and standing height were measured to the nearest 0.1 kg and 0.1 cm, respectively, using medical scales (Radwag, Poland).

2.2.1. Aerobic Performance

Aerobic performance was assessed on the basis of VO_{2max}. For this purpose, the subjects' performed graded exercise test (GXT) on a treadmill (SEG-TA7720 treadmill, in SPORT line, Prague, Czech Republic). The test started at a speed of 6 km/h and the speed was increased by 2 km/h every 3 min. Each participant performed the test until failure (i.e., until developing fatigue and discomfort made it difficult to run at the imposed speed). Data were analyzed breath-by-breath and respiratory parameters (VO_2, VCO_2, VE) were registered with a Quark b^2 ergospirometer (Cosmed sri, Rome, Italy).

The device was calibrated with atmospheric air and with a gas mixture (5% CO_2, 16% O_2, and 79% N_2). The data of each inhalation and exhalation were averaged in 30 s intervals. During the GXT, maximal oxygen uptake VO_{2max} (mL/min) and VO_{2max} (mL/min/kg), maximal pulmonary ventilation (VE_{max}), tidal volume (TV), the time of the test duration, and maximal velocity (V_{max}) were assessed. The obtained VO_{2max} was confirmed using established physiological criteria [43]. Heart rate (HR) was measured continuously by telemetry with the use of a POLAR m 400 sport tester (Polar Electro OY, Kempele, Finland). Before and after the GXT, finger capillary blood samples were collected and LA concentrations were determined in 5 min of rest.

2.2.2. Anaerobic Performance

Anaerobic performance was evaluated on the basis of the Wingate anaerobic test (WAnT), performed on a cycloergometer Monark 894E Peak bike (Monark Exercise AB, Vansbro, Sweden). The Wingate test is a cycle test of anaerobic leg power, conducted over 30 s. This test was designed to measure the maximal anaerobic power and anaerobic capacity, which are extremely essential factors in sports with all-out efforts. Maximal anaerobic power reflects the maximal rate of anaerobic adenosine triphosphate (ATP) synthesis. Anaerobic capacity assessment is the maximal amount of ATP that can be supplied by anaerobic metabolism [44]. The load was individually selected and corresponded to 7.5% of the participant's body weight. The test was preceded by a 5-minute warm-up with a 50 W load. The following parameters were recorded: maximum power (P_{max}–*W; W/kg*), time to obtain P_{max} (T1), time of P_{max} maintenance (T2), mean power (P_{mean}), minimal power (P_{min}) generated in the last second of test, index of fatigue (IF), total work (TW–*kJ; J/kg*) during the test, and LA concentration measured 5 min after the test.

2.3. Biochemical Analysis

At baseline and after the 8-week training, a fasting basilic vein blood sample was collected between 8:00 am and 10:00 am on the day before laboratory testing. The blood was placed in a tube with rapid serum separation granules (Sarstedt, Poland). The blood was then centrifuged, serum was extracted, and the samples were frozen at a temperature of −80 °C. After obtaining the serum from all study participants, the samples were defrosted and irisin concentrations were determined.

In addition to the above fasting sampling, arterialized capillary blood was also drawn at rest (day 0) as well as on test days, before and 5 min after GXT and WAnT, to determine acid–base balance parameters (pH, pO_2, pCO_2, BE, HCO_3^-) by RAPIDLab 348 analyzer (Siemens Healthcare, Germany).

Serum irisin concentrations were assessed using the enzyme-linked immunosorbent assay (ELISA) with a reagent kit by BioVendor Laboratorni medicina (Brno, Czech Republic), in accordance with the manufacturer's instructions (intra-assay coefficient of variation: 6.90%, inter-assay coefficient of variation: 9.12%). The lowest detectable irisin concentration in the assay was 1 ng/mL, with an assay range of 0.001–5 μg/mL.

LA concentration in biochemical laboratory conditions was measured by means of the colorimetry method using an Lactate Cuvette Test kit (Hach Lange GmbH, Düsseldorf, Germany) in a Mini Photometer Plus LP20 (Dr. Lange, Germany). The normal range of values was 0.6–0.9 mmol/L. LA concentration during the training in the fitness club was assessed in capillary blood with the enzymatic amperometric method using the Lactate Scout system (RedMed, Warszawa, Poland). The assay range for the method was 0.5–25 mmol/L.

2.4. High Intensity Interval Training (HIIT) Training

The training lasted 8-weeks and was performed twice a week (Tuesday and Friday) between the evening hours of 20:00 and 21:00. Overall, 16 training sessions were carried out. Each session lasted 60 min and consisted of a 10-minute warm-up, a 40-minute HIIT training primary portion, and a 10-minute final stretching portion. During the main portion of the session, the participants completed eight exercise series in each training session. Each series lasted 4 min and consisted of eight repetitions of exercises with 20 s of work alternated with 10 s of rest [24]. The main goal of each training session was to perform exercises with maximum intensity. Each series was followed by a 1 min passive break. In each series, the subjects performed different systemic exercises in the following order: Series 1: lower limb muscle exercises (Squats with jumps); Series 2: dorsal muscles exercises (Back Extensions); Series 3: straight abdominal muscle exercises *(Crunches)*; Series 4: chest muscle exercises (Push-ups); Series 5: arm muscle exercises (Triceps Dips); Series 6: abdominal oblique muscle exercises (Side Crunch); Series 7: shoulder girdle muscle exercises (Military press with medicine ball); and Series 8: trapezius muscle exercises (Chin-ups). The final part of the training lasted 10 min and was devoted to calming and stretching exercises. The intensity of each training session was assessed by monitoring heart rate and was averaged for each participant and across entire session. For this purpose, the Polar Team 2 (Kempele, Finland) measuring equipment was used. The energy expenditure was calculated based on the session's HR of each participants and averaged. Previously, the relation between VO_2 and respiratory quotient (RER) and HR and VO_2 was established from the GXT results and energy expenditure calculated.

Additionally, finger capillary blood samples were collected in order to determine the LA concentrations. These samples were collected 5 min after the main portion of the second training. The training schedule is shown in Figure 1.

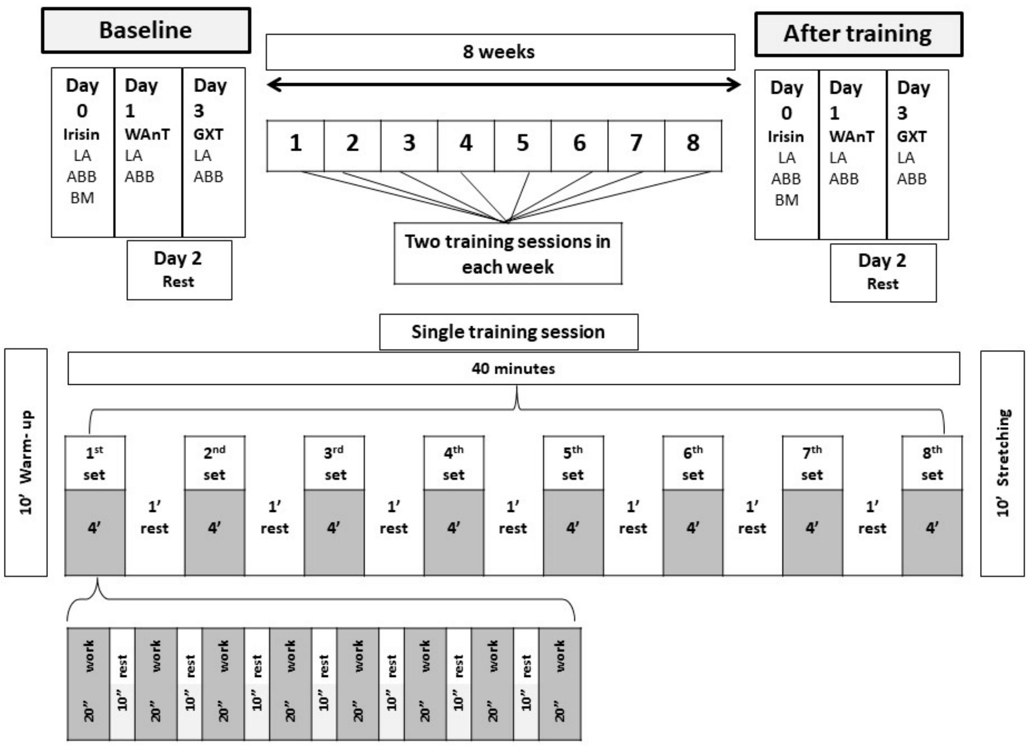

Figure 1. Scheme of the training sessions. LA = Lactate, ABB = Acid–Base Balance, BM = Body mass.

2.5. Statistical Analysis

The statistical analysis of the obtained results was performed with Statistica 13.0 software (TIBCO, Palo Alto, CA, USA). The sample size (n = 25) for two samples and effect size (0.8) resulted in power (0.79), and the study group proportion 0.7/0.3 showed an optimal group sample size of n = 24. Normality of distribution was assessed with the Shapiro–Wilk test. The training intensity and LA level was analyzed using the analysis of variance (ANOVA) for repeated measurements in the training sessions and training weeks (intensity/LA × week/set), followed by the Student's t-test to identify the point of differences between variables. The Student's t-test was used to evaluate the differences between anthropometric, condition, and LA and irisin variables at baseline and post-intervention.

Between-group differences were established with the use of the Mann–Whitney U test. The Pearson's correlation was used to check the irisin correlation with the other parameters of acid–base balance and both adopted performance tests. The level of $p < 0.05$ was assumed as statistically significant.

3. Results

A total of 16 training sessions were performed, with the total working time equaling 80 min each week with associated energy expenditure averaging 882.46 ± 34.25 kcal/week. Training intensity was measured on the basis of heart rate and expressed as % HR_{max} obtained from the GXT. The intensity of work during each training session is shown in Figure 2.

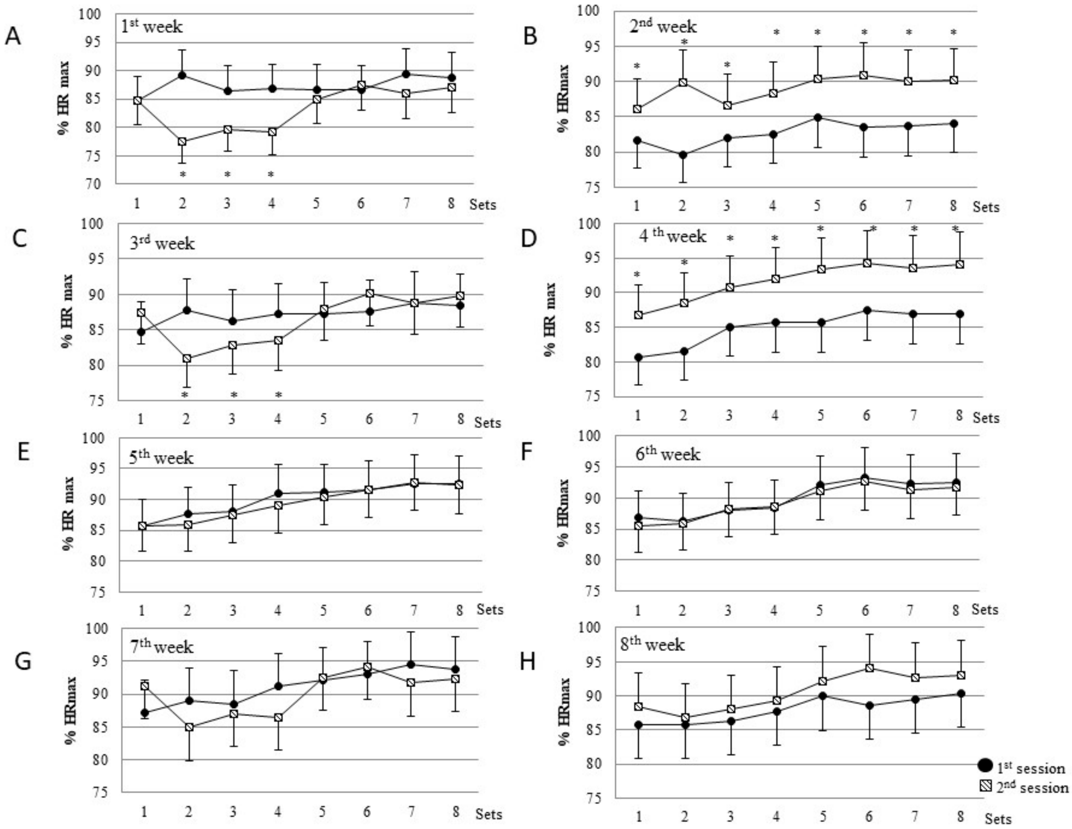

Figure 2. Mean intensity of eight sets in each training session during eight weeks training expressed as % HR_{max}. (**A**–**H**) present the intensity of all eight training sets during the first session in the week (black circle) and second session in the week (dotted square) * $p < 0.05$ in comparison to the same sets during the first training session (Student's t-test). HR = hart rate.

In the first and third week, the second training session was characterized by a significantly lower intensity of work (Figure 2A,C). In these weeks, the mean HR_{max} of work in series 2, 3, and 4 was lower than 80% HR_{max}. In the third training week, the lowest intensity of work was observed, which also corresponded to the lowest LA concentration value after training sessions during the 8-weeks of training (Figure 3). In the second and fourth week, the intensity of the second training session was higher than that of the first session and varied between 87–95% HR_{max} (Figure 2B,D). No significant differences in intensity between the two training sessions were observed after the fifth week of HIIT (Figure 2E–H). The heart rate during both weekly training sessions remained within the range of 85–95% HR_{max}.

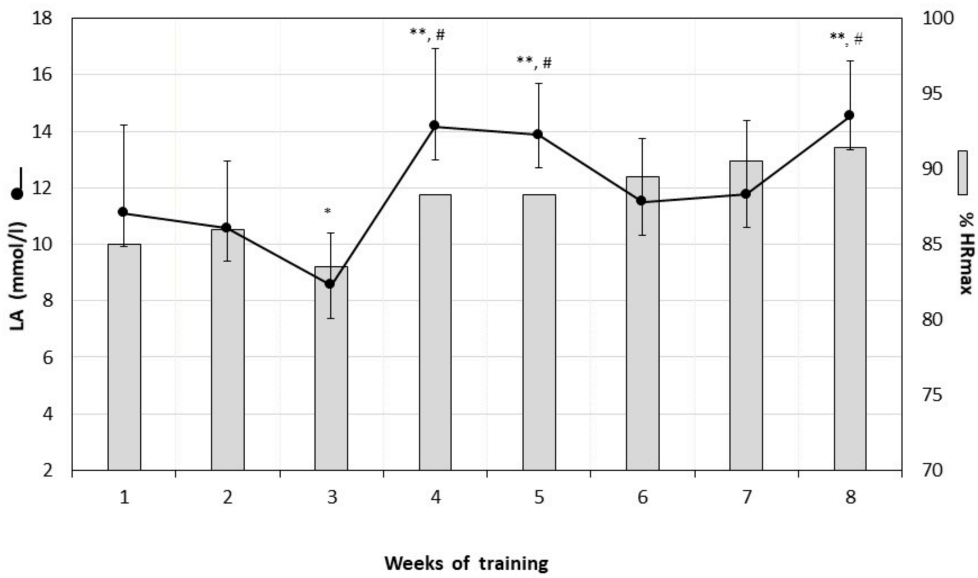

Figure 3. Mean lactate level after two training sessions in each training week and mean % HR_{max} of the two training sessions in each training week. * $p < 0.05$ in comparison to lactate after the first; second; sixth; seventh training weeks; ** $p < 0.005$ in comparison to the third week; # $p < 0.01$ in comparison to the first; second; sixth and seventh weeks of training (Student's t-test for dependent values). LA = lactate, HR = heart rate.

LA concentration, measured every week after the training session, exceeded the value of 12 mmol/L, with the exception of the third week, in which the lowest LA concentration was recorded after training, along with the lowest work intensity assessed as HR_{max}.

After the 8-weeks of HIIT, reduced body weight ($p = 0.032$), reduced FAT (*kg*) ($p = 0.043$), % FAT ($p = 0.018$), and increased LBM ($p = 0.047$) were observed in the HT group (Table 1).

Table 1. Chosen anthropological and physiological parameters at the baseline and after 8-weeks of training.

Groups	HT			Sedentary			HT vs. Sedentary	
Variable	Baseline	8 Weeks	*p*	Baseline	8 Weeks	*p*	Baseline	8 Weeks
Body mass (kg)	81.01 ± 12.44	79.05 ± 9.19	0.032	79.03 ± 12.05	79.70 ± 9.69	0.243	0.342	0.346
LBM (kg)	64.37 ± 9.58	68.62 ± 9.50	0.047	67.34 ± 8.36	67.72 ± 8.69	0.156	0.254	0.432
FAT (kg)	11.64 ± 4.05	10.43 ± 3.61	0.043	10.92 ± 3.42	11.32 ± 3.72	0.046	0.044	0.087
% FAT	14.44 ± 3.33	13.61 ± 3.16	0.018	12.44 ± 3.97	13.00 ± 4.21	0.096	0.009	0.324
% LBM	84.56 ± 3.37	86.39 ± 3.95	0.028	87.55 ± 6.79	72.34 ± 8.5	0.047	0.010	0.012
LBM/FAT (kg)	1.53 ± 0.70	1.85 ± 0.81	0.041	1.66 ± 0.60	1.59 ± 0.57	0.213	0.432	0.047
VO_{2max} (mL/min)	3658.10 ± 487.04	3982.07 ± 575.95	0.028	3962.00 ± 568.19	4001.23 ± 695.33	0.102	0.021	0.134
VO_{2max} (mL/kg/min)	44.86 ± 5.74	50.16 ± 5.80	0.005	47.16 ± 5.01	47.73 ± 5.07	0.231	0.432	0.059
VE_{max} (L/min)	139.52 ± 23.58	146.70 ± 24.68	0.048	151.50 ± 22.35	153.04 ± 25.31	0.212	0.040	0.062
HR_{max} (b/min)	185.30 ± 8.14	186.33 ± 6.89	0.193	190.11 ± 9.65	190.78 ± 7.81	0.342	0.254	0.102
VT (L/min)	2.86 ± 0.55	2.97 ± 0.69	0.124	2.87 ± 0.71	2.72 ± 0.57	0.143	0.110	0.231
V_{max} (km/h)	16.60 ± 2.32	17.11 ± 1.76	0.049	17.71 ± 1.38	17.95 ± 1.65	0.219	0.231	0.232
Time to exhaustion (min)	16.40 ± 2.94	17.31 ± 2.79	0.005	17.34 ± 1.60	16.90 ± 1.69	0.025	0.097	0.058

The values shown as the mean ± SD; Student's t-test for dependent values between baseline and eight weeks and Student's t-test for independent value between groups. HIIT = high intensity interval training, LBM = lean body mass, HR = heart rate, VO_2 = oxygen uptake, V_{max} = maximum velocity, VT = tidal volume, VE = pulmonary ventilation. HT = group performing high intensity interval training.

At baseline, a significant difference in FAT between the both groups was noted. The HT group was characterized by having considerably higher fat content, and lower LBM compared to the sedentary group. After the 8-weeks of training, body weight in the HT group decreased and fat content was reduced by 10%. There was also a significant reduction in BMI in the HT group without changes in the SED group (25.75 ± 2.94 kg/m^2 to 25.24 ± 2.84 kg/m^2; p = 0.035). In addition, LBM and the LBM/FAT index increased in the HT group. After 8-weeks, the SED still presented lower BMI values than those before or after the training in group HT; however, there was no difference in fat content between the two groups. In the SED, % LBM turned out to be significantly lower after 8-weeks compared with the baseline values. When analyzing aerobic capacity before training, we observed that VO_{2max} was significantly lower in the HT group compared to the SED group However, after 8-weeks of HIIT, the aerobic capacity in the HT group significantly improved (Table 1). There was no difference in VO_{2max} between the groups after eight weeks. In the HT group, VO_{2max} increased by 11%, while maximum ventilation and maximum tidal volume were also increased. Additionally, the HT group increased the length in the progressive test performance period. With regard to the WAnT results, a significant improvement in speed and strength abilities among the HT group participants was observed. A significant increase of P_{max} (W and W/kg) and shortening of the time to obtain P_{max} were noted. LA concentration was significantly lower following the test (Table 2).

Table 2. Wingate test parameters at baseline and after 8-weeks of training.

Groups	HT			Sedentary			HT vs. Sedentary	
Variables	**Baseline**	**8 Weeks**	***p***	**Baseline**	**8 Weeks**	***p***	**Baseline**	**8 Weeks**
P_{max} (W)	794.2 ± 125.9	825.6 ± 127.4	0.046	840.3 ± 67.9	836.4 ± 68.8	0.043	0.031	0.437
P_{max} (W/kg)	10.23 ± 0.64	11.87 ± 0.67	0.032	10.56 ± 0.66	10.46 ± 0.42	0.324	0.543	0.032
T_1 (s)	4.84 ± 1.62	3.79 ± 0.93	0.037	4.71 ± 1.47	4.11 ± 0.65	0.049	0.231	0.031
T_2 (s)	3.45 ± 1.90	3.09 ± 1.12	0.143	3.41 ± 1.77	2.96 ± 0.75	0.132	0.432	0.237
P_{end} (W/kg)	6.51 ± 0.59	6.35 ± 1.55	0.212	6.41 ± 0.55	6.43 ± 0.62	0.345	0.453	0.543
P_{mean} (W/kg)	8.07 ± 0.69	8.09 ± 1.55	0.103	8.33 ± 0.48	8.28 ± 0.43	0.372	0.076	0.067
IF (%)	24.03 ± 4.85	24.12 ± 3.90	0.324	22.72 ± 5.14	23.63 ± 2.17	0.105	0.003	0.049
TW (kJ)	19.03 ± 2.53	18.86 ± 2.64	0.097	19.91 ± 19.54	19.54 ± 1.66	0.432	0.231	0.067
TW (J/kg)	240.14 ± 13.08	240.72 ± 17.08	0.342	252.85 ± 14.64	242.76 ± 16.50	0.041	0.040	0.342
LA (mmol/L)	11.5 ± 1.5	10.11 ± 1.7	0.022	9.3 ± 2.2	9.2 ± 2.0	0.436	0.032	0.012

Values shown as the mean ± SD; Student's t-test for dependent values between baseline and eight weeks into group, and the Student's t-test for independent value between groups. LA = lactate, TW = total work, IF = index of fatigue, P = power, T_1 = time to reach P_{max}, T_2 = time to maintain P_{max}. HT = group performing high intensity interval training.

Before training, resting irisin concentration in the HT group was significantly lower than in the SED group (Figure 4). After 8-weeks of training, however, the irisin concentration increased significantly (29.7%) in the HT group and remained unchanged in the SED group. No correlation between irisin concentration and body composition parameters was observed; however there was a relationship between irisin concentration and pO_2 (r = 0.48; p = 0.003) measured in day 0 during the fasting stage.

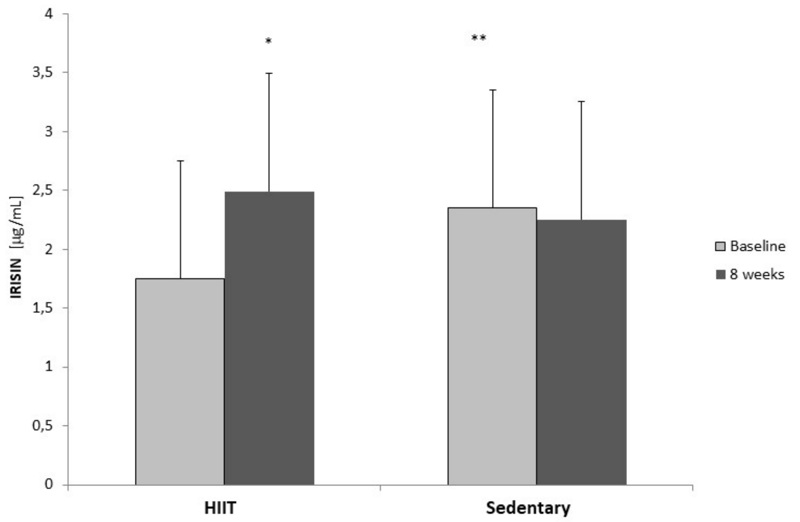

Figure 4. Irisin level in HT and sedentary group at the baseline and after eight weeks; * $p < 0.05$ in comparison to baseline value: ** $p < 0.05$ in comparison to the HT baseline group (Mann–Whitney U-test).

4. Discussion

In this study, improvement in cardiopulmonary performance was observed after 8-weeks of HIIT in the training group of men. In addition, changes in body composition parameters and an increase in blood irisin concentration were shown. Overall, VO_{2max} increased by 11%, fat content was reduced by 10%, and irisin concentration raised by 29%. This translated into increased LBM and LBM/FAT index, lengthened work period during the progressive test under conditions of severe acidosis, and improved speed and power generated by muscles in the Wingate test. This means that the HT participants were able to perform more work in the progressive test compared to their sedentary counterparts. Therefore, we can confirm our hypotheses and recommend this HIIT protocol for men with normal or high fat content in the body mass. According to Roca-Rivada et al. [28], in cases of abnormal BMI, obesity, or overweight, fat tissue can be a significant source of irisin. In this study, the men in the HT group had BMI values higher than normal when compared to the sedentary group at the beginning of the study. Despite this, irisin concentration was lower in this group than in the sedentary group, with BMI values falling within the physiological norm, which may be due to the LBM in both groups. In the sedentary group before training, the LBM and % LBM was higher in comparison to the HT group. After the eight weeks, this parameter in sedentary group did not change while in the HT group, the LBM significantly improved.

The influence of different forms of physical activity on irisin concentration is not clear. In this study, irisin concentration increased by 30% after 8-weeks of training and was correlated with pO_2. Huh et al. [39] indicated that irisin concentration increased in less than 5 min after high intensity interval exercise, remained high after 1 h, and then returned to the baseline and correlated with exercise intensity. They also reported that baseline irisin levels were lower in old (vs. young) and physically active (vs. sedentary) subjects. Murawska-Cialowicz et al. [45] noted significantly higher irisin values in women compared with men as well as a lower concentration after 3-months of CrossFit training among women only, without significant changes in men. This was accompanied by a reduction in fat content and an increase in LBM in women. The authors believed that perhaps the higher irisin concentration in women before training resulted from a higher % FAT, which was reduced after training. Stengel et al. [46] reported that irisin concentration was higher in obese patients than in normal body weight and anorexic patients. Moreover, in their studies, irisin showed a correlation with fat mass, BMI, and insulin level. As reported by Timmons et al. [47] irisin is not always stimulated by effort. Additionally, older, and not younger, physically active people are characterized by 30% higher expression of the *FNDC5* gene compared to those with a sedentary lifestyle. Kurdiova et al. [48] also did not find that a 3-month workout in overweight and obese individuals increased *FNDC5* expression in skeletal muscles or blood irisin concentration. In contrast to these studies, Düunwald et al. [33] revealed a significant increase in blood irisin concentration in obese individuals with type 2 diabetes subjected to HIIT training.

The heterogeneous direction of changes in irisin concentration after exercise reported in various authors' studies may be caused by the study procedure and the time of collecting blood samples after effort. In the research presented in this paper, blood was collected 15 min after test completion. In the study by Dascalopoulou et al. [49], an increase in irisin concentration was observed after various types of effort but remained unchanged immediately upon cessation and for as long as 24 h. Similarly, Norheim et al. [36] reported an increase in the hormone concentration immediately after the effort discontinuation. It seems that the season in which the investigation is carried out may also affect the results, as seasonal variation of irisin secretion was found with peaks in winter (January, February) and in summer (July, August) [50].

Relating our results to the values presented in the available literature, one may presume that the changes of resting irisin concentration in the experimental group were influenced by the increase in aerobic capacity levels. It can be assumed that the increase in irisin concentration is stimulated by oxygen deficiency and glycolytic rate during very short intensive exercise. These anaerobic conditions contribute to mitochondrial biogenesis and thus to increased oxygen uptake and fat disposal. The direction of post-workout irisin concentration changes could also confirm the influence of HIIT training on the improvement of oxygen performance and fat tissue reduction and LBM enlargement.

In our study, a significant increase in maximum power and a shorter time to reach it were observed after the end of the training period in the group subjected to the interval training (reduction by 12%). The same direction of change after eight weeks of HIIT was reported by Foster et al. [51]. These changes indicate an improvement in the participants' phosphagen power, which can result from an increase in LBM as well as improvements in the maximum rate of phosphocreatine (PCr) consumption, the main determinant of phosphagen power. This depends primarily on the composition of muscle fibers and the degree of their adaptation. Burgomaster et al. [52] achieved raised PCr and ATP concentrations after HIIT training. HIIT training according to the Tabata protocol is characterized by high intensity work alternated with short rest breaks, during which the body is not able to fully regenerate before the next repetition of the effort. Due to the short restitution, the workout may resemble continuous training with variable intensity in heart rate responses. This in turn promotes oxygen capacity development and an increase in VO_{2max}.

It can be assumed that the increase in irisin concentration may be stimulated in metabolic acidosis conditions and glycolytic rate during very short intensive exercise. These anaerobic conditions contribute to mitochondrial biogenesis and thus to increased oxygen uptake and fat disposal [31]. The direction of post-workout irisin concentration changes could also confirm the influence of HIIT training on the improvement of oxygen performance and fat tissue reduction and LBM enlargement. In our study, the 8-week training resulted in body weight reduction and higher LBM values in the HT group. Trapp et al. [53] recorded a similar reduction in overall body weight during their 8-week interval training program. These changes took place with a simultaneous VO_{2max} increase.

VO_{2max} changes after interval exercises have been reported by numerous authors. Among them, Talanian et al. [54] implemented a program of 10×4 min of work/2 min of rest for two weeks. Burgomaster et al. [52] noted improvements in oxygen uptake after only 6-weeks of HIIT. As shown by Wasserman et al. [55], a higher value of oxygen uptake allows for a larger volume of oxygen extraction from inhaled air as a result of the respiratory system adaptation. This change was also observed in our research. The average increase in the ventilation value equaled 7.18 L/min, which significantly contributed to the rise in VO_{2max}. Our sedentary group started the program with higher VO_{2max} in L/min (Table 1), which was not different than the slightly older HT group after the intervention, thus we still can anticipate some improvement in the HT group.

In the current study, the training intensity was in the range of 80–95% HR_{max}. LA concentration after training, especially in the last training weeks, varied between a range of 10–14 mmol/L. Such intense training provoked the glycolytic rate to lactate and forced the body to adapt.

In our study, higher LA concentrations were observed in subsequent training weeks. This may prove that the participants were able to use the energy from glycolytic transformations for a longer time and were more efficient at removing LA from the muscle cells and releasing it into the blood. Such a change in direction indicates an improvement of the blood buffer capacity and tolerance of metabolic acidosis induced by work, promoting the use of anaerobic glycolysis as the main metabolic pathway. There is evidence that anaerobic conditions induce the glycolytic rate during exercise and HIF-1 (hypoxia inducible factor-1) facilitates the expression of glycolytic genes that encode phosphofructokinase (PFK), a key enzyme in glycolysis. This contributes to an increase in muscle glycolytic capacity [56–60]. Summer matter et al. [61] indicated that interval training increased the number of LA transporters: monocarboxylate transporter-1 (MCT-1) and MCT-4. Research shows that HIF-1 raises the expression of MCT-4, the isoform predominant in glycolytic fibers that facilitates LA removal from these fibers, and MCT-1, the isoform predominant in oxidative fibers, facilitating LA pick-up and disposal [58]. The lower LA concentrations in our study observed after the WAnT in the second post-interval training assessment can be explained by higher PCr resources that prevent the additional glycolytic need. This is different than other research protocol, where Perry et al. [62] observed increased LA concentrations in blood plasma after a 6-week HIIT program. This change indicates a raised tolerance of metabolic acidosis and a greater share of glycolytic transformations in energy supply. These differences might be due to the duration of intervention and participant condition before the intervention. On the other hand, the HR group increased the LA production during the HIIT sessions.

We have attempted to diminish the limitations of this research to the best of our ability. However, we acknowledge the small sample size, which may limit the applicability of our findings. Nonetheless, the results of this research may be utilized for future studies to calculate effects sizes and future sample sizes. In addition, it may be that the Tabata protocol used in this study may be very strenuous for individuals with low physical fitness levels (i.e., overweight or obese); thus, future studies should consider modifying the training protocol to make it more appropriate for individuals enrolled in the study. Finally, our study evaluated male individuals who, although considered overweight, were relatively healthy. Future studies should consider implementing this type of training with women and individuals with different BMI to more properly evaluate the effects of this type of training in these populations. Another limitation might be in the approach to VO_2 testing, where current recommendations are the use of breathing averaging [63], which was not applied in our study. On the other hand, the main strength of this study is in the high control of the intervention.

5. Conclusions

HIIT training significantly affected blood irisin concentration, which likely resulted from the improvement of the participants' oxygen performance and changes in their body composition, namely the reduction of FAT and increase of LBM. The training was beneficial in improving aerobic and anaerobic capacity, proving that it also has a high application value for improving physical performance. Implementation of a HIIT program in men with low physical activity resulted in improved aerobic and anaerobic performance and higher fat reduction. HIIT increased irisin levels, helping in fat utilization. Our results could be implemented in practice as a form of therapy for individuals with low physical activity, are overweight, and have metabolic disorders. To our knowledge, this is the first study relating the influence of HIIT programing over an 8-week period among low physically active men. Our study showed that HIIT exercise with a Tabata protocol provided significant improvements in physical performance, body composition, and irisin concentration in men. Further research should be conducted to elucidate the effects of HIIT programs among individuals of different sexes and genders as well as among individuals with different BMIs and % FAT, and in a larger population to further evaluate its effectiveness in the prevention and treatment of metabolic disorders.

Author Contributions: E.M.-C., D.G., and P.W. designed the study. D.G., P.W., and J.Z.-J. collected the data and performed the statistical analysis. E.M.-C., P.W., D.G., Y.F., and P.S. analyzed and interpreted the data and drafted the manuscript. E.M.-C., Y.F., J.K., M.P., and P.S. critically revised the paper. All authors discussed the results and contributed to the final version of the article. All authors have read and agreed to the published version of the manuscript.

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Review

Identification, Computational Examination, Critical Assessment and Future Considerations of Distance Variables to Assess Collective Tactical Behaviour in Team Invasion Sports by Positional Data: A Systematic Review

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Abstract: The aim of the study was the identification, computational examination, critical assessment and future considerations of *distance* variables to assess collective tactical behaviour in team invasion sports by positional data. A total of 3973 documents were initially retrieved. Finally, 72 articles met the inclusion criteria, but only 26 suggested original tactical variables based on the *distance* variables. The *distance* variables can be classified into player–player, player–space, player–ball, and Geometrical Centre (GC)–GC /player/space/goal. In addition, several nonlinear techniques have been used to analyse the synchronisation and predictability of the *distance* variables in team invasion sports. Player–opponent *distance* is of special interest in those sports in which man-marking is commonly used, and in the micro-structure close to scoring situations in all sports. In addition, player–player distances are used to measure the length and the width of the team and player–GC *distance* to assess the dispersion of the team. Player–space distances have been measured to assess the *distance* of the player/team-line to relevant areas of the playing space. Several techniques have been applied to analyse the synchronisation (i.e., Hilbert transformation and cluster analyses) and the complexity and regularity or predictability (i.e., approximate entropies, sample entropy, cross-sample entropy and average mutual information) of the *distance* variables in team invasion sports, revealing the lack of consensus. Although the *distance* variables may be interesting tactical variables when considered in isolation, it would be enriching to analyse the relationship among these variables.

Keywords: team behaviour; tactic; dyad; entropy; relative phase

1. Introduction

Although all players constantly interact with one another during team invasion sports matches and tasks, the nature [1] of these interactions differs considerably, according to the location of the ball [2,3], the location of players with respect to the goal [4,5], and the team in possession of the ball [6,7]. For this reason, the decomposition of the team into micro-structures (or sub-systems [1]) has been suggested in order to assess team behaviour. This decomposition means a reductionist approach [1] of the social system (i.e., a collective duel) [8–10], but allows analysis of relevant and special interactions among several players. Tactical behaviours can be assessed at the individual, dyadic, sub-group (e.g., sectorial) and/or team level [9,11–13]. One of the most analysed micro-structures in team invasion sports has been the dyad [11–13].

Based on studies of racket games [14], the assessment of the interaction of two players (i.e., *distance* variables) has been suggested through the measurement of the *distance* between both players (i.e., player –player, and player–opponent) [4,5,15–20]. In addition, several studies have considered the *distance* of the players in a particular zone of the pitch; that is, they have measured several player–space distances [5,21,22]. After more than twenty years, many types of *distance* variables have been used to assess team behaviour in team invasion sports [4,5,7,16–18,20,21,23–27]. However, it would be interesting to classify and analyse these *distance* variables in order to assess their practical application in team invasion sports training and matches.

The inherent complexity of team invasion sports [28] suggests the use of nonlinear tools to analyse the synchronisation and predictability of the *distance* variables [12]. These types of analysis are essential to understanding the dynamics and the performance in team invasion sports [28]. Based on previous studies that examine bimanual coordination [29] and periodic movements with one limb while watching each other [14], Palut and Zanone [14] computed the relative phase to assess epoch synchronisation in tennis. This was suggested as a collective variable to capture the modes of movement that two oscillators demonstrate during games (i.e., in-phase and anti-phase [14]). The relative phase has been widely used to assess the synchronisation between several types of oscillators [2,15,30,31]. On the other hand, several measures of entropy [28] have been proposed to assess the results, the complexity, the regularity or the predictability of the time series of a system [17,19,20,32] of nonlinear dynamical systems as an example (i.e., team invasion sports [19]). While a decrease in entropy reflects a decrease in unpredictability, a high entropy means that the minimum information necessary to describe the system has increased with system variability and its behaviour is more unpredictable [28]. Thus, it is necessary to review the origin, application [33], and different mathematical concepts and computations applied [19,30] to identify the differences in the measurement of the relative phase and entropy in the *distance* variables.

The aim of the present study was the identification, computational examination, critical assessment and future considerations of *distance* variables to assess collective tactical behaviour in team invasion sports by positional data.

2. Materials and Methods

2.1. Search Strategy

This systematic review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines [34]. The protocol was not registered prior to initiation of the project and did not require Institutional Review Board approval. A systematic search of four databases was performed by the authors (MR, ALA, JPO) to identify articles published before 13 November of 2018. The authors were not blinded to journal names or manuscript authors. The PICO [34] design was used to provide an explicit statement of question. The search was carried out using two filters where the database allowed this (journal article and title (TI)/abstract), except in WoS, which was searched throughout the text. In addition, in the last-mentioned database in the sports sciences branch was selected. The search was made using combinations of the following terms linked with the Boolean operators "AND" (inter-group Boolean operator) and "OR" (intra-group Boolean operator). Three main groups were created: (1) "Soccer", "football", "team sport*", "basketball", "rugby", "handball", "hockey"; (2) "GPS", "global position system*", "GNSS", "Global navigation satellite system*", "UWB", "ultra wide band", "local position", "LPP", "LPS", "LPS", "EPTS", "electronic performance and tracking systems*", "video", "video tracking", "tracking system*", "electronic*", "satellite system*", "GIS", "geographical information system*"; and (3) "formation*", "tactic*", "behaviour*", "performance*", "position*", "spatiotemporal", "spatio-temporal", "synchronization*", "coordination*", "pattern*", "synerg*", "Voronoi", "Delaunay", "decision-making", "decision making".

2.2. Screening Strategy and Study Selection

When the referred authors had completed the search, they compared their results to ensure that the same number of articles had been found. Then, one of the authors (MR) downloaded the main data from the articles (title, authors, date, and database) to an Excel spreadsheet (Microsoft Excel, Microsoft, Redmond, USA) and removed the duplicate records. Subsequently, the same authors screened the remaining records to verify the inclusion/exclusion criteria, using a hierarchical approach in two phases: Phase 1, titles and abstracts were screened and excluded by two authors (MR, ALA) against criteria 1–5 where possible; Phase 2, full texts of the remaining papers were then accessed and screened against inclusion criteria 1–5 by the same authors (MR, ALA). The papers that were included after these phases and met the 6th inclusion criteria were included in the systematic review. The inclusion criteria were: (1) Team sports in which the use of the mobile (e.g., ball, puck) is simultaneous (e.g., soccer, hockey); (2) The main objective of the study is to assess tactical performance or dimension in team players; (3) Studies that include a tactical variable regarding the position of the players using Electronic Performance and Tracking Systems (EPTS); (4) Studies that aim to measure a tactical variable; (5) Studies that aim to analyse the position of more than one player, whether they are rivals or not; (6) Studies that measured the *distance* variables or modified this variable, and provided their computational criteria. The studies included in the review met all inclusion criteria. The quality of the included studies was individually assessed using a modified Downs and Black checklist by Sarmento et al. [35].

Any disagreements on the final inclusion/exclusion status were resolved through discussion in both the screening and excluding phases. Moreover, relevant articles not previously identified were also screened in an identical manner and the studies that complied with the inclusion/exclusion criteria were included and labelled as 'not identified from search strategy'.

3. Results

A total of 3973 documents were initially retrieved, of which 1779 were duplicates. A total of 2178 articles were screened. Next, the titles and abstracts were verified against criteria 1–5 and studies were excluded where possible. The full texts and abstracts of the remaining articles were screened and the inclusion/exclusion criteria were applied, leading to the exclusion of 2142 articles. Therefore, 36 articles were initially included in this review having met the inclusion criteria 1–5. In addition, the authors found and added 36 articles that met inclusion criteria 1–5. Finally, 72 works were analysed and 26 articles were included in the systematic review after meeting the 6th inclusion criterion (Figure 1). Among them, eighteen were originals or showed modification of *distance* variables (Tables 1 and 2) and twelve were originals or proposed modifications of non-linear techniques (Table 3).

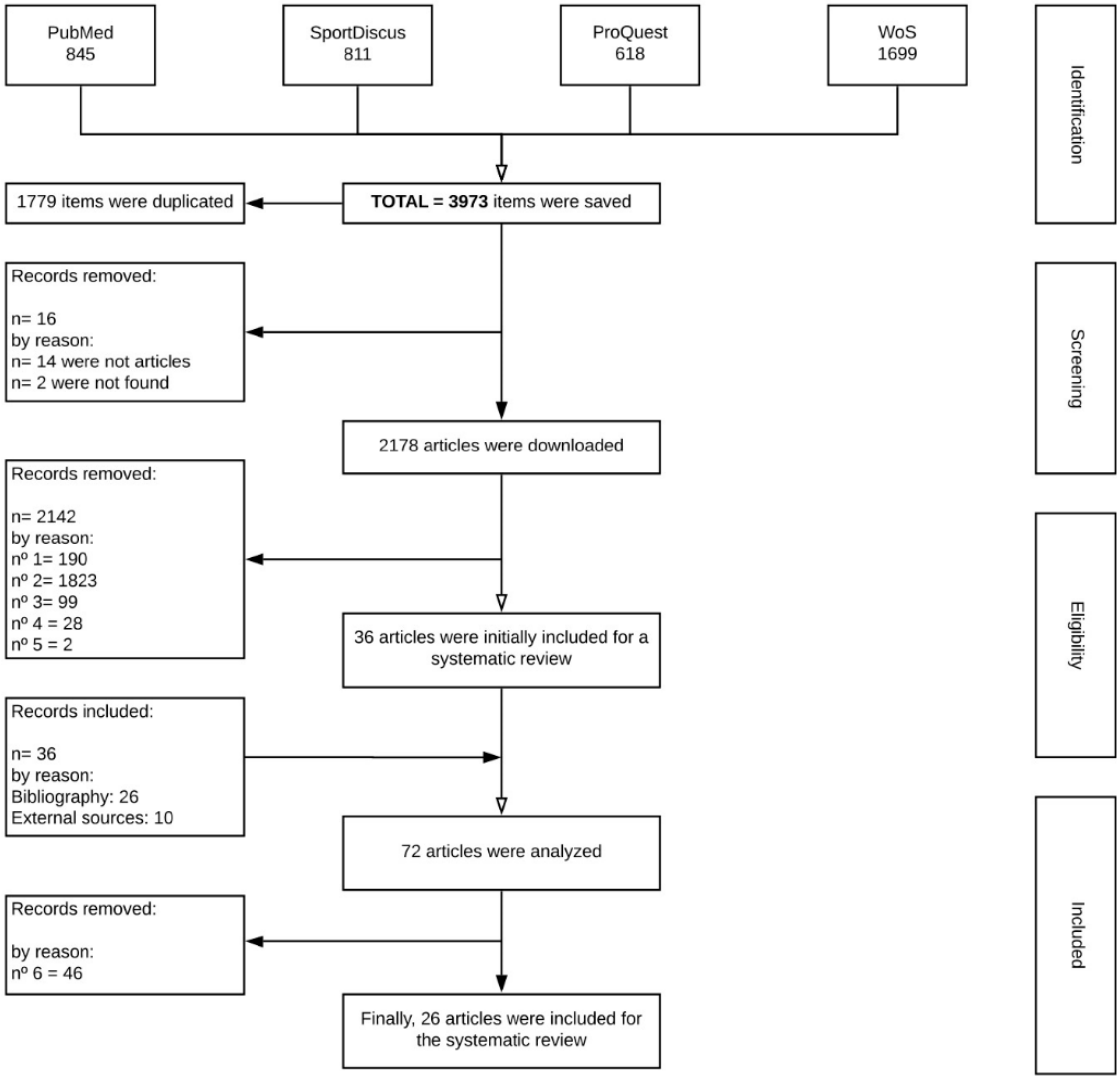

Figure 1. Flow diagram of the study.

Table 1. Classification of the *distance* variables.

Variable	Group and Sub-Groups of Variables	Variables Included in Each Group
Distance variables	Distance between two points (i.e., GC of several players, players, space, ball)	
	Player–player	
	Player–opponent	Player–opponent. Team separateness
	Player –teammate	Player–teammate. Length; Width
	Player–space	Player–line. Player–goal.
	Player–ball	Player–ball
	GC–GC	GC–GC
	GC–Player	Own/opponent GC–player
	GC–Space	GC-defensive line /goal

GC: Geometrical centre. Italic for the main groups and no italic for the subgroups: *Player-player (main group)*; Player-opponent (subgroup); Player-teammate (subgroups); *Player-space (main group)*; *Player-ball (main group)*; *GC-GC (main group)*; *GC-player (main group)*; *GC-space (main group).*

Table 2. Origin and modifications of the *distance* variables.

Author	Type of *Distance* variable	Definition	Sport	Competition Level	Task	EPTS	Q
Passos et al. [24]	*Player–opponent*	Attacker–defender distance: interpersonal *distance* and relative velocity	Rugby	Young	1vs. 1 task	OPTs	87
Bourbousson et al. [16]		Player–opponent *distance* matched for playing position	Basketball	Professional	Match	OPTs	81
Silva et al. [20]		The TS for a team was defined as the sum of distances between each team player and the closest opponent.	Soccer	National-level and RLP-regional-level players	4 vs. (4+GK)	GPS	87
Silva et al. [36]		The average *distance* between all players and their closest opponent (TS)	Soccer	U-15	3 vs. 3 4 vs. 4 5 vs. 5	GPS	93
Silva et al. [4]		Teams' horizontal and vertical opposing line-forces (i.e., the distances separating the teams' vertical opposing line-forces and the distances separating the teams' horizontal opposing line-forces)	Soccer	National-level and RLP-regional-level players	5 vs. 5 5 vs. 4 5 vs. 3	GPS	87
Shafizadeh et al. [26]		Closing *distance* gap between shooter and goalkeeper	Soccer	Professional	Match (1 vs. 1 direct shoot situations)	OPTs	93
Lames et al. [37]	*Player–teammate*	Range per team. Difference between max and min position of players except goalkeeper	Soccer	Professional	Match	OPTs	-
Bourbousson et al. [16]		The inter-team distances made between two players of each position	Basketball	Professional	Match	OPTs	81
Goncalves et al. [17]		Variability in the *distance* between players	Soccer	Professional	3 experimental conditions	GPS	87
Olthof et al. [18]		Represents the space between *goalkeeper* and nearest defender (defending line).	Soccer	Young	4 vs. (4 + GK)	LPS	93
Passos et al. [22]	*Player–space*	Player (attacker and defender)–try line distance	Rugby	Young	1 vs. 1	OPTs	93
Passos et al. [22]		Player (attacker and defender)–both lateral lines distance	Rugby	Young	1 vs. 1	OPTs	93
Vilar et al. [5]		Relative *distance* to the goal.	Futsal	Professional	Match (1 vs. 1 sequences)	OPTs	87
Esteves et al. [21]		The *distance* of the ball carrier to the basket at the time of either shooting or losing ball possession.	Basketball	Young	Match	OPTs	87
Yue et al. [7]	*Player–ball*	Player–ball *distance* in the x- and y-direction	Soccer	Professional	Match	OPTs	73
Frencken & Lemmink [6]	GC–GC	Distance between two GCs of the teams	Soccer	Elite Youth	4 vs. (4 + GK)	LPM	-
Frencken & Lemmink [6]	GC–Player	Distance between GCs and players	Soccer	Elite Youth	4 vs. (4 + GK)	LPM	-
Yue et al. [7]	*Own team GC–player*	*Average distance* between all players and the GC of the team [Radius]	Soccer		Match	OPTs	75
Bartlett et al. [23]		Radial, along pitch and across pitch Frobenius norm	Soccer	Professional	Match	OPTs	87
Sampaio & Maçãs [25]		*Absolute distance* of each player from the GC of the team	Soccer	University Student	5 vs. 5	GPS	87
Sampaio & Maçãs [25]		Maximal *distance* of the farthest player from the GC of the team	Soccer	University Student	5 vs. 5	GPS	87
Sampaio & Maçãs [25]		Minimal *distance* of the nearest player from the GC of the team	Soccer	University Student	5 vs. 5	GPS	87
Sampaio et al. [38]	*Opponent team's GC–player*	Distance between each player and the opponents' centroid	Basketball	Junior	5 vs. 5	GPS	93
Sampaio et al. [38]	GC–Space	Distance between GCs and a point in the space	Basketball	Junior	5 vs. 5	GPS	93
Duarte et al. [39]	*GC–defensive line*	the smallest *distance* of the centroid to the defensive line using x-component motion values	Soccer	Young	3 vs. 3	OPTs	87
Silva et al. [4]	*GC–goal*	The centroid's *distance* to the goal centre	Soccer	National-level and RLP-regional-level players	5 vs. 5 5 vs. 4 5 vs. 3	GPS	87

GC: geometrical centre; GK: Goalkeeper; GPS: Global Positioning Systems; LPM: local position measurement; LPS: local position system; OPTs: optic-based systems; Q: Quality score (%); TS: team separateness.

Table 3. Origin and modifications of the application of the data processing techniques in the *distance* variables.

Author	Variable	Sport	Competition Level	Task	EPTS	Q
Relative phase						
Passos et al. [19]	Player–opponent	Rugby	Young, national level	1 vs. 1	OPTs	81
Bourbousson et al. [16]	Player–teammate	Basketball	Professional	Match	OPTs	81
Bourbousson et al. [16]	Player–opponent	Basketball	Professional	Match	OPTs	81
Bourbousson et al. [15]	Stretch indexes	Basketball	Professional	Match	OPTs	81
Travassos et al. [3]	Player–ball for attacking and defending teams *	Futsal	National Futsal University	5 vs. (4 + GK)	OPTs	75
Travassos et al. [3]	Player–teammate for attacking and defending teams *	Futsal	National Futsal University	5 vs. (4 + GK)	OPTs	75
Travassos et al. [3]	Player–opponent *	Futsal	National Futsal University	5 vs. (4 + GK)	OPTs	75
Travassos et al. [2]	Defending team–ball	Futsal	National Futsal University	5 vs. (4 + GK)	OPTs	87
Travassos et al. [2]	Attacking team–ball	Futsal	National Futsal University	5 vs. (4 + GK)	OPTs	87
Travassos et al. [2]	Teams–ball	Futsal	National Futsal University	5 vs. (4 + GK)	OPTs	87
Duarte et al. [30]	Every player–team	Football	Professional	Match	OPTs	80
Duarte et al. [30]	Player–team *	Football	Professional	Match	OPTs	80
Folgado et al. [31]	Player–teammate *	Football	Professional	Match	GPS	87
Entropy						
Passos et al. [19]	Player–opponent	Rugby	Young, national level	1 vs. 1		81
Sampaio & Maçãs [25]	Absolute *distance* of each player from the GC of the team	Soccer	University Student	5 vs. 5	GPS	87
Sampaio & Maçãs [25]	Maximal *distance* of the farthest player from the GC of the team	Soccer	University Student	5 vs. 5	GPS	87
Sampaio & Maçãs [25]	Minimal *distance* of the nearest player from the GC of the team	Soccer	University Student	5 vs. 5	GPS	87
Fonseca et al. [40]	Player–opponent	Rugby	-	1 vs. 1		87
Silva et al. [20]	Player–opponent	Soccer	Young (regional and national level)	(4 + GK) vs. (4 + GK)	GPS	87
Barnabé et al. [32]	Player–teammate (team' length)	Soccer	Young	(5 + GK) vs. (5 + GK)	GPS	80
Barnabé et al. [32]	Player–teammate (team width)	Soccer	Young	(5 + GK) vs. (5 + GK)	GPS	80
Barnabé et al. [32]	Player–GC (stretch index)	Soccer	Young	(5 + GK) vs. (5 + GK)	GPS	80
Goncalves et al. [17]	Player distances formed by the outfield teammates	Soccer	Professional	10 vs. 9 LSG	GPS	87

ApEn: Approximate entropy; GPS: Global Positioning System; LSG: large-sided game; OPTs: optic-based systems; game; Q: Quality score (%); SampEn: Sample entropy; *: cluster analysis was applied.

4. Discussion

The aim of the study was the identification, computational examination, critical assessment and future considerations of *distance* variables to assess collective tactical behaviour in team invasion sports by positional data. According to the nature of the oscillators or points, the *distance* variables can be classified into player–player, player–space, player–ball, and geometrical centre (GC)–GC/player/space/goal. Player–opponent distances are of special interest in those team invasion sports in which man-marking is commonly used and in the micro-structure close to scoring situations in all team invasion sports. In addition, player–player distances are used to measure the length and the width of the team and player–GC distances to assess the dispersion of the team. The player–space distances have been measured to assess the *distance* of the player/team-line to relevant areas of the playing space. Several techniques have been applied to analyse the synchronisation (relative phase by the Hilbert transformation and the cluster analyses) and the complexity and regularity or predictability (various approximate entropies, sample entropy, cross-sample entropy and average mutual information (AMI)) of the distances in team invasion sports, revealing the lack of consensus among researchers.

The interaction between two players, assessed in *distance* (i.e., dyad [13,41]), is the most commonly analysed micro-structure in team invasion sports [2,5,7,16–18,21,24,26], although the same concept has been also used to assess the *distance* between different types of oscillators or points (i.e., points of union): GC–GC, GC–player, GC–space, GC–ball, player–space, player–ball [7,20,25,39,42]. In fact, the first proposed *distance* variables considered the *distance* between the player and the basket [41].

4.1. Player–Player

4.1.1. Player–Opponent

The measurement of distances in team invasion sports was suggested by Araujo et al. [43]. Specifically, the author proposed the positional balance between attacker and defender in basketball [43]. Although Passos et al. [22] considered the attacker and defender as oscillators, they calculated the *distance* of each player from the try and lateral lines. Thus, Passos et al. [24] measured the *distance* between a defender and their opponent (i.e., player–opponent) for the first time. The authors compared the impact of both interpersonal *distance* and relative velocity on attacker–defender distances during an experimental task that was representative of a typical sub-phase of rugby union (i.e., 1 vs. 1 near the try line) [24]. Next, Bourbousson et al. [16] measured the *distance* between the attacker and the defender in fixed player–opponent distances (i.e., the players of the *distance* do not change during the analysis) in a basketball match and Silva et al. [20] calculated the distances separating each player from their nearest opponent, that is, no fixed player–opponent distance, in order to assess their uncertainty during soccer small-sided games (SSG) and conditioning games. Thus, player–opponent distances (i.e., individual duels) have been assessed during play considering the same two opponents (i.e., fixed *distance* variables continuously, and varying the opponents of the *distance* during play). Fixed player–opponent *distance* variables are of special interest in those sports in which man-marking is commonly used, such as basketball [16] and futsal [3], although it is also interesting to measure this micro-structure close to scoring situations in other team invasion sports such as soccer and rugby [5,24,44]. Non-fixed player–opponent *distance* variables could be more relevant in sports in which zonal marking is applied by the trainers.

Based on the defender–attacker *distance* variables, Silva et al. [20] proposed team separateness (TS), the sum of distances between each team player and the closest opponent (i.e., a collective computation) during small-sided and conditioned games (SSCG), because this could be a more interesting variable than the GC to analyse the pressure exerted by one team on another. The authors defined TS as a measure of the degree of free movement that each team has available [20]. Silva et al. [36] proposed a modification of the TS. They understood the TS as the average *distance* between all players and their closest opponent and this was interpreted as the average radius of action free of opponents [36]. Based on the *distance* between the opponents, Silva et al. [4] proposed the measurement of the distances separating the teams' horizontal and vertical opposing line-forces in order to examine inter-team coordination. As the authors explained, they assessed these variables instead of the GC because the former did not capture the existence of eventual differences in the players' interactive behaviours at specific team locations (e.g., wings and sectors) [4]. The idea in this study was to calculate two horizontal lines and two vertical lines per team in several SSGs [4]. Each team's horizontal lines were calculated by averaging the longitudinal coordinate values of the two players furthest from, and nearest to, their own goal line, which corresponded to the forward and back lines, respectively. Similarly, the vertical line-forces of each team were computed by averaging the mean lateral coordinates of the players furthest to the left and to the right of the pitch, corresponding to the left and right lines, respectively [4]. Finally, Shafizadeh et al. [26] assessed the distances between the shooter and the goalkeeper, regarding this measure as a candidate action-relevant variable informing goalkeepers about co-adapted positioning needed for goal saving.

4.1.2. Player–Teammate

Another player–player distance, the *distance* between two teammates, has been widely assessed in team invasion sports [16–18,37]. The first time that the *distance* between two teammates was assessed, Lames et al. [37] measured the *distance* between the maximum and minimum position of the players (i.e., non-fixed *distance* variables) of the same team (i.e., the range per team) in order to assess the occupation of the space in the direction of goal to goal. Soon after, several studies proposed the measurement of the range in both directions (i.e., length and width) [45,46]. Later, Bourbousson et al. [16] assessed the player–teammate *distance* variable, but considering the *distance* between fixed *distance* variables (i.e., two playing positions), that is, the *distance* between the same teammates during a basketball match. A further study took into consideration all possible player–teammate *distance* variables formed by the outfield players in order to asses intra-team relations (the absolute values (m) and variability in the *distance* between players) [31]. Moreover, Olthof et al. [18] proposed different non-fixed player–teammate *distance* variables that considered the goalkeeper. Specifically, they measured the *distance* that remained behind the defensive line, which was a measure of the *distance* between the goalkeeper and the last defender. Thus, player–opponent and player–teammate *distance* variables were analysed independently in order to observe the positional balance between both players [22], and then as a collective index considering all or several *distances* [16–18,37,47] in order to assess intra-team and inter-team distances.

4.2. Player–Space and Player–Ball

As mentioned above, Passos et al. [22] measured a *distance* variable in team invasion sports for the first time. Specifically, a player–space distance: the *distance* of the attacker and the defender from the try line (i.e., absolute *distance* of each player from the try line over time, calculating the *distance* along a straight line between the closest point of the try-line and each player) and *distance* of attacker and defender from both lateral lines (i.e., absolute *distance* of each player from the lateral lines) during a rugby training task. Besides presenting a 3-D analysis of interpersonal dynamics of attacker-defender distances, the authors also aimed to identify parameters to measure dynamical system properties in these *distance* variables [22]. Similarly, Vilar et al. [5] suggested measurement of the difference between the attacker's and defender's distances to the centre of the goal (i.e., relative *distance* to the goal) in order to analyse how players coordinate their actions to create/prevent opportunities to score goals in futsal matches. Moreover, they proposed the assessment of the defender´s angle to the goal and the attacker (i.e., inner product of the defender´s vector to the centre of the goal, and the defender´s vector to the attacker) [5]. Maybe further studies should consider and add the influence (i.e., distance) of the goalkeeper in this type of analysis. In the same line of thought, Esteves et al. [21] linked the *distance* between the ball carrier and their immediate defender (i.e., player coordinates) and the *distance* of the ball carrier to the basket (i.e., player and space coordinates) in order to assess the *distance* between these two points when a shot is attempted or when possession is lost during competition basketball games.

Thus, player–space distances have been measured taking into account the player–opponent relative position and *distance* to the goal, basket, or end zone [5,21,22]. Regarding the player–ball distance, Yue et al. [7] measured this type of *distance* variable for the first time, with several studies considering the position of the ball in the analysis of the team behaviour variables [3].

4.3. GC–GC/Player/Space

Taking into account the relative positioning of each team, expressed in single x and y coordinates, Frencken and Lemmink [6] measured the *distance* between the GCs of the teams in order to assess the "pressure" between the teams. Later, several studies proposed other tactical variables [20] as the GC–GC could be an excessive reduction in the relation between both teams. Since the same GC location can be due to very different player positions, it is necessary to assess the location of the players with respect to the GC of the team (i.e., the dispersion). Together with the computation of the GC, Yue et al. [7] proposed the measurement of the instantaneous radius (also named stretch index or spread [7]) of each team, calculating the average *distance* between all players and the GC of the team at that moment. In a later study, Barttlet et al. [23] picked up Yue's idea [7] but applied a new calculation formula. It summarised the distances of all players from the team GC (x_c), and because the team GC is computed from the position (x_i) of all players, then the stretch index incorporates all inter-player distances.

The radius was used to analyse the counterphase relation in which it was observed how the team with possession expanded against the contraction of the defending team [7]. In 2012, Sampaio and Maçãs [25] proposed the measurement of the absolute *distance* between the GC and each player to assess the coordination of each player and GC using the relative phase (this data processing technique will be discussed in the next section). In addition, these authors proposed the measurement of the maximal and minimal *distance* of the farthest and closest player with respect to the GC [25]. Together with the *distance* from their own GC, Sampaio et al. [38] suggested the *distance* between each player and the opponent´s GC in order to assess how player movement patterns are coordinated with all their teammates' and opponents' positioning expressed as a single value (i.e., GC).

Similarly to the player–space *distance* [5,21,22], the GC–space *distance* variable was suggested in order to assess the collective behaviour of particular sub-groups of players involved in the creation/prevention of goal scoring [39]. Specifically, Duarte et al. [39] implemented a 3 vs. 3 SSG task in which a line was drawn to simulate the task constraints of the 7-a-side offside rule for this age level (i.e., *defensive line*) and the *distance* measured between the GC and the defensive line in soccer. In the same line of research, Silva et al. [4] calculated the centroid's *distance* to the goal centre defended by a goalkeeper and to the end line where the mini-goals were placed during several soccer SSGs. Thus, the GC–space *distance* has been suggested for assessing the relative position of the team, expressed as a single value, with respect to different types of goals.

4.4. Non-Linear Analysis Techniques

4.4.1. Synchronisation

Regarding the relative phase for intra-team *distance* variables, Bourbousson et al. [16] suggested the analysis of the relationship between several playing positions (i.e., centre vs. guard; shooting guard vs. smart-forward; small forward vs. power forward). Further studies calculated the relative phase for all pairs of players [31] and suggested the assessment of the relative phase for every player with respect to the team and individual's relative phase with the group measure [30]. On the other hand, regarding the relative phase for inter-team *distance* variables, Bourbousson et al. [16] assessed the five inter-team *distance* variables made between two players from each position, and due to the importance of the score, several studies suggested this analysis of the 1 vs. 1 *distance* close to the target (e.g., goal or basket) in order to assess the performance in these special play situations in team invasion sports [44,48].

Later, Travassos et al. [3] assessed the relative phase of five new types of *distance* variables: player–ball and player–teammate distances differentiating attacking and defending teams and the player–opponent distances. In addition, Travassos et al. [2] measured the relative phase for several new *distance* variables by the Hilbert transform: defending team–, attacking team–, teams–ball (i.e., GC–ball), and defending–attacking distances (i.e., GC–GC). These studies suggested that ball dynamics determine the relations between players [2,3]. In-phase attractions between players were reported to be stronger between defenders than attackers [3], and (a) stronger phase relations with the ball for the defending team than the attacking team [2] and (b) phase relations between each team and ball, and, to a lesser extent, between teams themselves, produced greater stability in the lateral (side-to-side) direction than the longitudinal (forward–backward) direction. The phase attraction between players and the ball showed how the mobile object and its dynamic is an important constraint on behaviour in a futsal game [3]. In addition, unlike other sports such as basketball [16], a greater in-phase relationship was found between defenders than attackers in the lateral directions [3]. In the same way, the second study found a higher in-phase relation between the defending team and the ball in both axes, and a higher in-phase relation between teams in the lateral direction [2].

The above-mentioned studies used the relative phase to measure synchronisation between two oscillators. In order to evaluate the synchronisation between more than two oscillators, Duarte et al. [30] applied the cluster method. Specifically, Duarte et al. [30] used the cluster method to measure player–team synchronisation (i.e., degree to which the behaviour of any one player in the team is synchronised to the movements of a team as a whole). In addition, after assessing the relative phase of all pairs of outfield players in several pre-season soccer matches, Folgado et al. [31] applied the k-means cluster analysis to capture intra-team *distance* variables with similar levels of synchronisation. This analysis was applied to the percentage of time of *distance* synchronisation and they classified each *distance* variable into one of three groups according to its synchronisation level: the higher, intermediate and lower synchronisation groups.

4.4.2. Predictability

To our knowledge, Passos et al. [19] used the Approximate Entropy (ApEn) in team invasion sports for the first time. Specifically, the authors measured ApEn in the micro-structure 1 vs. 1, that is, in a player–opponent *distance* variable [19]. Based on the proposal of Stergiou et al. [49], the authors considered the number of observation windows to be compared (m) and the tolerance factor for which similarity between observation windows is accepted (r). Higher values of ApEn, close to 2, signified more complexity and less regularity and predictability. After analysing the relative position between defender and attacker during the micro-structure 1 vs. 1 near to the try line in rugby, they found that system complexity increased with changes in relations between players [19]. Moreover, the authors suggested the use of ApEn for other micro-structures involving more agents [19], and several studies have followed this proposal [20,50,51]. A further study suggested two normalised measures based on the original ApEn (i.e., normalised with respect to a maximum value of ApEn of a series of length N or of that particular set of points), which are less dependent on time series length, in order to measure the complexity and the regularity and predictability of a rugby union attacker–defender micro-structure [40].

Silva et al. [20] analysed the uncertainty of interpersonal *distance* values during soccer small-sided and conditioned games by means of sample entropy measures (SampEn), specifically the SampEn of *distance* to nearest opponent, i.e., the entropy of player–opponent distance. The use of SampEn instead of ApEn was suggested by Richman and Moorman [52] for two main reasons: a) ApEn was heavily dependent on the record length and is uniformly lower than expected for short records and b) it lacks relative consistency.

Also using SampEn, Barnabé et al. [32] measured the predictability of the team´s length (i.e., between the most forward and the most backward players) and width (i.e., between the farthest players on both sides) and stretch index. In addition, the same authors [32] used the cross-SampEn to assess the asynchrony of the same variables. Cross-SampEn was developed by Richman and Moorman [52] because Cross-ApEn presents the necessity for each template to generate a defined nonzero probability, and cross-SampEn remains relatively consistent for conditions where cross-ApEn does not. A new step was suggested by Gonsalves et al. [17], who, unlike Barnabé et al. [32], measured the predictability in the *distance* between all player distances formed by outfield players using ApEn.

5. Conclusions

Several types of *distance* variables have been suggested during the last two decades. According to the nature of the oscillators or points, they can be classified into player–player (i.e., player–opponent, player–teammate), player–space, player–ball, and GC–GC/player/space/goal *distance* variables. The measurement of the *distance* between players allows the assessment of the interaction between a couple of players, teammates or opponents. It is of special interest in those sports in which man-marking is commonly used, such as basketball and futsal, and in the micro-structure close to scoring situations in all team invasion sports. Moreover, player–player distances are used to measure the length and the width of the team and player–GC distances to assess the dispersion of the team. The player–space distances have been measured to assess the *distance* of a player (or team line) from relevant spaces, such as the target or the external borders of the playing space. Although these variables may be interesting considering each one independently, it would be worthwhile to analyse the relationship among them.

The application of the relative phase and entropy has allowed the analysis of the synchronisation and the complexity and regularity or predictability of several GC and distances tactical variables (i.e., *relative phase*, *cluster method*; *entropy*, ApEn, $ApEn_{ratioRandon}$, $ApEn_{ratioSuffle}$, SampEn, cross-SampEn, AMI). Usually, the relative phase has been used to measure the synchronisation between two oscillators (i.e., Hibert transform), but several authors have suggested the cluster method in order to evaluate the synchronisation among more than two oscillators. This suggestion comprises a more complex analysis of team invasion sports. Regarding entropy, different types of techniques have been suggested (i.e., ApEn, $ApEn_{ratioRandon}$, $ApEn_{ratioSuffle}$, SampEn, cross-SampEn). There is no consensus, and this makes the comparison among studies difficult.

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Tactical Analysis According to Age-level Groups during a 4 vs. 4 Plus Goalkeepers Small-sided Game

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Abstract: This study aimed to compare the collective dynamics of three different age-level groups (i.e., U13, U15 and U18) during a 4 vs. 4 plus goalkeepers small-sided game (SSG). Fifty-four male outfield soccer players aged between 13 and 18 years took part in the study. Team tactical behaviors were assessed by measuring (a) the area occupied by players of each team, (b) the distance between both teams' centroids, (c) the players' distance to their own team and d) the stretch index during a 4 vs. 4 plus goalkeepers SSG format. The main results revealed that larger areas were occupied by the older players ($p < 0.001$; Effect size (ES) = 0.44–0.25, small). Additionally, the mean distance between teams' centroids was greater in older groups ($p < 0.001$; ES = 0.44–0.81, large–small). Finally, the distance between players ($p < 0.001$; ES = 0.75–0.81, moderate–large) and the stretch index ($p < 0.001$; ES = 0.44–0.47, small) were also greater in older age categories. The evidence provided in the present study might help coaches identify the influence of age on collective dynamics during SSGs and help them find task conditions that could help to improve the behaviors and positioning of younger players.

Keywords: soccer; collective behaviors; categories; centroid; stretch index

1. Introduction

Positive interactions among teammates and negative interactions with opponents make soccer a social system [1], with tactical behaviors being crucial for making a soccer performance successful [2]. Tactical behaviors can be assessed as individual (i.e., the player), sectorial (i.e., several players) and/or collective [2], by means of electronic performance and tracking systems [3]. Thanks to these devices, it is possible to measure collective tactical variables such as the average position of the players (i.e., the centroid), the relationship between players based on distance (i.e., the dyad) and the use of the playing space [2,3]. The analysis of these tactical variables is crucial because it allows for the assessment of the overall team organization during training tasks and match play [2]. Thus, it would be interesting for coaches to investigate the certain tactical behaviors of players during training tasks in order to understand the collective dynamics of the team.

Since soccer training strategies are mainly designed to improve individual, sectorial and collective tactical performance, tactical analyses of the training tasks have become one of the main objectives for coaches in their training context. As such, small-sided games (SSGs), which are conditioned soccer games featuring a reduced number of players and two goals [4], are frequently used in youth soccer training [5,6]. Many studies have found that SSGs are effective for maintaining and improving physical fitness performance [7,8] and promote significantly higher physical enjoyment than analytical physical training strategies [9] in young soccer players. The major research in SSGs has been focused on the quantification of internal and external training loads [7,8]; however, little literature has investigated tactical analyses in young soccer players [2]. In addition, coaching staff need greater knowledge of collective tactical behavior during training tasks in order to help them select the appropriate SSG according to the objective of the session.

Several studies have found that age determines collective tactical behavior during SSGs in young soccer players [10,11]. The oldest players occupied a greater area in comparison to young players during different SSGs [10,12,13]. Similarly, the distances between teams' centroids were greater when older soccer players played in SSGs [10,12,13]. In addition, Olthof et al. [10] found that the mean distance between players within a team was greater among the oldest of the young soccer players during SSGs. These changes between age-groups can also be influenced by some factors such as maturation [14,15]. A study that tested the effects of maturation on tactical efficacy [16] highlighted that maturation and proficiency of peripheral perception (important contributor to making decisions) may justify a better identification of the teammates in a timely position to receive the ball, assertively predict the movements of the teammates and improve searches for new information without central vision. Moreover, the effects of accumulated experience and tactical efficacy (as discriminator of expertise) may lead to changes in exploratory behaviors of players [17]. In a study conducted on youth football players it was possible to observe that youth players with better tactical skill levels and older-age groups presented greater exploratory behaviors in games [17]. Thus, there are reasons to hypothesize that collective dynamics can be affected by age, maturation and expertise level. While a few studies have measured and compared tactical behaviors during SSGs according to age-level groups, more studies are necessary to confirm, or refute, the different collective dynamics of players in the same SSG.

Despite the importance of identifying how SSGs can influence the collective dynamics of players, studies testing the influence of small formats on the dynamics within and between teams are still scarce. Knowledge about the effects of formats on different competitive levels or age-groups is still limited (considering that different levels may react differently to the same drills/challenges). For these reasons, the aim of the study was to compare the collective dynamics of three different age groups (i.e., U13, U15 and U18) during a 4 vs. 4 plus goalkeepers small-sided game (SSG).

2. Materials and Methods

2.1. Participants

Fifty-four male outfield soccer players aged between 13 and 18 years (age: 16.1 ± 1.9 years, height: 166.0 ± 1.0 cm, body mass: 58.77 ± 10.33 kg, body fat: 20.67% ± 7.08%, and body mass index (BMI): 21.13 ± 2.31 kg/m^2) took part in the study (statistical power > 0.80). Participants belonged to the same soccer academy, where their teams competed at the maximum competitive level for each age level. The training hours (h) of practice per week were 4.5 h for U13, 6.0 h for U15 and 7.5 h for U18 players. The inclusion criteria were that players had to be participants of systematic training and official competitions, who had been free of muscular or skeletal injuries for at least the last month. Although goalkeepers were used as part of the study, they were excluded from the statistical analysis. The final sample consisted of 48 players, with 16 players in each age-level group (Table 1). All the participants were informed of the objectives of the research, participated voluntarily and had the possibility of withdrawing at any time without penalty. All the participants and/or their parents or tutors signed a written informed assent (players) or consent (parents). The study was conducted according to the Declaration of Helsinki, and the protocol was fully approved by the ethics committee of the university (Code: FUI1-PI002) before recruitment.

Table 1. Characteristics of the soccer players according to their age-level group.

Age-level Group	Age (years)	Height (cm)	Body mass (kg)	BMI (kg/m^2)	Body fat (%)
U13 (n = 16)	13.9 ± 0.3	157.2 ± 1.0	50.41 ± 9.57	20.50 ± 3.07	24.41 ± 5.50
U15 (n = 16)	15.7 ± 0.5	171.1 ± 1.0	60.53 ± 7.89	20.59 ± 1.85	15.94 ± 2.93
U18 (n = 16)	18.4 ± 0.8	177.3 ± 1.0	67.78 ± 6.97	21.68 ± 1.84	15.21 ± 3.27

BMI: body mass index.

2.2. Procedures

The investigation was conducted over three weeks in the middle of the 2019–2020 competitive season. A previous month was used for familiarization with the study protocol, including the use of global positional system (GPS) units (WIMU PRO^{TM}, RealTrack System, Almería, Spain) and the realization of the 4 vs. 4 plus goalkeepers SSG. The SSG lasted 28 min and was divided into four bouts of 4 min, with 3 min of recovery time during which players were allowed to drink fluids ad libitum. The SSG was performed on the same day of the week (i.e., Tuesday) by each age group (i.e., U13, U15 and U18), providing an interval of at least 48 h after the last high-load session (i.e., match-play) under similar weather conditions (18–22 °C, 70%–75% humidity).

Players completed the SSG on the same third-generation artificial pitch and wore their normal soccer boots. For measuring tactical variables, the players' positions were recorded by GPS (WIMU PRO^{TM}, RealTrack System, Almería, Spain). Prior to the SSG, players undertook a 20-min standardized warm-up, consisting of 7 min of slow jogging and strolling locomotion followed by 10 min of specific soccer drills and finishing with 3 min of progressive sprints and accelerations. Twenty-four hours prior to the experimental session, the players and their parents were instructed to maintain their usual habits, which included 8 h of sleep the night before each data collection session and adequate hydration and carbohydrate intake [18].

2.3. Data Collection and Processing

Soccer players carried GPS devices (WIMU PRO^{TM}, RealTrack System, Almería, Spain) operating at a sampling frequency of 10 Hz. The technology used to collect the GPS data had been previously validated and was shown to be reliable for monitoring soccer players [19]. Participants wore a fitted body vest, and the GPS device was inserted in a purpose-built harness prior to games. To download the tactical variables, the data were transformed into raw position data (x and y coordinates). Prior to being placed on the players, the GPS devices were calibrated and synchronized following the manufacturer's recommendations [19]. The procedure was as follows: (a) turn on the devices, (b) wait approximately 30 s after turning them on, (c) press the button to start recording once the device's operating system is initialized and (d) analyze the data obtained from the devices using SPRO^{TM} software (RealTrack Systems, Almería, Spain). The GPS was used under good satellite conditions (number of connected satellites = 9.5 ± 0.3).

2.4. Tactical Variables

Team tactical behaviors were assessed by measuring (a) the area occupied by the players of each team, (b) the distance between both teams' centroids, (c) the players' distances to their own teams and (d) the stretch index. The effective playing area was represented by the convex hull occupied by the positions of the players on each team. This area was calculated (in m^2) by computing the area occupied by all outfield players during the SSG, excluding the goalkeeper. Additionally, the centroid of each team was calculated using the mean values of all four outfield players' positions (x, y) from each team in each individual frame [20]. The mean distance between each team's centroids and the players' distances to their own teams were then calculated over the time series [2]. Finally, the stretch index was calculated using the mean distance from each player's position to the geometrical center (i.e., the centroid) of the corresponding team [21]. Thus, the stretch index represents the mean deviation of each player from his team's spatial center [13]. No distinction was made between offensive and defensive phases.

2.5. Small-Sided Game (SSG)

Previous research used the 4 vs. 4 plus goalkeepers SSG format as a talent identification tool to determine young soccer players' skill proficiencies [22] and as a setting for assessing the physical and physiological demands encountered by soccer players [18]. On the other hand, this SSG format was used to analyze the tactical differences among U13, U15 and U18 groups. Players completed four bouts of 4 min, each with a 3-min passive rest break between bouts aimed at minimizing the influence of fatigue [23]. The SSG pitch was 30 m long by 20 m wide (playing area = 600 m^2 and individual interaction space = 75 m^2 per player). The relative pitch proportions were kept constant and had the same length-to-width ratio as an official soccer field (i.e., 1.46) [24].

The teams were organized according to playing positions (i.e., one goalkeeper, one central defender, two wingers, one attacker), technical–tactical level, competitive experience and qualitative evaluation by coaches [18]. Coaches did not provide any strategic or tactical feedback during the process. All players received standardized instructions on the purpose of the game, which was to win each bout as a normal competitive match. Minor rule modifications were applied, including playing without the off-side rule, restarting the game after a goal by the goalkeeper and awarding kick-ins to the opposing side of the player who last touched the ball [18]. In addition, verbal encouragement was provided to ensure a high level of commitment from the players during the games.

2.6. Statistical Procedures

Results were presented as means and standard deviations (SD). The Shapiro–Wilk test ($p > 0.05$) was applied to evaluate the normal distribution of data. As such, all analyzed variables had a normal distribution and parametric analysis was used. A one-way ANOVA with a Bonferroni post hoc test was used to examine the tactical differences among age groups (i.e., U13, U15 and U18). Practical differences were calculated using Cohen's *d* effect size (ES, trivial < 0.2; small: between 0.5 and 0.2; moderate: between 0.8 and 0.5; large: > 0.8) [25]. The data analysis was carried out using the Statistical Package for Social Sciences (SPSS 25.0, SPSS™ Inc., Chicago, IL, USA). Statistical significance was set at $p < 0.05$.

3. Results

Figure 1 shows the area of each team occupied by the players during the 4 vs. 4 plus goalkeepers SSG according to age group. The U18 players used a higher area per team than the U15 ($p < 0.001$; ES = 0.44, small) and U13 ($p < 0.001$; ES = 0.25, small) players. In addition, the area occupied by U15 players during the SSG was greater than that occupied by U13 players ($p < 0.001$; ES = 0.13, trivial).

Figure 2 presents the mean distance between the centroids of each team during the 4 vs. 4 plus goalkeepers SSG according to age group. The U18 players recorded a higher mean distance than the U15 ($p < 0.001$; ES = 0.81, large) and U13 ($p < 0.001$; ES = 0.44, small) players. However, no significant differences were reported between U15 and U13 soccer players in terms of the mean distance between centroids.

Table 2 shows the mean distance among the four players who formed each team and the stretch index during the SSG of 4 vs. 4 plus goalkeepers according to age groups. The U18 players recorded a higher mean distance in these two variables than the U15 ($p < 0.001$; ES = 0.26–0.39, small) and U13 ($p < 0.001$; ES = 0.75–0.81, moderate–large) players. In addition, the mean distance reported for these two tactical variables for U15 players was greater than that reported for U13 players ($p < 0.001$; ES = 0.44–0.47, small).

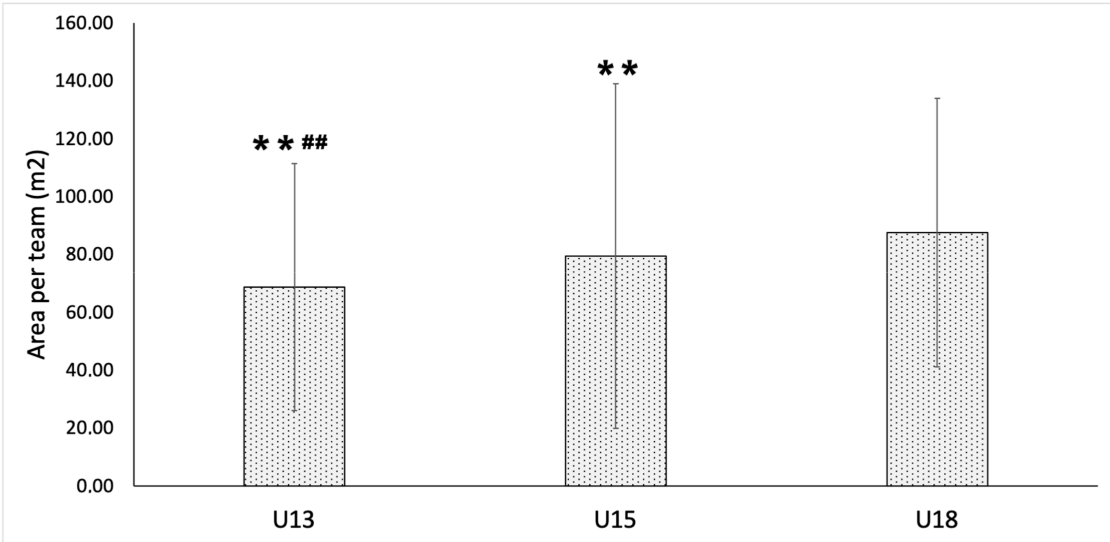

Figure 1. Area occupied by players of each team during the 4 vs. 4 small-sided game (SSG) plus goalkeepers according to age-level groups. ** $p < 0.001$, differences with U18 age-level group; ## $p < 0.001$, differences with U15 age-level group.

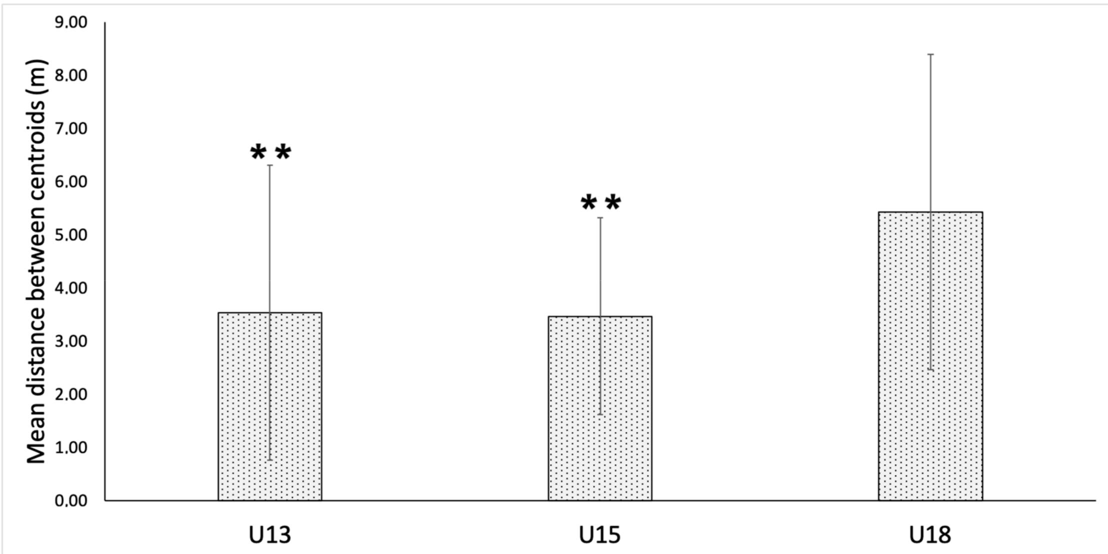

Figure 2. Teams' centroid distance recorded during the 4 vs. 4 small-sided game (SSG) plus goalkeepers according to age-level groups. ** $p < 0.001$, differences with U18 age-level group.

Table 2. Mean distance recorded among the four players of each team and from players to the centroid during the 4 vs. 4 small-sided game (SSG) plus goalkeepers according to age-level groups.

Tactical Variables	U13	U15	U18	U13 vs. U15 (p; ES)	U13 vs. U18 (p; ES)	U15 vs. U18 (p; ES)
Mean distance among players per team (m)	10.43 ± 2.91	11.72 ± 2.76	12.79 ± 4.33	0.000; 0.44	0.000; 0.81	0.000; 0.39
Stretch index (m)	7.76 ± 2.34	8.86 ± 2.50	9.50 ± 3.87	0.000; 0.47	0.000; 0.75	0.000; 0.26

p: level of significance; ES: effect size (standardized effect size of Cohen).

4. Discussion

The present study aimed to compare the collective dynamics of three different age categories during a 4 vs. 4 plus goalkeepers SSG format. This is one of the few studies to have tested the effects of age on the collective dynamics of players during SSGs, and the main results revealed that larger areas were occupied by older players. Moreover, it was also found that the mean distances between teams' centroids were greater in older age categories. Finally, the distances between players, and the distances from players to the centroid, were also larger for players in the older age categories.

SSGs are often used by coaches to augment the perceptions of players for a given tactical issue [26], and the implications of those games on tactical behaviors and collective dynamics can be different based on the skill levels and tactical knowledge of players [10,21,27]. Likewise, assessing the technical–tactical knowledge could be an interesting strategy to understand the level of tactical awareness, decision making and skill of youth players [28]. Our study aimed to use the 4 vs. 4 plus goalkeepers format in different age groups to identify the influence of age on the area occupied by the players. The results revealed that the largest areas were occupied by U18 players (~88 m^2), and this value progressively decreased for U15s (79 m^2) and U13 players (69 m^2).

This significant and progressive decrease of area occupied by the players is in line with previous studies that tested similar hypotheses for U17, U16 and U15 players in a 6 vs. 6 plus goalkeepers format [13], as well as a study that compared U13, U11 and U9 players in 3 vs. 3 plus goalkeepers and 4 vs. 4 plus goalkeepers formats [21]. Barnabe et al. [13] found that older and more experienced players exhibited greater dispersion and wider occupation while attacking, and other authors observed that declarative and procedural tactical knowledge influenced the cognitive effort of younger soccer players in making soccer performance decisions [29]. Moreover, Folgado et al. [21] found that young players tended to explore the length more than the width of the pitch, while older players tended to decrease the length per width ratio.

Occupying less area during a game can be linked to the attempt by less experienced and younger players to quickly reach the goal by swarming around the ball instead of using ball possession and positional attacks [13]. The tendency to explore width more during attacking was also revealed in a study that compared U19 and U17 players, showing that older players try to explore more opportunities from the lateral direction of the pitch [10]. As such, from a conditional perspective, younger soccer players do not have the same technical ability and experience as older ones; and consequently, their activity during the 4 vs. 4 in a 30 x 35 m playing space induces a greater physical demand due to their lack of experience [30]. The tendency to spread more or less, as reflected in the age categories of the players, should be considered by coaches when defining the length-to-width ratio of the pitch and the main objective of the game.

Our study also tested the distances between the centroids of both teams finding similar results as Aguiar et al. [31], who showed a distance of around 3 m between the team centroids in a 4 vs. 4 format played in a 40 × 30 playing space. The results revealed that the mean distance between centroids was significantly higher for U18 players (5.43 ± 2.96 m) than for U15 (3.47 ± 1.85 m) and U13 players (3.54 ± 2.77 m), although no significant differences were found between U15 and U13 players. Our results are partially in line with previous studies that compared distances between centroids for U13, U11 and U9 players [21] and between U18 and U16 players [10]. Folgado et al. [21] found that distances between centroids progressively increased as age increased from U9 to U13 for a 3 vs. 3 plus goalkeepers format and was kept relatively similar between ages for a 4 vs. 4 plus goalkeepers format. Furthermore, Olthof et al. [10] revealed that older players tend to exhibit higher correlations between centroids of both teams (more synchronized, eventually). Moreover, small differences were found in both longitudinal and lateral inter-team distances when comparing U19 and U17 age groups. These findings should also be relativized based on the pitch dimensions considering that increases in the pitch length and width can result in an increase of inter-team distances along both axes [32].

Mean distance among players per team was greater for U18 (~12.79 m) and decreased progressively to ~11.72 m (U15) and ~10.43 (U13) as age decreased. The differences between U18 and U13 players were moderate, and the remaining pairwise comparisons were small. The distances from players to the centroid were the greatest for U18 players (~9.5 m) and progressively decreased to ~8.86 m (U15) and ~7.76 m (U13) as age decreased. Moderate differences were found between U18 and U13 players, and small differences were found in the remaining comparisons. These data could be very interesting to apply on trainings; however, coaches should consider that the game status and team imbalance could influence the distance-to-team centroid with higher values when winning in superior conditions [33]. By using stretch index data to measure the spread of the players in terms of distance to the centroid, a study comparing U18 and U16 players during a 4 vs. 4 plus goalkeepers format [10] revealed greater lateral displacement in the older group. Additionally, using the stretch index, a study comparing regional- and national-level U17 players revealed that national-level players presented larger dispersion values than regional-level players [27]. Thus, it seems that older and more experienced players move farther from the team's centroid, possibly in an attempt to explore opportunities to create imbalances among the opponents and generate space to act.

This study had some limitations. As we did not analyze moments both with and without possession of the ball, we cannot identify specific collective dynamics or measure the distances between teammates at those moments. In the future, such a methodological approach should be taken in order to improve the capacity to explain the results. Moreover, the use of just one format limits the understanding of how players behave during different SSGs. Despite that, our study is useful in terms of considering that age and possible experience might lead to different collective dynamics during SSGs, which should be considered by coaches when adjusting the task conditions to the players' needs. A third limitation of this study is related to the non-presentation of physical demands. Such information would be useful for a mixed approach related to collective dynamics and its influence on physical demands. Such a fact should be considered in future studies.

As for practical implications, we highlight that age plays an important role in the behaviors and collective dynamics that emerged during SSGs and that, possibly, if the coach wants to increase exploration of the pitch in younger players it will be necessary to use additional conditions that may augment the perception of the players to do that, namely, using specific corridors on the width or to use small penetration zones in those zones. Future studies could consider using the same SSGs format throughout a full season to test possible variations in collective dynamics. It would also be interesting to organize the comparison by considering the declarative and processual tactical knowledge of the players.

5. Conclusions

This study compared the variations in the collective dynamics of players of different ages using the same SSG format. The main results of the present study revealed that older players occupy larger areas and present greater mean distances between a team's centroids, and larger distances between players and from players to the centroid. The evidence in the present study can help coaches to identify the influence of age on collective dynamics during SSGs and possibly help them find task conditions that improve the behaviors and positioning of younger players.

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Article

Pacing and Performance Analysis of the World's Fastest Female Ultra-Triathlete in 5x and 10x Ironman

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Abstract: The aim of the present case study was to analyse the performance data of the world's best female ultra-triathlete setting a new world record in a Quintuple (5xIronman) and Deca Iron (10xIronman) ultra-triathlon, within and between race days, and between disciplines (cycling and running) and races (Quintuple and Deca Iron ultra-triathlon). The subject was an elite female triathlete (52 kg, 169 cm) born in 1983. At the time of her world record in Quintuple Iron ultra-triathlon she had an age of 35 years and at the time of the world record in Deca Iron ultra-triathlon 36 years old. The distribution of time spent in each discipline and transitions was 8.48% in swimming, 51.67% cycling, 37.91% running, and 1.94% transitions. There was no difference between the race days of the average speed neither in cycling nor running. The running pace had a within-day variation larger than the cycling pace, and also varied more between race days. In conclusion, the world's best female ultra-triathlete adopted a steady (even) pacing strategy for both cycling and running, without substantial variations within- or between race days, for both the world record in a Quintuple and a Deca Iron ultra-triathlon.

Keywords: cycling; fatigue; running; swimming; ultra-endurance

1. Introduction

Women started to participate in ultra-endurance triathlons in 1988, and ever since with a very low number of participants [1]. Ultra-triathlons are race events including distances beyond the traditional Ironman distance (3.8 km swimming, 180 km cycling and 42.195 km running) [2]. Popular multi-day types of ultra-triathlon have taken place since 1985, where the athletes have to perform two to ten times the Ironman distance [1]. The large physical demands of extreme ultra-endurance events preclude large participations [3].

Women are slower than men in swimming, cycling, and running in ultra-triathlons [1]. Moreover, women have less participants than men from Double Iron ultra-triathlon (2x the Ironman distance) to Deca Iron ultra-triathlon (10x the Ironman distance). But despite their low participation numbers in comparison to men, the participation increases in a higher rate than men in all endurance events throughout the years. Moreover, women's endurance performance is also increasing, closing the performance gap to men in many endurance events, such as open-water swimming [4], Olympic distance triathlon [5], Ironman triathlon [6], and also ultra-triathlons [1].

Regarding to endurance performance, there is evidence that women have less fatigability than men [7]. Pacing strategy is another aspect that could affect women's performance in ultra-endurance events [8,9]. Different pacing strategies, such as negative, positive, or steady pacing may be closely related to performance in endurance events [8]. Nevertheless, the literature on women's performance is still very poor. To the best of our knowledge, there are no studies that investigated the race strategy and pacing variation of a female athlete in ultra-triathlon events.

Therefore, we analyzed the performance data of the best female ultra-triathlete setting a new world record in both a Quintuple (5xIronman) and Deca Iron (10xIronman) ultra-triathlon. The aim was to investigate the performance within and between race days, also comparing between disciplines (i.e., cycling and running) and races (i.e., Quintuple and Deca Iron ultra-triathlon). Additionally, we also aimed to determine whether the pacing variation has an association with overall performance. These results would be the first scientific report of a female ultra-triathlete performance for athletes and coaches to reference for a race strategy plan.

2. Materials and Methods

2.1. Ethical Concerns

This study was approved by the Institutional Review Board of Kanton St. Gallen, Switzerland, with a waiver of the requirement for informed consent of the participants as the study involved the analysis of publicly available data (EKSG 01-06-2010). The athlete also gave an informed consent that all her personal data provided were going to be published. All procedures adhered to the ethical standards set by the Declaration of Helsinki.

2.2. Athlete Characteristics and Competition Background

Our subject was an elite female triathlete (52 kg, 169 cm) born in 1983 in Switzerland. The athlete's body mass remained stable during training routine for both races. At the time of her World record in Quintuple Iron ultra-triathlon she had an age of 35 years and at the time of the World record in Deca Iron ultra-triathlon 36 years old. She improved the existing world record in Quintuple Iron by more than 9 h and the existing world record in Deca Iron ultra-triathlon by more than 11 h.

She started her athletic career as short distance triathlete in 2005 at the age of 22 years where she achieved several podiums at national level (Switzerland). In 2006 (23 years) she obtained 2nd place in her age group in Ironman Lanzarote. From 2007 to 2008, she competed as elite cyclist at national level (Switzerland). Between 2009 and 2015 she made a break due to pregnancies and trained only a few hours per week. In 2016, she started competing in multi-day races with first place women in Gigathlon Switzerland, an event consisting of 5 disciplines (i.e., swimming, cycling, running, inline skating and mountain biking). In 2017, she won Gigathlon Czech Republic and obtained 2nd places in Megathlon Germany, Gigathlon Switzerland, and Biennathlon Switzerland. Also, these races consisted in several disciplines. In 2019, she won the Rocky Mountain Bike marathon in Germany and a Double Iron ultra-triathlon (7.6 km swimming, 360 km cycling, and 84.4 km running) held in Austria in a new Swiss record.

Regarding her training, she invested as triathlete 8–16 h per week with a maximum of 35 h per week before the world record races. She invested <5% of her time in swimming, ~50% in cycling, ~40% in running, and the rest in resistance training (upper body). As an elite cyclist, she trained at that time for 10–15 h per week.

2.3. Races Characteristics

The athlete achieved the world records at the races of the "swissultra" [10]. This race has been held annually in August since 2015 and offers 5xIronman, 10xIronman, and 20xIronman.

The Quintuple and Deca Iron ultra-triathlon consist of a race to be performed in multiple days (5 days for a Quintuple and 10 days for a Deca Iron ultra-triathlon). Each athlete has to perform an Ironman original distance on each race day (i.e. 3.8 km swimming, 180 km cycling and 42.2 km running). These races take place in closed circuits where the athlete performs several laps until the goal distance is achieved. Swimming is held in a 50-m outdoor pool with a temperature of 20−23 °C. Cycling is held on a completely flat and traffic-free course where 20 laps of 9 km must be performed. Running is held on a completely free course where 35 laps of 1.2 km must be completed. Each lap is measured electronically with a chip system. The race is held in the last two weeks of August where temperatures vary during the day from 25−35 °C. Often, rain falls in the late afternoon and evening. The cycling course is held in a large and broad valley (Rheintal) where the first half turns from north to south to a turning point to complete the second half from south to north. Early in the morning the wind is blowing from south to north and changes before noon from north to south. Each athlete had their own support for proper hydration, nutrition, and eventual mechanical issues during the race.

2.4. Race Strategy of the Athlete

During the Quintuple Iron ultra-triathlon, the athlete had her husband as only support. During the Deca Iron ultra-triathlon, a crew of six persons was working in shifts. The athlete and her husband had their motorhome just a few meters away from the race centre for short distances before and after each stage. Overall, she followed no specific pacing strategy. Regarding nutrition, she consumed primarily during all three disciplines liquid energy from commercial products (WOO®). During cycling, she ate a sandwich, and during running she drank Coca Cola and a carbohydrate-electrolyte beverage. After each stage, she ate the set meal consisting of carbohydrates, protein, and fat which was provided by the race organizer. However, she does not eat vegetables due to stomach discomforts.

2.5. Data Analysis

Overall race times, split times (i.e. swimming, cycling and running) and lap times (i.e., cycling and running) were obtained from the official race website, athlete's staff and the athlete. Data from each day of the Quintuple and Deca Iron ultra-triathlon were displayed in overall and split analyses. Data are expressed as mean, standard deviation (SD) and the coefficient of variation (%) calculated based on each lap for each race day. Additionally, a repeated measures ANOVA with within- and between-interactions was applied to detect interactions in average performance throughout the days (within; time) for cycling and running (between; group). Linear and non-linear regression were performed to investigate the trend of split and overall race times over days. The significance level was set as $p < 0.05$. Statistical Software for the Social Sciences was used in all statistical procedures (SPSS v25, Chicago, Ill, USA).

3. Results

Table 1 shows the split and overall race time in each day for the Quintuple Iron ultra-triathlon of the athlete. The distribution of time spent in each discipline and transitions were as follows: swimming = 8.6%; cycling 51.7%; running = 37.9%; transitions = 1.9%. Table 2 shows the split and overall race time in each day for the Deca Iron ultra-triathlon of the athlete. The distribution of time spent in each discipline and transitions were as follows: swimming = 8.5%; cycling 50.4%; running = 39.3%; transitions = 1.7%.

Table 1. Race time in a Quintuple Iron ultra-triathlon.

	Race time (hours : minutes : seconds)				
	Overall	**Swimming**	**Cycling**	**Running**	**Transitions**
Day 1	12:20:45	1:05:56	6:14:28	4:50:51	0:09:30
Day 2	13:48:37	1:08:25	7:09:37	5:16:29	0:14:06
Day 3	13:17:49	1:09:12	6:58:10	4:54:36	0:15:51
Day 4	13:58:01	1:07:00	7:03:47	5:30:46	0:16:28
Day 5	13:27:00	1:09:47	7:06:59	4:48:28	0:21:46
Average (SD)	13:22:26 (38:04)	1:08:04 (01:35)	6:54:36 (22:50)	5:04:14 (18:32)	0:15:32
Total	66:52:12	5:40:20	34:33:01	25:21:10	1:17:41

SD: standard deviation (minutes:seconds). Each day consists of 3.8 km of swimming, 180 km of cycling and 42.195 km of running.

Table 2. Race time in a Deca Iron ultra-triathlon.

	Race time (hours : minutes : seconds)				
	Overall	**Swimming**	**Cycling**	**Running**	**Transitions**
Day 1	12:08:39	1:09:55	6:02:55	4:43:19	0:12:30
Day 2	13:24:56	1:17:28	6:50:04	5:07:27	0:09:57
Day 3	13:31:41	1:11:45	6:53:49	5:15:35	0:10:32
Day 4	13:44:39	1:12:47	7:14:34	5:05:02	0:12:16
Day 5	13:19:25	1:09:47	7:08:04	4:46:30	0:15:04
Day 6	13:59:33	1:10:35	7:09:48	5:21:21	0:17:49
Day 7	14:20:33	1:09:38	7:11:04	5:46:10	0:13:41
Day 8	14:24:21	1:08:20	7:25:29	5:35:13	0:15:19
Day 9	14:23:19	1:10:52	6:55:04	6:00:35	0:16:48
Day 10	15:03:52	1:08:24	6:55:53	6:44:24	0:15:11
Average (SD)	13:50:06 (48:16)	1:10:57 (02:40)	6:58:40 (22:31)	5:26:34 (36:42)	0:13:55 (02:35)
Total	138:20:58	11:49:31	69:46:44	54:25:36	02:19:07

SD: standard deviation (minutes:seconds). Each day consists of 3.8 km of swimming, 180 km of cycling and 42.195 km of running.

Figure 1 displays the average speed to complete each lap in cycling and running in each day in a Quintuple Iron ultra-triathlon completed by the female athlete. Figure 2 displays the average speed to complete each lap in cycling and running in each day in a Deca Iron ultra-triathlon completed by the female athlete. In the Deca Iron ultra-triathlon, the non-linear regression shows a negative slope for both cycling (slope = −3.52; R^2 = 0.75) and running (slope = −0.74; R^2 = 0.33). Time-effect was not significant neither to cycling or running in Deca Iron ultra-triathlon; and cycling was faster than running in all race days (Figure 3B). The non-linear regression shows a negative slope for cycling (slope = -1.82; R^2 = 0.82) and close to zero for running (slope = 0.01; R^2 = 0.81).The overall performance analysis showed a positive slope for increasing race time throughout the race days for both Quintuple (slope = 85.7; R^2 = 0.69; Figure 3A) and Deca (slope = 21.0; R^2 = 0.84; Figure 3B) Iron ultra-triathlon. Swimming performance analysis showed a positive slope for increasing race time throughout the race days for Quintuple (slope = 1.66.7; R^2 = 0.43) and negative for Deca (slope = -0.43; R^2 = 0.35) Iron ultra-triathlon.

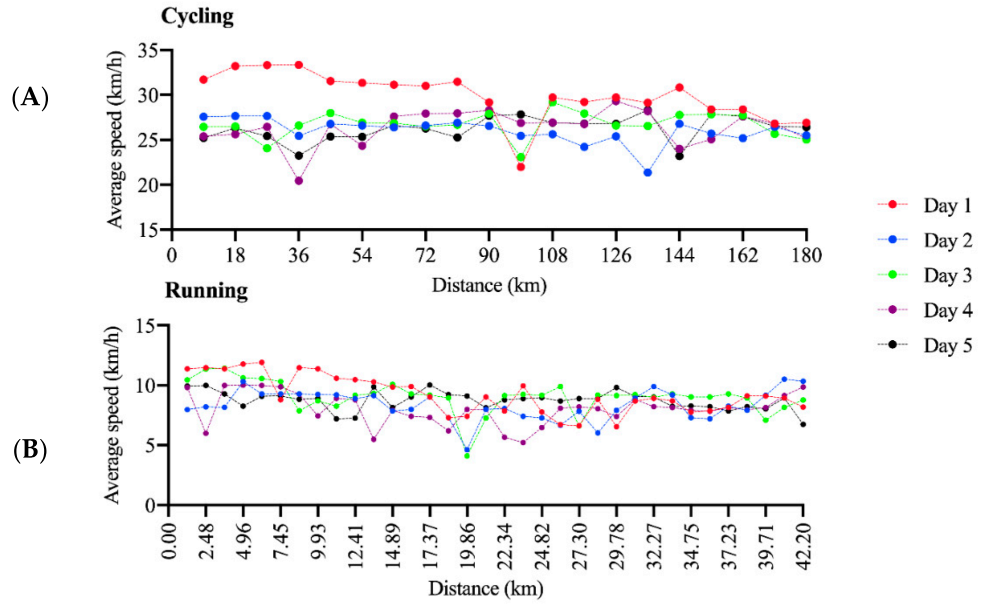

Figure 1. Pacing in each of the five days in a Quintuple Iron ultra-triathlon in the cycling (**A**) and running (**B**) split.

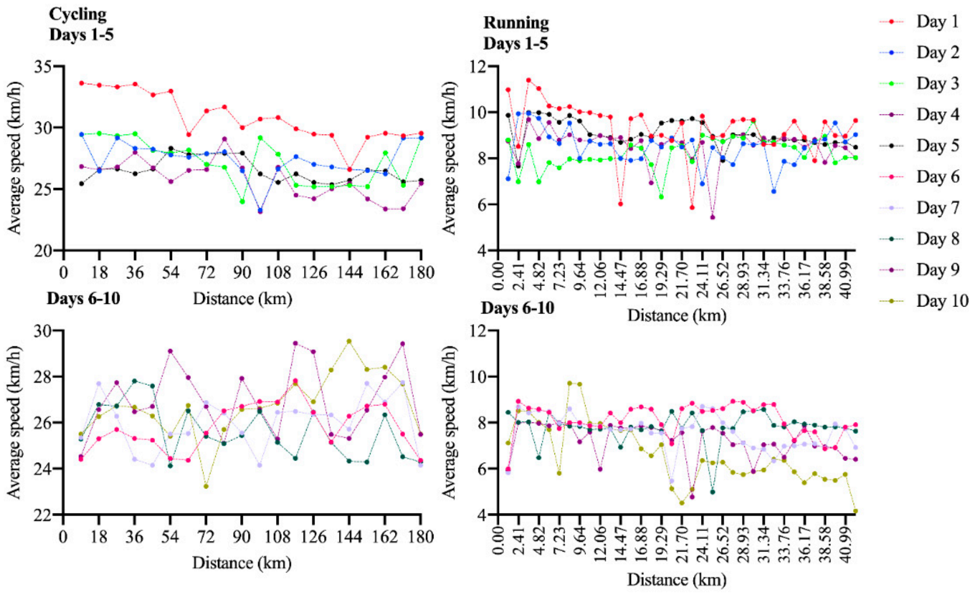

Figure 2. Pacing in each of the ten days in a Deca Iron ultra-triathlon in the cycling (**A**) and running (**B**) split.

The running started (Day 1) with the highest CV (17.1%) and had the lowest in the last day (9.0%). The average speed in Deca Iron was not significantly different along race days to neither cycling or running (Figure 4A). The coefficient of variation (CV) was similar throughout the five days for the cycling, with the highest CV in the first day (8.9%) and lowest in day 5 (5.3%).The average CV in Deca Iron was higher in running than cycling (Figure 4B). The CV was very stable (~4.5%) for the cycling throughout the ten race days. Whereas for the running it started very high (12.1%), with variations in the mid days (6 to 10%) and reached a peak in the last day (20.2%).

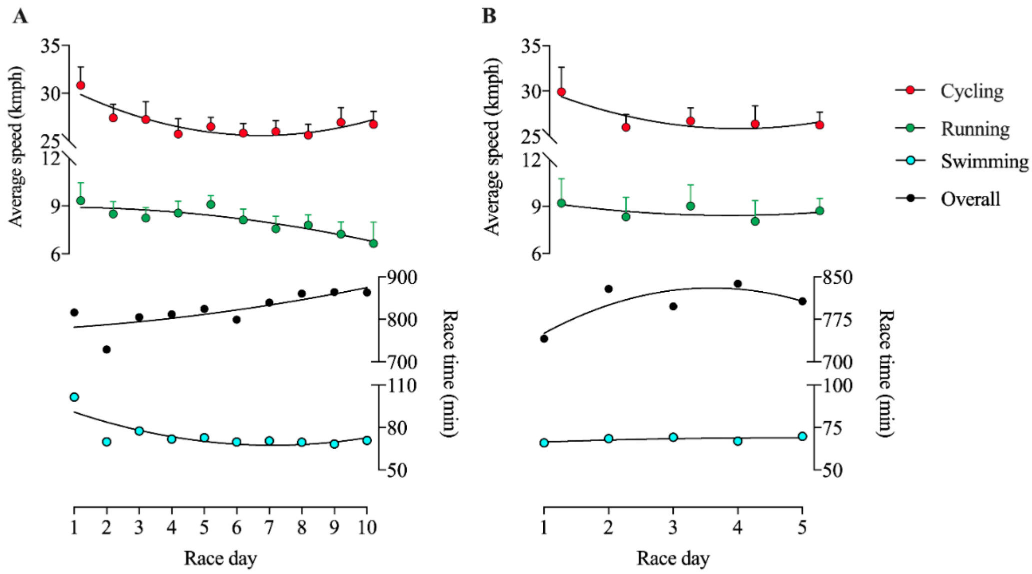

Figure 3. Performance (pacing, speed or race time) in each five days in a Deca (**A**) and Quintuple (**B**) Iron ultra-triathlon in the cycling and running.

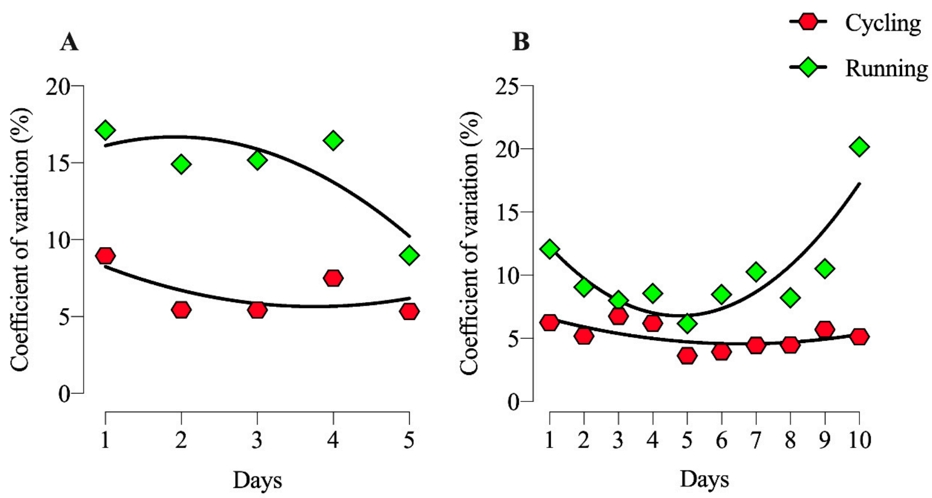

Figure 4. Pacing variation (coefficient of variation; CV) in each of the race days in a Quintuple (**A**) and Deca (**B**) Iron ultra-triathlon in the cycling and running.

4. Discussion

This is the first case report analysing performance data of a Quintuple and a Deca Iron ultra-triathlon of a female triathlete setting in both races a new world record. The main results were (i) an even pacing during cycling and running for each stage, (ii) a positive pacing for all split disciplines and overall race time across days, (iii) no difference between the race days of the average speed neither in cycling nor running, and (iv) the running pace has a within-day variation larger than cycling, and also varies more between race days.

The present case report with the world's fastest female ultra-triathlete shows that she applied a steady strategy (even pacing) for both running and cycling for each day. A pacing pattern can be categorized as positive (i.e., slow start, increasing speed throughout the course); negative (i.e., fast start, decreasing speed throughout the course); steady or even (i.e. close to the average throughout the course); or an irregular or specific strategy based on external factors, such as course variations, adversaries, weather [11]. Evidence shows that, in general, the best strategy to achieve the fastest possible average pace is a steady pace [12]. It is noteworthy that, in the present results, some splits were very below the average due to quick stops to reload hydration and nutrition supplies.

The finding of an even pacing during the cycling and running split in an Ironman triathlon is in contrast to existing reports about pacing of elite female and male Ironman triathletes. A study analysing 7687 cycling and 11,894 running split times of 1,392 elite Ironman triathletes (1,263 men and 129 women) showed a continuous decrease (i.e., positive pacing) in both cycling and running [13]. A potential explanation for the even pacing of this athlete could be her background as elite cyclist and her previous experience in achieving podiums or victories in similar races (e.g., Megathlon Germany, Gigathlon Switzerland, and Biennathlon Switzerland). The finding of a positive pacing across days is, however, consistent with findings of elite male triathletes competing in a Deca Iron ultra-triathlon [14,15]. In six male official finishers in a Deca Iron ultra-triathlon, split and overall race times increased linearly across the ten days [14].

Running showed a higher pacing variation than cycling. These results corroborate with previous data of men in similar races [11]. It is often reported by triathletes that ingesting solid food or even drinking, since is harder in running then cycling, and a quick reduction or quick stop (to unwrap or eat something) in running suddenly drags the speed to zero, whereas in cycling even when one stop stroking, speed drops slowly, reducing substantial variations. In other ultra-endurance running event, like a mountain ultra-endurance race the pacing pattern was negative, showing the difficulty of pace control in mountain events [16], as well as in ultra-endurance relay probes, where the rest periods could detract the real fatigue state of the athletes allowing them to show a negative pacing too [17].

The coefficient of variation in the first five days of the Deca Iron ultra-triathlon showed a similar pattern than in the Quintuple Iron ultra-triathlon in both, running and cycling. Nevertheless, at the end of the Deca Iron ultra-triathlon, the coefficient of variation in running was increased (reaching double the previous values) being cycling maintained. The lower muscular demands and the possibility of continuous food and hydration supplies, with lower assimilation problems (no vertical movements of centre of gravity) [18] could allow for a better control of pace, showing lower variations. In contrast, running limited the ingestion of both hydration and food supplies (vertical movements of centre of gravity, impact, movements) [19], fact that could modified the energy input necessary to maintain a steady pace during the race. Taking into account research in extreme environments, strenuous activities during various days could negatively affect cortical arousal, decreasing the information processing, hydration perception and rated of perceived exertion of the subjects [20]. This fact could also negatively affect operative pace control, increasing the coefficient of variation in the running segment. In this line, and even athletes in these ultra-endurance probes showed large resilience and stable psychological profile [3]. The maintenance of high motivation in such big events is an important fact that could affect the pace control and performance, but future studies should control this variable to allow to a better compression of psychological and physiological patter related with success in this extreme sport events.

Although the present case study brings valuable and novel information, it is not free of limitations. Nutritional intake reports would be practical information to be analysed and reported for future athletes. Acute physiological responses and anthropometrics during and after the race are also very important measures to assess the metabolic demand in each race day that could be related to the pacing strategy. Nonetheless, the present data it is important for athletes and coaches of such races and to give insight for new study designs to investigate the physiological responses along the race days or larger studies with a representative sample.

Practical Applications

Considering the increased participation of female triathletes in ultra-endurance races, there has evolved a need of coaches for information on performance aspects of elite athletes. Strength and conditioning coaches working with triathletes should be aware of the relative contribution of a race's discipline (i.e., time spent in swimming, cycling, and running) in overall race time in order to tailor training. The present case study of an elite triathlete provided a performance profile that coaches might use as a guide for their own female triathletes when planning a race strategy.

5. Conclusions

The world's best female ultra-triathlete adopted a steady (even) pacing strategy for both cycling and running, without substantial variations within- or between race days, for both the world record in a Quintuple and a Deca Iron ultra-triathlon. In summary, this case study shows that a female world record setter in a multi-day Ironman triathlon competes with an even pacing during the cycling and running splits but adopts a positive pacing over days. Most probably, such a strategy can only be achieved after long-term preparation and the experience of having completed and finished several similar races on the podium.

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Article

Influence of Contextual Variables in the Changes of Direction and Centripetal Force Generated during an Elite-Level Soccer Team Season

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Abstract: The study of the contextual variables that affect soccer performance is important to be able to reproduce the competition context during the training sessions. Therefore, the aim of the present study was to evaluate the effect of match outcome as related to goal difference (large win, >2 goals, LW; narrow win, 1–2 goals, NW; drawing, D; narrow loss, 1–2 goals, NL; or large loss, >2 goals, LL), match location (home, H; away, A; neutral, N), type of competition (international, INT; national, NAT; friendly, F), phase of the season (summer preseason, SPS; in-season 1, IS1; winter preseason, WPS; in-season 2), and the field surface (natural grass, NG; artificial turf, TF) on the change of direction (COD) and centripetal force (CentF) generated during official games. Thirty male elite-level soccer players (age: 26.57 ± 5.56 years) were assessed while using WIMU PRO™ inertial devices (RealTrack Systems, Almeria, Spain) in 38 matches during the 2017–2018 season, selecting for analysis the number of COD at different intensities and the CentF, depending on the turn direction. Statistical analyses comprised a one-way ANOVA with the Bonferroni post-hoc and *t*-test for independent samples. The main results showed that the match outcome ($\omega_p{}^2$ = 0.01–0.04; NW = D = NL > LL), match location ($\omega_p{}^2$ = 0.01–0.06; A = N > H), type of competition ($\omega_p{}^2$ = 0.01–0.02; INT > NAT > F), and period of the season ($\omega_p{}^2$ = 0.01–0.02; SPS = IS1 = WPS > IS2) all exert some influence. No effect was found for the playing surface. Therefore, match outcome, match location, type of competition, and period of the season influence the demands of centripetal force and changes of direction. These aspects should be considered in the design of training sessions and microcycle workload planning during the season to improve competitive success.

Keywords: competition; contextual variables; non-lineal locomotion; inertial devices; monitoring; sports performance

1. Introduction

Outdoor team sports, especially soccer, are characterized by the performance of high-intensity intermittent efforts, where repeated sprints, rapid accelerations and decelerations, rapid changes of directions, jumps, throws, and duels are continuously performed with incomplete recovery [1]. These abilities and locomotion are dynamic and unpredictable in addition to varying in the intensity and duration during the competition [2].

Among these, the ability to perform a sprint and change direction is considered to be essential for physical performance in soccer, allowing for the players to get ahead in the duel over the ball and create or block clear opportunities to achieve a goal [3,4]. This ability requires a high mechanical load, such as eccentric contractions and a physiological load [5], which are reflected in an increase in muscle damage during training sessions [6] and official matches [7].

Research into external workload during match play has tended to focus on distance covered, speed, or number of efforts above a predetermined threshold [8,9]. Furthermore, the approach that many authors have used in these studies often focuses on linear actions. However, linear actions are trivial and, due to the open nature of soccer, the critical actions will often be curvilinear [10]. In this respect, it has been shown that soccer players perform hundreds of changes of direction throughout the game [2]. Of note, approximately 85% of the actions that are executed at maximum velocity in elite teams consist of curvilinear sprints, that is to say the upright running portion of the sprint completed with the presence of some degree of curvature [11]. Nonetheless, there is a lack of research regarding the performance of changes of direction and centripetal force generated in official competition despite their critical importance.

On the other hand, curvilinear displacement technique presents different kinetic and kinematic features [12–14]. These differences can be reviewed in the work of Churchil et al., (2015) [15], but a key factor is the trunk rotation and, consequently, the neuromechanical requirements that this implies. For this reason, linear and nonlinear sprint performances embody different physical and technical capabilities, and they should be independently assessed and trained. A proper design and management of training loads are important to keep the player available the maximum time possible, especially in elite soccer [16]. For this, it is recommended to monitor demands while using electronic devices [17,18], which are portable and non-invasive, and they contain different sensors (accelerometers, gyroscopes, magnetometers, global positioning systems, and ultra-wide band sensors) for recording external workload (kinematic and neuromuscular) [17,19], and internal workload [20,21].

These internal and external workloads are influenced by different contextual variables, of which the most relevant are: (a) loss of performance throughout the game, with a decrease between the first and second half in variables, such as distance traveled, high intensity activity, or sprints [22,23]; (b) the specific demands depending on the game position in relation to playing formation and competitive dynamics [23–25]; (c) the period of the season, higher demands being found at the end of the season [26]; (d) match location, higher demands being found for home than away matches [27]; (e) game outcome: wins are less exhausting than draws or defeats [28–30]; (f) the competitive level [31]; or, (g) the playing surface, with greater demands as the playing surface is softer and unstable (sand > natural grass > artificial turf > hard surface) [32].

It is hypothesized that they can also have an effect on the performance of non-linear locomotion because the influence of these variables has already been studied previously as having an effect on other physiological and kinematic parameters in soccer. Therefore, the objective of the present study was to analyze the effect of the contextual variables of match outcome, match location, type of competition, period of the season and playing surface on the centripetal force, and changes of direction recorded with electronic devices during a competitive season in elite soccer.

2. Materials and Methods

2.1. Participants

Thirty elite-level soccer players participated voluntarily in this research (age: 26.57 ± 5.56 years; height: 1.82 ± 0.05 meters; body mass: 77.2 ± 2.76 kg.; fat percentage: 8.44 ± 1.08%; body mass index: 22.31 ± 1.32 kg/m^2). All of the players belonged to the same team, which participated in the Russian

Premier League, Russian Cup, Champions League and Europa League in the 2017–2018 season. All of the participants had to meet the requirement of the absence of any type of physical limitations or musculoskeletal injuries that could affect the workload monitoring during official matches. Besides, to be included in the final analysis, players had had to play the full length of a game in order to be included in the analysis (~90 min.). The Bioethics Commission of the University approved the study, which was conducted according to the Declaration of Helsinki (Reg. Code 2595-2019). The participants were informed of the risks and discomforts that are associated with testing and provided written informed consent.

2.2. Material

2.2.1. Anthropometric Measurements

Height was measured to the nearest 0.5 cm during a maximal inhalation while using a wall-mounted stadiometer (SECA, Hamburg, Germany). Body mass was obtained using an eight-electrode segmental body composition monitor BC-601 model (TANITA, Tokyo, Japan).

2.2.2. Inertial Device

Each participant wore an inertial device, called a WIMU PRO^{TM} (RealTrack Systems, Almeria, Spain), which was placed on the upper back (interscapular line, T2-T4 vertebrae) in a specific harness to achieve the best GPS signal reception [33]. This device has been given the FIFA certificate for use during official competition and it is composed of different sensors: (a) four triaxial accelerometers (1000 Hz) with a full-scale output range of ±16, ±16, ±32, and ±400 g; (b) three triaxial gyroscopes (1000 Hz) with a full-scale output range of 2000 degrees/seconds; (c) a three-dimensional (3D) magnetometer; (d) a 10 Hz GPS chip; and, (e) a 20 Hz UWB chip. During the present study, the sampling frequency of the microelectromechanical sensors (accelerometer, gyroscope, and magnetometer) was 100 Hz, and the GPS sensor was 10 Hz.

The accuracy and reliability of the GPS, gyroscope and accelerometer in the inertial device have been previously evaluated with satisfactory results [34–36]. Besides, the inter-unit reliability (ICC = 0.75–0.96) and the validity (Bias, counter-clockwise = −2.19N; clockwise = 1.75N) for measuring centripetal force have been analyzed with satisfactory results (Unpublished data). Two matches were deleted from the final analysis, because the operating conditions for the GPS were not optimal [37]. During the recording process, the GPS sensor was connected to 12.8 ± 2.5 satellites and the horizontal geometric dilution of precision (HGDOP) for Global Navigation Satellite Systems (GNSS) was practically ideal, with a result of 0.96 ± 0.14 [38].

Prior to placement, the inertial devices were calibrated and then synchronized following manufacturer guidelines. For this, three aspects were considered to improve the data accuracy: a) to leave the device immobile for 30 s; (b) on a flat surface; and, (c) without electromagnetic devices nearby [38,39].

2.3. Variables

2.3.1. Non-Linear Locomotion

Table 1 shows the variables selected to analyze non-linear locomotion. All of them were calculated through two main variables: (a) *Centripetal force (CentF)*, as the force or force component acting on a moving object on a curvilinear trajectory which is directed towards the center of the curvature of the path [40]; and, (b) *Change of direction (COD)*, considered as the specific event where the athlete performed "a movement or skill to change direction, velocity, and locomotion mode" [41].

Table 1. Description of centripetal force and change of direction analyzed variables during the present research.

Variable	Sub-Variable	Description
Centripetal Force (CentF)	$+CentF_{AVG}$	Average of the centripetal force generated by the player throughout the game when he turned clockwise.
	$-CentF_{AVG}$	Average of the centripetal force generated by the player throughout the game when he turned counterclockwise.
	$+CentF_{MAX}$	Maximum centripetal force generated by the player throughout the game when he turned clockwise.
	$-CentF_{MAX}$	Maximum centripetal force generated by the player throughout the game when he turned counterclockwise.
	$DifCentF_{AVG}$	Average difference of centripetal force as a function of the direction of rotation.
Changes of Direction (CODs)	CountCOD	Number of total changes of direction performed in a match.
	$CountCOD_{HIA}$	Number of total changes of direction performed in a match at high intensity (above 16 km/h).
	$CountCOD_{SPRINT}$	Number of total changes of direction performed in a match at maximum intensity (above 21 km/h).
	$R_{20}COD$	Number of total changes of direction performed in a match with a recovery time less than 20 s.
	$R_{60}COD$	Number of total changes of direction performed in a match with a recovery time less than 60 s.
	$R_{20}COD_{HIA}$	Number of total changes of direction performed in a match at high intensity (above 16 km/h) with a recovery time less than 20 s.
	$R_{60}COD_{HIA}$	Number of total changes of direction performed in a match at high intensity (above 16 km/h) with a recovery time less than 60 s.
	$R_{20}COD_{SPRINT}$	Number of total changes of direction performed in a match at maximum intensity (above 21 km/h) with a recovery time less than 20 s.
	$R_{60}COD_{SPRINT}$	Number of total changes of direction performed in a match at maximum intensity (above 21 km/h) with a recovery time less than 60 s.

2.3.2. Contextual Variables

In the present study, the influence of the following contextual variables related with the official competition dynamics was analyzed:

- *Period of the season*. This variable is divided into four periods due to the climatic conditions that do not allow playing matches in the winter period: (a) Summer preseason, SPS (July–August) (n = 5); (b) In-season 1, IN1 (September to December) (n = 11); (c) Winter preseason, WPS (January–February) (n = 9); and, (d) In-season 2, IN2 (March to June) (n = 13).
- *Type of competition*. With respect to the nature of the competition, it is divided into three groups: (a) international, INT (Champions League and Europa League) (n=7); (b) national, NAT (League and Cup) (n = 15); and, (c) friendly matches, F (n = 16).
- *Match location*. Classified into three groups: (a) home, H (n = 7); (b) away, V (n = 17); and, (c) neutral, N (n = 14).
- *Match outcome*. As a function of the goal difference in the final result of the game, this variable was divided into five groups: (a) large win, LW, winning the game with a difference of over two goals (n = 10); (b) narrow win, NW, winning the game with a difference of between one and two

goals (n = 12); (c) drawing, D, the same number of goals by each team or no goals in the game (n = 10); (d) narrow loss, NL, losing the game with a difference of between 1 and 2 goals (n = 6); (e) large loss, LL, losing the game with a difference of over 2 goals (n = 0).

- *Playing surface*. Divided according to the different types of surface allowed by the Federation International of Football Associations (FIFA) into two types: (a) natural grass, NG (n = 31), and (b) artificial turf, TF (n = 7).

2.4. Procedures

The data were collected during the 2017–2018 season in the matches played by a male elite-level soccer team that participated in domestic and international competitions. All of the matches were played on natural grass or artificial turf according to FIFA quality standards. The playing formation used during the investigation was 4-4-2. The players were familiar with the functions of their specific position and the playing formation.

The players arrived in the locker room 45 minutes before the start of the matches for placement of the inertial devices. The devices were worn during the warm-up and the entire match. The information from the devices was downloaded to a computer at the end of the match. All of the raw files were synchronized with the time selection of first and second periods that were made in real-time while using a tablet with SVIVO^{TM} software (RealTrack Systems, Almeria, Spain). Time selections and raw files were synchronized in the SPRO^{TM} software (RealTrack Systems, Almeria, Spain). Subsequently, the data were exported and entered into an Excel database. Finally, the database was imported into the SPSS software (IBM Corporation, Armonk, USA) for statistical analysis.

2.5. Data Analysis

The descriptive analysis was performed and is presented as mean (M) ± standard deviation (SD) for each variable. Data distribution was subsequently analyzed by the Kolmogorov–Smirnov test and data homoscedasticity by the Levene test to confirm a normal distribution. A one-way ANOVA was performed with the Bonferroni post-hoc for the comparative analysis among contextual variables (match outcome, match location, type of competition, and period of the season) and non-linear locomotion (change of direction and centripetal force), while an independent sample t-test was used for the playing surface analysis. The magnitude of differences was obtained while using the statistical test partial omega squared (ω_p^2) interpreted as: >0.01 low; >0.06 moderate; or >0.14 high; and, Cohen's d (d) interpreted as: trivial (0–0.19), low (0.20–0.49), moderate (0.50–0.79), or high (>0.80) [42]. The statistical analyses were performed with IBM SPSS Statistics software (release 24.0; SPSS Inc., Armonk, NY, EE. UU.). The statistical significance was established at $p < 0.05$ and the p values were corrected for multiple comparisons by the software.

3. Results

3.1. Period of the Season

Table 2 shows the comparative analysis between the non-linear locomotion (change of direction and centripetal force) and the period of the season (summer preseason, in-season 1, winter preseason, in-season 2). The highest demands were found in the winter preseason, showing significant differences in $+CentF_{AVG}$, COD_{SPRINT}, $R_{60}COD_{HIA}$, $R_{60}COD_{SPRINT}$ ($F > 3.59$; ω_p^2 = 0.01–0.02, *low effect*) with respect to the in-season 2. However, similar demands were found between in-season 1 and in-season 2, except in $+CentF_{AVG}$ and $R_{20}COD_{HIA}$, with greater values in the first part of the season ($F > 2.89$; $\omega_p^2 = 0.01$, *low effect*).

Table 2. Descriptive and comparative analysis of centripetal force and changes of direction related to the period of the season.

Variables	**Summer Preseason (n = 42) M ± DE**	**In-Season 1 (n = 86) M ± DE**	**Winter Preseason (n = 60) M ± DE**	**In-Season 2 (n = 117) M ± DE**	F	p	ω_p^2
$+CentF_{MAX}$	937.14 ± 362.75	949.43 ± 285.89	**958.75 ± 350.13**	922.14 ± 274.43	1.76	0.151	0.00
$-CentF_{MAX}$	−925.62 ± 281.00	**−932.59 ± 267.19**	−926.77 ± 314.83	−899.68 ± 264.68	1.66	0.171	0.00
$+CentF_{AVG}$ *	209.30 ± 19.19	**210.48 ± 19.20** [d]	210.14 ± 17.71 [d]	207.28 ± 17.41	4.16	0.006	0.02
$-CentF_{AVG}$	−208.15 ± 19.94	**−209.75 ± 17.56**	−209.61 ± 24.11	−207.60 ± 15.95	1.73	0.159	0.00
Difference (+% vs. −%) *	1.46 ± 12.42	−0.42 ± 12.82	0.52 ± 17.45	**2.12 ± 10.32** [b]	3.68	0.012	0.01
COD	592.52 ± 153.45	622.96 ± 161.13	**657.00 ± 165.70**	637.08 ± 159.79	0.69	0.557	0.00
COD_{HIA} (>16 km/h)	57.84 ± 15.85	62.24 ± 17.11	**62.96 ± 16.54**	55.64 ± 16.08	1.66	0.173	0.00
COD_{SPRINT} (>21 km/h) *	14.4 ± 4.74	15.44 ± 5.08	**18.56 ± 6.03** [d]	14.96 ± 5.44	3.85	0.009	0.01
$R_{20}COD$	528.20 ± 138.21	559.80 ± 146.27	550.84 ± 138.38	**572.48 ± 144.67**	0.35	0.793	0.00
$R_{60}COD$	56.52 ± 15.12	56.88 ± 15.85	53.72 ± 14.41	**59.00 ± 15.30**	0.81	0.488	0.00
$R_{20}COD_{HIA}$ *	16.56 ± 5.16	**19.68 ± 6.22** [d]	18.92 ± 5.64	16.36 ± 5.70	2.89	0.034	0.01
$R_{60}COD_{HIA}$ *	11.36 ± 3.61	11.80 ± 4.07	**13.20 ± 4.18** [d]	10.28 ± 3.71	3.59	0.013	0.01
$R_{20}COD_{SPRINT}$ *	2.44 ± 1.11	2.84 ± 1.37	**4.04 ± 1.78** [a,b]	3.12 ± 1.66	5.59	0.001	0.02
$R_{60}COD_{SPRINT}$ *	0.80 ± 0.60	1.04 ± 0.69	**1.44 ± 0.84** [a,d]	0.88 ± 0.60	5.26	0.001	0.02

Note. M: Mean; SD: Standard deviation; CentF: Centripetal force (+: clockwise, −: counterclockwise); COD: Changes of direction; RCOD: Ability to repeat a change of direction; p: p value; F: ANOVA's F value; ω_p^2: Partial omega squared; * Statistical differences ($p < 0.05$) with [a] Summer preseason (july-august); [b] In-season 1 (September-December), [c] Winter preseason January-February), [d] In-season 2 (March-June); Bold numbers represent maximum values of each variable.

3.2. Match Location

Table 3 shows the comparative analysis between centripetal force and change of direction in relation to match location (home, away, neutral). The home matches recorded lower demands with statistically significant differences with respect to away and neutral conditions in all non-linear performance variables ($F > 3.02$; $\omega_p^2 = 0.01$–0.06, *moderate to low effect*), except in Difference (+% vs. −%), COD, R_{20}COD, and R_{60}COD. The workload demands in matches played away and neutral conditions were similar and no differences were found between both conditions.

Table 3. Descriptive and comparative analysis of centripetal force and changes of direction related to the match location.

Variables	Home (n = 77) M ± DE	Away (n = 138) M ± DE	Neutral (n = 90) M ± DE	F	p	ω_p^2
+ $CentF_{MAX}$ *	902.71 ± 310.53	952.41 ± 269.57 [a]	**955.54 ± 358.17** [a]	4.69	0.009	0.02
−$CentF_{MAX}$ *	−893.29 ± 276.00	−920.52 ± 257.57	**−934.13 ± 318.01**	3.02	0.049	0.01
+ $CentF_{AVG}$ *	205.07 ± 18.35	**210.51 ± 17.92** [a]	210.20 ± 18.20 [a]	15.13	<0.001	0.05
−$CentF_{AVG}$ *	−206.20 ± 15.78	−209.36 ± 17.05 [a]	**−209.88 ± 24.30**	5.25	0.005	0.02
Difference (+% vs. −%)	1.13 ± 10.90	**1.25 ± 13.25**	0.09 ± 16.33	1.81	0.164	0.00
COD	601.60 ± 148.26	644.40 ± 165.69	**645.60 ± 163.79**	0.79	0.453	0.00
COD_{HIA} (>16 km/h) *	51.84 ± 14.68	**62.80 ± 17.45** [a]	61.32 ± 16.17 [a]	4.32	0.013	0.02
COD_{SPRINT} (>21 km/h) *	11.32 ± 3.69	**17.44 ± 5.89** [a]	17.24 ± 5.67 [a]	13.12	<0.001	0.04
R_{20}COD	540.28 ± 134.50	**579.60 ± 150.41**	537.84 ± 135.86	1.35	0.260	0.00
R_{60}COD	56.16 ± 14.54	**58.56 ± 15.95**	53.84 ± 14.46	1.24	0.290	0.00
$R_{20}COD_{HIA}$ *	14.80 ± 5.10	**19.72 ± 6.30** [a]	18.08 ± 5.42 [a]	6.78	0.001	0.02
$R_{60}COD_{HIA}$ *	9.88 ± 3.64	11.76 ± 4.05	**12.84 ± 4.01** [a]	4.57	0.010	0.02
$R_{20}COD_{SPRINT}$ *	1.60 ± 0.78	**3.80 ± 1.77** [a]	3.52 ± 1.61 [a]	19.31	<0.001	0.06
$R_{60}COD_{SPRINT}$ *	0.64 ± 0.45	1.16 ± 0.71 [a]	**1.32 ± 0.82** [a]	8.14	<0.001	0.03

Note. M: Mean; SD: Standard deviation; CentF: Centripetal force (+: clockwise, −: counterclockwise); COD: Changes of direction; RCOD: Ability to repeat a change of direction; p: p value; F: ANOVA's F value; ω_p^2: Partial omega squared; * Statistical differences ($p < 0.05$) with [a] Home, [b] Away, [c] Neutral; Bold numbers represent maximum values of each variable.

3.3. Match Outcome

Table 4 shows the comparative analysis between non-linear locomotion (centripetal force and change of direction) as a function of match outcome (drawing, narrow win, large win, narrow loss, and large loss). The effect of match outcome produced differences in +$CentF_{MAX}$, −$CentF_{MAX}$, +$CentF_{AVG}$, −$CentF_{AVG}$, Difference (+% vs. −%), $R_{60}COD_{HIA}$, and $R_{60}COD_{SPRINT}$ with a lower effect size ($F = 2.95$–10.77; $\omega_p^2 = 0.01$–0.04). Specifically, large wins presented the lowest demands, obtaining statistically significant differences in +$CentF_{AVG}$ and −$CentF_{AVG}$ with drawing, narrow wins and narrow losses, in −$CentF_{MAX}$ with narrow wins and losses, in +$CentF_{MAX}$ and $R_{60}COD_{SPRINT}$ with drawing, and in $R_{60}COD_{HIA}$ with narrow losses.

3.4. Type of Competition

Table 5 shows the results of the comparative analysis between the centripetal force and change of direction in relation to type of competition (international, national, and friendly matches). In general, the greatest demands were experienced in international matches. Specifically, significant differences were found in Difference (+% vs. −%), $R_{60}COD_{HIA}$, and $R_{20}COD_{SPRINT}$ with higher values in international matches with respect to national and friendly matches with a low effect size ($F > 2.95$; $\omega_p^2 = 0.01$–0.02).

Table 4. Descriptive and comparative analysis of centripetal force and changes of direction related to the match outcome.

Variables	Drawing (n = 76) M ± DE	Narrow Win (n = 104) M ± DE	Large Win (n = 77) M ± DE	Narrow Loss (n = 48) M ± DE	F	p	ω_p^2
+ $CentF_{MAX}$ *	**959.73 ± 306.04** [c]	952.25 ± 349.73	912.77 ± 278.64	959.67 ± 290.31	2.95	0.032	0.01
−$CentF_{MAX}$ *	−903.03 ± 250.49	**−950.78 ± 328.78** [a,c]	−883.64 ± 259.06	−949.03 ± 257.87 [c]	8.45	<0.001	0.03
+ $CentF_{AVG}$ *	**211.71 ± 17.82** [c]	209.84 ± 19.09 [c]	206.07 ± 16.35	210.46 ± 19.20 [c]	10.77	<0.001	0.04
−$CentF_{AVG}$ *	−209.44 ± 17.22 [c]	**−211.18 ± 24.52** [c]	−205.37 ± 15.77	−209.00 ± 17.41 [c]	10.46	<0.001	0.04
Difference (+% vs. −%) *	1.57 ± 12.29 [b]	−0.99 ± 15.67	**2.53 ± 13.61** [b]	0.76 ± 13.85	8.48	<0.001	0.03
COD	627.96 ± 157.65	628.40 ± 159.10	**654.80 ± 167.42**	647.40 ± 168.64	0.27	0.847	0.00
COD_{HIA} (>16 km/h)	63.16 ± 16.79	58.76 ± 16.29	56.00 ± 15.58	**65.48 ± 18.31**	1.69	0.167	0.00
COD_{SPRINT} (>21 km/h)	**17.76 ± 5.87**	16.04 ± 5.44	14.40 ± 5.10	16.16 ± 5.32	2.03	0.108	0.00
$R_{20}COD$	544.16 ± 137.29	561.04 ± 143.48	556.32 ± 142.00	**580.72 ± 152.70**	0.25	0.860	0.00
$R_{60}COD$	58.64 ± 15.23	53.36 ± 14.37	57.88 ± 15.31	**59.88 ± 17.37**	1.32	0.267	0.00
$R_{20}COD_{HIA}$	18.84 ± 5.81	18.00 ± 5.76	16.32 ± 5.31	**20.92 ± 6.77**	2.42	0.064	0.00
$R_{60}COD_{HIA}$ *	12.60 ± 4.06	11.12 ± 3.79	10.52 ± 3.69	**14.00 ± 4.70** [c]	3.70	0.011	0.01
$R_{20}COD_{SPRINT}$	**3.44 ± 1.68**	3.41 ± 1.63	2.92 ± 1.44	3.01 ± 1.40	1.01	0.386	0.00
$R_{60}COD_{SPRINT}$ *	**1.24 ± 0.80** [c]	1.24 ± 0.73 [c]	0.68 ± 0.49	1.16 ± 0.78	4.86	0.002	0.02

Note. M: Mean; SD: Standard deviation; CentF: Centripetal force (+: clockwise, −: counterclockwise); COD: Changes of direction; RCOD: Ability to repeat a change of direction; p: p value; F: ANOVA's F value; ω_p^2: Partial omega squared; * Statistical differences ($p < 0.05$) with [a] Drawing, [b] Narrow win, [c] Large win and [d] Narrow loss; Bold numbers represent maximum values of each variable.

Table 5. Descriptive and comparative analysis of centripetal force and changes of direction related to the type of competition.

Variables	**International (n = 77) M ± SD**	**National (n = 138) M ± SD**	**Friendly (n = 90) M ± SD**	F	p	ω_p^2
+ $CentF_{MAX}$	935.96 ± 203.33	**947.15 ± 285.86**	943.61 ± 335.64	0.56	0.945	0.00
- $CentF_{MAX}$	−910.95 ± 239.23	**−924.37 ± 272.68**	−919.50 ± 296.62	0.12	0.892	0.00
+ $CentF_{AVG}$	**212.48 ± 15.96**	209.60 ± 18.83	209.17 ± 17.91	0.97	0.380	0.00
- $CentF_{AVG}$	−208.93 ± 14.48	**−209.28 ± 17.33**	−208.83 ± 21.82	0.14	0.872	0.00
Difference (+% vs. −%) *	**4.88 ± 10.34** ^{b,c}	0.27 ± 12.34	0.90 ± 15.33	2.95	0.050	0.01
COD	**709.28 ± 186.17**	633.08 ± 163.04	636.88 ± 160.31	0.37	0.695	0.00
COD_{HIA} (>16 km/h)	**75.00 ± 21.57**	59.24 ± 16.75	60.06 ± 16.08	1.50	0.224	0.00
COD_{SPRINT} (>21 km/h)	**21.56 ± 7.54**	15.96 ± 5.54	16.02 ± 16.08	1.78	0.168	0.00
$R_{20}COD$	**644.28 ± 170.51**	567.80 ± 147.44	546.81 ± 5.30	1.00	0.370	0.00
$R_{60}COD$	**59.56 ± 15.73**	59.04 ± 16.10	54.56 ± 137.60	1.44	0.238	0.00
$R_{20}COD_{HIA}$	**24.16 ± 8.22**	18.36 ± 6.04	17.76 ± 14.46	2.05	0.129	0.00
$R_{60}COD_{HIA}$ *	**16.16 ± 5.40** ^{b,c}	10.72 ± 3.79	12.24 ± 5.49	4.56	0.011	0.02
$R_{20}COD_{SPRINT}$ *	**5.72 ± 2.67** ^{b,c}	3.28 ± 1.61	3.12 ± 4.02	4.64	0.010	0.02
$R_{60}COD_{SPRINT}$	**1.16 ± 0.78**	1.08 ± 0.69	1.12 ± 0.72	0.83	0.920	0.00

Note. M: Mean; SD: Standard deviation; CentF: Centripetal force (+: clockwise, −: counterclockwise); COD: Changes of direction; RCOD: Ability to repeat a change of direction; p: p value; F: ANOVA's F value; ω_p^2: Partial omega squared; * Statistical differences (p < 0.05) with ^{a} International, ^{b} National, ^{c} Friendly; Bold numbers represent maximum values of each variable.

3.5. Playing Surface

Table 6 shows the results of the comparative analysis between non-linear locomotion (centripetal force and change of direction) as a function of playing surface (natural grass and artificial turf). No differences were found in the non-linear workload between both types of surfaces (t < 2.77; d < 0.14).

Table 6. Descriptive and comparative analysis of centripetal force and changes of direction related to playing surface.

Variables	Natural Grass (n = 77) M ± SD	Artificial Turf (n = 138) M ± SD	t	p	d
+ $CentF_{MAX}$	944.59 ± 325.44	**945.28 ± 272.29**	−0.04	0.966	−0.00
- $CentF_{MAX}$	**−923.53 ± 296.25**	−911.16 ± 244.47	−0.84	0.401	−0.05
+ $CentF_{AVG}$	209.27 ± 18.62	**209.95 ± 16.46**	−0.73	0.465	−0.04
- $CentF_{AVG}$	−208.96 ± 21.02	**−209.17 ± 16.04**	0.25	0.834	0.01
Difference (+% vs. −%) *	0.38 ± 14.36	**2.32 ± 13.50**	−2.77	0.006	−0.14
COD	633.68 ± 161.54	**651.44 ± 163.52**	−0.54	0.596	−0.03
COD_{HIA} (>16 km/h)	58.92 ± 16.32	**64.12 ± 17.23**	−1.51	0.132	−0.08
COD_{SPRINT} (>21 km/h)	15.68 ± 5.37	**17.60 ± 5.81**	−1.67	0.095	−0.09
$R_{20}COD$	549.36 ± 140.75	**588.40 ± 149.13**	−1.31	0.204	−0.07
$R_{60}COD$	56.40 ± 15.27	**56.96 ± 14.95**	−0.17	0.860	−0.01
$R_{20}COD_{HIA}$	17.76 ± 5.77	**19.64 ± 5.95**	−1.55	0.128	−0.08
$R_{60}COD_{HIA}$	11.52 ± 3.91	**12.36 ± 4.14**	−0.98	0.340	−0.05
$R_{20}COD_{SPRINT}$	3.12 ± 1.56	**3.72 ± 1.63**	−1.83	0.067	−0.09
$R_{60}COD_{SPRINT}$	**1.12 ± 0.72**	1.08 ± 0.68	0.14	0.893	0.01

Note. M: Mean; SD: Standard deviation; CentF: Centripetal force (+: clockwise, −: counterclockwise); COD: Changes of direction; RCOD: Ability to repeat a change of direction; p: p value; t: independent samples t-test value; d: Cohen's d effect size; * Statistical differences (p < 0.05) between groups; Bold numbers represent maximum values of each variable.

4. Discussion

Soccer performance consists of a combination of physical characteristics, technical skills, and tactical organization [26,43]. Regarding the tactical organization and technical skills, recent studies have indicated that greater technical efficiency [31,43] and better synchronization among team players [44,45] are associated with a greater probability of achieving success. Related with physical characteristics, previous research has determined that the winning teams perform better in high intensity locomotion (above 16 km/h) and speed changes (accelerations and decelerations above 3 m/s) [29,46]. Conversely, a greater volume of locomotion (distance, accelerations, decelerations) is associated with a poorer performance due to the losing teams attempt to recover from an unfavorable position, both in small-sided games [47,48] and during official matches [49,50].

Regarding physical performance indicators, centripetal force and changes of direction are two essential components in team sports, allowing for the players to get ahead in the duel over the ball and create or block clear opportunities to get a goal [3,4]. For this reason, different research has investigated to what extent the training of different variables influences the performance of changes of direction, such as strength training of the lower limbs [51], trunk stability [52], or gait biomechanics [12–14]. However, the question is whether it is worth improving performance in changes of direction and centripetal force, and if they have an effect on performance during the competition. Therefore, the purpose of this study was to evaluate the effect of contextual variables, such as the period of the season, match outcome, match location, type of competition, and type of surface in non-linear locomotion in an elite-level soccer team. All of the contextual variables had an effect on non-linear locomotion, except playing surface. The greatest demands were experienced in the winter preseason (Europa League final phase and friendly matches against elite-level international teams between January and February) with drawing or narrow wins and losses, in international matches and away or in neutral conditions.

A significant increase of centripetal force and COD values were reported during in-season 1 and the winter preseason with respect to the summer preseason and in-season 2. This could confirm two findings that were developed by previous studies: (i) on the one hand, some authors suggest that the locomotion requirements in matches or the team's level could be related with the activity of the opposing team [53], (ii) on the other hand, Rampinini et al. [26] show how elite-level teams achieved higher values in physical performance variables (total distance, high-intensity distance, sprinting distance) when they faced better quality teams. Therefore, these results are in the same line as these studies, which show how the opponent influences physical development in the competition, when the obvious thing would have been to increase throughout the season. However, small effect size differences in non-linear locomotion suggest that the influence of the period of the season on general fatigue or the required work rate is relatively small. Even so, the current results indicate that elite-level soccer players must be physically prepared, so that they can cover not only greater distances and at greater intensity, but also develop a more non-linear locomotion with changes of direction.

Similarly, Rampinini et al. [26] showed that the type of competition is related to an opposing team with a higher or lower quality, both at the physical and technical-tactical level. This has been found in the results of the present study, where the highest demands in centripetal force and changes of direction were found in international matches, then in national matches and, finally, with the lowest demands, in friendly matches. It is suggested that the training microcycles that end with an international match require a specific design with higher demands in all types of locomotion by the soccer player and at all intensities, specifically in non-linear trajectories, as shown in this study.

With respect to the match location, from the study by Schwartz and Barsky [54], the advantage in the home condition has been identified from amateur to professional level in most sports [55]. Specifically for soccer, it has been shown that this home advantage has existed since the beginning of the soccer league in England in 1888–1889 and has since continued at all levels of professional matches [56]. Even with this evidence, there is a lack of research on this phenomenon, and only a few studies have addressed its influence on external workload in soccer players. The present results showed a significant decrease in the performance of non-linear trajectories in official matches in the home condition ($p < 0.05$). In contrast, previous studies found higher values in workload demands, such as maximum speed and percentage of high intensity actions ($p < 0.05$) [50,57], and technical-tactical indicators, such as on-goal shooting and goal-scoring opportunities [58]. Although the present findings require a more detailed study (only one elite-level team during a season), they are suggesting in a low to moderate magnitude ($\omega_p{}^2 = 0.01$ to 0.06) that non-linear locomotion demands do not follow the same dynamics as linear locomotion. This phenomenon also occurred with the match outcome. While in the study by Aquino et al. [50] higher values were reported in high intensity variables and total distance covered, in the present study lower values were found when the team was winning, especially in large wins (a difference of over two goals).

Finally, in the type of surface analysis, although higher values were reported in centripetal force and changes of direction when the match was played on artificial turf with respect to natural grass, the null hypothesis that a different surface was going to influence the centripetal force and the changes of direction performed during official games was rejected. This comparison of surfaces has been investigated in other approaches, such as: (a) the incidence of injury with no differences between surface, but a higher number of instances of low back and chronic pain was found on artificial turf [59]; (b) speed performance, with faster values on artificial turf so that greater skill is needed in order to avoid injuries [60]; and (c) fatigue with greater acute decrement in hamstring peak torque on natural grass, but no delay in the recovery process was found between surfaces. Therefore, although there exist differences in fatigue, injury incidence, and linear locomotion, during official matches the non-linear locomotion demands are similar and the training process should address these findings to achieve an optimum performance and decrease the injury risk, depending on the type of surface.

After the analysis of the competition, the coach will be able to know the specific profile of his players in non-linear locomotion, both in the changes of direction made and in the centripetal force generated [61]. While using this information, it would be advisable to design tasks either in specific game situations (small-sided games and specific individual and collective tasks with the ball) or in others (curvilinear locomotion at maximum intensity, zigzag movements).

While the results of this study have provided information about the non-linear performance of professional players that belonged to an elite-level soccer team, thanks to the use of electronic performance and tracking systems, and while considering multiple contextual factors, such as period of the season, type of competition, match location, match outcome, and playing surface, some limitations to the study must be acknowledged. One of the limitations in this research concerns the sample studied. Only the non-linear performance of one soccer team through centripetal force and change of direction has been analysed during an entire season because of limited access to elite-level soccer players. This meant that only one playing system and one playing style of the team conditioned the results of the study. Despite this fact, the authors did not influence the natural dynamics of the competition, giving an ecological treatment to the study. Finally, data collection was performed following the same protocol throughout the matches, but the environmental influence was not controlled.

5. Conclusions

The contextual variables analyzed: period of the season, match outcome, match location, and type of competition had an effect on non-linear locomotion, such as changes of direction and the centripetal force generated during the competition. In contrast, the playing surface had no influence on these demands. Therefore, the following suggestions could be considered for using the information obtained in the present study in a practical way for performance improvement and proper training planning based on the conclusions obtained:

- The period of the season had a significant effect on the non-linear locomotion workload. A progressive increase in change of direction and centripetal force performance was found in the team studied from summer preseason to winter preseason, maintaining these values until the end of the season. Following the results that were obtained, a progressive increase in non-linear locomotion workload, reaching the highest values in winter preseason, allows for maintaining performance between in-season periods.
- Match location had a direct effect on workload management in every microcycle, with the need to increase the load of these individual technical abilities when the end of the competitive microcycle coincides with an official away or neutral location match.
- The non-linear locomotion performance determines the soccer match outcome. A large goal difference both in the winning and losing team produced a drastic reduction in the centripetal force and a change of direction demands. In this respect, it is interesting to design game-based tasks and conditional tasks that represent different match outcome scenarios to prepare the players both physically and psychologically for these contexts during the competition with the aim of maintaining the best competitive performance.
- Regarding the type of competition, international matches required higher demands in comparison to national and friendly matches. In this respect, a higher-level competition needs a special preparation period with an increase of non-lineal locomotion demands with the aim of facing the match in optimal conditions.
- The type of surface did not show differences in the performance of non-linear locomotion. Therefore, due to this peculiarity that occurs in countries with cold climates, where low temperatures complicate the maintenance of natural grass, combined training on artificial and natural surfaces is necessary to adapt the player to both, because they present the same demands for changes of direction and centripetal force.

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writing—original draft preparation, P.G.-G., A.B.-C., C.D.G.-C. and D.R.-V.; writing—review and editing, P.G.-G., E.d.l.C.S., and J.P.-O.; supervision, E.d.l.C.S., and J.P.-O.; funding acquisition, E.d.l.C.S., and J.P.-O. All authors have read and agreed to the published version of the manuscript.

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Evaluation of the Pre-Planned and Non-Planed Agility Performance: Comparison between Individual and Team Sports

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Abstract: This study assessed differences in agility performance between athletes of team and individual sports by assessing change-of-direction speed (CODS) as pre-planned agility and reactive agility (RA) as non-planed in different spatial configurations. The study involved 36 individual (sprint, hurdles, jumping, tennis, and judo) and 34 team (soccer, basketball, and handball) athletes. CODS and RA were measured with a light-based reactive training system in a frontal (FR), universal (UN), semicircular (SC), and lateral (LA) design. Lower limb power and sprint performance were also measured in a 10 m single leg jump test and 15 m sprint. Individual athletes showed significantly better performance in three of the eight agility tests: LA-RA, UN-RA, and SC-CODS ($p < 0.008$, $p < 0.036$, and $p < 0.027$, respectively) and were found to present stronger correlations ($p < 0.01$) between jump test performance and the CODS condition. Team athletes showed stronger associations between sprint performance and the CODS condition. In the RA condition both jump and sprint performance showed stronger correlations in the group of individual athletes. Agility performance as measured by CODS and RA should improve with enhanced of motor proficiency. Finally, the tests applied in this experiment seem to be multidimensional, but require spatio-temporal adjustment for their implementation, so that they meet the requirements of the particular sport.

Keywords: agility; reaction time; CODS; testing; athletic performance; cognition

1. Introduction

The particular demands of a sport are reflected in the physical, technical, and tactical abilities of athletes [1]. These abilities are abetted by a particular anthropometric or physiologic profile encompassing a wide variety of variables from body height, body type, and muscle fiber composition to metabolic capacity, muscle contractile properties, or motor proficiency. In addition to these characteristics, there are also a number of psychological factors that dictate performance such as athlete motivation, cognitive skills, and emotional intelligence [2]. All of the above factors influence the rate at which an athlete can achieve mastery and can be treated as determinants of competitive success.

A sport can generally be distinguished as an individual or team sport, in which performance is dictated exclusively by the effort of the individual compared with the collective interaction of multiple teammates (or at least two individuals). Other more complex categorizations are based on the division of sports by their motor and technical characteristics or physiological demands. While individual sports such as singles tennis or judo are recognized as individual sports compared with soccer or basketball,

all of these disciplines are intermittent in activity whereby athletes are required to frequently transition between brief bouts of high-intensity activity and longer periods of low-intensity activity [3,4]. In contrast, some of the sports that comprise individual track and field events such as sprinting, hurdling, or jumping all rely on speed and power, whereas others are based entirely on endurance (distance running) or strength (throwing events). On this basis, several sports categories have been identified: target games, net/wall games, striking/fielding games, and territory games [5]. One uniting factor is that almost all individual and team sports require a great deal of technical proficiency in changing direction, speed, and position. Known as agility, many of these movements comprise a "hinged moment" condition involving both linear and angular momentum [6].

The criteria that guided the division of individual disciplines into team sports and individual sports are based on the individual entity (player) who implements the goals set by individual sport performance. He is a single perpetrator of the action (individual sport) or cooperates with many entities (players) and pursues their common goal of particular sport performance (team sports). According to Kłyszejko [7], the analysis of factors influencing the course of sports performance and assessment of movements structure, that actually apply and play a specific role in this performance, allows the classification of sport's disciplines according to their movement separateness. There is no strong articulation that the course of the sports performance, as well as the effects of the athlete's actions, depend on the level of motor abilities. In this context, it seems obvious that the sports result (performance) is also influenced by motor skills. Based on the thoughts of Kłyszejko [7], Naglak [8,9] took into account the subjectivity and manner of achieving the objectives of sports performance, and on this basis distinguished the sport disciplines on individual, group, and team disciplines.

In individual sport disciplines (all types of races, wrestling, fencing, judo, gymnastics, sprints, various types of jumps, tennis) only single athletes take part. He/she relies on their own technical skills, and the performance requires them to be physically active and ready to take action to achieve the performance goal-victory. When two or more athletes compete together with other athletes, we are talking about the group type of sport disciplines. This is characterized by assigning specific positions of each athlete in the group or specific responsible roles which they need to perform. In addition to psycho-physical requirements, sports performance requires from each athletes the ability to predict the behavior of a partner and competitors. It occurs during rowing and canoeing races, relay races, and when playing in pairs e.g., in badminton or tennis.

In team disciplines, a certain number of athletes must participate in sports performance. Each member of the team carries out the assigned tasks and cooperates with partners to achieve the set goals. The team enhances its effectiveness through appropriate organization of conducting sports performance (games), taking into account the goals of particular sports, and players' dispositions, opponents' dispositions, thus using the capabilities of individual athletes to achieve the best synchronization of sport actions. There is no perfect division of sport into disciplines and there will always be some exclusion or departure from the rule, but it does not change the basic fact of some division and the correctness of its methodological use.

Generally, the definition of agility is simple, and at the same time its context is very complex, which means that it can be widely used in practice. This manifests itself in both the selection of agility exercises and assessment tests. In all of the above sports (except of track and field), agility plays a major role in both motor preparation and competition. Its manifestation may vary, but the ability to start, stop, change the direction of displacement, and restart requires the implementation of the same movement structures.

Agility is a significant component of athletic performance as it encompasses the ability to perform whole-body and local movements rapidly, effectively, and efficiently [10–14]. While the classic definition of agility is understood as the ability to change the direction or speed of a movement both quickly and precisely, more recent definitions have integrated a cognitive component. This encompasses factors such as anticipation, visual and perceptual recognition, reaction speed, and attention skills [14,15]. Both agility definitions are correct and determine their significance and usefulness in selected sports. Their application, however, depends on what agility component we measure and evaluate. Consequently, movement scenarios that involve a reaction to an unplanned or random stimulus are known as reactive agility (RA), whereas pre-planned movement situations with no stimulus are determined more by change-of-direction speed (CODS) without any reactive or cognitive component [14,15]. In sports situations, RA is more common than pre-planned CODS since sport-specific situations are frequently unpredictable and determined by the movement or actions of an opponent or object (e.g., a ball) and therefore require a cognitive response [16]. Several authors have reported that reactive agility is a significant criterion of performance in football, handball, basketball, volleyball, hockey, rugby, and other team sports [12,15].

An important element in assessing the level of agility are agility tests. They are inseparably associated with the ability to accelerate, decelerate (slow down) or almost completely stop, and restart, or change the direction of running at different angles. Depending on the spatio-temporal configuration of the test, the time it takes to overcome depends on many factors, but mainly on the level of basic motor skills and body composition including body mass, body height, or length of the lower limbs [17–21]. Additionally, considering the dynamics of each sport, it is likely that athletes of individual and team sports would show differences in the non-planned reactive component of agility (RA) compared against planned and anticipated changes in either direction or speed (CODS). Surprisingly, no studies to date have compared agility performance between athletes of team and individual sports. Considering the importance of CODS and RA for successful performance, the aim of this study was to assess differences in agility performance between athletes of team and individual sports by assessing change-of-direction speed (CODS) and reactive agility (RA) in different spatial configurations.

Neither individual nor team athletes encounter a light-based stimulus in their respective sport although track athletes, namely sprinters and hurdlers, need to instantaneously respond to the auditory signal of a starting pistol [22–24]. However, this is a simple stimulus compared with the more complex visual, auditory (verbal communication), and kinesthetic stimuli experienced by athletes when confronting an opponent [25–29]. Furthermore, the group of individual athletes also included tennis players and judokas who, like team athletes, react to the external stimuli generated by an opponent. As the present study involved a stimulus unknown to both groups of athletes, it was inferred that the type of external stimuli would be a controlled factor [15,30]. Therefore, it can be hypothesized that team athletes would show enhanced performance in agility tests with a RA component due to the greater number of random stimuli experienced by this group.

2. Methods

2.1. Subjects

The study involved 36 athletes of individual sports and 34 athletes of team sports. The distribution of sex across the groups of particular sports was not equal. In game sports there were 20 males and 14 females (soccer: n = 7/9, basketball: n = 9/3, and handball: n = 4/2, respectively). In turn, the individual athletes were divided into 24 males and 12 females (track-sprint, hurdles, jumping: n = 15/9, tennis: n = 5/2, and judo: n = 4/1, respectively). Individual athlete mean age was 20.58 ± 1.44 years, body height was 174.08 ± 8.41 cm, body mass was 68.77 ± 11.34 kg, and lower limb length was 97.89 ± 5.87 cm. For team athletes mean age was 21.31 ± 1.72 years, body height was 179.21 ± 10.85 cm, body mass was 78.13 ± 12.39 kg, and lower limb length was 101.23 ± 7.02 cm. Participants were recruited from local university teams or local sport clubs. All had a minimum of 4 years competitive experience, trained regularly (3 to 4 sessions per week), and were free of injury or illness. All had experience in plyometrics (unilateral or bilateral), linear speed, and agility training. As the participants competed in different disciplines, they were at different phases in the training macrocycle. The team athletes were in the pre-competitive and competitive season, track and judo athletes were in the preparatory phase, and the tennis players in the pre-competition phase. In addition, while both males and females were recruited and sex differences in CODS and RA had been previously reported [14], this variable was not analyzed due to the unequal distribution of sex (41 male and 29 female). The participants were informed about the purpose and procedures of the study and written consent was obtained. Participation was voluntary and could be terminated at any time. The study design was approved by the Human Ethics Committee of the University of Ljubljana (Code: 14_2019-1433).

2.2. Procedures

Agility in the CODS and RA condition was measured using the FitLight Trainer (Sport Corp., Ontario, Canada). This is a reaction training system composed of a wireless controller and several lights placed on 40 cm cones. The lights can be arranged in various spatial configurations and coded for specific light activation sequences. The light can then be turned off by a proximity sensor located on the light. Testing began from a centrally placed light. The participant would wave their hand over the central light to activate one of the lights according to the sequence required by the CODS or RA condition. The participant would sprint to the light and deactivate it, then return and deactivate the central light and then sprint to the next activated light. The test ended when the participant deactivated all the lights and returned to the central light. Performance was measured by the time to completion.

In order to provide a comparative task in the CODS and RA condition across a variety of movement scenarios, a frontal (FR), universal (UN), semi-circular (SC), and lateral (LA) spatial configuration was applied in accordance with previous research [14]. The arrangement and distances between the lights are presented in Figure 1. Due to number of participants and number of trials, testing occurred over four sessions in a period of 1 month where frontal change-of-direction speed (FR-CODS) and frontal reactive agility (FR-RA) were assessed in the first session, universal change-of-direction speed (UN-CODS) and universal reactive agility (UN-RA) in the second session, semicircular change-of-direction speed (SC-CODS) and semicircular reactive agility (SC-RA) in the third session, and lateral change-of direction speed (LA-CODS) and lateral reactive agility (LA-RA) in the fourth session. An additional testing session evaluated the participants for sprint and jump performance.

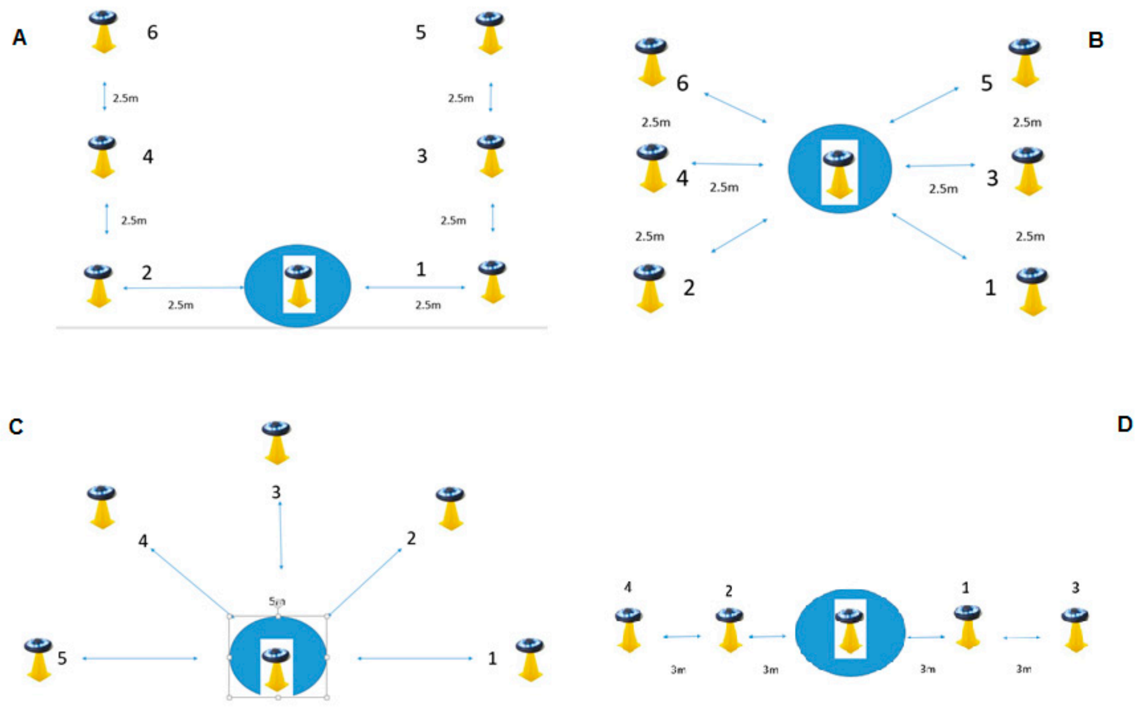

Figure 1. Arrangement of FitLight Trainer lights in the frontal (**A**), universal (**B**), semi-circular (**C**), and lateral (**D**) spatial configurations.

2.2.1. Agility Testing

A familiarization session was administered 1 week before the first session in order to acquaint the participants with the procedures and FitLight Trainer system. In each session the CODS condition was performed first and then the RA condition second after approximately 60 min of rest. The procedure for the pre-planned CODS condition involved activating the lights in sequence with the participants given advanced notice on the order (FR: 1-2-3-4-5-6, UN: 1-2-3-4-5-6, SC: 1-2-3-4-5, LA: 1-2-3-4). Two trials were performed (separated by 90 s of rest) and the best time to completion was selected. The same configurations were used in the unplanned RA condition although the order of light activation was non-sequential and unknown to the participants (FA: 2- 6-4-3-6-1, UN: 6-3-2-4-1-5, SC: 4-2-3-1-5, LA: 3-1-4-2). Similar in the CODS condition, two trials were completed and the best time to completion was recorded. A standardized warm-up was performed before each trial.

2.2.2. Sprint and Explosive Power Testing

A 15 m straight-line sprint was used to measure sprint performance from a standing start (S15m) and a flying start (F15m). An indoor track was equipped with timing gates (Brower Timing System) at the start (0 m) and finish (15 m) lines. For the flying start a 20 m approach was used to ensure attainment of maximal speed prior to entering the 15 m stretch. The participants completed two trials for S15m and two trials for F15m (with a 2 min rest between each trial) and the shortest time was selected for data analysis. Prior to sprinting the participants performed a short warm-up of light jogging, stretching, skipping drills, and several 30–50 m sprints. Upon completing the sprint component, the participants rested for 5 min and then completed the 10 m single leg jump test (SLJ10m) on the same indoor track to assess lower limb explosive power. Starting from a stationary position, the participant stood on one leg in front of the timing gate and was to jump as quickly as possible across the 10 m distance. Participants performed two trials for each leg with each trial separated by 3 min of rest. The best time to completion was selected.

2.3. Statistical Analysis

Data analysis was performed with SPSS for Windows 15.0 (IBM, Armonk, NY, USA). Descriptive statistics (mean ± SD) were calculated for all dependent variables. Between-group comparisons were made with Student's *t*-test for independent samples. Because of the normal distribution, Fisher's Least Significant Difference test was applied post hoc to calculate the pairwise differences when significant F ratios were obtained. Pearson's product-moment correlation analysis was used to assess the linear relationship between the variables. Effect sizes were evaluated by calculating Cohen's d with 95% confidence intervals. Cohen suggested that $d = 0.2$ be considered a 'small' effect size, 0.5 represents a 'medium' effect size, and 0.8 a 'large' effect size. Statistical power was at the 0.90 level and significance was accepted at alpha = 0.05. The test–retest reliability of the agility and motor tests was evaluated by intraclass correlation coefficients (ICC). All four configurations in the CODS condition were found to have strong reliability with the highest values obtained for FR-CODS and LA-CODS ($r = 0.88$ and $r = 0.91$, respectively). The RA condition showed less reliability ($r = 0.81$–0.85) with UN-RA showing the strongest reliability ($r = 0.85$). ICC for the S15m and F15m tests were $r = 0.86$ to $r = 0.90$, respectively, whereas the ICC for the SLJ10m was $r = 0.92$.

3. Results

No between-group differences were observed for age (Table 1). A statistically significant difference was observed for body height (2.9% differences), and body mass and lower limb length differed by 13.6% and 3.4%, respectively. Significant differences between the groups were found in three of the eight agility tests (UN-RA, SC-CODS, and LA-RA), with individual athletes outperforming team players (Table 2). The greatest absolute difference was in LA-RA by 1.07 s (7.8%) and then in UN-RA by 1.04 s (6.5%) and SC-CODS by 0.85 s (4.9%). Individual athletes also showed enhanced sprint (S15m) and jump performance (SLJ10m), with the greatest between-group difference in right and leg SLJ10m by 10.1% and 9.1%, respectively (Table 3).

Table 1. Age and anthropometric characteristics and between-group comparisons.

Variables	Group	*N*	Mean	SD	95% Confidence Interval of the Mean		*d*	*F*	*p*
					Lower	Upper			
Age [years]	Individ. Team	36 34	20.58 21.32	1.44 1.72	20.10 20.72	21.07 21.92	0.47	3.83	0.055
Body height [cm]	Individ. Team	36 34	174.08 179.21	8.41 10.85	171.24 175.42	176.93 182.99	0.54	4.90	0.030
Body mass [kg]	Individ. Team	36 34	68.77 78.13	11.34 12.39	64. 40 73.80	72.61 82.45	0.80	10.87	0.002
Lower limb length [cm]	Individ. Team	36 34	97.89 101.23	5.87 7.02	95.91 98.78	99.88 103.68	0.53	4.68	0.034

Table 2. Change-of-direction speed (CODS) and reactive agility (RA) performance in the frontal (FR), universal (UN), semi-circular (SC), and lateral (LA) configurations and between-group comparisons.

Variables	Group	*N*	Mean	SD	95% Confidence Interval of the Mean		*F*	*p*	*d*
					Lower	Upper			
FR-CODS [s]	Individ. Team	36 32	16.68 16.16	1.77 1.75	16.08 15.53	17.28 16.78	1.51	0.223	0.30
FR-RA [s]	Individ. Team	35 31	19.08 18.63	1.87 1.87	18.44 17.94	19.73 19.32	0.97	0.328	0.25
UN-CODS [s]	Individ. Team	31 25	13.01 13.25	1.38 1.53	12.51 12.62	13.52 13.88	0.37	0.546	0.17
UN-RA [s]	Individ. Team	31 24	17.06 16.02	1.64 1.96	16.46 15.19	17.67 16.85	4.62	0.036	0.59
SC-CODS [s]	Individ. Team	29 26	16.81 15.96	1,29 1.48	16.32 15.36	17.31 16.56	5.18	0.027	0.62
SC-RA [s]	Individ. Team	28 22	18.94 18.31	1.19 1.89	18.48 17.47	19.40 19.14	2.11	0.153	0.42
LA-CODS [s]	Individ. Team	25 20	12.54 12.12	1.43 1.41	11.94 11.46	13.13 12.78	0.95	0.336	0.30
LA-RA [s]	Individ. Team	25 19	14.41 13.37	1.12 1.37	13.95 12.71	14.87 14.03	7.72	0.008	0.86

Frontal (FR), Universal (UN), Semi-circular (SC), Lateral (LA).

Table 3. Linear sprint speed and lower limb explosive power and between-group comparisons.

Variables	Group	*N*	Mean	SD	95% Confidence Interval of the Mean		Mean Square	*F*	*p*	*d*
					Lower	Upper				
S15m [s]	Individ. Team	27 27	2.52 2.62	0.19 0.16	2.44 2.55	2.59 2.68	0.142	4.46	0.039	0.59
F15m [s]	Individ. Team	27 27	2.07 1.98	0.18 0.17	1.99 1.91	2.14 2.04	0.114	3.58	0.064	0.53
SLJ10m–right leg [s]	Individ. Team	27 26	2.69 2.42	0.39 0.31	2.54 2.29	2.83 2.54	0.789	5.82	0.020	0.78
SLJ10m–left leg [s]	Individ. Team	29 26	2.65 2.41	0.39 0.34	2.50 2.27	2.81 2.55	0.971	7.76	0.007	0.67

Significant differences were observed in both groups between the CODS and RA condition for each of the spatial configurations (Table 4), with the greatest difference in the UN configuration (by 31.1% for individual athletes and 20.9% for team athletes), FR configuration (by 15.3% for team athletes), and LA configuration (by 14.9% for individual athletes). The smallest difference between CODS and RA performance was in the LA configuration (by 10.3% for team athletes and 12.7% for individual athletes).

Table 4. Within-group comparisons of change-of-direction speed (CODS) and reactive agility (RA) performance in different configurations.

Agility Performanc1			Paired Differences					*t*	df	*p*
			Mean	SD	SEM	95% Confidence Interval of the Difference				
						Lower	Upper			
Pair 1	FR-CODS–FR-RA [s]	Team Individ	−2232.52 −2547.68	1571.86 1115.79	282.32 188.60	−3109.08 −2930.95	−1955.95 −2164.37	−8.971 −13.51	30 34	0.000
Pair 2	UN-CODS –UN-RA [s]	Team Individ	−2929.00 −4048.39	2851.29 2447.37	594.53 439.56	−4161.99 −4946.09	−1696.01 −3150.69	−4.927 −9.210	22 30	0.000
Pair 3	SC-CODS –SC-RA [s]	Team Individ	−2337.41 −2171.50	1444.59 1063.14	307.99 200.91	−2977.90 −2583.74	−1696.92 −1759.68	−7.589 −10.81	21 27	0.000
Pair 4	LA-CODS–LA-RA [s]	Team Individ	−1314.89 −1873.56	652.67 1346.79	149.73 269.36	−1629.47 −2429.49	−1000.32 −1317.63	−8.782 −6.96	18 24	0.000

Frontal (FR), Universal (UN), Semi-circular (SC), Lateral (LA).

Correlation analysis revealed strong positive correlations between CODS and RA performance in the majority of the spatial configurations (Table 5). The strongest correlations were observed in individual athletes for the LA and FR configurations at $r = 0.89$ and $r = 0.80$, respectively. Significant correlations were also observed between CODS and RA performance, sprint and jump performance, and a variety of the anthropometric characteristics (Table 6). Body mass was significantly correlated with CODS and RA performance in both groups. Strong negative associations were found between body mass and SC-CODS in team athletes ($p = 0.40$), and FR-CODS and LA-CODS in individual athletes. Stronger correlations for both CODS and RA were observed with body height, with the strongest correlation for UN-CODS and LA-CODS ($r = 0.40$, $r = 0.55$, respectively) in team athletes. The jump test measuring lower limb explosive power was also strongly correlated with CODS performance for UN-CODS and LA-CODS, particularly in team athletes for both limbs (left and right). In turn, individual athletes showed a correlation only with UN-RA. A similar trend was also observed in both sprint tests (S15m and F15m), where stronger correlations were found with 15 m sprint form flying start with CODS performance among the team athletes, whereas stronger correlations were found with RA performance among the individual athletes for UN-RA and LA-RA ($r = 0.46$ and $r = 0.50$ respectively).

Correlations between the spatial configurations for each of the agility conditions revealed few strong associations. In the CODS condition, the strongest correlations were between FR-CODS, SC-CODS, and LA-CODS in team athletes ($r = 0.62$, $r = 0.45$, and $r = 0.60$, respectively) and between FR-CODS and UN-RA in individual athletes ($r = 0.48$). In the RA condition, correlations were found between LA-RA and UN-RA and SC-RA in group of individual athletes.

Table 5. Within-group correlations of change-of-direction speed (CODS) and reactive agility (RA) performance in) different configurations.

	Agility Performance		**Mean**	**SD**	***r***	***p***
Pair 1	FR-CODS	Team	16.16	1.77	0.805	0.000
		Individ.	16.68	1.75		
	FR-RA	Team	18.63	1.87	0.622	0.000
		Individ.	19.08	1.87		
Pair 2	UN-CODS	Team	13.25	1.53	−0.308	0.152
		Individ.	13.01	1.38		
	UN-RA	Team	16.02	1.96	−0.297	0.105
		Individ.	17.06	1.64		
Pair 3	SC-CODS	Team	15.96	1.48	0.666	0.010
		Individ.	16.81	1.29		
	SC-RA	Team	18.31	1.89	0.636	0.000
		Individ.	18.94	1.19		
Pair 4	LA-CODS	Team	12.12	1.41	0.890	0.010
		Individ.	12.54	1.43		
	LA-RA	Team	13.37	1.37	0.466	0.019
		Individ.	14.41	1.12		

Frontal (FR), Universal (UN), Semi-circular (SC), Lateral (LA).

Table 6. Correlations between change-of-direction speed (CODS) and reactive agility (RA) in the frontal (FR), universal (UN), semi-circular (SC), and lateral (LA) configurations, sprinting and jumping performance, and anthropometric characteristics, * $p < 0.05$.

(A)

Team Athletes								Variables	Individual Athletes							
[8]	**[7]**	**[6]**	**[5]**	**[4]**	**[3]**	**[2]**	**[1]**		**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**
			0.453 *					Body mass	–0.342 *			0.452 *			–0.405 *	
	–0.546 *				0.401 *			Body high						–0.432 *		
	–0.487 *				0.515 *			Leg length							–0.456 *	
	0.655 *				–0.449 *			SLJ0m (LL)				0.395 *				0.460 *
	0.566 *				–0.423 *			SLJ0m (RL)				0.410 *				
	0.626 *							S15m				0.465 *				0.506 *
	0.629 *				–0.491 *			F15m								

[1] FR-CODS, [2] FR-RA, [3] UN-CODS, [4] UN-RA, [5] SC-CODS, [6] SC-RA, [7] LA-CODS, [8] LA-RA

(B)

Team Athletes								Variables	Individual Athletes							
[8]	**[7]**	**[6]**	**[5]**	**[4]**	**[3]**	**[2]**	**[1]**		**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**
			0.453 *				-	[1] FR-CODS	-			0.373 *				
						-	0.622 *	[2] FR-RA		-						
					-			[3] UNCODS			-					
				-				[4] UN-RA	0.373 *			-				0.483 *
			-				0.453 *	[5] SC-CODS					-			
0.624 *		-						[6] SC-RA						-		0.414 *
	-						0.606 *	[7] LA-CODS							-	0.466 *
-								[8] LA-RA				0.483 *		0.414 *	0.466 *	-

4. Discussion

Individual athletes showed better agility performance than team athletes as evidenced by the significant differences observed in three agility tests (LA-RA, UN-RA, and SC-CODS). This result was particularly surprising in regard to the RA condition and implicates that athletes of individual sports may show an improved enhanced reactionary response, cognitive processing, or better conditioning which translate to improved acceleration, braking, dynamic balance, and change of direction or speed ability.

The obtained data is the result of the application of group analysis (comparison between two groups of sport disciplines). This is a fact. However, explaining why one group of athletes achieved better results than the other in individual tests requires a slightly different approach. To answer the question why this phenomenon took place and what could cause it, one should delve deeper into the analysis of individual motor structures that meet the definition of agility. This means that differences in results between groups must be analyzed based on internal analysis within the group, which take into account a comparative group analysis. However it should have more general character. Both approaches are not mutually exclusive, they complement each other, even though we can get the impression that it is methodologically incorrect

Therefore, various sports disciplines, can be assessed in terms of agility level with the same test, despite the fact that there is a variety of movement structures defining agility as a motor ability. The ability to start, stop, change the direction of displacement, and restart requires the implementation of the same movement structures. They are different only in time-space configuration. For example, judoka needs one, or maybe two small steps, taken quickly and dynamically to attack the opponent and reach the throw position; conversely a tennis player needs 4–5 steps to reach the coming ball [31] and a soccer player needs a dozen or so [32]. Therefore, everyone needs a start that implements a special movement structure that must be learned. When we need to stop to do another movement—for example judoka jump away from the opponent, the tennis player returns to hit the ball again [31], and the basketball player makes a throw [17]—it requires the stopping ability and its optimal performance in terms of technique and efficiency. It is similar with changing the direction where, judoka will do it in one, or two small steps with a choice of left or right turn, tennis in one direction moving toward incoming ball, and the basketball player due to the action of the opponent, partners or moving ball multi-direction. Everyone must complete a change-of-direction movement and restart maneuver. These elements should be learned, practiced, and checked by appropriate test for correctness and effectiveness of performance.

In retrospect, the measurement of the time from light activation and initial movement to light deactivation would have allowed us to discriminate the groups by reaction time. Unfortunately, this reaction time was not measured and future research ought to include this valuable measure as well as determine if other forms of stimuli may influence response time and execution. However, if we can assume that both groups exhibited a similar response time, it is possible that the difference in performance between both groups in LA and UN configurations can be explained by the technical difficulty of the test regardless of the RA or CODS condition [15,31]. When executing the LA configuration, the participant has to complete a series of side shuffles. This movement structure may be surmised as less natural for track and field athletes than for handball players and basketball players, whom frequently perform this type of multi-directional activity [32]. However, individual athletes such as tennis players and judokas not only frequently perform lateral shuffles, but need to perform this movement very frequently which may have influenced this group's performance in the LA configuration [33].

Regarding the UN configuration, this spatial scenario can be recognized as the most complex of the four as it requires significant visual perception, concentration, and movement dynamics [14,16,34]. While team athletes may have greater experience with performing movements associated with the UN structure, it is possible that individual athletes showed better cognitive processing during task execution [23,35]. Previous studies have highlighted this difference where peripheral perception and other cognitive components are more critical for effective performance than in team sports in which the final results rely on teamwork [2,35]. Therefore, it seems that the spatio-temporal variability in implementing agility in a particular discipline had a significant impact on obtained results in applied agility tests. We must remember that these tests had the same configuration but were performed as non-planed implementing RA and planned implementing CODS. In this case, with the time–space restriction of movement execution (1–2 steps, 3–5 steps, and so on), it should be assumed that a small group of (4) judokas and slightly larger tennis players (6) did not show much influence on the results obtained. It should be assumed that track and field athletes decided about the results, despite the fact that they do not use agility in competition and training. To a large extent, the tests were based on a straight run (different lengths of sections) with the initiation of a quick start. In this respect track athletes have much more experience and above all motor potential to achieve better times. However, each run ended with braking and change of direction and a move either sideways, diagonally, or backwards. In this element, athletes show little skill, but tennis players deal with this element very well. This can also support better performance by individual sports groups.

Another explanation for the difference in agility performance between the two groups may lie with the motor potential of the athletes. In the assessments of sprint and jump performance, individual athletes outperformed team athletes in the RLJ10m and LLJ10m by 10.1% and 9.1%, respectively, and had better times in the S15m. The majority of the participants who comprised the group of individual athletes were sprinters, hurdlers, and jumpers, for whom a fundamental aspect of training is the improvement of linear sprint performance and lower limb power and strength [35–37]. As a result, the enhanced level of lower limb explosive power and sprint acceleration may have been more important than various cognitive aspects or the spatial configuration of the agility tests. This may contradict the findings of Holmberg [11] who concluded that straight-line sprinting does not translate to enhanced agility performance and instead supports the position of Popowczak [38] in that linear running speed and jumping ability are important determinants of CODS.

Correlation analysis revealed a dependency between performance in the single leg jump and agility tests, confirming the conclusions of previous studies in which this association is due to the similar biomechanical foundation of the tested movement structures—rapid change in eccentric/concentric contractions and short response times [14,39]. These associations differed between groups, in which individual athletes showed stronger correlations between jump performance and RA, whereas team athletes showed stronger correlations between sprint performance and CODS. Both jump and sprint performance were more strongly correlated with the CODS tests in the group of team athletes.

We also cannot forget about the connections between body structure and performance of agility [17–21]. In our research, only a few tests carried out in two CODS and RA configurations showed significant relationships with body weight, body height, and leg length (Table 6). Statistically significant relationships were confirmed in both groups and concerned body length factors in the area of planned change of direction (CODS), respectively: UN-CODS, SC-CODS and LA-CODS, with an indication of players from team games. These values did not exceed $r = 0.60$. In turn, body weight showed two negative relationships related to RA and CODS tests among individual sports. There is no reference in the literature to these data due to the lack of repeated tests in this spatio-temporal configuration. However, the results suggest that the more complex the movement structure during agility testing, the stronger the relationship between motor proficiency and RA and CODS performance is.

Finally, after a comprehensive analysis of the collected material, it can be seen that, there are significant differences in the times of particular agility tests between both groups of disciplines. This applies to both CODS-related tests and RA tests. There are also significant differences between the individual sport athletes and team games players when we analyze the relationships between special motor ability tests and the results of agility tests. Individual athletes showed stronger correlations between jump performance and the RA condition, whereas team players showed stronger correlations between sprint performance and CODS. In the RA condition, stronger correlations with both jump and sprint performance were found in individual athletes. This indicates that the results in both tests for the assessment of agility level (times), as well as the improvement in the performance of movement structures determining the level of agility, depend on the general level of other motor skills, mainly power and speed.

The present results need to be interpreted with caution as the study featured certain limitations. First, as previously acknowledged, was the lack of measuring reaction time from the moment of light activation and movement initiation to light deactivation as it would have allowed us to examine agility performance in more detail. Second, while the assessment of athletes according to the generalized category of individual and team sports appears to be valid, future research should refine or even further differentiate the groups to different criteria as the groups included athletes for whom agility is a far more important quality than in others. Therefore, when it comes to team games, this division is quite often used, despite the differences in terms of play game, technique and motor ability requirements. Individual sports show too many differences that limit their integration into one common dimension. In future scientific research, only two sports should be analyzed and compared, e.g., one team game and one of individual sports, or a comparison of each game from team sports or comparison of track and field to another sport. Third, because of the high number of participants from different sports and number of trials, testing occurred over four sessions in a period of 1 month. It can may create a problem because the athletes during this period was exposed to many training factors that may impact their physical and psychological status. A more in-depth comparison of RA and CODS performance between athletes should involve larger groups of homogenous athletes in terms of sport, performance level, experience, and sex. Another division of sport may be a limiting factor. It also seems reasonable to analyze and demonstrate differences athletes who train for sport that include change of direction speed and reactive agility ant those that do not.

5. Conclusions

There are differences in the results achieved between the group of sport discipline for individual and team in particular agility tests. This indicates that each group achieved better results in specific tests This applies to both CODS-related tests and RA tests. It should be assumed that one of the elements affecting this phenomenon is the spatial-temporal configuration of agility testing, which in most cases also differs from the spatial-temporal movement structures determining the level of agility in a given sport discipline, except for track and field.

The second important factor is that, the differences in the results between the two groups of disciplines may result from the level of basic motor skills such as strength, power of the lower limbs, or speed, which undoubtedly affects the level of tasks carried out within agility. Here we should distinguish track and field athletes who, thanks to their high level of motor ability, have contributed to achieving better results in selected tests. This suggest that regardless of the practiced sport or discipline, agility performance as measured by CODS and RA could be better enhanced by improving motor proficiency.

The third conclusion and probably the most important is that the tests applied in this experiment seem to be multidimensional, but require spatio-temporal adjustment for their implementation, so that they meet the requirements of the particular sport.

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Article

Ultra-Short-Term and Short-Term Heart Rate Variability Recording during Training Camps and an International Tournament in U-20 National Futsal Players

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Abstract: The aim of this study was to examine ultra-short-term and short-term heart rate variability (HRV) in under-20 (U-20) national futsal players during pre-tournament training camps and an official tournament. Fourteen male U-20 national futsal players (age = 18.07 ± 0.73 yrs; height = 169.57 ± 8.40 cm; body weight = 64.51 ± 12.19 kg; body fat = 12.42% ± 3.18%) were recruited to participate in this study. Early morning 10 min resting HRV, Borg CR-10 scale session rating of perceived exertion (sRPE), and general wellness questionnaire were used to evaluate autonomic function, training load, and recovery status, respectively. Log-transformed root mean square of successive normal-to-normal interval differences (LnRMSSD) was used to compare the first 30 s, first 1 min, first 2 min, first 3 min, and first 4 min with standard 5 min LnRMSSD. Mean ($LnRMSSD_{mean}$) and coefficient of variation ($LnRMSSD_{cv}$) of LnRMSSD were used to compare the different time segments of HRV analysis. The result of $LnRMSSD_{mean}$ showed nearly perfect reliability and relatively small bias in all comparisons. In contrast, $LnRMSSD_{cv}$ showed nearly perfect reliability and relatively small bias from 2-4 min time segments in all study periods. In conclusion, for accuracy of HRV measures, 30 s or 1 min ultra-short-term record of $LnRMSSD_{mean}$ and short-term record of $LnRMSSD_{cv}$ of at least 2 min during the training camps are recommended in U-20 national futsal players.

Keywords: futsal; performance; heart rate variability; training load; general wellness; autonomic function

1. Introduction

Futsal is a high-intensity and competitive indoor sport [1]. This sport requires energy cost in mixed aerobic and anaerobic consumption, strenuous physical contacts, locomotion activities, and skill acquisitions [2]. The intensive nature of the futsal competition is extremely high and very often causes physiological and psychological stress to the players [3]. It has been reported that high-speed running (18.1–25 km·h^{-1}) and sprint (> 25 km·h^{-1}) is about 22.6% of the total covering distance. Also, the average heart rate (HR) responses reach to 170-190 beats·min^{-1} in Liga Nacional de Futbol Sala (around 83% of maximal HR during the match time) [1]. Locomotion activities of the futsal match change in every 8–9 s, indicating intermittent patterns of physical activity [4].

Heart beat (HR) rhythm is regulated by the autonomic nervous system (ANS). Assessing the R-R intervals (RRI) variation of HR beats in a set of time series can be used to understand HR variability (HRV), which indicates the strength of sympathetic and parasympathetic activities [5,6]. The characteristics of HRV modulation after exercise depend upon intensity, duration, and modality of exercises [7–9]. The variation of HRV indices is also associated with training adaptation to aerobic capacity after longitudinal endurance training [10] and preseason futsal training [11].

Ultra-short-term HRV refers to an extremely short time segment of RRI record from consecutive heart rate beats less than 1 min, while short-term time segment of RRI record refers to an HRV measure lasting 2-5 min duration. An ultra-short-term HRV record provides time efficiency of data collection in sports training [12,13], psychological measure [14,15], and clinical proposal [16]. Previous studies suggested that a 1 min ultra-short-term HRV record can be used as a surrogate to a traditional 5 min short-term HRV record [12,13,17–20]. Esco and his colleagues [17] reported that the ultra-short-term record of natural algorithm of root mean square of successive RRI (LnRMSSD) is suggested to assess 1 min time segment in order to avoid errors of measures in athletic population. Moreover, excellent limit of agreement and accuracy of 1 min ultra-short-term record of LnRMSSD measures was observed during a 5 min stabilization period in athletes [13,21].

Monitoring quantity and intensity of training workloads becomes a primary consideration in periodization and injury prevention of sports participation [22]. However, evaluation of recovery status is also receiving great attention in strength and conditioning coaches and sports scientists to optimize players' performance and understand the most appropriate periods to apply the right stimulus [23,24]. Session rating of perceive exertion (sRPE) and general wellness questionnaire (e.g., Hooper) are two common tools to assess the psychophysiological stress in responses to the training workload and individual perception of recovery status [25]. Measuring daily change of resting HRV can be used to understand the autonomic modulation in relation to consequence of training adaptation [10,26]. The modulation of HRV during training period is in adjunction with intensity of training load (TL) and recovery status in daily football or futsal training sessions [27–29].

The standard process to record short-term HRV suggests measuring at least 5 min, followed by a 5 min stabilization [30]. Recent studies suggest that ultra-short-term HRV assessment can provide valid and reliable information for monitoring autonomic adaptation to sports training while LnRMSSD is used as the parameter [12,13,18,20]. Studies conducted by Nakamura et al. [20] and Pereira et al. [13] investigated the ultra-short-term HRV of elite futsal players who undertook futsal training and matches in seasonal periodization. In contrast, national futsal teams organized the tournament preparation based on irregular short-term training camps due to limitations of player recruitment, budget, and team schedule. Currently, there are no studies to investigate the ultra-short-term HRV during tournament preparation and tournament competition in under-20 (U-20) futsal players. Therefore, the first aim of this study was to compare the degree of validity and agreement of ultra-short-term and short-term HRV records of LnRMSSD variable (0-4 min) with standard 5 min LnRMSSD record during three pre-tournament training camps and an official tournament in U-20 national futsal players. The second aim of this study was to determine the relationship between the training load (TL) and general wellness during these four periods. On the basis of previous studies, we hypothesized that validity and agreement of ultra-short-term and short-term LnRMSSDs decrease during the study periods with high TL and low wellness scores.

2. Materials and Methods

2.1. Subjects

Fourteen male Chinese Taipei U-20 national team futsal players were recruited in this study. Twelve field players and two goalkeepers were included in this study (mean ± standard deviation:

age = 18.07 ± 0.73 yrs; height = 169.57 ± 8.40 cm; body weight = 64.51 ± 12.19 kg; body fat = 12.42% ± 3.18%). The data were collected during the first training camp (TC_{1st}; n = 13; July 10th and 15th 2018), invitation tournament (IT; n = 11; July 28th and August 2nd; 2018); second training camp (TC_{2nd}; n = 14; November 6th and 11th 2018), and official tournament of 2018 AFC U-20 Futsal Championship East Asia Qualified Games (OT; n = 14; November 27th and December 2nd 2018). One goalkeeper did not attend the TC_{1st} and IT, while two field players did not attend the IT period. All participants signed an informed consent form and were familiarized with experimental procedures. The study has been approved by the human ethics committee of University of Taipei and was conducted in according to the Declaration of Helsinki.

2.2. Experimental Procedure

The team schedule consisted of two domestic training camps (TC_{1st} = 7 days, 8 training sessions; TC_{2nd} = 7 days, 11 training sessions), one oversea invitation tournament (IT = 6 days, 1 training session, 4 matches), and one official tournament (OT = 8 days, 3 training sessions, 3 matches) (Table 1). The players' morning resting HRV, general wellness questionnaire, and sRPE were measured during these four periods. The players' height and weight were measured via a portable stadiometer (Seca 213, SECA, Germany) and electrical weight scale (Xyfwt382, Teco, Taiwan) in the registration day of training camp. Four skinfold thickness measurements were used to assess the percentage of body fat via a skin folder (Lange Skinfolder Caliper, Beta Technology, USA). The percentage of body fat was obtained by using the formula 5.783 + 0.153 * (the sum of triceps, subscapular, suprailiac, abdominal skinfolds) / 100 [31]. For the HRV data collection, a portable Polar HR monitor (Polar team Pro, Polar Electro, Kemple, Finland) was mounted onto the participant's front chest to record resting HRV in a sitting position. The participants were instructed to control breath with self-controlled patterns. After 10 min resting HRV record, the players reported the score of general wellness questionnaire. The measurements were taken in a quiet and spacious room between 7 a.m. and 8 a.m. For TL monitoring, sRPE was used to record TL during the training sessions and matches. The participants reported the individual perception of TL to the sport trainer within 30 min after completion of the training sessions. During the invitation and official matches, individual sRPE was reported to the sport trainer in the dressing room after the end of matches. A qualified sports trainer conducted the anthropometric measurement and collected all data during these periods. The methods to record anthropometric measurement, resting HRV, sRPE, and general wellness questionnaire have been reported in our previous study [32].

Table 1. The schedule of domestic training camps, invitation tournament, and official tournament.

Periods	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
TC_{1st}	Registration and TD (116 min)	TD (116 min)	TD (115 min)	TD (109 and 121 min)	TD (116 min)	TD (132 min)	TD (113 min)	
IT	Travelling to Shenzhen and TD (115 min)	FM vs. Hong Kong; 5:2; Win (89 min)	FM vs. Macau; 10:0; Win (100 min)	FM vs. Shenzhen; 5:0; Win (101 min)	FM vs. Hong Kong; 5:3; Win (91 min)	Travelling to Taiwan		
TC_{2nd}	TD (136 min)	TD (115 min and 103 min)	TD (121 min and 121 min)	TD (99 min)	TD (121 min and 118 min)	TD (116 min and 100 min)	TD (121 min)	
OT	Travelling to Mongolia	TD (123 min)	TM vs. Japan; 10:1; Lost (101 min)	TD (94 min)	TD (48 min)	OM vs. Mongolia; 3:1; Win (86 min)	OM vs. China; 7:3; Win (97 min)	Travelling to Taiwan

TD = training day; FM = friendly match; TM = training match; OM = official match; TC_{1st} = first training camp; IT = invitation tournament; TC_{2nd} = second training camp; OT = official tournament.

2.3. Heart Rate Variability

All participants were required to measure the resting HRV in a sitting position in the morning prior to the breakfast. Participants sat on chairs in a comfortable position for 5 min, followed by 5 min data collection. A telemetric HR monitor system was used to record the resting HRV (Polar team Pro, Polar Electro, Kemple, Finland). The HRV data were exported to Polar team pro web service and then extracted to personal laptop for data analysis. Kubios HRV analysis software (Premium version 3.2, Kubios, Kuopio, Finland) was used to calculate LnRMSSD. Medium artefact correction and smoothing priors set at 500 Lambda were used for HRV analysis [33]. The time segments of HRV records were divided into first 30 s ($LnRMSSD_{30s}$), first 1 min ($LnRMSSD_{1min}$), first 2 min ($LnRMSSD_{2min}$), first 3 min ($LnRMSSD_{3min}$), first 4 min ($LnRMSSD_{4min}$), and standard 5 min LnRMSSD ($LnRMSSD_{5min}$). Average ($LnRMSSD_{mean}$) and coefficient of variation ($LnRMSSD_{cv}$) of daily LnRMSSD during each training camp or tournament were used to compare the different time segment of HRV analysis.

2.4. Training Load

The perceived exertion of players after the training session was assessed by using the Borg CR-10 scale [34]. The players were asked to answer the question "how intense was the session?" using a visual analog scale in which 0 means "nothing at all" and 10 means "extremely strong". After collection of the player's answers, the score was multiplied by the time of the training session in minutes, thus providing the sRPE in arbitrary units (a.u.) [35]. An educational session to familiarize the use of sRPE was organized for all participants in the registration day of the training camp. The answers were provided individually to avoid the players hearing their colleagues' scores.

2.5. Recovery Status

The general wellness questionnaire [36] was used to assess recovery status. The general wellness questionnaire consists of five components to assess fatigue, sleep quality, muscle soreness, stress, and mood status. Each component consists of five points, in which the highest score (i.e., point 5) represents the better state and the lowest score (i.e., point 1) represents the worst state. The sum of five components scored (lowest score: 5 points, highest score: 25 points) was calculated to evaluate the general aspect of fatigue and recovery status [36]. The answers were provided individually to avoid the players hearing their colleagues' scores.

2.6. Statistical Analyses

Statistical analyses were conducted using SPSS® Statistics version 25.0 (IBM, Armonk, NY, USA) and Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA, USA). Descriptive data of the measured variables are presented as mean ± standard deviation (SD) and 90% confidence intervals (90% CI). The intra-subject coefficient of variation of LnRMSSD during each study period was used to calculate the $LnRMSSD_{cv}$ [37]. Between training camps/tournament differences of ultra-short-term and short-term LnRMSSD were analyzed by using the standardized differences of the effect size (ES). The level of ES was interpreted as trivial (0.0–0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), very large (> 2.0) [37]. Interclass correlation coefficients (ICC) with two-way random model and single measure was used to determine relative values of reliability. The level of ICC values was expressed as nearly perfect (0.9–1), very large (0.70–0.89), large (0.50–0.69), moderate (0.31–0.49), and small (0–0.3) [38]. Probabilities were calculated via 0.2 * between-participants standard deviation (smallest worthwhile changes, SWC) [38]. Qualitative probabilistic mechanistic inferences about the true effects were made using the scale of qualitative probabilities as follows: 25–75% = possible; 75–95% = likely; 95–99% = very likely; > 99% = almost likely. Relationships between TL and general wellness were assessed by using Pearson's product-moment correlation (r). The magnitude of the correlation coefficients was determined as trivial ($r < 0.1$), small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), high ($0.5 < r < 0.7$), very high ($0.7 < r < 0.9$), nearly perfect ($r > 0.9$), and perfect ($r = 1$) [38]. Lastly, Bland–Altman plots were used to evaluate the upper and lower limits of agreements among time segments of LnRMSSD [39].

3. Results

3.1. Heart Rate Variability

The mean ± SD of $LnRMSSD_{mean}$ and $LnRMSSD_{cv}$ for all time segments comparisons during four study periods is presented in Figure 1.

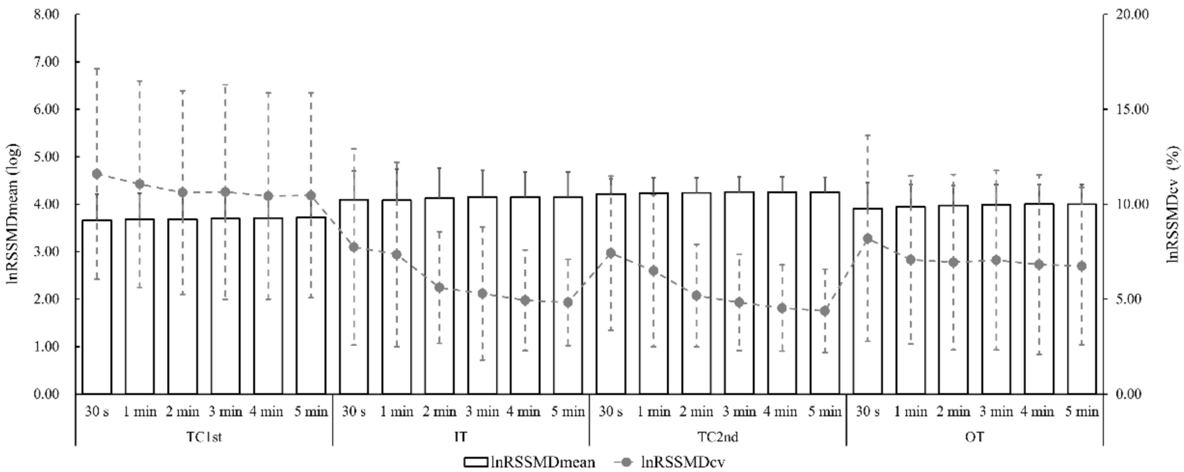

Figure 1. Mean and standard deviation of average ($LnRMSSD_{mean}$) and coefficient of variation ($LnRMSSD_{cv}$) of natural algorithm of root mean square of successive R-R intervals in first training camp (TC_{1st}), invitation tournament (IT), second training camp (TC_{2nd}), and official tournament (OT). Ultra-short-term (30 seconds and 1 minute) and short-term (2 minute, 3 minute, 4 minute, and 5 minute) records are presented in each study period.

For $LnRMSSD_{mean}$, it was found that the ES and ICC values showed trivial and nearly perfect in all comparisons, respectively. In addition, limits of agreements showed relatively small values of bias in all comparisons (Table 2).

Table 2. Mean of natural logarithm of the root mean square differences between adjacent normal R-R intervals during 30 seconds, 1 minute, 2 minute, 3 minute, 4 minute, and 5 minute of time segments in first training camp, invitation tournament, second training camp, and official tournament.

Study Periods	Time Segments	ES (90% CI)	ICC (90% CI)	Bias (± 1.96*SD)
TC_{1st} (n = 13)	Standard 5 min	-	-	-
	0–30 s	0.11 (−0.53; 0.76)	0.98 (0.95; 0.99)	0.07 (−0.19; 0.32)
	0–1 min	0.07 (−0.57; 0.72)	0.99 (0.97; 1.00)	0.05 (−0.14; 0.24)
	0–2 min	0.08 (−0.57; 0.72)	0.99 (0.98; 1.00)	0.04 (−0.09; 0.18)
	0–3 min	0.06 (−0.59; 0.70)	1.00 (0.99; 1.00)	0.03 (−0.08; 0.14)
	0–4 min	0.02 (−0.63; −0.67)	1.00 (1.00; 1.00)	0.01 (−0.03; 0.06)
IT (n = 11)	Standard 5 min	–	–	–
	0–30 s	0.08 (−0.62; 0.78)	0.98 (0.96; 0.99)	0.05 (−0.23; 0.33)
	0–1 min	0.11 (−0.59; −0.82)	0.98 (0.95; 0.99)	0.06 (−0.24; 0.37)
	0–2 min	0.05 (−0.65;−0.75)	0.99 (0.96; 1.00)	0.03 (−0.25; 0.30)
	0–3 min	0.00 (−0.70; −0.70)	1.00 (0.99; 1.00)	0.01 (−0.11; 0.10)
	0–4 min	0.00 (−0.70; −0.70)	1.00 (1.00; 1.00)	0.00 (−0.05; 0.04)

Table 2. *Cont.*

Study Periods	Time Segments	ES (90% CI)	ICC (90% CI)	Bias (± 1.96*SD)
TC_{2nd} (n = 14)	Standard 5 min	–	–	–
	0–30 s	0.12 (−0.50; 0.75)	0.98 (0.95; 0.99)	0.04 (−0.13; 0.20)
	0–1 min	0.09 (−0.53; −0.72)	0.99 (0.96; 0.99)	0.02 (−0.12; 0.17)
	0–2 min	0.06 (−0.56; −0.69)	1.00 (1.00; 1.00)	0.02 (−0.06; 0.09)
	0–3 min	0.00 (−0.62; −0.62)	1.00 (1.00; 1.00)	0.00 (−0.05; 0.05)
	0–4 min	0.00 (−0.62; −0.62)	1.00 (1.00; 1.00)	0.00 (−0.03; 0.03)
OT (n = 14)	Standard 5 min	–	–	–
	0–30 s	0.18 (−0.44; −0.81)	0.96 (0.88; 0.98)	0.09 (−0.28; 0.45)
	0–1 min	0.13 (−0.49; −0.76)	0.98 (0.95; 0.99)	0.05 (−0.14; 0.25)
	0–2 min	0.05 (−0.57; −0.67)	1.00 (0.99; 1.00)	0.02 (−0.07; 0.12)
	0–3 min	0.02 (−0.60; −0.65)	1.00 (1.00; 1.00)	0.01 (−0.06; 0.08)
	0–4 min	0.00 (−0.62; −0.62)	1.00 (1.00; 1.00)	0.00 (−0.05; 0.04)

s = seconds; min = minutes; SD = standard deviation; ES = effect size; CI = confident interval; ICC = intraclass correlation coefficient; TC_{1st} = first training camp; IT = invitation tournament; TC_{2nd} = second training camp; OT = official tournament.

For $LnRMSSD_{cv}$, the result demonstrated a large variation of ES in all comparisons (from 0.00 - -0.91). The ICC values showed nearly perfect in $LnRSSMD_{cv2min}$, $LnRSSMD_{cv3min}$, and $LnRSSMD_{cv4min}$ comparisons despite the type of camps (ICC range = 0.93 - 1). In addition, limits of agreements showed relatively small value of bias in $LnRSSMD_{cv4min}$ across four study periods (Table 3).

Table 3. Coefficient of variation of natural logarithm of the root mean square differences between adjacent normal R-R intervals during 30 seconds, 1 minute, 2 minute, 3 minute, 4 minute, and 5 minute of time segments in first training camp, invitation tournament, second training camp, and official tournament.

Study Periods	Time Segments	ES (90% CI)	ICC (90% CI)	Bias (± 1.96*SD)
TC_{1st} (n = 13)	Standard 5 min	-	-	-
	0–30 s	−0.20 (−0.85; 0.44)	0.83 (0.55; 0.94)	−1.13 (−9.24; 6.98)
	0–1 min	−0.10 (−0.76; 0.54)	0.97 (0.93; 0.99)	−0.60 (−3.97; 2.78)
	0–2 min	−0.02 (−0.67; 0.62)	0.99 (0.98; 1.00)	−0.16 (−2.05; 1.73)
	0–3 min	−0.03 (−0.68; 0.61)	0.99 (0.98; 1.00)	−0.19 (−2.29; 1.92)
	0–4 min	0.00 (−0.64; 0.65)	1.00 (0.99; 1.00)	0.02 (−1.39; 1.44)
IT (n = 11)	Standard 5 min	–	–	–
	0–30 s	−0.70 (−1.45; 0.00)	0.65 (0.06; 0.87)	−2.92 (−9.98; 4.15)
	0–1 min	−0.64 (−1.38; 0.07)	0.69 (0.15; 0.89)	−2.52 (−8.88; 3.84)
	0–2 min	−0.29 (−1.00; 0.41)	0.94 (0.77; 0.98)	−0.78 (−2.85; 1.29)
	0–3 min	−0.15 (−0.86; 0.55)	0.94 (0.84; 0.98)	−0.47 (−3.14; 2.21)
	0–4 min	−0.04 (−0.75; 0.66)	0.99 (0.97; 1.00)	−0.11 (−1.21; 0.98)
TC_{2nd} (n = 14)	Standard 5 min	–	–	–
	0–30 s	−0.91 (−1.58;−0.27)	0.55 (−0.07; 0.82)	−3.04 (−9.22; 3.13)
	0–1 min	−0.64 (−1.30;−0.01)	0.67 (0.15; 0.87)	−2.11 (−7.84; 3.62)
	0–2 min	−0.32 (−0.95;−0.30)	0.93 (0.74; 0.98)	−0.81 (−2.89; 1.28)
	0–3 min	−0.18 (−0.81;−0.44)	0.95 (0.87; 0.98)	−0.45 (−2.34; 1.44)
	0–4 min	−0.07 (−0.69;−0.56)	0.99 (0.98; 1.00)	−0.15 (−1.02; 0.72)
OT (n = 14)	Standard 5 min	–	–	–
	0–30 s	−0.29 (−0.93; 0.33)	0.95 (0.76; 0.98)	−1.46 (−4.61; 1.69)
	0–1 min	−0.08 (−0.70; 0.54)	0.98 (0.95; 0.99)	−0.33 (−2.78; 2.12)
	0–2 min	−0.06 (−0.68; 0.56)	0.99 (0.98; 1.00)	−0.20 (−1.57; 1.16)
	0–3 min	−0.07 (−0.69; 0.55)	0.99 (0.97; 1.00)	−0.31 (−2.08; 1.46)
	0–4 min	−0.02 (−0.64; 0.60)	0.99 (0.98; 1.00)	−0.08 (−1.60; 1.44)

s = seconds; min = minutes; SD = standard deviation; ES = effect size; CI = confident interval; ICC = intraclass correlation coefficient; TC_{1st} = first training camp; IT = invitation tournament; TC_{2nd} = second training camp; OT = official tournament.

3.2. Session Rating of Perceived Exertion and General Wellness Score

The results showed that lowest daily TL was found in IT (334.90 ± 44.21 a.u.), whereas highest daily TL was found in TC_{2nd} (906.29 ± 93.60 a.u.). The daily TL in TC_{1st} and OT was 553.15 ± 114.84 (a.u.) and 482.75 ± 81.22 (a.u.), respectively. Qualitative probabilities for effect magnitude of TL were revealed as most likely large in TC_{1st} vs. IT (209.81; 23.05) and TC_{2nd} vs. OT (421.17; 1.9). In contrast, most likely small probabilities of mean difference were found in TC_{1st} vs. TC_{2nd} (-363.56; 8.30), IT vs. TC_{2nd} (-573.38; 1.20), and IT vs. OT (-152.20; 12.50) (Table 4).

Table 4. The qualitative probabilities of daily session rating of perceived exertion and general wellness score in first training camp, invitation tournament, second training camp, and official tournament.

Parameters	TC_{1st}	IT	TC_{2nd}	OT	Qualitative Inferences for Effect Magnitude (Mean Difference; ± 90% CL)	
sRPE (a.u.)	553.15 ± 114.84	334.90 ± 44.21	906.32 ± 93.60	482.75 ± 81.22	Most likely large:	TC_{1st} vs. IT (209.81; 23.05); 100/0/0
						TC_{2nd} vs. OT (421.17; 1.9); 100/0/0
					Most likely small:	TC_{1st} vs. TC_{2nd} (-363.56; 8.30); 0/0/100
						IT vs. TC_{2nd} (-573.38; 1.20); 0/0/100
						IT vs. OT (-152.20; 12.50); 0/0/100
					Unclear:	TC_{1st} vs. OT (57.61; -); 50/0/50
Wellness (score)	16.74 ± 1.61	20.00 ± 3.18	16.63 ± 2.44	17.18 ± 0.98	Most likely large:	IT vs. TC_{2nd} (3.69; 1.6); 99.2/0.3/0.5
						IT vs. OT (2.81; 1.8); 97.6/1.0/1.3
					Most likely small	TC_{1st} vs. IT (-3.24; 0.5); 0/0/100
					Unclear:	TC_{1st} vs. TC_{2nd} (0.46; -); 50/0/50
						TC_{1st} vs. OT (-0.43; -); 50/0/50
						TC_{2nd} vs. OT (-0.89; -); 50/0/50

sRPE = session-rating of perceived exertion; SD = standard deviation; ES = effect size; CL = confident limit; TC_{1st} = first training camp; IT = invitation tournament; TC_{2nd} = second training camp; OT = official tournament.

The results of general wellness score showed low daily score in TC_{1st} (16.74 ± 1.61), TC_{2nd} (16.63 ± 2.44), and OT (17.18 ± 0.98). In contrast, high daily score was observed in IT (20.00 ± 3.18). The probabilities of mean difference were revealed as most likely large in IT vs. TC_{2nd} (3.69; 1.6) and IT vs. OT (2.81; 1.8). In contrast, most likely small probability of mean difference was identified in TC_{1st} vs. IT (-3.24; 0.5) (Table 4).

Results of Pearson's correlation between TL and general wellness revealed that trivial positive correlation was found in TC_{1st} ($r = 0.07$; $p = 0.81$; CI 90%: −0.42 to 0.53). Small negative correlation was found in OT ($r = -0.21$; $p = 0.48$; CI 90%: −0.61 to 0.28). Moderate negative correlation was observed in IT ($r = -0.53$; $p = 0.09$; CI 90%: −0.82 to −0.01) and TC_{2nd} ($r = -0.53$; $p = 0.05$; CI 90%: −0.79 to -0.09) (see Figure 2).

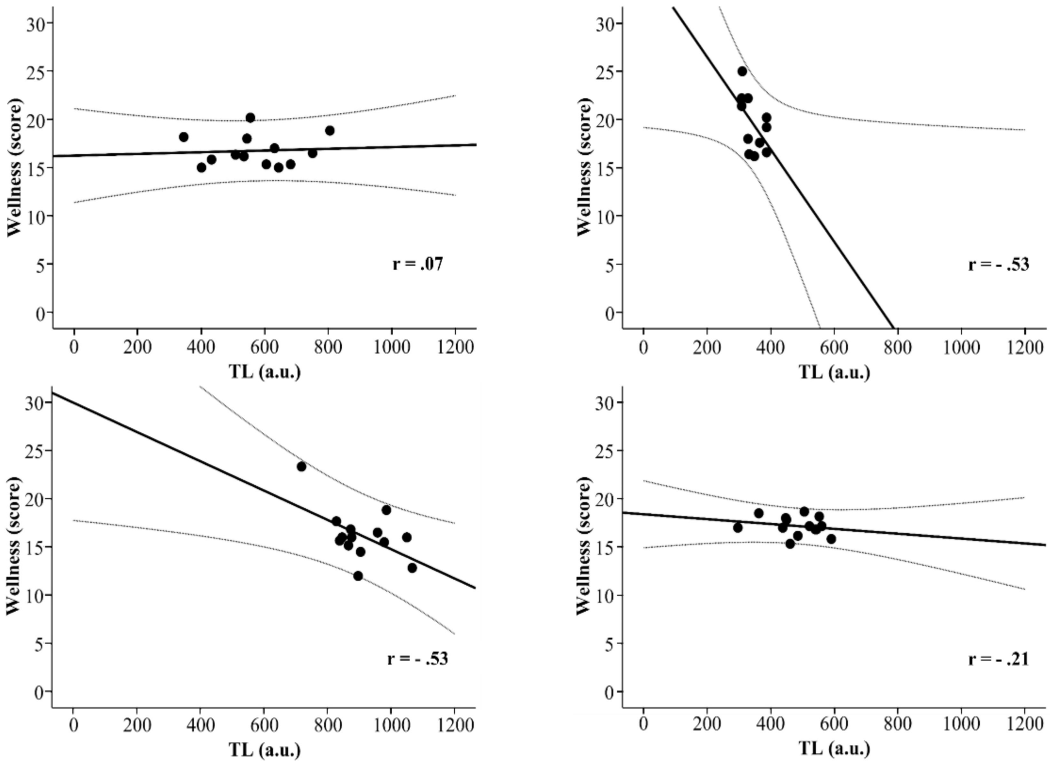

Figure 2. Pearson correlation between session rating of perceived exertion and general wellness score in first training camp (TC_{1st}), invitation tournament (IT), second training camp (TC_{2nd}), and official tournament (OT). sRPE = session rating of perceived exertion; TL = training load; AU (arbitrary units).

4. Discussion

This study is the first to report the reliability and degree of agreement of ultra-short-term and short-term HRV during national team training camps and an official tournament in U-20 futsal players. The main findings in the present study were that ultra-short-term $LnRMSSD_{mean}$ 30 s or 1 min provided valid and accurate to estimate the vagal-related change of autonomic activity despite TL and functions of training camps and tournaments. However, a shorter time segment of $LnRMSSD_{cv}$ record less than 2 min showed large bias and invalid outcome, compared with standard 5 min measure. Moreover, correlation between TL and general wellness score was trivial in the first training camp and was a negatively small correlation during the official tournament. A moderate negative relationship between TL and general wellness score was found during the invitation tournament and training camp with high TL. The implementation of LnRMSSD parameter for ultra-short-term (within 1 min) and short-term (2-4 min) HRV records to monitor the training adaptation and recovery status during training camps and official tournament is warranted.

To date, this is first study to report ultra-short-term and short-term LnRMSSD in U-20 national futsal players during different TLs of training camps and a continental tournament. Our findings revealed that $LnRMSSD_{mean}$ showed no large variability and disagreement of measures in all time segments across the study periods, as evidence by nearly perfect of ICC values (0.96 – 1.00) and relatively narrow values of limits of agreements (0.00 - 0.09) in all comparisons. It is well documented that $LnRMSSD_{mean}$ can be used to indicate training adaptation of vagal-related activities in association with enhancement of aerobic capacity [10,11,40]. Accurate and reliable measure of 1 min ultra-short-term HRV as indicated by mean of LnRMSSD has been reported in rugby players [41], futsal players [13,20], youth female basketball players [12], collegiate cross-country athletes [21], and collegiate soccer and basketball players [17]. These studies reported excellent validity and sensitivity of 1 min ultra-short-term HRV record during a 5 min stabilization period. For nonathletic population, Krejčí et al. [42] demonstrated that 90 s of $LnRMSSD_{mean}$ record can provide strong agreement of HRV measurements in collegiate students. It is interesting to note that these studies conducted the HRV measures in pre and post-training periods or a cross-sectional time point. In contrast, our study collected the HRV measures on a longitudinal basis (four study periods in 5 months). Collectively, our findings extended the notion in consistence of excellent validity and agreement of ultra-short-term LnRMSSD record during domestic training camps, oversea invitation tournament, and official tournament in U-20 male national futsal players when mean value of LnRMSSD was used.

Another major finding in our study demonstrated that $LnRMSSD_{cv}$ had large bias and could potentially cause invalid and inaccurate measure if the record duration was less than 2 min during the training camps (ICC: lowest 0.55, highest 0.97; Bias: lowest −3.04, highest −0.60). However, validity and reliability of ultra-short-term and short-term $LnRMSSD_{cv}$ was observed during OT (ICC: 0.95–0.99; Bias: −0.08–−1.46). $LnRMSSD_{cv}$ is a sensitive parameter that can be used to understand the daily variation of autonomic adaptations in response to TL and fatigue status [43]. The paradoxical relationship between $LnRMSSD_{mean}$ and $LnRMSSD_{cv}$ provides a true measurement of autonomic adaptation to sports training and avoids the misinterpretation of daily fluctuation of vagal-related changes and psychometric status [44]. Nakamura et al. [37] recently reported that increase in ultra-short-term records of $LnRMSSD_{mean}$ and decrease in $LnRSSMD_{cv}$ were associated with improving performance of Yo-Yo intermittent recovery level 1 test after 4 weeks preseason training in Portuguese professional futsal players. Nakamura et al. recorded the LnRMSSD 3 times per week, whilst our study recorded daily morning of resting LnRMSSD through the training camps. It is arguably that the decrease in number of measures may result in a loss of sensitivity to detect the variation of entire measure [45]. Thus, HRV should be recorded for at least 2 min to avoid the potential bias of individual variant of resting HRV when coefficient of variation of LnRMSSD is used to monitor the autonomic function during training camps.

The TL and recovery status are primary factors to affect the resting HRV records in athletes. Our finding demonstrated that correlation analysis between TL and general wellness score showed trivial in the first training camp and was a negatively small correlation during the official tournament. A negative relationship between TL and general wellness score was found during the invitation tournament and training camp with high TL. It is accepted that higher TL and lower general wellness score is associated with lower cardiac-vagal tone and vice versa [45,46].

Our results showed low variation of $LnRSSMD_{cv}$ (4.38% ± 2.20%–7.42% ± 4.05%) among all time segments during TC_{2nd}, which displayed largest TL (906.29 ± 93.60 a.u.) among the study periods. This finding was against the previous studies that demonstrated large $LnRSSMD_{cv}$ in association with high TL [11,40]. One possible explanation to this finding may be related to good physical preparation prior to the OT, as evidenced by highest $LnRMSSD_{mean}$ (4.22 ± 0.32–4.26 ± 0.31 log) among the study periods. This finding was consistent with our recent study that reported that the LnRSSMD and general wellness score were not associated with accumulation of TL in adult national futsal players during a five-day oversea training camp prior to a continental tournament [32]. Nevertheless, our findings suggested that the bias and variation of LnRSSMD is not accompanied with TL and recovery status during training camps and tournament.

The limitations in this study were twofold. Firstly, the number of players for statistical analyses were unequal during the study periods. As there was a limited number of final registration players in the official competition, data from 14 players called up for final list of the tournament were used for data analysis. The players who were not selected in the final squad involved in domestic training camps and oversea invitation tournament were excluded. Interpretation of such information to team sports with a large number of squad (i.e., rugby or soccer) should be cautioned because of small samples in futsal teams. Secondly, we did not conduct fitness assessments across the study periods due to time constraints of the team schedule. We were unable to evaluate information regarding the initial status of physical capacities in relation to physiological and psychometric adaptations to the study periods. Thus, we limited the sample size and fitness assessment in this study. Implementation of submaximal intensity of fitness assessments on the arrival day of each training camp could be convenient as a friendly alternative to subsequent training sessions. Future studies should continue to analyze ultra-short-term and short-term HRV assessments in this population and identify the physical adaptations as a co-variable to explain some of the possible findings. Despite that, the study presents new and interesting findings in a growing team sport.

For practical implication, HRV measure has become a popular tool to evaluate the health and recovery status of autonomic function in athletes due to its positive correlation with fatigue, overtraining syndrome, and training adaptation in aerobic capacity. Time management is critical for elite sports teams. The routine of physiological and psychological evaluations in team sports requires time efficacy and convenience to athletes and coaches. Since the categories of under-age international competition have grown dramatically in recent years, implementation of LnRMSSD measure of at least 30 s can be considered to detect daily variation of cardiac autonomic functions as an easy and convenient alternative to practitioners and coaches in sports teams.

5. Conclusions

In conclusion, for accuracy of HRV measures, 30 s and 1 min $\mathrm{LnRMSSD_{mean}}$ records after 5 min stabilization were revealed as a valid and reliable assessment for training adaptation of autonomic functions during short-term training camps and a tournament in U-20 national futsal players. The current finding suggested that measuring $\mathrm{LnRMSSD_{mean}}$ for 30 s or 1 min after postural stabilization during daily morning assessment was acceptable despite the types of training camp. Moreover, consideration should be taken when $\mathrm{LnRMSSD_{cv}}$ is used to evaluate the cardiac-autonomic activity in response to training loads. Short-term record of $\mathrm{LnRMSSD_{cv}}$ of at least 2 min during the training camps and an official tournament was suggested for use in young adult national futsal players.

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Conflicts of Interest: We certify that no party has a direct interest in the results of the present research.

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Train Like You Compete? Physical and Physiological Responses on Semi-Professional Soccer Players

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Abstract: Background: Decision-making in soccer has repercussions and depends on the environment of training or competition. The demands on the players can reveal if the decision-making is similar or different from that required during competition. **Objectives:** The aim of this study was to assess the physical and physiological responses of players in training matches (TM) and official competition matches (CM) according to the playing position (external defenders, internal defenders, midfielders, and forwards/extremes). **Methods:** Twenty semi-professional male soccer players and 10 CM (n = 40) and 10 TM (n = 40) were studied using global positioning system technology, and paired and one-way ANOVA tests were carried out to compare physical (distances and number of sprints) and physiological (heart rates) responses with the factors a) match environments (TM and CM) and b) the playing position, respectively. **Results:** The results revealed that during CM, players covered higher total distance, partial distances, and sprints at different speeds (0–21 km/h) and produced higher physiological responses. Midfielders covered the greatest total distance in both TM (7227.6 m) and CM (11,225.9 m), in comparison to the other playing positions. However, forwards and extremes spent more time (56.8% of the CM [d = 0.78]) at 76% to 84% of their maximal heart rates. **Conclusions:** First, the physical and physiological responses in TM were significantly lower than in CM. Second, these responses were different according to the playing position, so this study was able to verify the exact amount of variation between the load produced in TM and CM. These results will help the coach and technical staff to design training tasks to complement the responses found in TM.

Keywords: soccer; training; competition; match; physical responses; physiological responses

1. Introduction

To achieve good sports performance, it is necessary that athletes and coaches take into account aspects related to biomechanics, psychology, physical condition, and technical-tactical aspects, among others [1]. Decision-making is a variable that determines how, when, how much and why an athlete performs an action or behaviour. For this reason, this focus of interest is currently a topic of discussion and research that has impacts on both training and competition. A fundamental aspect is that the athlete can make correct decisions and thus perform optimal physical, technical, and tactical actions [2]. In this case, the impulsivity of the athlete can predetermine the decision-making. It is known that defensive players can be characterized as less impulsive and more concentrated and premeditated than players with an offensive role, so it is estimated that the physical and physiological responses can be differentiated according to the role being played [3].

Currently, soccer is one of the most popular sports in the world, practised by 300 million persons with more than 1.7 million teams throughout the world [4,5]. This popularity has resulted in a considerable rise in the number of research studies with the goal of improving the understanding of demands on players to optimize training time.

To this end, in order to understand the physical and physiological demands required of the soccer player during training matches (TM) and competition matches (CM), global positioning system (GPS) devices were used to measure speed, with high reliability and validity [6]. It has been seen that in TM, the soccer player spends more time at lower levels of speed, while, in CM, more time is spent at higher speeds [7]. Thus, the maximum speed achieved during TM and CM was different. Additionally, different physical responses such as total distance (TD) covered and physiological responses such as heart rate (HR) depend on the playing position [8,9]. Midfielders are players whose position of play is midway between the attacking forwards and the defenders, and they cover higher TD during CM [10].

Soccer matches require different periods of activity that vary in intensity and duration and alternate between periods of incomplete recuperation and scarce activity [11]. In this sense, the decrease in fatigue and increase in sport performance are the objective of training, and the process of recuperation plays an important role. The effect of these training sessions will vary depending on the physical and physiological responses [12].

On the other hand, the level of the teams seems to be determined by the TD covered by the players. In the Premier League, the lowest ranked teams cover more TD at high-speed than do the highest ranked teams [13]. These authors demonstrated that the technical-tactical aspect prevails over physical-physiological responses in terms of sports success. Similarly, repeated sprints sequences depend on the playing position, with a range between 1000–1400 activity changes [14]. Physiologically, midfielders report higher mean heart rate (meanHR) and internal defenders demand lower internal load, in general [1,15]. These studies concluded that players occupying central positions in the field are subjected to higher internal and external loads. The coaches and physical trainers play an important role in attempting to reproduce the physical and physiological demands on players during competition, with the end goal of attaining sport success [16].

In this way, understanding the physical and physiological demands on soccer players will enable the optimization of individual and team performance, thereby determining the level of play [17]. This information is relevant for coaches, physical trainers, and technical staff, in general, as well as for the players themselves, helping them prepare for future matches, could determine their individual needs [18], and more importantly, understand technical staff decisions in the preparation of the training sessions. Therefore, the aim of this study is to assess the physical and physiological responses in TM and CM according to the playing position on semi-professional soccer players.

2. Methods

2.1. Subjects

Twenty semi-professional soccer players (age 24.7 ± 3.9 years, height 181.4 ± 6.0 cm, and weight 77.9 ± 7.0 kg) were the subjects of the present study, which was conducted in the middle of soccer season (weeks 18–32 of 42). The players had an average age that started playing football at a competitive level of 8.4 ± 2.2 years, being 5 and 12, the lower and upper starting ages. All of the players were members of the same team (Third Division in Spain). In total, 10 matches were recorded in each context (40 TM and 40 CM). They were classified into 4 groups based on their playing position: external defenders (ED), internal defenders (ID), midfielders (MI), and forward/extremes (FO), pursuant to the classification established in the studies of Cardenas-Fernandez et al. [19] and Lago–Penas et al. [20] All subjects were informed of the objectives and procedures and completed the corresponding voluntary consent form pursuant to the guidelines established by the Declaration of Helsinki (2016) [21]. The University of Granada Ethics Committee approved the implementation of this study (471/CEIH/2018).

2.2. Instruments

2.2.1. Physical Demands

GPS technology (SPI-PRO devices, GPSports, Canberra, Australia) along with Team AMS 1.2 software was used in this study. These devices operate at 5 Hz and its validation was performed by Petersen et al. [22] Five categories were established for speed movements, in sprints (S) and in longer distances (D), adopting the criteria established in other studies, but adding a last interval that values sprints over 21 km/h [23]: walking from 0.1 to 7.0 km/h (distances [DW] and number of sprints [SW] covered by walking), running at low-speed from 7.1 to 13.0 km/h (distances [DL] and number of sprints [SL] covered by low-speed), running at medium-speed from 13.1 to 18.0 km/h (distances [DM] and number of sprints [SM] covered by medium-speed), running at high-speed from 18.1 to 21.0 km/h (distances [DH] and number of sprints [SH] covered by high-speed), and sprinting at >21.0 km/h (distances [DS] and number of sprints [SS] covered by sprinting). Moreover, the TD, mean speed, and maximum speed were also collected as physical responses.

2.2.2. Physiological Demands

HR was measured using Polar S610i devices (Polar Electro Oy, Helsinky, Finland). Four categories were established based on theoretical maximum HR (maxHR) [23]: HR1 (HR ≤ 75%), HR2 (HR between 76 and 84%), HR3 (HR between 85 and 89%), and HR4 (HR > 90%). Minimum HR (minHR), meanHR, and maxHR values for each half of the match were obtained by graphic analysis (Polar Precision Performance 5.0 and Team AMS 1.2).

2.3. Procedures

This study used a transversal observational method in order to examine the internal and external loads of the soccer players during CM and TM through GPS technology. Four players were monitored for each TM and for each CM. Ten matches per playing position were recorded. All matches took place in outdoor installations with artificial grass fields and with 11 players on each team. Tactically, the team used a 1-5-3-2 formation, with a variation of 1-4-4-2. The time period recorded was 2 × 45 min. Data for time movement was included only for the players who participated in the entire match. The opposing teams were all at a similar level. Four players were monitored for each TM and for each CM. Ten matches per playing position were recorded. The procedure carried out was as follows. First, a warm-up was developed, exactly the same in duration (volume) and intensity in both contexts. Then, they had a few minutes rest between the warm-up and the match so that the head coach could indicate the basic and specific notions or rules of play. During TM, the coach did not stop the match to explain faults in the play, just as in CM. The rest time carried out between the 2 halves was the same (15 min).

2.4. Statistical Analyses

The statistical package SPSS for Windows version 22 (IBM SPSS Statistic, Chicago, USA) and Microsoft Office Excel (Microsoft Corp., Redmond, Washington, DC, IL, USA) were used. The Shapiro-Wilks test was used to verify normality of variables. Although some variables did not follow a normal distribution, the sample size in each group was adequate (n ≥ 20) to apply the central boundary theorem, which provides normally distributed sample means [24]. Therefore, parametric analyses were performed in this study. A test of repeated measures (paired test) was used to assess the difference between the CM and TM, and subsequently, one-way analysis of variance (ANOVA) was run on the internal and external load variables in relation to playing position. To evaluate the difference between distinct comparisons between groups, a Bonferroni post hoc test was performed. The threshold values for the Cohen effect sizes detected in a t-test (d) are 0.20 for small effects, 0.50 for moderate effects, and 0.80 for large effects. For ANOVA tests, those values (η^2) were 0.10 for small effects, 0.25 for moderate effects, and 0.40 for large effects [25]. The level of significance was established at $p < 0.05$.

3. Results

First, the differences between the TM and CM were analysed. Table 1 shows the values of the physiological response of the players in both CM and TM. There are multiple differences between both environments, except for the variable HR2 ($p > 0.05$). In CM, the physiological responses were greater, except in HR1 ($p = 0.001$; $d = 0.55$).

Table 1. Paired tests of physiological responses of soccer players in competition matches (CM) and training matches (TM).

	CM (N = 40)	TM (N = 40)	*p*	*d*
minHR (bpm)	116.1 ± 14.3	102.1 ± 18.5	0.025	0.53
meanHR (bpm)	164.0 ± 7.7	152.3 ± 13.0	0.004	0.48
maxHR (bpm)	186.2 ± 8.0	178.3 ± 9.8	0.021	0.46
HR1 (% time)	10.2 ± 8.0	33.9 ± 27.4	0.001	0.55
HR2 (% time)	32.0 ± 17.5	35.7 ± 20.4	0.592	0.10
HR3 (% time)	26.7 ± 9.1	16.1 ± 10.6	0.006	0.48
HR4 (% time)	31.1 ± 24.3	14.3 ± 24.1	0.070	0.33

p: significant value; *d*: effect size; CM: competition match; TM: training match; bpm: beats per minute; minHR: minimum heart rate; meanHR: mean heart rate; maxHR: maximum heart rate; HR1: heart rate covered until 75% (inclusive) of the theoretical maxHR; HR2: heart rate covered from 76% until 84% of the theoretical maxHR; HR3: heart rate covered from 85% until 89% of the theoretical maxHR; HR4: heart rate covered greater than 90% of the theoretical maxHR.

Furthermore, the physical responses of the players in both CM and TM are shown in Table 2. Multiple differences were found between both environments, in particular, there were significant differences in the TD, DW, DL, DM, DH, DS, SW and SL variables. The remaining variables did not show significant differences ($p > 0.05$). The physical responses in the CM were higher, except for the maximum speed variable, and the SS variable had similar values in both environments.

Table 2. Paired tests of physical responses of soccer players in CM and TM.

	CM (N = 40)	TM (N = 40)	*p*	*d*
meanS (km/h)	6.8 ± 0.6	6.5 ± 1.0	0.331	0.36
maxS (km/h)	28.2 ± 2.3	28.6 ± 3.6	0.698	0.41
TD (m)	10,022.7 ± 1180.0	6213.2 ± 933.1	0.000	0.80
DW (m)	4010.5 ± 509.9	2578.5 ± 220.9	0.000	0.61
DL (m)	3467.9 ± 713.7	2120.9 ± 653.8	0.000	0.51
DM (m)	1755.0 ± 542.3	1004.6 ± 407.2	0.002	0.42
DH (m)	457.3 ± 146.6	293.0 ± 127.3	0.011	0.34
DS (m)	332.2 ± 134.3	216.3 ± 107.1	0.030	0.15
SW (number)	426.8 ± 46.4	343.7 ± 75.7	0.001	0.57
SL (number)	616.8 ± 73.1	487.2 ± 136.5	0.002	0.53
SM (number)	292.1 ± 65.7	239.1 ± 92.5	0.072	0.32
SH (number)	98.4 ± 19.5	91.3 ± 38.4	0.496	0.12
SS (number)	29.0 ± 6.6	28.9 ± 13.7	0.993	0.01

p: significant value; *d*: effect size; CM: competition match; TM: training match; meanS: mean speed; maxS: maximum speed; TD: Total distance; DW and SW: distance covered and number of sprints run between 0 and 6.9 km/h; DL and SL: distance covered and number of sprints run between 7.0 and 12.9 km/h; DM and SM: distance covered and number of sprints run between 13.0 and 17.9 km/h; DH and SH: distance covered and number of sprints run between 18.0 and 20.9 km/h; DS and SS: distance covered and number of sprints run from 21.0 km/h.

On the other hand, taking into account the general differences between TM and CM, the responses of the players in the matches were analysed according to the playing position and the match environments. Table 3 shows the values of the physiological responses of the soccer players in both CM and TM according to the playing positions. There were multiple differences between different playing positions, except for the minHR, meanHR, and maxHR variables ($p < 0.05$). In the CM, the physiological responses were greater, except in the HR1 and HR2 variables, where it was lower in the CM. For all variables, external defenders could be detected as those players with a higher HR, both in the TM and in CM.

Table 3. One-way ANOVA of physiological responses of soccer players in TM and CM according to the playing position.

		ED (N = 10)	ID (N = 10)	MI (N = 10)	FO (N = 10)	$F_{(1,39)}$	p	d
minHR (bpm)	TM	104.6 ± 19.3	106.4 ± 26.9	108.7 ± 29.2	95.4 ± 23.8	0.442	0.725	0.15
	CM	112.0 ± 10.6	119.1 ± 4.6	116.3 ± 33.3	108.2 ± 13.7	0.294	0.829	0.12
meanHR (bpm)	TM	150.7 ± 28.3	147.6 ± 32.3	145.8 ± 38.3	139.6 ± 29.8	0.173	0.914	0.09
	CM	163.3 ± 6.1	161.8 ± 3.0	151.2 ± 39.7	152.7 ± 1.9	0.477	0.702	0.16
maxHR (bpm)	TM	177.1 ± 32.0	171.1 ± 36.9	162.2 ± 42.7	165.0 ± 35.2	0.274	0.844	0.12
	CM	190.0 ± 7.5	187.9 ± 8.0	166.7 ± 41.5	181.4 ± 11.1	1.150	0.359	0.24
HR1 (% time)	TM	20.4 ± 22.6	14.3 ± 15.8	7.1 ± 7.8	33.5 ± 26.0	2.408	0.089	0.33
	CM	9.6 ± 6.9 ^{FO}	5.8 ± 4.2 ^{FO}	3.5 ± 3.6 ^{FO}	19.7 ± 5.1 ^{ED,ID,MI}	8.200	0.002	0.55
HR2 (% time)	TM	28.9 ± 5.7	31.6 ± 16.3	22.4 ± 21.8 ^{FO}	49.8 ± 18.0^{MI}	4.151	0.015	0.42
	CM	29.0 ± 4.5 ^{MI,FO}	22.8 ± 6.5 ^{FO}	14.5 ± 9.7 ^{ED,FO}	56.8 ± 8.7 ^{ED,ID,MI}	28.906	0.000	0.78
HR3 (% time)	TM	29.1 ± 10.4 ^{FO}	26.4 ± 7.9	19.2 ± 8.4	15.0 ± 11.0 ^{ED}	3.681	0.024	0.40
	CM	33.6 ± 5.1 ^{FO}	28.9 ± 7.3	21.8 ± 9.7	20.7 ± 9.0 ^{ED}	3.271	0.050	0.38
HR4 (% time)	TM	21.7 ± 13.0 ^{MI}	27.7 ± 21.2	51.4 ± 30.5 ^{ED,FO}	1.8 ± 3.9 ^{ED,MI}	8.649	0.000	0.56
	CM	27.8 ± 10.0 ^{MI,FO}	42.5 ± 12.9 ^{FO}	60.2 ± 22.7 ^{ED,FO}	2.8 ± 4.8 ^{ED,ID,MI}	15.139	0.000	0.66

p: significant value; *d*: effect size; CM: competition match; TM: training match; bpm: beats per minute; minHR: minimum heart rate; meanHR: mean heart rate; maxHR: maximum heart rate; HR1: heart rate covered until 75% (inclusive) of the theoretical maxHR; HR2: heart rate covered from 76% until 84% of the theoretical maxHR; HR3: heart rate covered from 85% until 89% of the theoretical maxHR; HR4: heart rate covered greater than 90% of the theoretical maxHR; ED: external defender; ID: internal defender; MI: midfielder; FO: forward. Bonferroni post hoc ($p < 0.05$) with playing position as the exponent.

Table 4 shows the values on the physical responses of the players both in the CM and TM according to the playing positions. It can be observed that the physical responses in the CM are greater, except on the external defender players in the DW, DS, SW, and SS variables; on the internal defender players in DL, DS, SW, and SL; on the midfielder players in DH, DS, SM, SH, and SS; and on the forwards in DW, DS, SW, and SS. The position with a higher TD was the midfielder, in TM (7227.6 m) and CM (11225.9 m). Finally, those with a maximum speed were the forward players, in TM (27.12 km/h) and CM (29.02 km/h).

Table 4. One-way ANOVA of physical responses of soccer players in TM and CM according to playing position.

		ED (N = 10)	ID (N = 10)	MI (N = 10)	FO (N = 10)	$F_{(1,39)}$	*p*	*d*
meanS (km/h)	TM	5.6 ± 1.2	5.7 ± 1.2	6.4 ± 1.7	6.2 ± 1.4	0.696	0.563	0.19
	CM	6.1 ± 0.4	6.2 ± 0.3	6.5 ± 1.7	6.7 ± 0.6	0.378	0.770	0.14
maxS (km/h)	TM	26.9 ± 5.3	25.8 ± 5.6	23.7 ± 5.5	27.1 ± 3.9	0.782	0.514	0.19
	CM	28.5 ± 2.3	28.3 ± 1.8	24.1 ± 6.2	29.0 ± 1.4	2.138	0.136	0.32
TD (m)	TM	5275.6 ± 786.5	5790.3 ± 393.1	7227.6 ± 53.0	6559.2 ± 951.3	3.501	0.129	0.40
	CM	9369.0 ± 1042.8	9697.7 ± 431.4	11,225.9 ± 673.3	10,104.8 ± 1491.5	2.710	0.080	0.36
DW (%)	TM	45.2 ± 7.3 ^{MI}	45.2 ± 4.6 ^{MI}	31.2 ± 4.1 ^{ED,ID}	37.6 ± 7.8	8.401	0.000	0.55
	CM	41.3 ± 4.0	45.9 ± 5.5 ^{MI}	32.0 ± 4.2 ^{ID}	36.1 ± 7.5	5.153	0.012	0.46
DL (%)	TM	31.2 ± 4.3 ^{MI}	35.9 ± 2.9	38.9 ± 4.2 ^{ED}	34.9 ± 5.4	4.391	0.012	0.43
	CM	33.6 ± 2.3	35.0 ± 1.9	39.6 ± 5.0	35.2 ± 6.1	1.721	0.205	0.29
DM (%)	TM	15.1 ± 3.0 ^{MI}	13.7 ± 2.9 ^{MI}	21.5 ± 3.8 ^{ED,ID}	18.1 ± 3.6	7.811	0.001	0.53
	CM	16.6 ± 2.3	13.9 ± 4.1 ^{MI}	21.8 ± 4.9 ^{ID}	19.4 ± 3.5	3.749	0.034	0.40
DH (%)	TM	4.6 ± 0.8 ^{ID}	3.0 ± 0.7 ^{ED,MI,FO}	5.2 ± 1.8 ^{ID}	5.6 ± 1.0 ^{ID}	7.692	0.001	0.54
	CM	4.9 ± 0.4	3.1 ± 0.8^{FO}	4.7 ± 1.9	5.6 ± 0.5 ^{ID}	4.748	0.016	0.45
DS (%)	TM	3.9 ± 1.3	2.3 ± 0.9	3.1 ± 2.5	3.9 ± 1.6	1.702	0.190	0.29
	CM	3.6 ± 1.0	2.2 ± 0.5	2.0 ± 1.1 ^{FO}	3.8 ± 1.5 ^{MI}	3.425	0.045	0.39
SW (%)	TM	71.9 ± 6.0 ^{MI}	69.1 ± 3.7 ^{MI}	56.1 ± 4.2 ^{ED,ID}	64.4 ± 8.2	10.348	0.000	0.59
	CM	68.6 ± 2.8 ^{MI}	69.0 ± 3.7 ^{MI}	56.8 ± 3.5 ^{ED,ID}	63.1 ± 8.6	5.135	0.012	0.46
SL (%)	TM	19.5 ± 4.1 ^{MI}	23.5 ± 2.7	29.6 ± 3.0 ^{ED}	24.2 ± 5.8	7.800	0.001	0.54
	CM	21.8 ± 2.0 ^{MI}	23.4 ± 1.8	29.7 ± 3.5 ^{ED}	24.7 ± 6.5	3.320	0.049	0.38
SM (%)	TM	6.2 ± 1.7 ^{MI}	5.9 ± 1.5 ^{MI}	11.1 ± 2.4 ^{ED,ID}	8.4 ± 2.4	10.590	0.000	0.59
	CM	7.0 ± 1.1 ^{MI}	6.1 ± 2.0 ^{MI}	11.0 ± 2.8 ^{ED,ID}	9.1 ± 2.4	4.968	0.014	0.45
SH (%)	TM	1.5 ± 0.3	1.0 ± 0.2 ^{MI,FO}	2.2 ± 1.0 ^{ID}	2.0 ± 0.6 ^{ID}	6.742	0.002	0.51
	CM	1.6 ± 0.1	1.0 ± 0.3 ^{FO}	1.9 ± 0.9	2.0 ± 0.4 ^{ID}	3.673	0.036	0.40
SS (%)	TM	1.0 ± 0.4	0.6 ± 0.3	1.1 ± 0.9	1.1 ± 0.5	1.572	0.219	0.28
	CM	1.0 ± 0.3	0.6 ± 0.2	0.7 ± 0.4	1.1 ± 0.4	2.724	0.081	0.35

p: significant value; *d*: effect size; CM: competition match; TM: training match; meanS: mean speed; maxS: maximum speed; TD: Total distance; DW and SW: distance covered and time of sprints run between 0 and 6.9 km/h; DL and SL: distance covered and time of sprints run between 7.0 and 12.9 km/h; DM and SM: distance covered and time of sprints run between 13.0 km/h and 17.9 km/h; DH and SH: distance covered and time of sprints run between 18.0 and 20.9 km/h; DS and SS: distance covered and time of sprints run from 21.0 km/h; ED: external defender; ID: internal defender; MI: midfielder; FO: forward. Bonferroni post hoc ($p < 0.05$) with playing position as the exponent.

4. Discussion

The aim of this study was to assess the physical and physiological responses of semi-professional soccer players in TM and CM depending on their playing positions. In this sense, the scientific literature confirms that players demand different internal and external load between training days and official-competition matches [7–9]. These demands may also vary according to the position occupied by the soccer players on the pitch based on the system designed by the coaches, and whether or not the team has possession of the ball [26].

On the other hand, during high-intensity actions, e.g., DH, DS, SH, and SS, among others, we can observe that they follow the same trend, with higher values in CM with respect to TM. Considering these results, the responses during TM by the same players are not replicated during CM, possibly due to the environment of the training, player cohesion, and satisfaction with the role on the pitch [27]. This is evident from the degree of arousal activation in players during CM [28], and the inclusion of situation of small-sided games in the trainings at present [29]. These tasks do not allow reaching high-intensity speeds or sprinting (>21 km/h) because of the evident reduced dimensions of the space [23].

The monitoring of distances and speeds has been carried out through studies in several sports, such as soccer [23], orienteering [30], athletics [31,32], cricket [33], rugby [34,35], and tennis [36,37], accepting the reliability of the GPS, and its practical application in most team sports, since errors are relatively scarce and predictable [38]. In addition, the devices used in this study show high reliability in order to measure TD and the distances developed at both low and medium speed [33].

Regarding TD during TM and CM by semi-professional players according to their playing positions, significant differences are observed for all positions ($p < 0.05$). Hartwig et al. [9], similarly to our study, found differences in the playing positions. The MI position covers the highest TD, both in TM and CM; the FO position achieves the highest maximum speed, both in TM and in CM; defensive players covered the lowest TD in both environments [14]. In addition, it is estimated that differences are found for all playing positions in all sub-categories of sprint in both environments (except in SS). This leads to the conclusion that the playing position has an important role in the influence of the sprint development [39]. This information reveals the specific demands during CM in semi-professional soccer players to prescribe specific trainings reproducing repeated sprint sequences, race distances and speed peaks [39], adapted to the individual demands of the players based on tactical training [40].

Nevertheless, the partial distances covered show a remarkable difference produced by the specific functions of players with different roles. Internal defenders showed lower values of distance at high-speed, while forwards and midfielders presented the highest values of TD, and, physiologically, the midfielder playing position had the lowest meanHR, measured in beats per minute (bpm). However, for the HR4 variable measured in percentage of time, the midfielder players have a value much higher than the rest of positions, becoming the position with the highest physiological demand. On the other hand, the wide differences between internal defenders and midfielders observed in this study could be related to tactical roles and training adaptations. The midfielder players have a liaison role in the team and need to complete quickly medium distance movements compared to the defending players, who practice more planned movements and demand a high concentration [41], with more sensible or prudent decisions than players with a bigger offensive role. Di Salvo et al. [12] indicated that the midfielder has functions to take advantage of the scoring opportunities while they must return to defend themselves when their team loses ball possession. Therefore, coaches should know that players do not train like they compete, and players need more attention during a TM to optimize physical and physiological performance during a CM [42]. For example, the encouragement of technical staff in different parts of the field, the fast inclusion of balls when the game is stopped or modifying the existence of the offside could cause an increase in these demands in a real game.

Certain limitations of this study should be considered. First, the sample size could have been larger in order to generalize the results to a large population such as semi-professional soccer players. In Spain, there are 300 semi-professional teams and a total of 6000 football players. To generalize the results, it would be necessary to propose a future project where teams from different areas are involved. On the other hand, the limitation in the number of GPS devices meant that the number of matches analyzed was greater, which implies that, in this study, it is very important to consider the size of the effect and even the possible coefficient of variation of the dependent variables. In this sense, knowing that the effect size is high, the conclusions have been established from this indicator. Finally, it could compare the responses produced both in their own field and in the opposite field in order to offer more information to coaches and athletes. In this sense, the teams that faced each other were taken into account; there were no notable differences in terms of the general classification, which would have been a contaminating variable.

5. Conclusions

The main finding of this study is that responses during CM are significantly higher than those obtained during TM. Physical (covered distances and sprints) and physiological responses (heart rate) developed by soccer players were different. Therefore, soccer players do not train as they compete. In addition, midfielder and forward players have the highest physical and physiological demands, and less so for internal defenders, which confirms different features influenced by the role assumed in the playing field.

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