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Article

Variability in the Load of Professional Basketball Referees during Competition

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Featured Application: The results obtained in this research are highly novel, as no previous studies have analyzed the external and internal loads of basketball referees based on the game or game quarter during elite games, such as those played in the analyzed tournament. However, this study has limitations that should be considered when interpreting the results. Firstly, although the entire sample of the preparatory tournament was recorded, the number of participants is small. Secondly, the equipment used (anatomical harness, WIMUPRO inertial devices, eight-antenna radiofrequency system, heart-rate monitor. . .) is costly, which limits the availability of previous studies for data comparison.

Abstract: Monitoring the demands on basketball referees is essential for optimizing their performance and reducing the risk of injuries. This study aimed to analyze the workload experienced by elite basketball referees during official games. Using a quasi-experimental empirical methodology, inertial devices (WIMUPRO) were used for four referees participating in the official tournament of the Spanish first-division basketball league. All the matches in the tournament were analyzed. Descriptive analysis and ANOVA were used to understand the referees' demands. Moreover, a Mixed Linear Model was used to take into account the individuality of each referee in the analysis of the variables. The results indicate that the analyzed external and internal load variables are specific to each basketball referee. The variability in referees' external and internal load demands was identified as low to moderate within performances, between matches, and between quarters. The external and internal load variables did not vary among the three analyzed games. The distance covered during the first quarter of the games was less than in the rest of the quarters, but it was performed at a higher intensity. Neuromuscular load (analyzed as Impacts, Player Load, and Power Metabolic) showed higher values in the first quarter of the games than in the rest. The referees' response to competition is individual and can be influenced by situational variables such as the moment or type of game.

Keywords: official game; internal load; external load; variability; inertial devices; referee

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1. Introduction

Basketball is a sport that has undergone significant changes in its rules over time (alternation of attacks, 24 s possession rule, the three-point line, etc.) [1], resulting in a faster and more appealing game for spectators [2] and different adaptive responses (linked to improving physical fitness) from teams to achieve victory [3]. As a result of these changes, a greater level of professionalization for basketball referees [4] has emerged, improving officiating practices [5]. Referees are responsible for applying the rules of the sport during each game [6], and their performance is crucial to the outcome, especially at higher levels of competition [7,8]. This is why referees' decision-making processes can be affected by many factors, such as pressure from spectators, home/away, noise [9], the gender of the referee [10], or stress [11]. For all these reasons, sports federations should establish training protocols dedicated to minimizing the influence of these factors on the referee's intervention.

According to Mitjana [12], refereeing involves the ability to coordinate knowledge (game, rules, experience. . .), actions (positioning, non-verbal communication. . .), skills (visual acuity, physical fitness), and resources (psychological, communicative, acceptance. . .) necessary to control a match. For example, researchers have examined basketball referees' performance from technical [11,13], psychological [13,14], and physical perspectives [10,15,16].

On the one hand, the analysis of internal load (IL) demands during competition in basketball referees is necessary to accurately establish their performance profile [17]. Monitoring and quantifying athletes' effort demands are essential for optimizing their performance [18], designing training programs tailored to the specific demands of each sport [19], and reducing the risk of injury [20]. The performance analysis of a referee can be approached from different perspectives (objective/subjective, external load (EL), internal load (IL), physical/psychological/technical), which ultimately allows for a comprehensive performance profile [21].

To monitor IL using subjective methods, one of the most commonly used tools in sports performance is the Rating of Perceived Exertion (RPE) scale [22], which establishes a Likert scale from 0 to 10 based on the athlete's perceived effort. In the monitoring of IL using objective methods for players and referees, various tools are used, such as lactate measurement [23], maximal oxygen consumption (VO2máx) [24], cortisol [25], or testosterone [26]. Some of these methods require specific equipment and proper use, which can disrupt the athlete's routine during competition, making them less engaged as they cannot obtain information without altering the dynamics of sports practice. Therefore, the most used method for analyzing objective IL is heart rate monitoring [13,27]. It is a measure that allows for the assessment of exercise intensity due to its close relationship with physiological stimulation [28]. It is easy to obtain, cost-effective, and does not disrupt the dynamics of athletes or referees during competition.

On the other hand, load can be measured externally. EL has been defined as the mechanical and locomotor stress caused by sports activity [29]. EL can be measured with kinematic variables that analyze displacements and their intensities, as well as neuromuscular variables that assess the effort exerted between the interaction between gravity and game-related agents [30]. In this regard, various objective systems are available for performance analysis. There is video-based tracking [2,31], where kinematic analysis is performed using mathematical algorithms with a camera system that allows for tracking the game and its participants. Also, there are Global Navigation Satellite Systems (GNSSs) [32] and Local Position Systems (LPSs) with Ultra-Wideband (UWB) technology [33].

For the localization of athletes in GNSSs and LPSs, athletes must carry an inertial measurement unit typically placed in an anatomical harness on their back to record data. In addition, thanks to their radiofrequency antenna system, LPSs with UWB technology allow for the analysis of load variables in indoor sports [34]. Some of these systems provide real-time information with ANT+ technology, allowing for more precise referee control as they determine kinematic variables (distance covered, accelerations, speeds, etc.) and neuromuscular variables (Player Load, Power Metabolic, and Impacts), which accurately assess the load involved in a game in real time [35], as well as the fatigue index produced [36].

The load demands of basketball referees are being studied to develop training programs tailored to competitive reality. Objective internal load (OIL) was evaluated by Suárez et al. [37] in a large population of basketball referees during FIBA international competitions. They identified differences in the average heart rate of referees in men's and women's games, as well as based on the category. It was evident that international competitions are more demanding for referees based on gender, level, and phase of the competition.

In a similar way, Leicht et al. [38] assessed the objective EL neuromuscular (Player Load) of semi-professional referees and identified that the volume and intensity of load were higher in women's games, which were officiated with two referees, compared with men's games, which had three referees. They also highlighted that, during the same period of the season (regular season vs. playoffs), the demands were similar, with differences among quarters and differences in load between different moments of the season and between game quarters.

Collecting data on load demands in players and referees is complex during official competitions, as sports organizations restrict the use of inertial devices that may interfere with the players. Therefore, there are limited studies in which referees are equipped with inertial devices using UWB systems for EL data acquisition, especially when monitoring the performance of referees with senior players in high-level professional leagues. In this sense, with a very limited sample size, Godoy-Hernández et al. [39] identified that both the maximum and average heart rate of referees decrease as the quarter of the games progresses, with the difference between the first and fourth quarter being statistically significant. They also observed a decrease in Maximum Speed, with statistically significant differences between the fourth quarter and the other three quarters. These findings contrast with an increase in distance covered. The referees moved themselves more, but the pace of the game in the final quarter resulted in a lower demand for OIL and a lower Maximum Speed. These authors did not identify differences in neuromuscular objective EL variables including Player Load and Impacts between game quarters. Garcia-Santos, Pino-Ortega, Garcia-Rubio, Vaquera, and Ibáñez [10] analyzed a European U-16 women's basketball competition and found differences between quarters in distance covered, distance covered per minute, Maximum Speed, Player Load, and Power Metabolic, with differences also found between the fourth quarter and the first quarter. In other words, referees start games more intensely, but the dynamics of the competition require less from them in the final quarter.

Despite the increasing number of publications analyzing the OEL and OIL of basketball referees [16,37,40], the body of knowledge is still in its early stages, especially when it comes to high-level professional player competitions, in terms of analyzing specific games or game quarters using validated Inertial Measurement Units (IMUs) for indoor spaces in order to tailor training processes to this specific population of referees. Therefore, the objective of this research was to characterize the load endured by referees during official games and identify differences between different games and game quarters during an official preparatory tournament for a senior elite competition in the Spanish first division of basketball, Copa de Andalucía 2022.

2. Materials and Methods

2.1. Design

The design of the present study is based on empirical methodology. Specifically, it is a quasi-experimental study [41] aiming to understand the OEL and OIL demands of basketball referees by analyzing different games and game quarters. A quasi-experimental design was used because the objective of this research is to test a hypothesis by manipulating a variable since a randomized group design cannot be carried out.

2.2. Participants

This study included four referees from the top category of the Spanish professional league, Liga ACB, who were responsible for officiating the Copa de Andalucía 2022 tournament. The refereeing team had a mean age and standard deviation of 41.8 ± 10.82 and an average competitive level experience of 16 ± 10.17 years. Moreover, all of them had extensive experience as referees in international competitions (9.75 ± 9.29 years). All referees participated in at least two games, with only one of them officiating in all three games (2.5 ± 0.5 games).

The inclusion criteria for participation in this study were (i) being a referee at the highest competitive level; (ii) not having a musculoskeletal injury in the 15 days prior to the competition; (iii) belonging to the regional referee committee where the championship was held; (iv) being familiar with the use of IMUs during referee performances; and (v) volunteering to participate in this study.

2.3. Sample

With the approval of the University's Bioethics Committee (reference number 79/2022) and following the procedures of the Helsinki Declaration [42], a database was created based on the registration of OEL and OIL variables of the four elite referees who participated in a basketball tournament of teams from the Spanish first division, Liga ACB, called Copa de Andalucía 2022. The tournament took place in the city of La Línea de la Concepción, Cádiz (Spain), during the month of September 2022, involving three teams that regularly compete in Liga ACB (Spanish first division). The unit of analysis was the game quarter. The sample consisted of the three individual records of the referees who officiated each of the game quarters in the three games played (*n* = 9). This research used a purposive sampling technique, in which the researchers established the inclusion criteria for the participants. The sample of referees in this study corresponds to the census of referees involved in the selected tournament.

2.4. Variables

Table 1 shows the dependent variables used in this study, which were grouped into activity duration, OEL variables (kinematic and neuromuscular), and OIL variables (Mean Heart Rate, Maximum Heart Rate), following the proposal by Ibáñez et al. [43]. In addition to these dependent variables, four independent variables were established to identify differences by referee, referee performance, games (first, second, and third), and game period (first, second, third, and fourth game quarters).

Table 1. Description of dependent variables.

Variable			Unit	Description
		Duration	**hh:mm:ss**	**Activity Time**
Objetive External Load	**Kinematics**	Distance	m	Space traveled
		Distance/min	m/min	Space traveled per minute
		Explosive Distance	m	Distance traveled with highest acceleration greater than 1.12 m/s^2
		Explosive Dist/min	m/min	Explosive Distance per minute
		Max Speed	Km/h	Maximum velocity
		AVG Speed	km/h	Average Speed
		Accelerations	counter	Number of accelerations; positive velocity change
		Decelerations	counter	Number of decelerations; negative speed change
		Accelerations/min	count/min	Average number of accelerations per minute
		Decelerations/min	count/min	Average decelerations per minute
		Max Acceleration	m/s^2	Maximum capacity to increase speed
		Max Deceleration	m/s^2	Maximum capacity to slow down
		AVG Acceleration	m/s^2	Average capacity to increase speed
		AVG Deceleration	m/s^2	Average capacity to slow down speed
	Neuromuscular	Impacts	Count G force	Total G forces supported by the athlete in the three planes
		Player Load	arbitrary unit	Cumulative load resulting from acceleration in the 3 axes
		Player Load/min	a.u./min	Cumulative load per minute
		Power Metabolic	watts/kg	Metabolic expenditure
		AVG Power Metabolic	Mean w/k	Average metabolic expenditure
		Power Metabolic/min	(w/k)/min	Metabolic expenditure per minute
Objetive Internal Load		Max Heart Rate	bpm	The arithmetic mean of the number of beats in a time interval
		AVG Heart Rate	bpm	Maximum number of beats reached
		AVG HR %	%	Percentage of the athlete's maximum heart rate

2.5. Materials

For the registration of OIL demands, GARMIN® Heart Rate Monitors were used, and for the registration of OEL, WIMU-PROTM inertial devices (Realtrack System, Almería, Spain) were used. The devices are composed of different location sensors. UWB technology was used for data collection in indoor spaces. Each referee was equipped with these two IMUs 30 min before each game. The initial data extraction was performed using S-PROTM software 989 version (RealTrack Systems, Almería, Spain). For the registration and operation of these devices in indoor facilities, a system of eight interconnected radiofrequency antennas with a sampling frequency of 18 Hz was utilized. The antenna system placement protocol is detailed in Figure 1, enabling triangulation of the signal for referee positioning. Eight UWB antennas were placed off the playing field to monitor the referees' movements, with two antennas on each end of the court and two antennas on each side of the court. The installation of UWB antennas was carried out 90 min before the start of the game, followed by calibration and data quality verification.

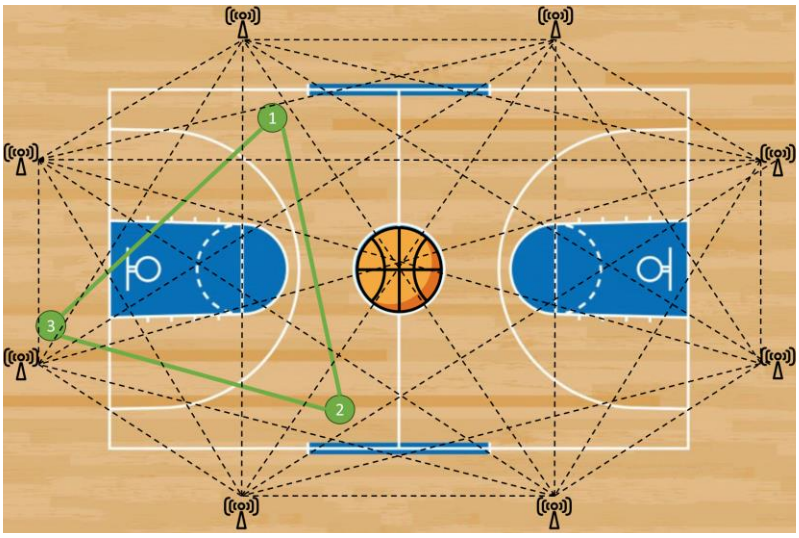


Figure 1. Antenna distribution in the field. 1: Referee number 1; 2: Referee number 2; 3: Referee number 3.

2.6. Procedure

Firstly, the study that was intended to be conducted was explained, and permission was obtained from the competition organizers. Subsequently, the benefits and potential risks of this study were explained to the referees who participated in this study. The Copa de Andalucía is a preparatory tournament played by the three regional teams participating in the Spanish professional league, Liga ACB. This tournament takes place over three consecutive days under the round-robin tournament system. The Regional Basketball Federation, which organized the tournament, authorized the participation and monitoring of all referees during the championship. Afterward, informed consent was obtained from the participants. The study participants were equipped with an anatomical harness, and a WIMU-PRO inertial device was placed on it to obtain OEL variables (kinematic and neuromuscular variables). For this purpose, an eight-antenna radiofrequency system was used to collect positioning data. Additionally, a heart rate monitor was used to obtain OIL variables (Heart Rate). All of this was performed with purpose and care to ensure that it did not interfere with the referees' technical and physical performance on the court. The placement of UWB antennas and the portable equipment carried by the referees was performed well in advance to avoid disrupting the dynamics of the game and the referees' warm-up. Only actual playing time was coded for this study. Warm-up time, timeouts, and rest quarters between game quarters were not included in the coding. After each game, the IMUs attached to the referees were removed, and data extraction was carried out for subsequent statistical analysis.

2.7. Statistical Analysis

Assumption checks were performed to ensure that the recorded variables met the normality criteria (*Shapiro–Wilk test*) [44] (Table 2). Therefore, a parametric hypothesis testing model was used. A descriptive analysis was conducted to explain the behavior of the dependent variables during the referees' performance (*means* and *standard deviation*).

Table 2. Results of the criteria assumption test. Test of normality.

	Shapiro–Wilk		
	Statistic	**df**	**Sig.**
Distance	0.948	9	0.667
Distance/min	0.895	9	0.222
Explosive Distance	0.853	9	0.080
Explosive Dist/min	0.877	9	0.147
Max Speed	0.906	9	0.289
AVG Speed	0.918	9	0.377
Accelerations	0.957	9	0.762
Decelerations	0.968	9	0.873
Accelerations/min	0.937	9	0.549
Decelerations/min	0.921	9	0.405
Max Acceleration	0.919	9	0.381
Max Deceleration	0.969	9	0.888
AVG Acceleration	0.896	9	0.230
AVG Deceleration	0.885	9	0.178
Impacts	0.923	9	0.416
Player Load	0.836	9	0.052
Player Load/min	0.868	9	0.117
Power Metabolic	0.957	9	0.762
AVG Power Metabolic	0.910	9	0.314
Power Metabolic/min	0.866	9	0.110
Max Heart Rate	0.907	9	0.293
AVG Heart Rate	0.927	9	0.453
AVG HR %	0.897	9	0.233

The *coefficient of variation* (*CV*) was used to measure the dispersion or variability (expressed as a percentage) of the dataset (Bluman, 2018). A higher *CV* value indicates greater relative data dispersion. Montgomery et al. [45] classified *CV* into three categories: low, when the value is less than 10%; moderate, when the value is between 10% and 30%; and high, when the value is greater than 30%. *CV* was applied to measure the dispersion by referee interventions, referees, games, and quarters.

In addition, inferential analysis using *ANOVA* was performed to identify differences between referee interventions, games, and game quarters. *Bonferroni's post hoc* analysis was used to identify significant differences in workload outcomes between games and game quarters. Effect size (ES), representing the magnitude of the difference between specific means and the magnitude of the difference between means according to game outcomes, was calculated using *Cohen's d*. A small effect size was considered as 0.20, a medium effect size was 0.50, and a large effect size was 0.80 [46]. Furthermore, the power of the effect was examined to adequately understand the results of the analyses performed, using a relevant test for study validity with *partial eta square*, obtaining ranges of small 0.01, medium 0.06, and large 0.14 sizes [47].

This analysis was completed using a Mixed Linear Model (MLM) to account for the individuality of each referee when performing comparative analyses between quarters and games (Gallucci, 2019). These models are essential for analyzing complex comparisons in which several independent and dependent variables intervene [48]. Similarly, pairwise comparisons were performed using the Bonferroni post hoc test.

For the graphical presentation of results, the referee load demand values were normalized by transforming them into *Z-scores*. To present a profile for each group of load variables, the data were transformed into a scale of 0–100 points.

Statistical analysis was conducted using SPSS 27.0 software for Windows (IBM SPSS Statistics for Windows, Version 27.0. IBM Corp., Armonk, NY USA), with statistical significance set at $p < 0.05$. Jamovi 2.3.13 software was used for the analysis and interpretation of the MLM (The Jamovi Project, 2022) using the R Statistical programming language (R core Team, 2021).

3. Results

Table 3 presents the individual study of each referee in each of the analyzed game quarters based on the coefficient of variation. The referees' response is quite stable, with low or moderate variation. Only a high variation in Explosive Distance/min was identified in referee 1, indicating that this referee had the highest explosiveness in their movements.

Table 4 presents the within-subject study by referee performance (behavior of each referee in each game quarter). The first three performances correspond to game 1, performances four, five, and six correspond to game 2, and the last three performances correspond to game 3. Visually, it can be observed that the variation in referees' demands within each of their interventions is low or moderate, demonstrating stability in the referees' behaviors during the games. Only a significant variability in Explosive Distance/min is identified. The dynamics of the game required an above-average explosive response from two referees. These responses with a high variation correspond to three interventions by a referee in the three games in which he intervened and that of another referee but only in one of his two interventions.

The results allowed for the identification of differences in referee interventions (Table 5). ANOVA was used to identify the differences since the MLM was not appropriate due to the sample size. Post hoc tests show the differences between the nine referee performances analyzed. Each number corresponds to a performance.

Despite not identifying high variability in the referees' responses to the demands of the competition, that is, the deviations of the referees' responses to the demands of the competition from their mean value is low or moderate, many differences were identified among them for individual adaptations in objective external load variables including Explosive Distance, Max Speed, Accelerations/min, Decelerations/min, Max Acceleration, AVG Acceleration, AVG Deceleration, Impacts, Player Load, Power Metabolic and all objective internal load variables. Bonferroni's post hoc tests revealed differences between each of the nine referee performances. Some of these differences occurred within the same referee in different games, as well as between referees. Each referee is an independent subject who adapts to the demands of the competition, varying their response compared with their colleagues and even themselves. The effect size shows that the strength or practical relevance of these differences is medium, except for Accelerations/min, Decelerations/min, Player Load, and AVG HR %, which is large. That is, in these variables, the individuality of each referee conditions his load demands during his performance. High values of the power of the effect show that significant differences between the variables are present in the population.

Figure 2 presents the results of the OEL kinematic demands, and Figure 3 shows the results of the OEL neuromuscular and OIL demands recorded in the performance of each referee during the tournament. The OIL data for performance 3 corresponds only to the values of the first and second game quarters. The average duration of the games was 1:24:55 ± 0:04:02 with a low CV (4.76).

Table 3. Descriptive analysis and individual variation of each referee by game quarter.

		Referee 1 (n = 12)			Referee 2 (n = 8)			Referee 3 (n = 8)			Referee 4 (n = 8)		
		Mean	*SD*	*cv (%)*	*Mean*	*SD*	*cv (%)*	*Mean*	*SD*	*cv (%)*	*Mean*	*SD*	*cv (%)*
Kinematics	Distance	995.73	82.25	8.26	1070.99	65.23	6.09	984.94	81.74	8.30	1100.25	108.93	9.90
	Distance/min	48.00	7.43	15.48	50.53	5.62	11.12	46.69	6.38	13.66	54.47	6.74	12.37
	Explosive Distance	93.65	12.42	13.27	115.67	13.10	11.32	98.86	15.51	15.68	133.82	13.14	9.82
	Explosive Dist/min	4.63	1.43	30.93	5.55	1.30	23.36	4.75	1.14	24.02	6.70	1.36	20.35
	Max Speed	19.35	1.38	7.14	19.85	0.79	3.96	19.57	1.35	6.90	21.64	1.46	6.73
	AVG Speed	4.28	0.37	8.67	4.58	0.31	6.79	4.65	0.34	7.29	4.75	0.30	6.33
	Accelerations	401.67	84.99	21.16	381.00	61.51	16.14	291.00	54.96	18.89	353.00	58.47	16.56
	Decelerations	404.08	85.54	21.17	382.88	61.98	16.19	291.13	55.29	18.99	354.63	58.70	16.55
	Accelerations/min	18.90	1.57	8.30	17.76	1.29	7.29	13.52	0.62	4.58	17.26	1.31	7.60
	Decelerations/min	19.01	1.55	8.17	17.84	1.17	6.55	13.53	0.59	4.33	17.34	1.34	7.73
	Max Acceleration	4.13	0.65	15.77	4.00	0.46	11.54	3.36	0.45	13.33	4.39	0.53	12.02
	Max Deceleration	−3.76	0.98	−25.96	−3.48	0.58	−16.80	−3.06	0.53	−17.23	−3.66	0.63	−17.32
	AVG Acceleration	0.61	0.09	15.34	0.67	0.07	10.53	0.63	0.05	7.24	0.79	0.07	8.96
	AVG Deceleration	−0.58	0.08	−13.27	−0.66	0.06	−9.30	−0.63	0.03	−5.04	−0.76	0.08	−9.82
Neuromusculars	Impacts	1361.50	61.23	4.50	1608.63	127.71	7.94	1336.75	133.05	9.95	1585.63	180.25	11.37
	Player Load	10.22	0.36	3.52	12.62	1.79	14.15	11.53	0.97	8.44	11.07	1.13	10.17
	Player Load/min	0.50	0.10	20.19	0.59	0.09	15.89	0.55	0.10	17.99	0.55	0.08	14.04
	Power Metabolic	2633.43	175.43	6.66	2876.21	128.72	4.48	2592.05	207.85	8.02	3031.01	281.91	9.30
	AVG Power Metabolic	6.28	0.65	10.41	6.81	0.57	8.36	6.77	0.57	8.48	7.25	0.57	7.88
	Power Metabolic/min	127.33	21.74	17.07	136.04	17.35	12.75	123.01	17.61	14.32	150.40	20.99	13.96
OIL	Max Heart Rate	159.17	5.64	3.54	154.88	4.26	2.75	141.38	4.24	3.00	158.50	4.14	2.61
	AVG Heart Rate	130.67	8.27	6.33	129.75	5.63	4.34	117.25	3.01	2.57	131.50	5.05	3.84
	AVG HR %	73.48	5.96	8.11	64.84	2.81	4.33	80.86	2.09	2.58	75.12	8.50	11.32

Low CV
Moderate CV
High CV

***SD**: standard deviation; **CV**: coefficient of variation (%)*

Table 4. Intra-game analysis of referee performance during the quarter of play of each game.

		Inter. 1 (n = 4)		Inter. 2 (n = 4)		Inter. 3 (n = 4)		Inter. 4 (n = 4)		Inter. 5 (n = 4)		Inter. 6 (n = 4)		Inter. 7 (n = 4)		Inter. 8 (n = 4)		Inter. 9 (n = 4)		Total		
		Mean	*cv (%)*	*Mean*	*cv (%)*	*Mean*	*cv (%)*	*Mean*	*cv (%)*	*Mean*	*cv (%)*	*Mean*	*cv (%)*	*Mean*	*cv (%)*	*Mean*	*cv (%)*	*Mean*	*cv (%)*	*Mean*	*dt*	*cv (%)*
Kinematics	Distance	997.01	5.27	1059.96	5.66	1122.90	8.97	934.64	6.82	950.25	9.62	1077.60	11.80	1055.55	8.59	1082.03	7.16	1019.64	6.22	1033.29	80.81	7.82
	Distance/min	49.40	14.40	52.35	11.43	55.29	9.90	47.15	23.79	47.40	16.57	53.65	16.05	47.44	9.92	48.72	11.07	45.99	12.28	49.71	6.89	13.86
	Explosive Distance	92.35	16.36	112.71	7.81	133.08	5.46	94.98	11.11	92.83	7.93	134.57	13.87	93.63	15.91	118.63	14.59	104.88	19.31	108.63	13.36	12.30
	Explosive Dist/min	4.67	33.88	5.64	23.36	6.60	16.23	4.89	35.41	4.65	19.11	6.79	26.19	4.34	31.13	5.46	26.95	4.85	30.74	5.32	1.41	26.48
	Max Speed	19.14	3.28	20.06	4.33	20.99	5.86	20.08	11.47	19.37	8.67	22.30	6.76	18.84	2.31	19.63	3.83	19.76	5.83	20.02	1.17	5.86
	AVG Speed	4.30	8.18	4.55	5.25	4.79	2.89	4.38	10.00	4.63	6.23	4.71	9.19	4.15	9.46	4.61	8.84	4.66	9.20	4.53	0.35	7.64
	Accelerations	417.75	16.72	380.50	14.72	342.75	13.44	353.00	21.02	286.00	19.94	363.25	20.56	434.25	24.35	381.50	19.78	296.00	20.63	361.67	68.89	19.05
	Decelerations	416.50	17.49	380.75	15.23	345.00	13.93	356.00	20.91	283.75	18.71	364.25	20.33	439.75	23.84	385.00	19.42	298.50	21.63	363.28	69.41	19.11
	Accelerations/min	20.33	1.41	18.58	3.47	16.81	8.88	17.23	6.67	13.95	3.57	17.71	6.32	19.13	5.56	16.93	7.68	13.10	3.17	17.08	0.89	5.18
	Decelerations/min	20.25	2.17	18.58	3.71	16.92	9.49	17.39	7.01	13.87	4.24	17.76	6.03	19.39	6.16	17.09	6.46	13.19	2.90	17.16	0.92	5.37
	Max Acceleration	3.82	16.60	4.06	14.99	4.29	15.52	4.57	11.44	3.54	14.77	4.49	9.49	4.00	17.21	3.94	8.76	3.19	10.62	3.99	0.53	13.24
	Max Deceleration	−3.61	−28.15	−3.57	−18.71	−3.54	−11.03	−3.98	−32.86	−3.21	−22.30	−3.78	−22.86	−3.71	−21.96	−3.39	−16.92	−2.91	−9.38	−3.52	0.74	−20.90
	AVG Acceleration	0.58	15.91	0.69	11.47	0.80	8.39	0.66	17.38	0.63	8.94	0.77	10.62	0.59	12.88	0.64	9.81	0.63	6.51	0.67	0.07	11.20
	AVG Deceleration	−0.56	−12.15	−0.67	−11.06	−0.77	−10.47	−0.62	−15.84	−0.63	−5.83	−0.76	−10.55	−0.56	−11.29	−0.64	−8.15	−0.63	−5.01	−0.65	0.07	−10.02
Neuromusculars	Impacts	1354.00	3.22	1531.00	2.44	1707.75	5.46	1342.00	6.82	1254.25	9.88	1463.50	11.30	1388.50	3.15	1686.25	8.51	1419.25	6.22	1460.72	92.29	6.32
	Player Load	10.44	1.50	11.03	3.26	11.62	6.74	10.02	5.70	10.93	8.84	10.53	11.83	10.19	0.79	14.21	5.25	12.13	4.61	11.23	0.61	5.41
	Player Load/min	0.52	18.83	0.55	14.51	0.57	10.61	0.51	26.68	0.55	18.95	0.53	17.69	0.46	17.53	0.64	14.26	0.55	19.86	0.54	0.09	17.48
	Power Metabolic	2624.68	3.05	2847.50	4.25	3070.31	7.88	2505.87	6.67	2491.64	9.65	2991.70	11.71	2769.75	6.45	2904.92	5.08	2692.46	4.72	2766.54	183.82	6.64
	AVG Power Metabolic	6.28	10.06	6.76	6.72	7.25	3.98	6.51	11.51	6.72	6.55	7.24	11.37	6.06	11.34	6.85	10.77	6.83	11.03	6.72	0.62	9.20
	Power Metabolic/min	130.34	16.05	140.90	13.15	151.45	11.40	126.79	25.52	124.31	16.78	149.35	18.06	124.85	12.09	131.19	13.12	121.72	13.85	133.43	20.67	15.49
OIL	Max Heart Rate	159.75	2.57	158.25	1.74	155.50	0.71	160.25	4.68	140.25	3.56	160.00	2.75	157.50	3.90	151.50	1.37	142.50	2.59	153.94	4.04	2.63
	AVG Heart Rate	135.50	6.39	132.75	4.41	129.50	4.95	130.50	7.15	116.00	2.54	132.50	4.16	126.00	4.25	126.75	3.11	118.50	2.44	127.56	5.49	4.31
	AVG HR %	67.75	6.39	66.31	4.45	64.75	2.47	77.68	7.14	80.00	2.58	80.30	4.12	75.00	4.28	63.38	3.11	81.73	2.42	74.02	3.09	4.24

Low CV; Moderate CV; High CV. The CIO data for Intervention 3 are from quarters 1 and 2 only, as during quarters 3 and 4, that referee lost the heart rate band tablet; *SD*: *standard deviation*; *CV*: *coefficient of variation (%)*

Table 5. Results of differences between performances.

			F	*p*	η^2	ϕ	Post hoc
		Duration	0.239	0.979	0.071	0.106	
Objetive external load	Kinematics	Distance	1.925	0.101	0.381	0.664	
		Distance/min	0.849	0.570	0.214	0.304	
		Explosive Distance	4.676	0.001	0.599	0.982	1-6, 4-6, 5-6, 6-7
		Explosive Dist/min	1.289	0.294	0.292	0.463	
		Max Speed	3.074	0.015	0.496	0.886	6-7,
		AVG Speed	1.137	0.374	0.267	0.409	
		Accelerations	1.789	0.127	0.364	0.626	
		Decelerations	1.840	0.116	0.371	0.641	
		Accelerations/min	27.173	0.000	0.897	1.000	1-4, 1-5, 1-6, 1-8, 1-9, 2-5, 2-9, 3-5, 4-5, 4-9, 5-6, 5-7, 5-8, 6-9, 7-9, 8-9
		Decelerations/min	27.144	0.000	0.897	1.000	1-4, 1-5, 1-6, 1-8, 1-9, 2-5, 2-9, 3-5, 4-5, 4-9, 5-6, 5-7, 5-8, 6-9, 7-8, 7-9, 8-9
		Max Acceleration	2.548	0.035	0.449	0.807	
		Max Deceleration	0.629	0.746	0.168	0.227	
		AVG Acceleration	3.122	0.014	0.500	0.892	
		AVG Deceleration	4.174	0.003	0.572	0.967	1-3, 1-6, 3-7, 6-7,
	Neuromuscular	Impacts	7.938	0.000	0.718	1.000	1-3, 1-8, 2-5, 3-5, 3-7, 3-9, 4-8, 5-8, 7-8, 8-9
		Player Load	12.761	0.000	0.803	1.000	1-8, 2-8, 3-8, 4-8, 4-9, 5-8, 6-8, 7-8, 8-9
		Player Load/min	0.988	0.469	0.240	0.355	
		Power Metabolic	3.653	0.006	0.539	0.939	
		AVG Power Metabolic	1.286	0.295	0.291	0.462	
		Power Metabolic/min	1.083	0.406	0.257	0.389	
Objetive internal load		Max Heart Rate	10.759	0.000	0.775	1.000	1-5, 1-9, 2-5, 2-9, 3-5, 4-5, 4-9, 5-6, 5-7, 6-9, 7-9
		AVG Heart Rate	4.837	0.001	0.607	0.985	1-5, 1-9, 2-5, 5-6,
		AVG HR %	17.865	0.000	0.851	1.000	1-4, 1-5, 1-6, 1-9, 2-4, 2-5, 2-6, 2-7, 2-9, 3-4, 3-5, 3-6, 3-9, 4-8, 5-8, 6-8, 7-8, 8-9

The results of the comparison using the MLM of OEL and OIL variables analyzed among the three games are presented in Table 6. The results of the MLM showed improvements in the marginal R2 with respect to the conditional R2 in all variables, controlling for the random factor of the individual response of the subjects. The model is only significant in 15 of the 23 variables analyzed, so in 8 variables, it would not be necessary to control the individual variability of the referees. In most of the variables analyzed, the Interclass Correlation Coefficient (ICC) is moderate-low, which suggests that the individuality of the referee has a poor effect on the results obtained. As can be observed, only three differences were identified in three variables. The differences were found in Impacts between game 2 and game 3 ($p < 0.001$), in Player Load between game 1 and game 2 compared with game 3 ($p < 0.001$), and in AVG HR% between game 1 and game 2 ($p < 0.002$).

Therefore, it can be stated that no differences were identified in the load demands between games for the referees. The results demonstrate that there are no significant differences in the OEL and OIL variables among the analyzed games.

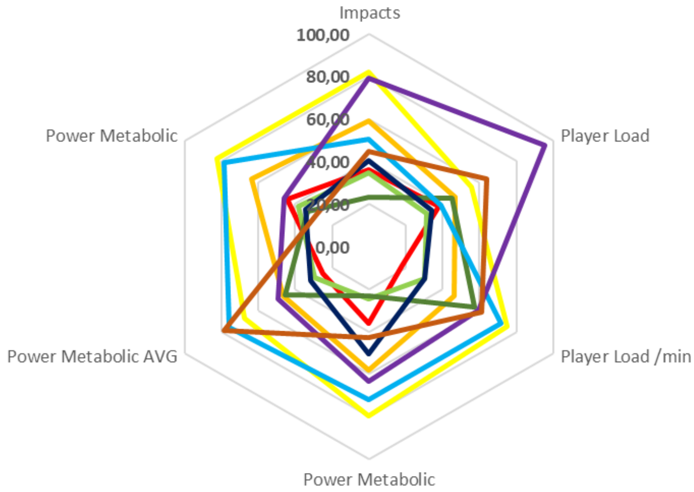
Table 7 shows the variability in the referees' demands among the three analyzed games, identifying low variation in the sample analyzed. The referees maintain stable responses to the demands of the competition, unaffected by the dynamics of the games.

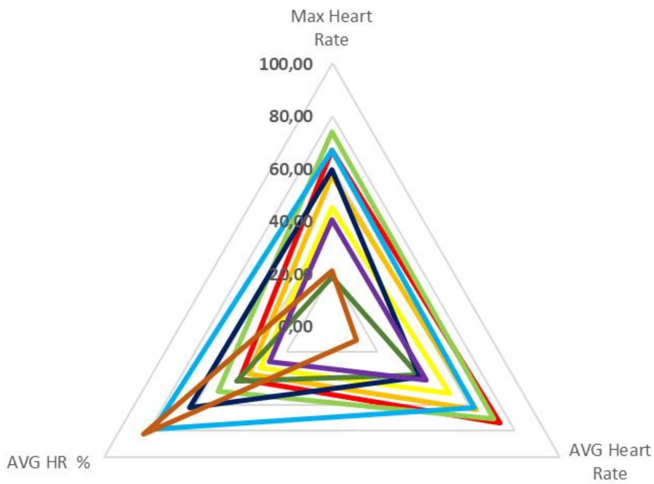
		CV(%)
Kinematics	Distance	6,09
	Distance/time	6,58
	Explosive Distance	15,70
	Explosive Dist	16,52
	Max Speed	7,53
	AVG Speed	4,95
	Accelerations	13,70
	Decelerations	13,89
	Accelerations	13,59
	Decelerations	13,60
	Max Acceleration	12,56
	Max Deceleration	-14,08
	AVG Acceleration	11,33
	AVG Deceleration	-11,44

Performance 1	
Performance 2	
Performance 3	
Performance 4	
Performance 5	
Performance 6	
Performance 7	Low CV
Performance 8	Moderate CV
Performance 9	High CV

Figure 2. Profile of OEL kinematic objective demands.

		CV(%)
Neuromuscular	Impacts	10,60
	Player Load	11,62
	Player Load/min	3,37
	Power Metabolic	7,43
	Power Metabolic AVG	6,73
	Power Metabolic	8,32
Internal Load	Max Heart Rate	5,28
	AVG Heart Rate	4,21
	AVG HR %	9,40





(red)	Performance 1		
(orange)	Performance 2		
(yellow)	Performance 3		
(light green)	Performance 4		
(dark green)	Performance 5		
(light blue)	Performance 6		
(dark blue)	Performance 7	(light green)	Low CV
(purple)	Performance 8	(light yellow)	Moderate CV
(brown)	Performance 9	(light pink)	High CV

Figure 3. Profile of OEL neuromuscular and OIL demands.

Table 6. Results of the comparison of referee claims in each game.

		Game 1 (*n* = 12)			Game 2 (*n* = 12)			Game 3 (*n* = 12)								Post hoc
		Mean	*SD*	*CV (%)*	*Mean*	*SD*	*CV (%)*	*Mean*	*SD*	*CV (%)*	*R2 M*	*R2 C*	*AIC*	*ICC*	*p LRT*	
Kinematics	Distance	1059.96	85.95	8.11	987.50	110.78	11.22	1052.41	75.43	7.17	0.118	0.389	407	0.307	0.036	
	Distance/time	52.35	6.17	11.78	49.40	9.01	18.24	47.38	4.90	10.35	0.068	0.104	237	0.039	0.738	
	Explosive Distance	112.71	19.98	17.73	107.46	23.28	21.66	105.71	19.18	18.15	0.009	0.649	310	0.646	<0.001	
	Explosive Dist	5.64	1.47	25.99	5.44	1.70	31.27	4.88	1.39	28.42	0.009	0.254	137	0.247	0.071	
	Max Speed	20.06	1.16	5.78	20.58	2.13	10.35	19.41	0.86	4.45	0.050	0.357	135	0.324	0.026	
	AVG Speed	4.55	0.31	6.92	4.57	0.39	8.43	4.47	0.44	9.86	0.005	0.217	45.9	0.213	0.061	
	Accelerations	380.33	61.54	16.18	334.08	72.04	21.56	370.58	95.70	25.82	0.033	0.271	396	0.246	0.062	
	Decelerations	380.75	62.64	16.45	334.67	72.13	21.55	374.42	96.69	25.82	0.037	0.287	397	0.259	0.052	
	Accelerations/min	18.57	1.73	9.32	16.29	1.95	11.99	16.39	2.75	16.80	0.048	0.752	161	0.740	<0.001	
	Decelerations/min	18.58	1.70	9.16	16.34	2.04	12.48	16.56	2.81	16.97	0.035	0.763	162	0.755	<0.001	
	Max Acceleration	4.06	0.61	15.06	4.20	0.66	15.75	3.71	0.59	15.79	0.078	0.423	77.6	0.374	0.019	
	Max Deceleration	−3.57	0.67	−18.68	−3.66	0.96	−26.32	−3.33	0.64	−19.18	0.028	0.083	91.9	0.056	0.614	
	AVG Acceleration	0.69	0.12	17.02	0.69	0.10	14.97	0.62	0.06	9.89	0.020	0.463	−45.1	0.452	0.002	
	AVG Deceleration	−0.67	0.11	−16.87	−0.67	0.09	−14.09	−0.61	0.06	−9.67	0.015	0.534	−48.8	0.527	<0.001	
Neuromuscular	Impacts	1530.92	161.33	10.54	1353.25	148.18	10.95	1498.00	166.64	11.12	0.134	0.652	444	0.598	<0.001	2-3;
	Player Load	11.03	0.68	6.16	10.49	0.96	9.13	12.18	1.78	14.63	0.202	0.544	123	0.429	0.001	1-3, 2-3
	Player Load/min	0.55	0.08	14.00	0.53	0.10	19.52	0.55	0.12	20.79	0.008	0.080	−43.3	0.072	0.464	
	Power Metabolic	2847.50	240.46	8.44	2663.07	340.30	12.78	2789.04	165.74	5.94	0.081	0.590	476	0.554	<0.001	
	Power Metabolic AVG	6.76	0.60	8.89	6.82	0.70	10.31	6.58	0.76	11.59	0.008	0.242	84.8	0.236	0.049	
	Power Metabolic/min	140.90	19.37	13.75	133.48	27.22	20.39	125.92	15.41	12.24	0.043	0.158	311	0.120	0.361	
OIL	Max Heart Rate	158.30	3.30	2.09	153.50	11.10	7.23	150.50	7.53	5.00	0.018	0.725	234	0.720	<0.001	
	AVG Heart Rate	133.20	6.68	5.02	126.33	9.66	7.65	123.75	5.43	4.39	0.088	0.491	228	0.442	0.005	
	AVG HR %	66.58	3.35	5.03	79.33	3.75	4.72	73.37	8.22	11.21	0.246	0.636	211	0.517	0.002	1-2;

Low CV

Moderate CV

High CV

SD: *standard deviation;* ***CV***: *coefficient of variation (%)*

R2 M: *R-square marginal;* ***R2 C***: *R-square conditional;* ***AIC***: *Akaike Information Criterion;* ***ICC***: *Intraclass Correlation Coefficient;* ***p LTR***: *p-value Random Effect LRT*

Table 7. Results of the variation in the total demands by game.

			Game 1	**Game 2**	**Game 3**	***Mean***	***SD***	***CV (%)***
		Duration	1:22:05	1:22:22	1:30:18	1:24:55	0:04:40	5.49
Objetive external load	**Kinematics**	Distance	4239.83	3950.00	4209.62	4133.15	159.33	3.86
		Distance/min	52.35	49.40	47.38	49.71	2.50	5.02
		Explosive Distance	450.84	429.84	422.84	434.51	14.57	3.35
		Explosive Dist/min	5.64	5.44	4.88	5.32	0.39	7.38
		Max Speed	20.71	23.12	20.31	21.38	1.52	7.11
		AVG Speed	4.55	4.61	4.65	4.60	0.05	1.11
		Accelerations	1521.33	1336.33	1482.33	1446.67	97.52	6.74
		Decelerations	1523.00	1338.67	1497.67	1453.11	99.92	6.88
		Accelerations/min	18.57	16.29	16.39	17.08	1.29	7.54
		Decelerations/min	18.58	16.34	16.56	17.16	1.24	7.21
		Max Acceleration	4.88	4.75	4.15	4.59	0.39	8.49
		Max Deceleration	−4.44	−4.67	−4.11	−4.40	0.28	−6.43
		AVG Acceleration	0.69	0.69	0.62	0.67	0.04	5.66
		AVG Deceleration	−0.67	−0.67	−0.61	−0.65	0.03	−5.12
	Neuromuscular	Impacts	6123.67	5413.00	5992.00	5842.89	378.07	6.47
		Player Load	44.11	41.97	48.71	44.93	3.44	7.67
		Player Load/min	0.55	0.55	0.55	0.55	0.00	0.56
		Power Metabolic	11,389.99	10,652.28	11,156.16	11,066.14	377.00	3.41
		AVG Power Metabolic	6.76	6.86	6.92	6.85	0.08	1.15
		Power Metabolic/min	140.90	133.48	125.92	133.43	7.49	5.61
Objetive internal load		Max Heart Rate	160.67	159.33	154.00	158.00	3.53	2.23
		AVG Heart Rate	132.58	131.00	123.75	129.11	4.71	3.65
		AVG HR %	66.27	73.07	73.37	70.90	4.01	5.66

	Low CV	***SD**: standard deviation; **CV**: coefficient of variation*
	Moderate CV	
	High CV	

The results of the intra-game quarter variation and differences between the game quarters of the analyzed OEL and OIL variables are presented in Table 8. The MLM presented better results than the *ANOVA* since the improvements in the conditional R2 compared with the marginal R2 occurred in all the variables. Thus, the random factor of the individual response of the referees affects the differences in load demands between quarters. The model is significant in 22 of the 23 variables analyzed. Only for Max Deceleration is it not necessary to control the individual variability in the referees. The ICC is moderate-high, which suggests that the individuality of the referee considerably affects the results obtained. Four variables (Explosive Distance, Accelerations/min, AVG Deceleration; Max Heart Rate) have an ICC > 0.7.

Table 8. Results of the analysis of intra-quarter variation and differences between game quarters.

		First Quarter (*n* = 9)			Second Quarter (*n* = 9)			Third Quarter (*n* = 9)			Fourth Quarter (*n* = 9)								
		Mean	***SD***	***CV* (%)**	***Mean***	***SD***	***CV* (%)**	***Mean***	***SD***	***CV* (%)**	***Mean***	***SD***	***CV* (%)**	***R2 M***	***R2 C***	***AIC***	***ICC***	***p* *LRT***	**Post hoc**
Kinematics	Distance	948.17	56.10	5.92	1089.53	93.62	8.59	1019.77	75.27	7.38	1075.68	89.98	8.37	0.316	0.581	390	0.388	0.005	1-2; 1-4
	Distance/min	58.29	5.79	9.94	46.76	4.14	8.86	49.18	3.63	7.38	44.61	5.45	12.21	0.523	0.706	210	0.384	0.007	1-2; 1-3; 1-4
	Explosive Distance	114.70	14.20	12.38	116.07	24.76	21.34	109.56	19.02	17.36	94.18	18.00	19.11	0.155	0.789	299	0.750	<0.001	1-4; 2-4; 3-4
	Explosive Dist/min	7.06	1.13	16.07	4.98	1.08	21.61	5.28	0.90	16.99	3.96	1.10	27.72	0.502	0.840	113	0.679	<0.001	1-2; 1-3; 1-4; 2-4; 3-4
	Max Speed	20.32	2.02	9.92	20.22	1.27	6.26	20.23	1.74	8.62	19.31	0.83	4.27	0.064	0.400	137	0.358	0.010	
	AVG Speed	4.94	0.24	4.78	4.44	0.30	6.73	4.51	0.23	5.01	4.24	0.36	8.49	0.443	0.699	29.3	0.460	<0.001	1-2; 1-3; 1-4
	Accelerations	290.11	50.83	17.52	393.56	64.54	16.40	352.89	54.74	15.51	410.11	85.69	20.89	0.325	0.624	377	0.444	0.001	1-2; 1-4
	Decelerations	290.56	49.64	17.09	397.11	64.57	16.26	355.33	56.22	15.82	410.11	87.76	21.40	0.322	0.629	378	0.452	0.001	1-2; 1-4
	Accelerations/min	17.66	2.22	12.58	16.85	2.52	14.93	17.01	2.57	15.11	16.82	2.53	15.02	0.017	0.758	167	0.754	<0.001	
	Decelerations/min	17.70	2.19	12.35	17.00	2.53	14.86	17.13	2.66	15.54	16.81	2.53	15.06	0.016	0.773	168	0.770	<0.001	
	Max Acceleration	4.38	0.57	13.02	3.89	0.70	17.98	4.06	0.60	14.64	3.62	0.51	14.11	0.166	0.504	76.7	0.405	0.005	1-4;
	Max Deceleration	−4.11	0.63	−15.26	−3.81	0.85	−22.30	−3.28	0.52	−15.71	−2.88	0.37	−12.90	0.373	0.469	78.6	0.154	0.197	1-3; 1-4; 2-4
	AVG Acceleration	0.76	0.10	12.57	0.64	0.07	11.29	0.66	0.08	12.04	0.60	0.09	14.19	0.298	0.818	−49.2	0.740	<0.001	1-2; 1-3; 1-4
	AVG Deceleration	−0.73	0.10	−13.15	−0.63	0.07	−10.73	−0.64	0.08	−11.93	−0.59	0.08	−13.13	0.274	0.856	−51.8	0.801	<0.001	1-2; 1-3; 1-4
Neuromuscular	Impacts	1397.78	151.96	10.87	1543.22	169.65	10.99	1435.44	164.28	11.44	1466.44	198.05	13.51	0.081	0.612	439	0.578	<0.001	
	Player Load	10.80	1.29	11.96	11.89	1.44	12.14	11.09	1.28	11.55	11.16	1.54	13.78	0.075	0.478	131	0.435	0.001	
	Player Load/min	0.66	0.05	7.79	0.51	0.08	14.99	0.54	0.07	12.53	0.46	0.07	14.33	0.551	0.681	−64.4	0.291	0.018	1-2; 1-3; 1-4
	Power Metabolic	2595.40	184.62	7.11	2925.37	307.70	10.52	2731.93	236.99	8.67	2813.44	230.36	8.19	0.182	0.667	461	0.592	<0.001	1-4;
	AVG Power Metabolic	7.47	0.46	6.12	6.59	0.52	7.87	6.67	0.39	5.89	6.16	0.62	10.04	0.466	0.759	65.7	0.549	<0.001	1-2; 1-3; 1-4; 3-4
	Power Metabolic/min	159.64	18.24	11.43	125.51	12.94	10.31	131.74	11.33	8.60	116.84	15.64	13.39	0.518	0.776	282	0.535	<0.001	1-2; 1-3; 1-4; 3-4
OIL	Max Heart Rate	157.11	10.13	6.45	153.44	7.57	4.93	155.25	7.17	4.62	149.25	8.36	5.60	0.088	0.821	323	0.804	<0.001	1-4; 3-4
	AVG Heart Rate	133.00	11.45	8.61	127.89	5.88	4.60	125.88	6.58	5.23	122.25	4.13	3.38	0.182	0.678	226	0.606	<0.001	1-4;
	AVG HR %	75.93	7.61	10.03	73.24	8.16	11.14	73.19	6.91	9.45	71.25	8.11	11.38	0.038	0.606	226	0.591	<0.001	

Low CV

Moderate CV

High CV

SD: *standard deviation*; ***CV***: *coefficient of variation*

R2 M: *R-square marginal*; ***R2 C***: *R-square conditional*; ***AIC***: *Akaike Information Criterion*; ***ICC***: *Intraclass Correlation Coefficient*; ***p LTR***: *p-value Random Effect LRT*

Differences in the kinematic demands of OEL were identified in eleven variables. In the first quarter, Q1, a shorter distance is traveled than in Q2 and Q4. However, when distance is normalized to time, a greater Distance/min is traveled compared with the rest of the quarters ($p < 0.001$). Q4 demands the least absolute Explosive Distance and Explosive Dis/min, with Q1 being the most demanding. The AVG Speed variable is higher in the first quarter compared with the rest of the quarters ($p < 0.001$). The load demands in the last quarter were lower compared with Q1 and Q2 in the Acceleration and Deceleration variables ($p = 0.001$). Furthermore, at the beginning of the game, there are greater demands for Max Acceleration and Max Deceleration than at the end of the game. This fact is also evident with AVG Acceleration and AVG Deceleration ($p < 0.001$).

OEL neuromuscular demands were greater at the beginning of the game. The Player Load/min was higher in Q1 compared with the rest of the quarters. These values are repeated in Power Metabolic, AVG Power Metabolic, and Power Metabolic/min.

Regarding OIL demands, differences were identified in the Max Heart Rate of the referees between the first and third quarters compared with the fourth quarter, where the fourth quarter makes lesser demands than the first and third quarters. Similar differences were identified between the AVG heart rate of the first and fourth quarters. The last quarter required less AVG heart rate.

Table 9 shows the variation in demands between game quarters in the three analyzed games. Once again, it is evident that the game sequence causes low to moderate variability in the load demands endured by the referees.

Table 9. Variation in total results by quarter.

		Q1	**Q2**	**Q3**	**Q4**	***Mean***	***SD***	***CV (%)***
	Duration	0:16:26	0:23:20	0:20:44	0:24:24	0:21:14	0:03:33	16.70
Kinematics	Distance	948.17	1089.53	1019.77	1075.68	1033.29	64.26	6.22
	Distance/min	58.29	46.76	49.18	44.61	49.71	6.02	12.10
	Explosive Distance	114.70	116.07	109.56	94.18	108.63	10.03	9.23
	Explosive Dist/min	7.06	4.98	5.28	3.96	5.32	1.29	24.18
	Max Speed	24.33	21.87	23.51	20.71	22.60	1.62	7.18
	AVG Speed	4.94	4.44	4.51	4.24	4.53	0.29	6.47
	Accelerations	290.11	393.56	352.89	410.11	361.67	53.42	14.77
	Decelerations	290.56	397.11	355.33	410.11	363.28	53.82	14.82
	Accelerations/min	17.66	16.85	17.01	16.82	17.08	0.39	2.31
	Decelerations/min	17.70	17.00	17.13	16.81	17.16	0.39	2.25
	Max Acceleration	5.24	5.20	4.76	4.28	4.87	0.45	9.25
	Max Deceleration	−4.80	−5.27	−4.24	−3.48	−4.45	0.77	−17.28
	AVG Acceleration	0.76	0.64	0.66	0.60	0.67	0.07	9.98
	AVG Deceleration	−0.73	−0.63	−0.64	−0.59	−0.65	0.06	−9.19
Neuromuscular	Impacts	1397.78	1543.22	1435.44	1466.44	1460.72	61.75	4.23
	Player Load	10.80	11.89	11.09	11.16	11.23	0.46	4.14
	Player Load/min	0.66	0.51	0.54	0.46	0.54	0.08	15.53
	Power Metabolic	2595.40	2925.37	2731.93	2813.44	2766.54	138.94	5.02
	AVG Power Metabolic	7.47	6.59	6.67	6.16	6.72	0.55	8.14
	Power Metabolic/min	159.64	125.51	131.74	116.84	133.43	18.51	13.87

Table 9. *Cont.*

		Q1	Q2	Q3	Q4	*Mean*	*SD*	*CV (%)*
OIL	Max Heart Rate	168.00	162.00	162.00	157.00	162.25	4.50	2.77
	AVG Heart Rate	133.00	127.89	125.88	122.25	127.25	4.49	3.52
	AVG HR %	75.93	73.24	73.19	71.25	73.40	1.92	2.62
	Low CV							
	Moderate CV							
	High CV							

SD: *standard deviation*; ***CV***: *coefficient of variation*; ***Q1***: *first quarter*; ***Q2***: *second quarter*; ***Q3***: *third quarter*; ***Q4***: *fourth quarter*

4. Discussion

The aim of this research was to characterize the load endured by professional basketball referees during games of an official tournament in the Spanish premier basketball division (Liga ACB), allowing for an understanding of each referee's individual response to the demands of an official competition. Furthermore, it was identified that the referees' response does not vary within the same referee or between performances, games, and game quarters. However, a change was identified in the objective kinematic and neuromuscular variables of OEL between game quarters, taking into account the individuality of the referees. These results must be analyzed with caution since they come only from a single sample from an official tournament.

4.1. Analysis of Physical Demands through Technology

The study of the technical and physiological demands of professional referees during official games is highly necessary for their development. So far, studies have focused on analyzing players [49], allowing for the establishment of training protocols tailored to competitive reality. Referees' responses to the demands of a competition are individual and can be influenced by factors such as age, anthropometric characteristics, level of experience, or level of competition, among others. Training planning for referees should be based on their specific responses, taking into account specific competitive characteristics [50].

The use of technology, such as heart rate monitors and/or multisensor IMUs, has provided a greater amount of objective information on OEL and OIL demands [17,37]. The use of such devices allows for understanding the individual responses of each athlete, either a referee or a player. Individualized training allows for personalized preparation for each referee. This individualization is adapted to each need, optimizing performance and reducing the risk of injury.

4.2. Analysis of the Physical–Physiological Demands of the Referees

It is necessary to understand the maximum movement demands based on the dynamics of the game and specific movements, influenced by aspects related to the technical intervention. In modern refereeing, games can be officiated by either two (2PO—two people officiating) or three referees (3PO—three people officiating) [51]. In many countries, at lower levels, games are officiated by two referees (2PO), while at higher levels, dynamic three-referee systems (3PO), approved by FIBA in 2000, are used. Therefore, the demands can vary depending on the refereeing technique with two or three referees, and as established by Leicht [52], the 3PO system can reduce stress generated by the games.

It was observed that referees' behavior remains stable during the analyzed games (two or three games), regardless of the game dynamics or the final result. This fact indicates that these officials require specific physical preparation based on the stability of their behavior. However, high variability was only identified in Explosive Distance/min in four refereeing interventions and in two referees. This high variability corresponds fundamentally to an intervention by a referee in the three games in which he participated. This referee was able to alternate between movements with a low intensity and others with a high intensity, so the CV manifested with a very high percentage. The individuality of the referee must be taken into account since very explosive movements have been identified in the interventions of a referee that must be taken into account for the physical preparation of this referee and taken into account for the prevention of injuries. The physical and musculoskeletal characteristics of these individuals allow us to identify that their movements were more explosive in response to specific game demands. Rojas-Valverde, Gómez-Carmona, Oliva-Lozano, Ibáñez, and Pino-Ortega [50] identified that fatigue appeared in referees during a series of very consecutive games, especially when the games demanded higher intensity due to the close and balanced nature of the games. This modification in referees' demands was not identified in these top-level referees in a top-level competition. The competition sequence has shown that as the game progresses, each quarter becomes longer (increased number of fouls and timeouts), with an increase in the number of breaks and a decrease in maximum velocity and Explosive Distance/min, allowing the referee's recovery.

The OEL borne by a basketball referee is a parameter that must be precisely known to adapt their preparation to different competitive scenarios [49]. The analysis of the performance profile of a basketball referee includes accumulated load resulting from acceleration in the three axes (Player Load), metabolic expenditure calculated as the product of instantaneous velocity, energy cost relative to body weight, and distance covered (Power Metabolic), which provide insights into the physical demands that may lead to injury risks [10,53]. In basketball, several studies conclude that referees show lower levels than players in these neuromuscular OEL variables [38,54] due to the limited movement of referees within their designated zones during the game. Additionally, referees do not perform jumps during their involvement in the game. Similarly, it has been identified that referees cover less distance when officiating with three referees compared with two referees [55].

The analyzed referees covered an average total distance of 4133.15 m (Figure 2), which is similar to distances previously recorded for professional basketball referees [10,54,56,57]. However, the distance covered is an insufficient variable to measure the physical demands of a basketball referee since 75% of the referee's movements during a game are walking or jogging [56]. Additionally, the results of this study reveal that the analyzed referees covered an Explosive Distance of 434.51 m (distance covered with acceleration greater than 1.12 m/s^2). Therefore, specific training for a referee should include continuous work on the distance that can be covered during a game, performed at various intensities.

Other indicators of OEL are the number of Accelerations and Decelerations, Maximum and Average Acceleration and Deceleration. As basketball is an intermittent sport, these variables partially determine the referee's performance during the game and their decision-making [15,58]. The results of this study indicate that the average number of Accelerations is 1446.67, while the average number of Decelerations is 1453.11, which is lower than what has been found in other studies [15,39]. This aspect could be explained by the fact that in professional senior basketball, possessions are longer with fewer transitions than in lower-level categories [59,60]. These data highlight the reality of competition for a top-level professional referee. Knowledge of these demands should allow for the customization of preparatory training for competition, taking into account that referees do not cover long distances: the distance covered at high intensity is not very long, and they perform many low-intensity Accelerations and Decelerations.

The number of Impacts recorded is very high, with an average of 5842.89 impacts per game, although these Impacts occur at very low intensities, as 84% of them are registered between 0 and 3 G forces. These values are lower than those received by basketball players and can be classified as moderate to low [61]. Reina, García-Rubio, Antúnez, and Ibáñez [35] identified that the number of impacts per minute decreases in three vs. three games compared with five vs. five games due to the explosiveness of the movements. Similarly, the same applies to referees since their movements are not influenced by other participants. This can be attributed to the fact that referees do not need to jump, make abrupt changes in direction, or collide with other players. Therefore, this kinematic variable is not relevant to a referee's performance.

Heart Rate has traditionally been the primary indicator used to assess the physical performance of athletes, specifically basketball referees [49,62,63]. The sample in this study shows an Average Heart Rate between 145 and 168 beats per minute and a percentage of the Average Heart Rate between 118 and 135 beats per minute. Previous research has shown similar intensity levels in professional referees [27,62]. The sample in this study shows a percentage of the Maximum Heart Rate between 145 and 168 beats per minute and a percentage of the Average Heart Rate between 118 and 135 beats per minute. Previous research has shown similar intensity levels in professional referees [10] perhaps because the demands of the games are higher in higher categories. Similarly, it was observed that the demands experienced by referees are similar to those of professional players during competition [54], highlighting the need for specific training programs for basketball referees based on their competitive level. This will enable them to sustain these physical demands throughout the game and delay the onset of fatigue, ultimately helping them make better decisions.

According to the results obtained in this study, no significant differences were found in the variation in Maximum and Average Heart Rate during different quarters of the game and among the analyzed games. In the scientific literature, both increasing demands throughout the game with higher load in the last quarter [13] and lower values in the last quarter compared with the rest have been found [10,39]. This disparity in results indicates that the OIL of basketball referees during competition could depend on several factors: (i) whether the score is balanced or not, with balanced scores reflecting physical demands (significant differences) or unbalanced scores not reflecting these demands (no significant differences) [50]; (ii) based on the variability in the game, there may be greater variability in the early quarter, as teams seek to impose their pace from the beginning, and less variability in the later quarter due to the high number of interruptions experienced [64]; (iii) depending on whether fatigue increases or not during the game, as fatigue is directly related to the OEL and OIL endured by referees [49,63]; (iv) considering the competition category, whether they are developmental players, senior players, or professionals; (v) taking into account the gender of the players; and (vi) considering refereeing mechanics [10,11,62]. Therefore, it is necessary to design comprehensive referee training programs considering internal and external factors that can influence their physiological response during competition.

The load borne was analyzed by referees during senior official games at the highest level. In this study, few differences were identified among different games and game quarters. The results showed that the analyzed OEL and OIL variables did not vary across games, indicating consistent load demands from one game to another.

Previous studies that have examined load dynamics throughout a game indicate a decrease in load during game progression [13,38,50]. In the present study, a significant variation in the demands placed on referees between different quarters was identified. The variability observed among the analyzed variables was moderate to low. The distance covered in the first quarter was lower than in the remaining quarter, but it was performed at a higher intensity. The first quarter exhibited peaks of higher velocity, with a greater Average Acceleration and Deceleration. Consequently, this led to a greater neuromuscular load, with higher values in Player Load/min and Power Metabolic/min compared with the other quarter. For a basketball referee, the first quarter is the most physically demanding, as it involves adapting to the dynamics of the game, starting with higher intensity and concluding with more moderate demands. These adaptations can be attributed to achieving optimal muscular dynamics between the start of the game and the onset of fatigue toward the end. Additionally, these alterations may be influenced by the dynamics of the game, as there are more interruptions, and the pace slows down in the final quarter.

Finally, it should be noted that the MLM substantially improved the precision of the analysis compared with the difference analysis carried out with the *ANOVA* since the individuality of each referee during the games and quarters was taken into account [65]. The use of this analysis model has been shown to be the most appropriate when analyzing the load demands of basketball players considering the individuality of each subject [66,67].

In this study, differences in the individual factors of each referee were revealed in the comparative analysis by quarters. The referees' demands change during the game, as those of the players do [68]. For a referee, the beginning of the game is more physically demanding than the end. Therefore, they must prepare adequately to face the high demands at the beginning of the game and have a good base of physical fitness to maintain these demands until the end of the game. Considering the characteristics of each referee, warm-ups must be personalized.

The results obtained in this research are highly novel, as no previous studies have analyzed the OEL and OIL of basketball referees based on the game or game quarter during elite games such as those played in the analyzed tournament. However, this study has limitations that should be considered when interpreting the results. Firstly, although the entire sample of the preparatory tournament was recorded, the number of participants is small. Secondly, the equipment used (anatomical harness, WIMUPRO inertial devices, eight-antenna radiofrequency system, heart rate monitor...) is costly, which limits the availability of previous works for data comparison. Future investigations should expand the sample size and study the analyzed OEL and OIL parameters in different professional basketball competitions at national and international levels.

5. Conclusions

The high-level competition referees participating in this study showed moderate to low variability in the OEL and OIL demands imposed by the official competition, both between games and between quarters. Their responses to the competition demands are individual and may be influenced by factors such as age, anthropometric characteristics, physical fitness, and competition requirements. Each referee has a personal load profile. Therefore, it is necessary to establish specific training programs for each referee. Game dynamics result in minimal differences in referee responses among the analyzed games. Variations in game pace generate differences in Accelerations/min, Decelerations/min, and consequently, Impacts, Player Load, and AVG Heart Rate. Despite these differences, referees maintain consistent responses with low variability, indicating consistent load demands from one game to another.

A low to moderate variability in referee responses was identified among different game quarters. However, there were differences in the change in demands between game quarters. The distance covered in the first quarter is lower than in the remaining quarters, but it is performed at a higher intensity. The first quarter exhibits peaks of higher velocity, with greater average acceleration and deceleration. In the fourth quarter, which has a longer duration, more distance is covered but at a lower intensity. Neuromuscular load, Player Load/min, and Power Metabolic/min show higher values in the first quarter compared with the other quarters. These variations can be due to optimal muscle dynamics at the beginning of the game and the appearance of fatigue in the last quarter, as well as to the inherent dynamics of the game.

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