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Profiling External Load in U14 Basketball: Cluster Analysis of Competition Performance Using Inertial Devices

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Abstract

Physical performance data is essential for planning youth training effectively; however, there is a lack of scientific information regarding performance in youth competitions. To address this gap, an innovative study was conducted with Portuguese U14 regional selections. Each player was equipped with a WimuPro™ inertial device. Six variables were considered: accelerations, decelerations, speed, player load, impacts, and high impacts. The objective of this study, based on data from official competitions, was to statistically analyze the distribution and intensity thresholds of six physical performance variables across five defined zones. A cluster k-means analysis was performed for a significance value of $p < 0.05$. Five zones were identified for all variables: acceleration [<0.37; 0.37 to 0.81; 0.81 to 1.54; 1.54 to 3.49; >3.49 m/s^2], deceleration [<−0.26; −0.27 to −0.63; −0.63 to −1.22; −1.22 to −2.545; >−2.54 m/s^2], speed [<5.42; 5.42 to 10.19; 10.20 to 14.63; 14.64 to 18.59; >18.59 km/h^2], player load [<1.07; 1.07 to 1.36; 1.37 to 1.63; 1.64 to 1.95; >1.95 u.a./min], impacts [<133.45; 133.45 to 158.75; 158.76 to 181.45; 181.46 to 206.59; >206.59 cont/min], and high impacts [<1.13; 1.14 to 2.11; 2.12 to 3.13; 3.14 to 4.42; >4.42 cont/min]. These intensity zones should be taken into account to optimize training and enhance the understanding of competition in U14 basketball.

Keywords: external load; Portuguese youth basketball; inertial measurement units; cluster analysis; performance metrics

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1. Introduction

The paradigm of training in sports has changed; the control and quantification of the loads that the player supports during training or competitions [1] is an increasingly explicit reality. External load refers to the physical demands placed on athletes during training or competitions and is a crucial indicator for training planning and evaluation [2]. With the knowledge of the data from external and internal loads that the competition requires of players, it enables the coaches to optimize training processes [2,3]. In this sense, the customization of the load should be based on the knowledge of the demands imposed by the competition [4]; however, without the individualization of the sample, serious consequences may affect the planning and results of the team during the competition [5]. As far as is known, there is little research that individualizes load thresholds according to youth population. Proposals have been made to individualize the demands of specific external loads in professional women [5] or professional men [6], but not in U14 men.

Despite growing interest in individualized load monitoring, research focused on youth athletes—particularly under-14 (U14) male basketball players—remains limited. While individualized external load thresholds have been established for professional female [5] and male athletes [6], similar approaches are lacking in youth contexts. Individual factors such as age, competitive level, and playing position significantly influence athletes' responses to training loads and must be considered when analyzing external load [7]. Individualizing both external and internal load thresholds allows training to be tailored to each athlete's age and physiological profile, enhancing adaptation, optimizing performance, and adjusting training volume and intensity according to individual needs [3,8–10]. Evidence from team sports supports this need for individualization, as external load data vary across contexts, including age, gender, sport, and competition level [2,7,8,11–13]. However, the scarcity of reference data for youth athletes highlights the need for further research to support developmentally appropriate training strategies.

Basketball performance is characterized by a predominance of aerobic activity, with decisive contributions from anaerobic efforts during high-intensity phases of play [14]. The sport involves intermittent, short-duration bursts of high intensity interspersed with periods of lower intensity [15], making the ability to sustain repeated high-intensity efforts a key determinant of success [3,16]. Research shows that elite players often cover less total distance but reach higher peak speeds during competition [17], and players from stronger teams tend to cover shorter distances at lower speeds compared to those from weaker teams [18]. Although some studies have proposed generic movement intensity classifications (standing >6 km/h, walking 6–12 km/h, jogging 12–18 km/h, running 18–24 km/h, sprinting >24 km/h) [19], these thresholds are typically based on manufacturer defaults and may not accurately reflect basketball-specific demands [20]. Therefore, individualized intensity zones—based on variables such as speed, acceleration, and deceleration—are essential for accurate external load monitoring [2,3,5,21–23].

Performance in basketball is closely linked to fundamental motor abilities, including strength, power, agility, speed, and coordination [24]. These capacities are reflected in mechanical and locomotor stress—collectively referred to as external load—which can be measured through kinematic variables such as speed, acceleration, deceleration, and distance covered [25]. Among these, acceleration and deceleration are particularly important, as they capture the frequency and intensity of explosive movement [8]. The ability to perform and recover from such efforts is a key performance indicator [26], with elite-level performance strongly associated with rapid changes in speed and direction, high-intensity displacements, and jumping actions [2,3,8,27]. Accurate assessment of these variables not only enhances performance monitoring but also contributes to injury prevention strategies [27,28].

Quantifying high-intensity actions during training and competition is critical for prescribing appropriate training loads [16]. However, methodological improvements are needed to establish individualized thresholds that account for contextual factors such as competitive level, gender, and biological maturation—particularly in youth populations [11]. Basketball is also an intermittent impact sport, characterized by frequent physical contact during actions such as rebounds, screens, and defensive plays, especially under high-level opposition [3,15]. Players positioned closer to the basket experience more frequent impacts and perform more jumps per minute [29]. As such, neuromuscular preparation should include quantification of contact load and impact intensity, tailored to the competitive context and developmental stage of youth athletes.

Kinematic load represents the intensity and nature of movement demands placed on athletes and can be quantified using localization technologies. These systems capture key performance variables such as acceleration, deceleration, speed, player load, impacts and high impacts (HI) [20], typically measured in meters per second squared (m/s^2) through ultra-wide band (UWB) positioning embedded in wearable devices [20]. Inertial measurement units (IMUs), which combine accelerometry and positional tracking, have become increasingly prevalent in sports science applications [20,30]. These devices enable both real-time and retrospective analysis of physical performance, supporting training load management, recovery strategies, and performance optimization [2,4,8,15,27,30–32]. In basketball, microtechnology has significantly enhanced the precision of external load monitoring, particularly in capturing acceleration and deceleration patterns, offering deeper insights into athletes' physical responses across various competitive contexts [33].

The availability of reference data is fundamental for the accurate analysis of external load in basketball players [12]. It enables coaches and researchers to benchmark individual performance against established standards [34], identify areas for improvement, and adjust training programs accordingly [35]. Reference values also play a critical role in validating new observational methodologies and technologies, ensuring measurement reliability and accuracy [20,36]. Their integration into training practices contributes to performance optimization and injury prevention [28,37,38], particularly in youth athletes, where benchmarks support progression to higher levels of competition by guiding skill development and talent identification [12,39]. Objective and measurable performance indicators further assist coaches in preparing young athletes for the physical and technical demands of elite basketball [11,40].

Few studies have quantified external and internal loads in youth sports [14,22,41]. In response, the present study profiles the external demands of U14 male basketball using inertial sensors to capture acceleration, deceleration, speed, player load, impacts, and HI. These data were used to generate representative intensity intervals that reflect competitive demands and provide context-specific, individualized benchmarks. The primary objective is to enhance the understanding of external load profiles in youth basketball through the application of inertial devices, which offer valuable insights into the contextualization and individualization of physical demands. This evidence can inform training design and monitoring practices while identifying performance patterns critical for athletic development and injury prevention in young players [28,38].

2. Materials and Methods

2.1. Design

This research is classified within the quantitative studies that follow an associative strategy through a cross-sectional comparative design [42] that explores the thresholds of intensity zones in external workload, and characterizes the performance of young male basketball players in official games [5 vs. 5] of the Portuguese competitive regions [42].

2.2. Participants and Sample

The study was carried out with eight teams from Group A of the Portuguese regional teams; 12 games were analyzed; each team played 3 games, making 24 moments of teams analyzed, for a total of 12 players per team, corresponding to 96 players analyzed in the U14 men's category in the qualifying phase for the finals of the national championship.

The research protocol was approved by the university's Bioethics Committee with the number 113/2024 and adhered to the ethical guidelines outlined in the Declaration of Helsinki (2024) [43].

The sample consisted of eight regional teams comprising the top-performing under-14 basketball athletes in each Portuguese region. The selected players were under-14 athletes with a mean age of 13.73 ± 0.43 years, a mean weight of 60.79 ± 12.63 kg, and a mean height of 174.89 ± 10.88 cm. Player selection was conducted by the respective regional coaches, based on performance evaluations of all eligible athletes within their districts. Each of the regional coaches identified and selected the players demonstrating the highest current performance competency in basketball for this age group. Player positions were not considered as a grouping variable, as fixed roles are not assigned in Portuguese U14 basketball, where all players are expected to rotate through multiple positions for developmental purposes.

Twelve games were analyzed, equivalent to 24 moments of investigation, corresponding to 3 games per team observed, where 96 players were monitored. During the 12 games, the total number of accelerations recorded was 74,319,181; the number decelerations was 53,248,532; the number of speed actions was 5,864,742; the number of player load data analyzed was 763 u.a./min; the number of impacts was recorded from 717 game quarters; and the number of HI actions was recorded from 717 game quarters (Table 1).

Table 1. Sample and amount of data.

Analyzed Sample	Elements of Analysis
Nº Teams	Eight Teams
Number of Games Analyzed	12 matches (3 matches per team)
Number of Participants	96 players
Number of Team Analysis Moments	24 moments
Amount of Acceleration Variable data	74,319,181
Amount of Decelaration Variable data	53,248,532
Amount of Velocity Variable data	5,864,742
Amount of Player Load Variable data	763 u.a./min
Amount of Impacts Variable data	717 (quarters)
Amount of HI Variable data	717 (quarters)

2.3. Variables

For this study, the independent variable was the competition, defined as the specific demands and the number of players involved in official game situations. In addition, six dependent variables were established: accelerations, decelerations, speed, player load, impacts, and HI. The variables were selected in accordance with the study by Ibáñez, López-Sierra, Lorenzo, and Feu [21]. They were chosen because they are the most relevant within the field under investigation, professional basketball, and are therefore the most suitable for training control and monitoring. These variables were recorded with the accelerometers using WIMU^{TM} inertial devices; in this case, the data were collected every hundredth of a second (100/s) [20]. The specific software SPRO^{TM} (v. 989) extracts raw data from the accelerometer automatically, and this process avoids possible errors by researchers. The following variables were selected:

Acceleration: the rate at which a player increases his velocity, measured in meters per second squared (m/s^2);

Deceleration: the rate at which a player decreases his velocity, measured in meters per second squared (m/s^2);

Speed: distance covered divided by the time employed in covering that distance, measured in kilometers per hour (km/h);

Player Load: measurement derived from the accelerometer of the total body load in its three axes of movement (vertical, anteroposterior, and mediolateral), calculated as the square root of the sum of the accelerations divided by sampling frequency [38];

Impacts: measuring the G-force to which the body is subjected to the different play actions, being the vector sum of the G-forces that a player endures in the three planes (x, y, z). The value of an impact is established when the G-force of the movement is higher than 5 Gs; the manufacturer's software (SPRO^{TM}) uses these reference measurements [3]. And it is measured in counts per min (n/min).

H1. *Total of impacts made over 8G.*

2.4. Process and Equipment

The research team contacted the Portuguese Basketball Federation to organize the data collection process. After the project was approved, the regional selections were contacted and provided with informed consent forms to be signed by the players' legal guardians. Once all players' participation was authorized, the equipment to be used during data collection was prepared.

Each player was equipped with a WIMUPro^{TM} inertial device that was attached and placed in a specific custom vest fitted tightly to the back of the upper torso, as is typically used in games. The SVIVO^{TM} software (v. 923.4) automatically analyzed all the data collected by the inertial device and sent it to the computer screen in real time. This UWB system solves the problem of satellite referencing, using time-based positioning techniques in which the signal propagates from the transmitter to the receiver [44]. The UWB system was adjusted to the reference field before the start of the investigation, covering the perimeter of the field so that it would be recognized as a reference system [25]. This system consisted of eight antennas placed in a rectangle outside the playing field (Figure 1) [45]. The ANT^{+} transmitter emits a wireless signal for several seconds, and inertial devices include ANT^{+} receivers that register a mark in the software when they receive a signal. This solution enables automatic synchronization of time and positioning data in the software (SPRO^{TM}) [46]. The WIMU Pro^{TM} inertial device, the UWB system, and the software come from the same organization [47].

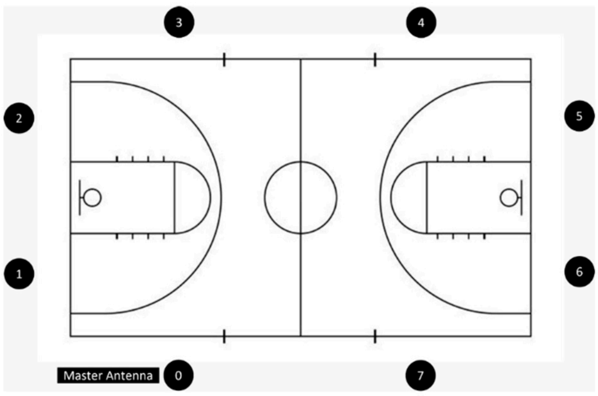

Figure 1. UWB system on basketball court [6].

For the analysis of the competition, the UWB system was calibrated 1 h before the start of the first games of the day, and the WIMUPro^{TM} inertial devices were synchronized with the UWB system through ANT^{+} technology. Following the protocol suggested by the device manufacturers, the court perimeter was traversed with two devices placed in close proximity, and the constancy of the distance between them was assessed using the UWB monitoring system at a sampling frequency of 100 Hz. The total measurement error was 0.08 ± 0.05 m. This margin of error is optimal for basketball monitoring, and the calibration of both the UWB system and the inertial devices was therefore deemed acceptable for this study. Each player was equipped with the inertial device 20 min before the start of the match. In this way, there was a familiarization period during the warm-up. Once the match started, total and live times were calculated using the SVIVO™ software, with total time referring to the entire time a player was on the field, including all stoppages of play, but excluding intervals between quarters and free time. Live time corresponds to the time when the game clock was running and the player was on the field. The SPRO™ software was used to automatically analyze all the information collected by the inertial device [48].

2.5. Statistical Analysis

Acceleration and deceleration data were extracted for each player in each match, selecting only the data present during the game (time on the bench is not included). Once the data were extracted, a filter of the outliers was performed from the Stem and Leaf Graph. A k-media cluster analysis was performed using 5 load zones as recommended in the literature [5,19,41,49]. Confirmation of differences between the groups was used through one-way ANOVA analysis. The software used for the analysis was SPSS version 25.0. The significance value was set at p <0.05.

3. Results

3.1. Accelerations Results

The acceleration data of U14 basketball players (ages 13–14) collected during official competition was categorized into five intensity zones based on magnitude. From a total of approximately 74 million recorded actions, soft acceleration (<0.374 m/s^2) accounted for the largest proportion, representing 43.4% of all data (≈32.2 million instances), with a mean value of 0.146 m/s^2. Low acceleration (0.374–0.811 m/s^2) comprised 18.7% of the dataset (≈13.9 million), with an average of 0.603 m/s^2. Moderate acceleration (0.811–1.545 m/s^2) represented 32.2% (≈23.9 million), with a mean of 1.019 m/s^2 (Table 2).

Table 2. Results of the five-k means cluster of the variable acceleration.

Accelerations (m/s^2)	Soft	Low	Moderate	High	Maximum
Cluster centers	0.146	0.603	1.019	2.074	4.920
Ranges	<0.374	0.374 to 0.810	0.811 to 1.545	1.546 to 3.496	>3.497
n	32,247,093	13,860,517	23,938,208	3,901,757	371,596
%	43.39	18.65	32.21	5.25	0.50

Higher intensity efforts were less frequent. High acceleration (1.546–3.496 m/s^2) constituted 5.3% of the total (≈3.9 million), with an average of 2.074 m/s^2, while maximum acceleration (>3.496 m/s^2) was rare, comprising only 0.5% of actions (≈372,000), with a mean value of 4.920 m/s^2 (Table 2).

Approximately 44% of all game actions performed by U14 players occur under low-intensity acceleration conditions, specifically within the range of 0 to 0.374 m/s^2. When considering all actions with accelerations up to 1.545 m/s^2 (encompassing soft, low, and moderate intensities), this proportion rises to 94.25% of the total. In contrast, high-intensity accelerations (1.546–3.496 m/s^2) account for only 5.25% of actions (≈3.9 million), with a mean value of 2.074 m/s^2. Maximum-intensity accelerations (>3.496 m/s^2) are rare, comprising just 0.5% of actions (≈371,600), with a mean of 4.920 m/s^2. Overall, only 5.75% of game actions are performed at high or maximum acceleration intensities (Figure 2).

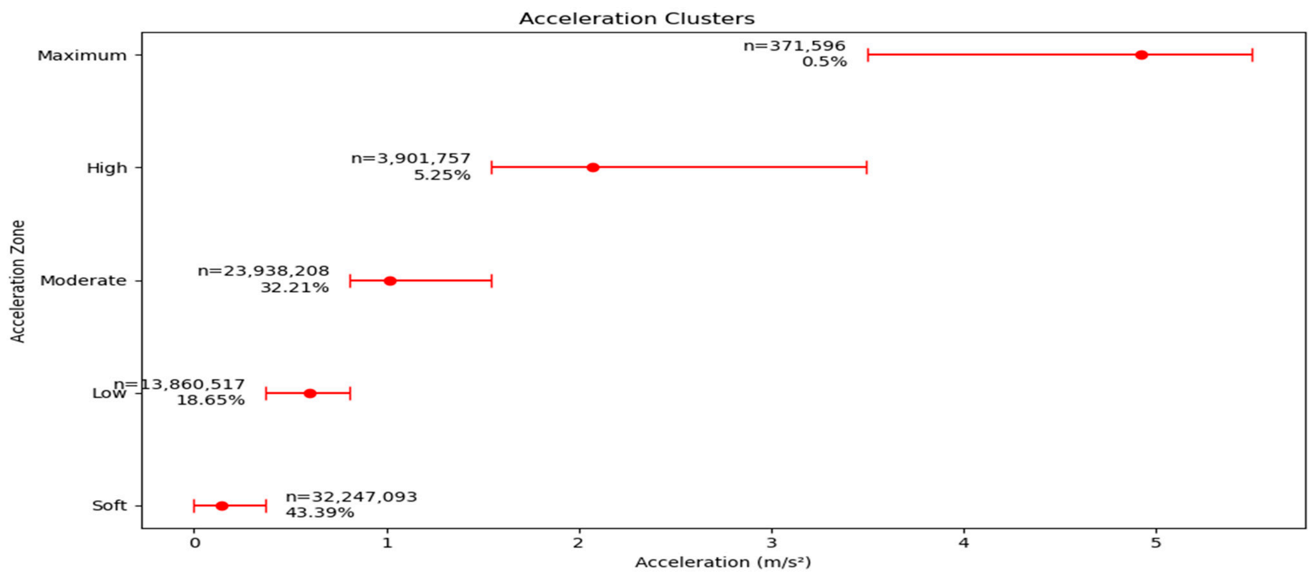

Figure 2. Graphical interpretation of all accelerations carried out in the national championship of men's under-14.

3.2. Decelerations Results

Regarding deceleration, the analysis of 53 million data points shows that soft decelerations (0 to −0.269 m/s^2) represent 49.55% of all actions (≈26.4 million), with a mean of −0.116 m/s^2. Low decelerations (−0.270 to −0.635 m/s^2) account for 30.12% (≈16 million), and moderate decelerations (−0.636 to −1.222 m/s^2) for 16.97% (≈9 million), with a mean of −0.848 m/s^2. High decelerations (−1.223 to −2.545 m/s^2) represent 3.03% (≈1.6 million), and maximum decelerations (>−2.546 m/s^2) only 0.32% (≈170,000), with a mean of −3.548 m/s^2. These results indicate that the vast majority of decelerative actions also occur at low to moderate intensities (Table 3).

Table 3. Results of the five-k means cluster of the variable deceleration.

Decelerations (m/s^2)	Soft	Low	Moderate	High	Maximum
Cluster centers	−0.116	−0.423	−0.848	−1.595	−3.548
Ranges	<−0.269	−0.270 to −0.635	−0.636 to −1.222	−1.223 to −2.545	>−2.546
n	26,384,648	16,038,458	9,036,276	1,613,430	170,395
%	49.55	30.12	16.97	3.03	0.32

In relation to deceleration (Figure 3), U14 players perform the majority of their actions at low intensity, with 49.5% of all game actions occurring within the range of 0 to −0.270 m/s^2. When extending the range to include moderate decelerations (up to −1.222 m/s^2), this proportion increases to 96.64% of the total actions, indicating a clear predominance of low-to-moderate deceleration demands during match play.

Only 3.02% of actions fall within the high-intensity deceleration range (−1.223 to −2.545 m/s^2), with a mean value of −1.595 m/s^2 across approximately 1.61 million instances. Maximum-intensity decelerations (>−2.545 m/s^2) are rare, representing just 0.32% of all actions (≈170,000), with a mean of −3.548 m/s^2. These findings confirm that only 3.34% of total game actions are performed at high or very high deceleration intensities (Figure 3).

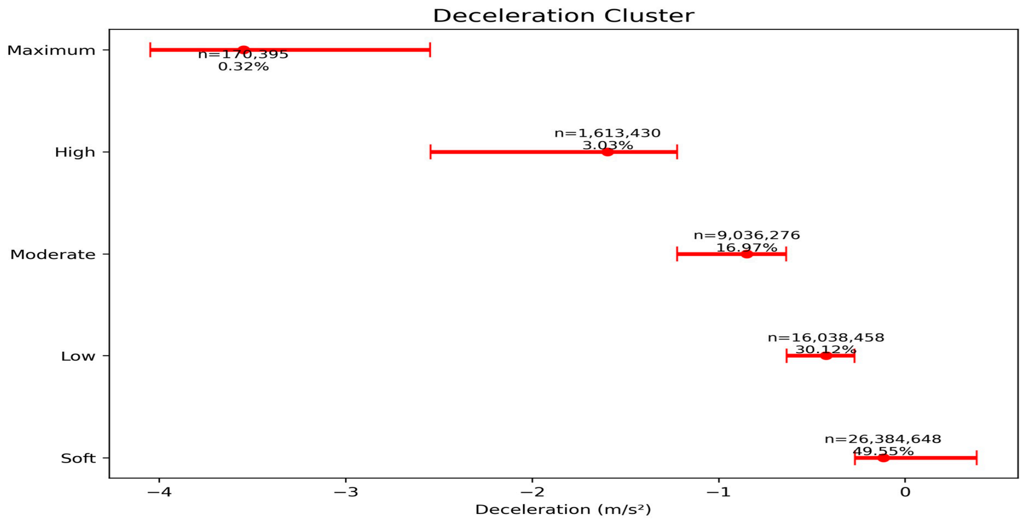

Figure 3. Graphical interpretation of all the decelerations made in the men's under-14 national championship.

3.3. Speed Results

The analysis of the speed variable (Table 4), based on a five-cluster k-means model, reveals that U14 players perform the majority of their actions at low movement speeds. Specifically, 63.6% of all game actions occur at speeds below 5.42 km/h, with a cluster center of 2.98 km/h, corresponding to approximately 3.73 million data points out of a total of 5.86 million. These values reflect moments when players are either stationary or moving at very low intensity.

Table 4. Results of the five-k means cluster of the variable speed.

Speed (km/h)	Very Low/Standing	Low/Walking	Moderate/Jogging	High/Running	Very High/Sprinting
Cluster centers	2.98	7.45	12.16	16.17	20.05
Ranges	<5.42	5.42 to 10.19	10.20 to 14.63	14.64 to 18.59	>18.59
n	3,730,195	1,286,446	621,004	192,342	34,755
%	63.60	21.94	10.59	3.28	0.59

In addition, 21.94% of actions occur at low speed (5.42–10.19 km/h), typically associated with walking, with a cluster center of 7.45 km/h (≈1.29 million data points). Moderate-speed actions (10.20–14.63 km/h), corresponding to jogging, represent 10.59% of the total (≈621,000), with a cluster center of 12.16 km/h. High-speed actions (14.64–18.59 km/h), associated with running, account for 3.28% (≈192,000), with a cluster center of 16.17 km/h. Very high-speed actions in this study were defined as movements exceeding 18.59 km/h, aligning with the general literature threshold of high-speed running (>18.5 km/h). Among U14 male basketball players, such actions were rare, representing only 0.59% of total movements (approximately 34,800 instances), with a cluster center of 20.98 km/h. This value also surpasses the commonly accepted sprint threshold of >20 km/h.

The analysis of movement velocity (Figure 4) among U14 male basketball players revealed a strong predominance of low-intensity locomotor activity during match play. Specifically, 63.60% of all recorded actions occurred at very low speeds (<5.42 km/h), corresponding to standing or walking intensities. When combined with low-speed walking (5.42–10.19 km/h) and moderate jogging (10.20–14.63 km/h), the proportion of actions performed at low to moderate intensities rises to 96.13% of total game actions.

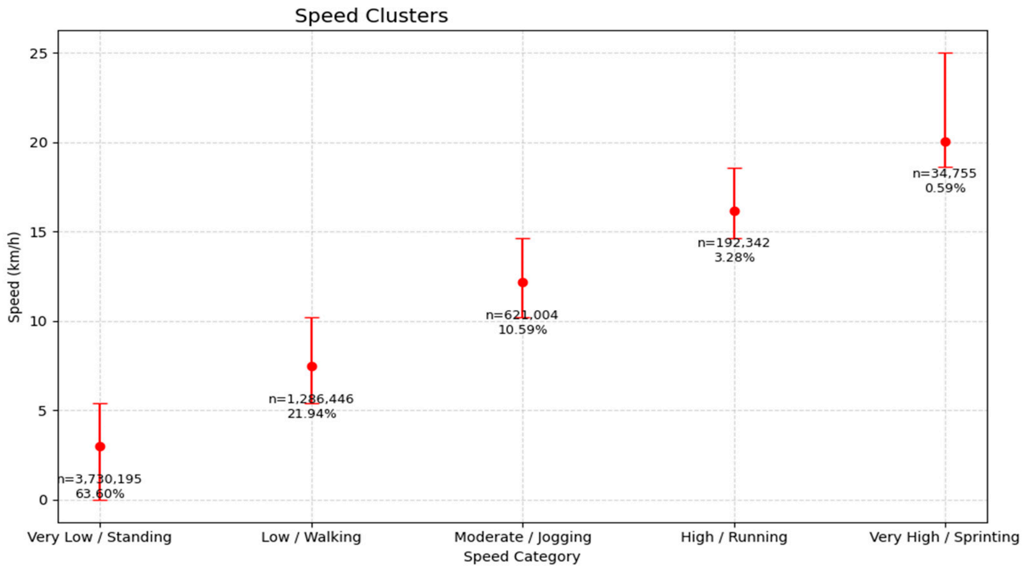

Figure 4. Graphical interpretation of results from five-k means cluster of the variable speed.

Only 3.28% of actions were classified as high-speed running (14.64–18.59 km/h), with a cluster center of 16.17 km/h. Very high-speed or sprinting actions (>18.59 km/h) were rare, accounting for just 0.59% of total actions (Figure 4). Notably, the sprint cluster center was 20.05 km/h, which exceeds the sprint threshold of 20 km/h.

3.4. Player Load Results

The analysis of the player load variable (Table 5), using a five-cluster k-means model, indicates that U14 basketball players distribute their physical effort across distinct intensity zones. In Zone 1 (<1.07 UA/min), players accumulate 3.41% of the total player load, with a cluster center of 0.91 UA/min. Zone 2 (1.07–1.36 UA/min) represents 19.66% of the total load, centered at 1.24 UA/min.

Table 5. Results of the five-k means cluster of the variable player load.

Player Load (u.a./min)	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Cluster centers	0.91	1.24	1.50	1.77	2.13
Ranges	<1.07	1.07 to 1.36	1.37 to 1.63	1.64 to 1.95	>1.95
n	26	150	207	235	145
%	3.41	19.66	27.13	30.80	19.00

Zone 3 (1.37–1.63 UA/min) accounts for 27.13% of the player load, with a cluster center of 1.50 UA/min, while Zone 4 (1.64–1.95 UA/min) comprises the largest share, 30.80%, centered at 1.77 UA/min. Finally, Zone 5 (>1.95 UA/min) represents 19.00% of the total load, with a cluster center of 2.13 UA/min (Table 5). These results suggest that the majority of physical demands are concentrated in moderate-to-high-intensity zones, with relatively few actions occurring at very low or maximum intensities.

The distribution of player load intensities (Figure 5) among U14 male basketball players demonstrates a clear predominance of moderate to high physical effort during match play. Specifically, Zones 3 and 4—representing intensities between 1.37 and 1.95 AU/min—accounted for the largest proportion of total effort, with 27.13% and 30.80%, respectively. Combined, these zones represent 57.93% of all player load activity, indicating that the majority of gameplay is performed at sustained moderate-to-high intensities.

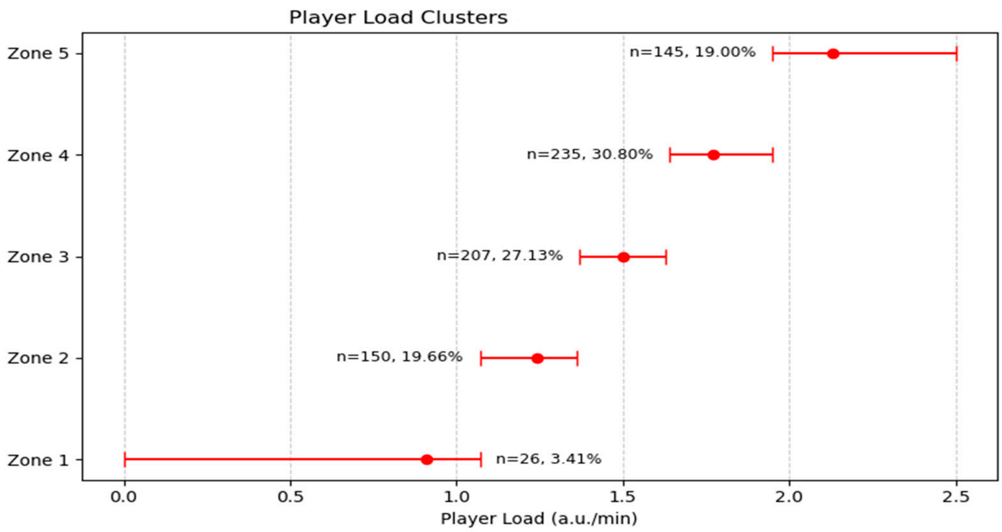

Figure 5. Graphical interpretation of results from five-k means cluster of the variable player load.

Zone 5, corresponding to very high-intensity efforts (>1.95 AU/min), comprised 19.00% of total player load, with a cluster center of 2.13 AU/min. This substantial proportion of high-load activity suggests that U14 players are capable of sustaining significant physical demands during competition. In contrast, only 3.41% of total effort occurred in Zone 1 (<1.07 AU/min), indicating that very low-intensity activity is relatively rare (Figure 5).

3.5. Impacts Results

The analysis of the impacts variable (Table 6), based on a five-cluster k-means model, shows that U14 basketball players distribute their mechanical load across a range of intensities during match play, an analysis from the 717 quarters of the 24 games. In Zone 1 (<133.45 contacts/min), players recorded 6.69% of total impacts, with a cluster center of 120.05 contacts/min. Zone 2 (133.45–158.75 contacts/min) accounted for 23.01% of impacts, centered at 147.39 contacts/min.

Table 6. Results of the five-k means cluster of the variable impacts.

Impacts (cont/min)	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Cluster centers	120.05	147.39	170.74	192.45	221.46
Ranges	<133.45	133.45 to 158.75	158.76 to 181.45	181.46 to 206.59	>206.59
n	48	165	262	177	65
%	6.69	23.01	36.54	24.69	9.07

The highest proportion of impacts occurred in Zone 3 (158.76–181.45 contacts/min), representing 36.54% of the total, with a cluster center of 170.74 contacts/min. Zone 4 (181.46–206.59 contacts/min) comprised 24.69% of impacts, centered at 192.45 contacts/min, while Zone 5 (>206.59 contacts/min) represented 9.07%, with a cluster center of 221.46 contacts/min (Table 6). These results suggest that the greatest number of impact-related actions occur within moderate-to-high-number contact zones, reflecting the physical demands of competitive youth basketball.

The analysis of impact frequency among U14 male basketball players revealed that the majority of in-game physical contacts occurred within moderate-to-high-intensity zones (Figure 6). Specifically, Zone 3 (158.76–181.45 contacts/min) accounted for the largest proportion of impacts at 36.54%, followed by Zone 4 (181.46–206.59 contacts/min) with 24.69%, and Zone 2 (133.45–158.75 contacts/min) with 23.01%. Combined, these three zones represented 84.24% of all recorded impacts, indicating that most physical contact during gameplay occurs within a sustained moderate-to-high intensity range.

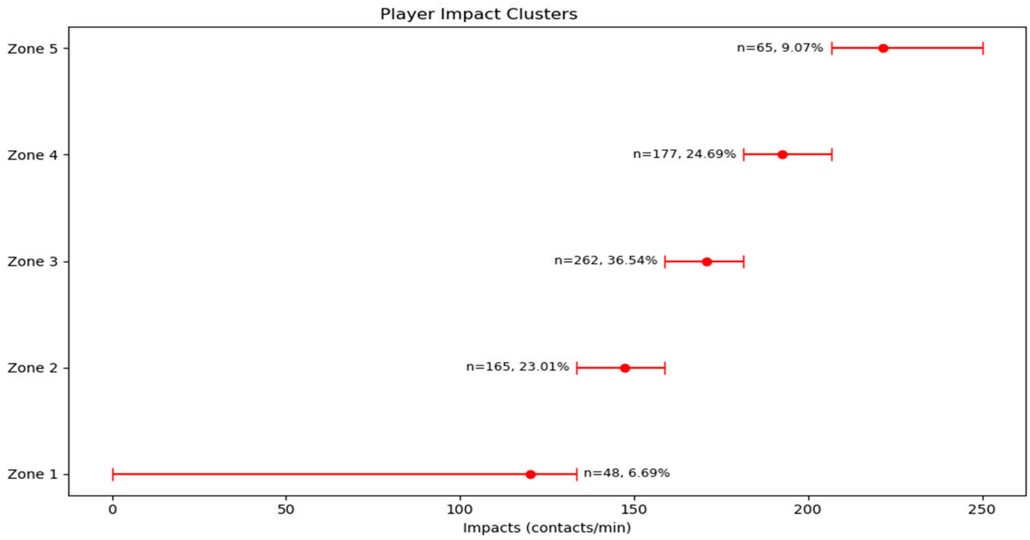

Figure 6. Graphical interpretation of results from five-k means cluster of the variable impacts.

Zone 5, corresponding to very high-intensity impacts (>206.59 contacts/min), comprised 9.07% of total impacts, with a cluster center of 221.46 contacts/min. This suggests that U14 players are capable of engaging in frequent and intense physical contact during competition. In contrast, only 6.69% of impacts occurred in Zone 1 (<133.45 contacts/min), reflecting a relatively low occurrence of minimal-contact phases.

3.6. HI Results

The analysis of HI from the 717 quarters of the 24 games (Table 7)—defined as impacts exceeding 8G—using a five-cluster k-means model, reveals the distribution of mechanical load intensity among U14 basketball players. In Zone 1 (<1.13 contacts/min), players recorded 27.20% of all HI, with a cluster center of 0.63 contacts/min. Zone 2 (1.14–2.11 contacts/min) accounted for 23.01% of HI, centered at 1.63 contacts/min.

Table 7. Results of the five-k means cluster of the variable HI.

HI (cont/min)	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Cluster centers	0.63	1.63	2.58	3.67	5.15
Ranges	<1.13	1.14 to 2.11	2.12 to 3.13	3.14 to 4.42	>4.42
n	195	179	178	105	60
%	27.20	24.97	24.83	14.64	8.37

Zone 3 (2.12–3.13 contacts/min) represented 24.83% of HI, with a cluster center of 2.58 contacts/min, while Zone 4 (3.14–4.42 contacts/min) comprised 14.64%, centered at 3.67 contacts/min. Finally, Zone 5 (>4.42 contacts/min) accounted for 8.37% of all HI, with a cluster center of 5.15 contacts/min (Table 7). These results indicate that the number of high-impact events are distributed across all zones; the majority occur at low to moderate numbers, with fewer numbers of events at the highest intensities.

The distribution of HI actions, from the 717 quarters of the 24 games (Figure 7)—defined as impacts exceeding 8G—among U14 male basketball players revealed a gradual decline in frequency across increasing numbers of zones. The majority of HI actions were concentrated in Zones 1 to 3, with Zone 1 (<1.13 contacts/min) accounting for 27.20% of total actions, followed closely by Zone 2 (1.14–2.11 contacts/min) at 24.97% and Zone 3 (2.12–3.13 contacts/min) at 24.83%. Collectively, these three zones represented 76.99% of all high-impact events, indicating that most HI actions occurred at low to moderate amounts.

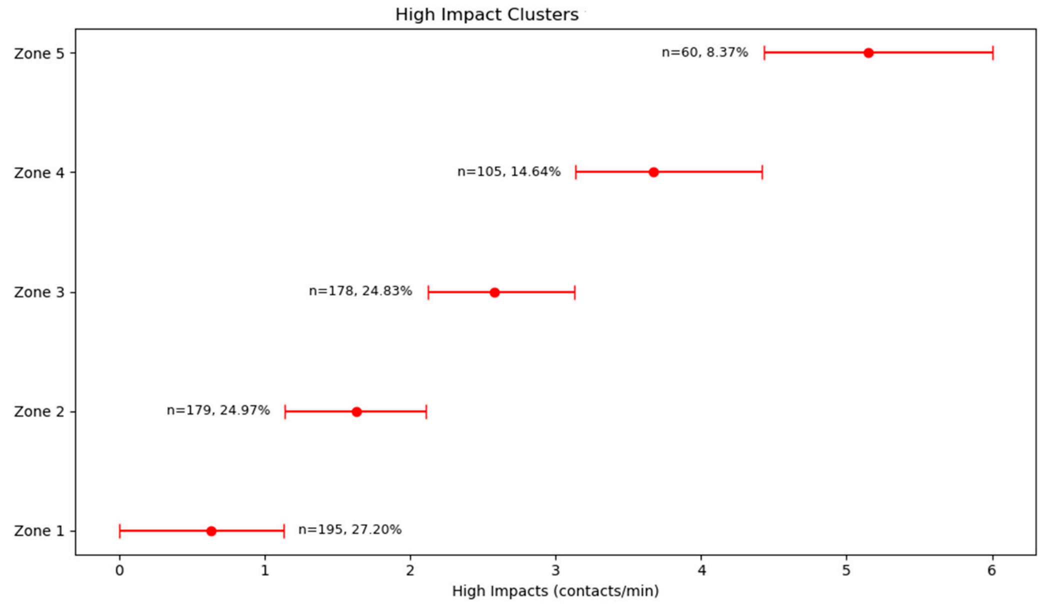

Figure 7. Graphical interpretation of results from five-k means cluster of the variable HI.

Zone 4 (3.14–4.42 contacts/min) comprised 14.64% of HI actions, while Zone 5 (>4.42 contacts/min)—representing the most extreme number of events—accounted for only 8.37% of total actions, with a cluster center of 5.15 contacts/min (Figure 7). This decreasing trend across zones suggests that although U14 players are capable of producing very high-intensity impacts, such occurrences are relatively infrequent during match play.

4. Discussion

This study was developed with the objective of analyzing the external load, with emphasis on the variables of accelerations, decelerations, velocity, player load, impacts, and HI, creating statistically representative intervals of the performance requested in the competition of U14 male players of the regional basketball teams, through inertial devices. The results have made it possible to identify the specific thresholds/ranges for this population of players.

4.1. Accelerations

Of the total game actions, only 3.34% were performed at high and very high acceleration intensities, suggesting that players require substantial recovery time following high-intensity efforts. This is supported by the fact that 96.64% of actions occurred at moderate and low intensities. Similarly, only 5.75% of total actions involved very high or maximum decelerations, reinforcing the notion that players tend to recover through lower-intensity movements, as evidenced by the 94.25% of actions performed at moderate and low deceleration intensities.

These findings indicate that young players engage in a game model that includes moments of high and maximum intensity, followed by extended periods of recovery. Notably, 49.5% of all deceleration actions occur within the low-intensity range (0 to -0.270 m/s^2), further emphasizing the predominance of submaximal efforts. It is important to note that the data observed in this study may differ from those reported in other investigations on acceleration and deceleration, which are often specific to different basketball contexts, such as competitive level [6,8,21,28], age group [50,51], or gender [5,14].

A comparative analysis of average acceleration across five teams per age group yielded the following results: U12 = 3.9 ± 1.2 m/s^2, 60-m sprint speed (SD) = 9.3 ± 2.0 m/s; U14 = 3.5 ± 1.0 m/s^2, SD = 9.3 ± 2.2 m/s; U16 = 3.8 ± 1.0 m/s^2, SD = 10.2 ± 1.8 m/s; U18 = 3.8 ± 1.1 m/s^2, SD = 9.2 ± 2.1 m/s; and Senior = 3.6 ± 0.9 m/s^2, SD = 9.2 ± 1.8 m/s [52]. In contrast, our analysis of 74 million game actions at the U14 level revealed that 94% of accelerations were below 1.5451 m/s^2—substantially lower than the reported average of 3.5 ± 1.0 m/s^2.

Despite the different study context, the interpretation of our findings aligns with previous research conducted on senior basketball players, where the intensity of accelerations during competition was similarly analyzed. In those studies, acceleration was classified into three zones: low (1.0–2.5 m/s^2), elevated (2.5–4.0 m/s^2), and sprint (>4.0 m/s^2); while deceleration was categorized as low (−1.0 to −2.5 m/s^2), high (−2.5 to −4.0 m/s^2), and sprint (<−4.0 m/s^2) [14].

According to that classification, senior athletes demonstrated high average acceleration intensities across game quarters: Q1 = 2.54 m/s^2, Q2 = 2.51 m/s^2, Q3 = 2.34 m/s^2, and Q4 = 2.41 m/s^2, which would fall within the high acceleration zone as defined in the present study. These high-intensity accelerations are typically associated with rapid directional changes, explosive movements, and speed variations—such as backdoor cuts and destabilizing actions aimed at outmaneuvering opponents [14].

Context-specific studies are essential for ensuring methodological rigor, supporting athlete development, and safeguarding physical integrity [36]. In this study, five acceleration intervals were defined for male U14 players: <0.37, 0.37–0.81, 0.81–1.54, 1.54–3.49, and >3.49 m/s^2. Analysis revealed that 94.25% of in-game actions occurred within low to moderate acceleration ranges (0–1.545 m/s^2), while only 5.75% involved high-intensity accelerations (>1.546 m/s^2). In comparison, previous research on senior players identified five distinct acceleration intervals: <0.50, 0.50–1.60, 1.61–2.87, 2.88–4.25, and 4.26–6.71 m/s^2 [5], indicating a clear difference in performance profiles between age groups.

Previous research on U18 basketball players reported peak in-game accelerations of up to 3.6 m/s^2 and recommended a threshold of 3.0 m/s^2 to define high-intensity accelerations [50]. Based on the present findings for male U14 players, high-intensity accelerations fall within the range of 1.546–3.496 m/s^2, while maximum accelerations exceed 3.497 m/s^2. These thresholds are lower than those proposed for U18 athletes, which appears appropriate given the expected progression in physical capacity and athletic performance over a four-year developmental period. Additionally, it has been emphasized that in basketball, understanding not only the external load intensity zones but also the distribution of movement speeds within these zones—and the behavioral patterns that lead athletes to different intensities—is essential for designing effective training programs and preparing players to meet competitive demands [11].

4.2. Decelerations

Similarly, five deceleration intervals were established for U14 players: <−0.26, −0.27 to −0.63, −0.63 to −1.22, −1.22 to −2.545, and >−2.54 m/s^2. Results showed that 96.64% of deceleration actions fell within low to moderate intensity (0 to −1.222 m/s^2), with only 3.36% classified as high-intensity decelerations (>−1.223 m/s^2). In contrast, senior players demonstrated deceleration intervals of <0.37, 0.37–1.13, 1.14–2.07, 2.08–3.23, and 3.24–4.77 m/s^2 [5], further highlighting the distinct physical demands experienced by younger athletes that are lower than those of professional players.

From a dataset comprising 53 million deceleration data points, 96% of actions were recorded below -1.222 m/s^2, a value markedly lower than the previously reported U14 average of 3.1 ± 1.6 m/s^2 [50]. This discrepancy suggests that, in real-game contexts, U14 players rarely reach high deceleration intensities, potentially due to developmental limitations in strength, coordination, or tactical demands. These findings highlight the importance of progressively developing deceleration capacity in youth athletes, as this component may be undertrained relative to its critical role in performance and injury prevention. Coaches should therefore implement age-appropriate training strategies that emphasize controlled deceleration mechanics and gradually introduce higher-intensity deceleration drills. Such an approach can help young players build the neuromuscular control required to safely manage the more demanding deceleration loads encountered at higher competitive levels.

4.3. Velocity

As emphasized in previous research [36,53,54], conducting studies within appropriate competitive and developmental contexts is essential for ensuring methodological rigor, supporting athlete progression, and safeguarding physical integrity. This study aimed to identify speed intensity zones during competition for male U14 basketball players. Five speed intervals were defined: <5.42 km/h, 5.42–10.19 km/h, 10.20–14.63 km/h, 14.64–18.59 km/h, and >18.59 km/h. Analysis revealed that 63.6% of all speed actions occurred below 5.42 km/h (n = 3,730,195), while 85.54% were below 10.19 km/h and 96.13% were below 14.63 km/h, indicating that the vast majority of actions were performed at low to moderate intensities. Only 3.28% of actions were classified as high-intensity running, and just 0.5% exceeded 18.5 km/h, with 34,755 sprint actions recorded above 20 km/h—demonstrating that U14 players are capable of reaching high-speed thresholds.

Comparative studies have proposed different speed zones based on context [18,49], competition level [17,50], gender [14,29], age [12,50], and playing position [11]. Among 25 studies analyzing speed-based intensity zones, eight used five-zone models with mean thresholds as follows: Zone 1 (0.0–4.6 $\pm$ 1.8 km/h), Zone 2 (4.7–9.4 $\pm$ 3.4 km/h), Zone 3 (9.5–14.5 $\pm$ 4.5 km/h), Zone 4 (14.6–19.7 $\pm$ 5.6 km/h), and Zone 5 (>19.7 $\pm$ 5.6 km/h) [22]. The present findings show that U14 players operate at the upper limits of these ranges. Notably, the sprint speed cluster for U14 players (20.05 km/h) exceeds that of ACB senior players (19.35 km/h) [11]. The sprint cluster center was 20.05 km/h, which exceeds the sprint threshold of 20 km/h and is higher than values reported for senior professional players in previous studies. This aligns with the literature suggesting that elite adult players cover less distance at moderate speeds and perform fewer high-intensity actions [1,17,18], likely due to more efficient technical–tactical execution. In contrast, younger players exhibit more frequent transitions and turnovers, leading to a higher incidence of fast-break scenarios.

Although the speed profiles of U14 players fall within the general ranges reported in the literature, these findings are specific to this age group and should not be generalized across gender, age, or competitive level. Each population requires targeted investigation to inform training prescriptions and ensure appropriate workload management aligned with the demands of competition. These findings indicate that while most movement during U14 basketball competition occurs at submaximal speeds, players are capable of reaching high sprint velocities when required. The low frequency of high-speed actions may reflect the intermittent nature of the sport, tactical constraints, or developmental characteristics of this age group. Nonetheless, the ability to reach elite-level sprint speeds suggests a strong physical potential that can be further developed through targeted training interventions.

4.4. Player Load

This study aimed to define player load intensity zones for male U14 basketball players. As previously emphasized, conducting research in age-appropriate competitive contexts is essential for methodological rigor, athlete development, and injury prevention [14,36,55,56]. Player load is a valuable metric for coaches, providing insight into the physical demands placed on athletes during training and competition [57].

For the U14 category, five player load intensity zones were established: <1.07, 1.07–1.36, 1.37–1.63, 1.64–1.95, and >1.95 arbitrary units per minute (AU/min). The highest proportion of effort was observed in Zone 4 (1.64–1.95 AU/min), accounting for 30.80% of total load, followed by Zone 3 (1.37–1.63 AU/min) with 27.13%. Combined, these two zones represent 57.97% of the total player load. Notably, 19.00% of the total effort was performed in Zone 5 (>1.95 AU/min), indicating that U14 athletes are capable of sustaining high-intensity workloads.

This finding contrasts with data from U18 and professional-level players (e.g., ACB/EuroLeague), where a lower proportion of high-intensity player load is typically observed [11,16,55]. This discrepancy may reflect tactical differences in game models rather than physical limitations of senior players. For example, a study analyzing six official ACB League matches reported five player load zones derived from k-means clustering: 0.19–0.50, 0.51–1.01, 1.02–1.27, 1.28–1.56, and 1.57–1.93 AU/min [11]. These intervals have lower upper thresholds compared to those observed in U14 players. Furthermore, only 4.67% of ACB player load occurred in Zone 5 (1.57–1.93 AU/min), compared to 19.00% in the U14 group (>1.95 AU/min), highlighting a substantial difference in the distribution of physical demands.

These findings highlight the physical capacity of U14 athletes to perform at intensities comparable to or exceeding those reported in older age groups [11]. The high representation of effort in Zones 4 and 5 underscores the importance of preparing youth players for the physical demands of competition through appropriately structured training programs that reflect these workload profiles. Coaches can better prepare youth athletes for competition while supporting long-term physical development and injury prevention.

4.5. Impacts

This study also aimed to identify impact intensity zones during competition for male U14 basketball players, providing specific and practical information for coaching staff and sport scientists. Such data support the individualization of training loads based on player characteristics and contextual team dynamics [5]. Impact zones offer valuable insight into the frequency and intensity of physical contact during gameplay (e.g., rebounds, screens, positional contests) [3]. While some studies have reported no significant positional differences in impact or jump variables during official matches [6], most existing research has focused on senior male [5,6,11,55] or female players [3,5].

For the U14 male category, five impact zones were defined: <133.45, 133.45–158.75, 158.76–181.45, 181.46–206.59, and >206.59 contacts per minute (cont./min). The highest proportion of impacts occurred in Zone 3 (158.76–181.45 cont./min), accounting for 36.54% of total impacts. Additionally, 24.69% of impacts were recorded in Zone 4 (181.46–206.59 cont./min), and 9.07% exceeded 206.59 cont./min (Zone 5), with a cluster center of 221.46 cont./min—indicating an extremely high level of physical contact. This elevated impact frequency may be attributed to tactical strategies such as full-court pressing and a moderate level of technical execution, which increases turnovers and contested possessions.

In comparison, senior players have been reported to operate within different impact zones: <78.00, 83.22–119.60, 120.53–143.60, 143.81–169.14, and 169.43–223.47 cont./min [11].

While senior athletes can reach high-impact levels (Zone 5: 169.43–223.47 cont./min), this zone accounts for only 14.01% of total impacts. Positional averages for senior players show point guards and centers typically perform at 143 cont./min—corresponding to 23.01% of U14 players' Zone 2—while forwards average 162 cont./min, aligning with 36.54% of U14 players' Zone 3. These comparisons highlight both the physical demands placed on U14 athletes and the influence of tactical and technical factors on impact frequency.

These findings underscore the physical nature of U14 basketball and highlight the importance of preparing young athletes for the contact demands of the sport. The high proportion of impacts in Zones 3 to 5 suggests that training programs should include components that develop physical resilience, body control, and contact readiness to support performance and reduce injury risk.

4.6. High Impacts

HI actions are a key component of basketball performance and serve as an important metric for defining training load. These actions typically occur during explosive movements in both offensive and defensive phases, such as drives, rebounds, blocks, screens, and one-on-one defensive efforts [16]. Incorporating these movements into training—both in volume and intensity—is essential for improving on-court performance [5]. Previous research has shown that high-intensity movement durations are often greater when players are off the ball [16], a pattern that may also apply to HI events.

Monitoring HI load provides valuable insights for designing individualized training programs that enhance physical performance and reduce injury risk [15,17,28,37,38]. In this study, five HI intensity zones were identified for U14 male basketball players: Zone 1 (<1.13), Zone 2 (1.14–2.11), Zone 3 (2.12–3.13), Zone 4 (3.14–4.42), and Zone 5 (>4.42 contacts/min). Notably, 8.37% of HI actions occurred in Zone 5 (cluster center: 5.15 contacts/min), and 14.64% in Zone 4 (cluster center: 3.67 contacts/min), indicating the significant portion of HI activity that occurs in U14 male basketball games.

These findings suggest a developmental trend in which the frequency of HI actions increases with age and competitive level, likely influenced by growth in anthropometric characteristics and game intensity [16]. Given that HI actions are strong predictors of fatigue during training and competition [55,56], their monitoring can support long-term training planning and workload management in youth basketball.

These findings reflect the developmental stage of U14 athletes, where high-impact actions are present but not yet dominant. The data also suggest a potential for increased frequency of HI actions as players mature and progress to higher competitive levels. Coaches and practitioners should consider these patterns when designing training programs that aim to build physical robustness and prepare athletes for the escalating contact demands of advanced play.

Although the present investigation establishes, for the first time, competition-derived intensity thresholds for six external load variables in male U14 basketball, the results should be interpreted with caution. The sample was restricted to one competitive season of regional play, thereby limiting the direct transferability of the zones to female athletes, other age categories, or higher performance levels where tactical structures and anthropometric profiles differ substantially. Nevertheless, the ecological acquisition of a very large volume of high-resolution data and the data-driven k-means approach represent notable strengths, providing practitioners with objective, context-specific reference values for training design and return-to-play decisions. Future research should adopt longitudinal designs that integrate physiological and contextual performance indicators and replicate the present methodology in female and elite youth cohorts to confirm or refine the proposed zones.

5. Conclusions

The analysis revealed that the majority of in-game actions among U14 players occurred at low to moderate intensities. Specifically, 94.25% of acceleration actions were below 1.546 m/s^2, and 96.64% of deceleration actions were above -1.223 m/s^2, indicating a predominance of submaximal efforts. Similarly, 96.13% of movement velocities were below 14.64 km/h, although players demonstrated the capacity to reach sprint speeds exceeding 20 km/h. Player load data showed that 77.59% of effort occurred within moderate to high intensity zones, with 19% in the highest zone (>1.95 AU/min), suggesting a substantial capacity for high-intensity effort in this age group.

Impact analysis indicated that 84.62% of contact events occurred within moderate-to-high-frequency zones (133.45–206.59 contacts/min), while only 3.36% exceeded this range. High-impact actions (>8G) were relatively infrequent, with only 8.37% occurring in the highest intensity zone (>4.42 contacts/min), reflecting the developmental nature of physical contact at this age. These findings underscore the importance of age- and context-specific monitoring to support appropriate training load management and long-term athlete development.

The five intensity zones established for each variable are as follows:

- For acceleration (n = 74 million actions), five zones were defined: <0.37, 0.37–0.81, 0.81–1.54, 1.54–3.49, and >3.49 m/s^2.
- For deceleration (n = 53 million actions), the zones were: <-0.26, -0.27 to -0.63, -0.63 to -1.22, -1.22 to -2.545, and >-2.54 m/s^2.
- For speed (n = 5 million actions), the intervals were: <5.42, 5.42–10.19, 10.20–14.63, 14.64–18.59, and >18.59 km/h.
- For player load (n = 763 AU/min), the zones were: <1.07, 1.07–1.36, 1.37–1.63, 1.64–1.95, and >1.95 AU/min.
- For total impacts (n = 717 game quarters), the intervals were: <133.45, 133.45–158.75, 158.76–181.45, 181.46–206.59, and >206.59 contacts/min.
- For high impacts (n = 717 game quarters), the zones were: <1.13, 1.14–2.11, 2.12–3.13, 3.14–4.42, and >4.42 contacts/min.

Finally, the comparative analysis reinforces the need for contextual specificity in sports science research. Performance characteristics in basketball vary significantly with age, competitive level, gender, and game structure. Therefore, generalizing findings across populations may lead to inaccurate interpretations. This study contributes to the growing body of evidence supporting individualized and developmentally appropriate approaches to load monitoring in youth sports.

Practical Application

The findings of this study offer valuable insights for basketball coaches working with U14 athletes, particularly in designing and managing training loads. The data show that the vast majority of in-game actions—such as accelerations, decelerations, and movement speeds—occur at low to moderate intensities. This suggests that training programs should be structured to progressively expose players to higher intensities, especially in controlled environments. Coaches can incorporate targeted drills that stimulate Zones 4 and 5 for acceleration and deceleration to enhance players' explosive capabilities and prepare them for the physical demands of competition.

Given that 77.59% of player load was recorded in moderate-to-high-intensity zones and 19% in the highest zone (>1.95 AU/min), coaches should monitor these values to manage fatigue and recovery. Players consistently operating in the highest zones may require adjusted workloads or recovery-focused sessions to prevent overtraining. Similarly, the speed data indicate that while most actions are performed below 14.64 km/h, U14 players are capable of reaching sprint speeds above 20 km/h. Conditioning drills that target high-speed running and sprinting can help develop speed endurance and game-specific movement efficiency.

The impact data reveal that most physical contacts occur within moderate-to-high-frequency ranges, with only a small proportion exceeding 206.59 contacts per minute. This supports the use of game-like contact drills in training, while also emphasizing the need to avoid excessive exposure to high-impact situations. High-impact actions (>8G) were relatively rare, which aligns with the developmental stage of these athletes. Coaches should therefore introduce contact progressively, ensuring that neuromuscular preparation is appropriate for the players' age and physical maturity.

Overall, the five-zone classification system established in this study provides a practical tool for benchmarking performance and monitoring progression. Coaches can use these zones to evaluate whether players are increasing their capacity to perform in higher intensity ranges over time. This individualized and context-specific approach to load monitoring supports safer, more effective training and contributes to long-term athletic development and injury control in youth basketball.

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

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to Organic Law 3/2018, of 5 December, on the Protection of Personal Data and Guarantee of Digital Rights of the Government of Spain, which requires that this information must be in custody.

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