Sports Medicine
https://doi.org/10.1007/s40279-020-01375-9

SYSTEMATIC REVIEW

Measuring Physical Demands in Basketball: An Explorative Systematic Review of Practices

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Abstract

Background Measuring the physical work and resultant acute psychobiological responses of basketball can help to better understand and inform physical preparation models and improve overall athlete health and performance. Recent advancements in training load monitoring solutions have coincided with increases in the literature describing the physical demands of basketball, but there are currently no reviews that summarize all the available basketball research. Additionally, a thorough appraisal of the load monitoring methodologies and measures used in basketball is lacking in the current literature. This type of critical analysis would allow for consistent comparison between studies to better understand physical demands across the sport.

Objectives The objective of this systematic review was to assess and critically evaluate the methods and technologies used for monitoring physical demands in competitive basketball athletes. We used the term 'training load' to encompass the physical demands of both training and game activities, with the latter assumed to provide a training stimulus as well. This review aimed to critique methodological inconsistencies, establish operational definitions specific to the sport, and make recommendations for basketball training load monitoring practice and reporting within the literature.

Methods A systematic review of the literature was performed using EBSCO, PubMed, SCOPUS, and Web of Science to identify studies through March 2020. Electronic databases were searched using terms related to basketball and training load. Records were included if they used a competitive basketball population and incorporated a measure of training load. This systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO Registration # CRD42019123603), and approved under the National Basketball Association (NBA) Health Related Research Policy.

Results Electronic and manual searches identified 122 papers that met the inclusion criteria. These studies reported the physical demands of basketball during training ($n=56$), competition ($n=36$), and both training and competition ($n=30$). Physical demands were quantified with a measure of internal training load ($n=52$), external training load ($n=29$), or both internal and external measures ($n=41$). These studies examined males ($n=76$), females ($n=34$), both male and female ($n=9$), and a combination of youth (i.e. under 18 years, $n=37$), adults (i.e. 18 years or older, $n=77$), and both adults and youth ($n=4$). Inconsistencies related to the reporting of competition level, methodology for recording duration, participant inclusion criteria, and validity of measurement systems were identified as key factors relating to the reporting of physical demands in basketball and summarized for each study.

Conclusions This review comprehensively evaluated the current body of literature related to training load monitoring in basketball. Within this literature, there is a clear lack of alignment in applied practices and methodological framework, and with only small data sets and short study periods available at this time, it is not possible to draw definitive conclusions about the true physical demands of basketball. A detailed understanding of modern technologies in basketball is also lacking, and we provide specific guidelines for defining and applying duration measurement methodologies, vetting the validity and reliability of measurement tools, and classifying competition level in basketball to address some of the identified knowledge gaps. Creating alignment in best-practice basketball research methodology, terminology and reporting may lead to a more robust understanding of the physical demands associated with the sport, thereby allowing for exploration of other research areas (e.g. injury, performance), and improved understanding and decision making in applying these methods directly with basketball athletes.

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Published online: 05 November 2020

Key Points

There is currently a lack of alignment in practices and methodological framework in basketball specific research, most commonly related to classifying competition level, measuring duration, participant inclusion/exclusion, and reporting validity and reliability of measurement tools.

A pattern of accepting poor-quality methods and anecdotal claims is evident in the basketball literature. Practitioners and researchers alike should seek to use validated methods, where available, and apply aggressive critical appraisal of any unsubstantiated emerging methods and technologies.

1 Introduction

Understanding the physical demands of basketball may help to inform physical preparation models that can optimize performance and develop periodization strategies [1]. Measuring the physical work and resultant acute psychobiological responses during exercise, commonly referred to as external and internal training load, is the first step towards identifying the physical characteristics and requirements of the sport. Once these characteristics are identified, the training targets can be defined, and monitoring the internal and external physical demands over time can contribute to the understanding of whether training programs are progressing appropriately. The term 'training load' indicates a construct encompassing the training stimulus induced by both training sessions and competitions, since the latter also induces training effects. This construct can be quantified using various proxy measures.

While the practice of measuring both internal and external training load has been popularized in the scientific literature in the last two decades [2], the earliest record of measuring the physical demands of basketball was a 1931 study by Messersmith and Corey describing distance covered in a collegiate game [3]. Since this time, there has been a wide-ranging evolution of load quantification strategies, and recent advancements in training load monitoring technology (e.g. wearables and local positioning/optical tracking systems) have coincided with increases in the literature related to the physical demands of basketball. The exponential growth of published basketball studies has resulted in a number of reviews published in the last 4 years, summarizing the demands of small-sided games based drills [4, 5], game play [6, 7], external load [8, 9], and monitoring techniques in basketball [10]. Collectively, these reviews aggregate the current literature based on the specific criteria (e.g. small sided games, game play, external training load), but there is currently no one review that examines all the basketball research related to the physical demands of training and/or competition.

Assessing the physical demands in basketball poses unique challenges compared to other team sports (e.g. soccer, rugby, handball, field hockey), and one major methodological consideration is that the game is not played with a running clock. Therefore, a range of methods may be used to record exercise duration, a fundamental first principal metric in load quantification. Other challenges that arise in team sports such as basketball include differentiating the training and competition demands according to playing position, player characteristics, and competition levels. These challenges are especially relevant in basketball, as there is a diverse spectrum of players and tactical approaches [11]. Distinguishing unique features of basketball (e.g. duration calculation methods, playing position, player characteristics) is a crucial first step toward establishing training load monitoring solutions specific to the sport, thereby creating alignment and understanding in future research when comparing and contrasting information between studies.

Developing conceptual suggestions related to measuring training load in basketball and operational definitions for the participants and competition levels also helps to improve understanding and decision making when applying these methods directly with basketball athletes. Currently, a thorough appraisal of the methodologies and measures used within basketball literature is lacking, which does not allow for comparing training load demands between studies or distinguishing differences among player groups While there are many features of basketball related studies that are commonly reported (i.e. sex, sample size, competition level, seasonal phase), this information has yet to be compiled in one review. A consolidated review of this information would allow for evaluation of similarities and differences in basketball methodologies and practices, thereby aiding future decision making around research methodology and best-practice approaches in applied settings.

Therefore, the objectives of the current explorative systematic review are to systematically explore the current practices of quantifying the physical demands of basketball, identify and critically appraise the methodologies used in basketball specific training load monitoring literature, establish operational definitions specific to basketball, and give recommendations for practitioners and researchers to measure physical demands in basketball settings.

2 Methods

This review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [12]. A systematic review protocol that included rationale, objectives, search strategy, eligibility, and exclusion and inclusion criteria was registered with the International Prospective Register of Systematic Reviews (PROPSERO Registration # CRD42019123603, 13 February 2019).

2.1 Data Sources and Searches

A systematic review of the literature was performed from the earliest record through March 2020. The electronic literature searches were performed using four online databases—EBSCO, PubMed, SCOPUS, and Web of Science. The following terms were searched for in 'all fields'—[(Basketball*) AND (Training OR Match OR Game OR Practice OR Competition) AND ((Training OR External OR Internal OR Physical OR Physiological OR Monitoring OR Athlete) AND Load)]. This search was performed by one author (JR), and search results were uploaded to Covidence software where duplicates were automatically removed. The title and abstracts of all remaining studies were screened by two authors (JR and BM) using the eligibility criteria below. Any disagreements about study inclusion/exclusion that could not be resolved by discussion between two authors (JR and BM), was decided by a third author (AC). After screening titles and abstracts, full text versions of the studies were retrieved for all potentially relevant studies and assessed by two authors (JR and BM) using the eligibility criteria below. Reference lists from studies and reviews [4, 6, 8–10] identified in the literature search were screened and potentially relevant works were included in the full text screening.

2.2 Eligibility Criteria

Studies were eligible for inclusion if they used a sample of competitive athletes participating in basketball and incorporated training load monitoring techniques in a basketball specific context. "Competitive athlete" was defined according to the Bethesda Conference as 'one who participates in an organized team or individual sport that requires regular competition against others as a central component, places a high premium on excellence and achievement, and requires some form of systematic and usually intense training' [13]. "Training load monitoring" referred to any systematic measurement of the physical work prescribed, by measuring/describing the organization, quality and quantity, or psychobiological responses of exercise [2]. Studies were excluded if they (1) related only to wheelchair or leisure basketball; (2) included no original data; (3) were not available in English full text; and/or (4) reported only laboratory-based monitoring or unauthentic (i.e. did not occur during normal team training or competition) basketball drills. No risk of bias assessment was used, because this review was descriptive, and we did not report or discuss effects, associations or prevalence.

2.3 Data Extraction and Analysis

Initial data extraction from the included studies included sex and sample size, competition category, seasonal phase and length of time for data collection, type of training load monitoring reported (i.e. internal/external) and equipment used, validity or reliability reported, method of duration calculation, and activities evaluated in the study, including: (1) training and competition, (2) competition only, (3) training only.

Data extraction was completed by one author (JR), with two other authors (BM & AC) checking for accuracy. Authors were not blinded to study journals, authors or institutions. A meta-analysis was not performed based on the heterogeneous nature of sport specific study designs and inability to pool data.

3 Results

3.1 Study Selection

The database searches yielded 988 results. All citation information was imported to Covidence, and duplicates ($n=514$) were automatically removed. 474 titles and abstracts were screened for inclusion, and of those there were 37 conflicts between 2 reviewers (JR and BM). Thirty of these conflicts were resolved via discussion between the two authors, while 7 conflicts were unresolved via discussion and, therefore, screened and decided on by a third reviewer (AC). A total of 175 studies qualified for full text screening, and the full texts were retrieved and assessed against eligibility criteria, resulting in an additional 63 studies being excluded. The reasons for exclusion at the full text level are shown in Fig. 1. Reviews included in full-text screening were included if they contained any original work, and from reviewing the reference lists, ten additional studies were included in the full text screening. Upon completion of screening, 122 studies were included in this systematic review.

3.2 Study Characteristics

Among the 122 included studies, 41 included measures of both internal and external training load, 29 measured external training load only, and 52 measured internal training

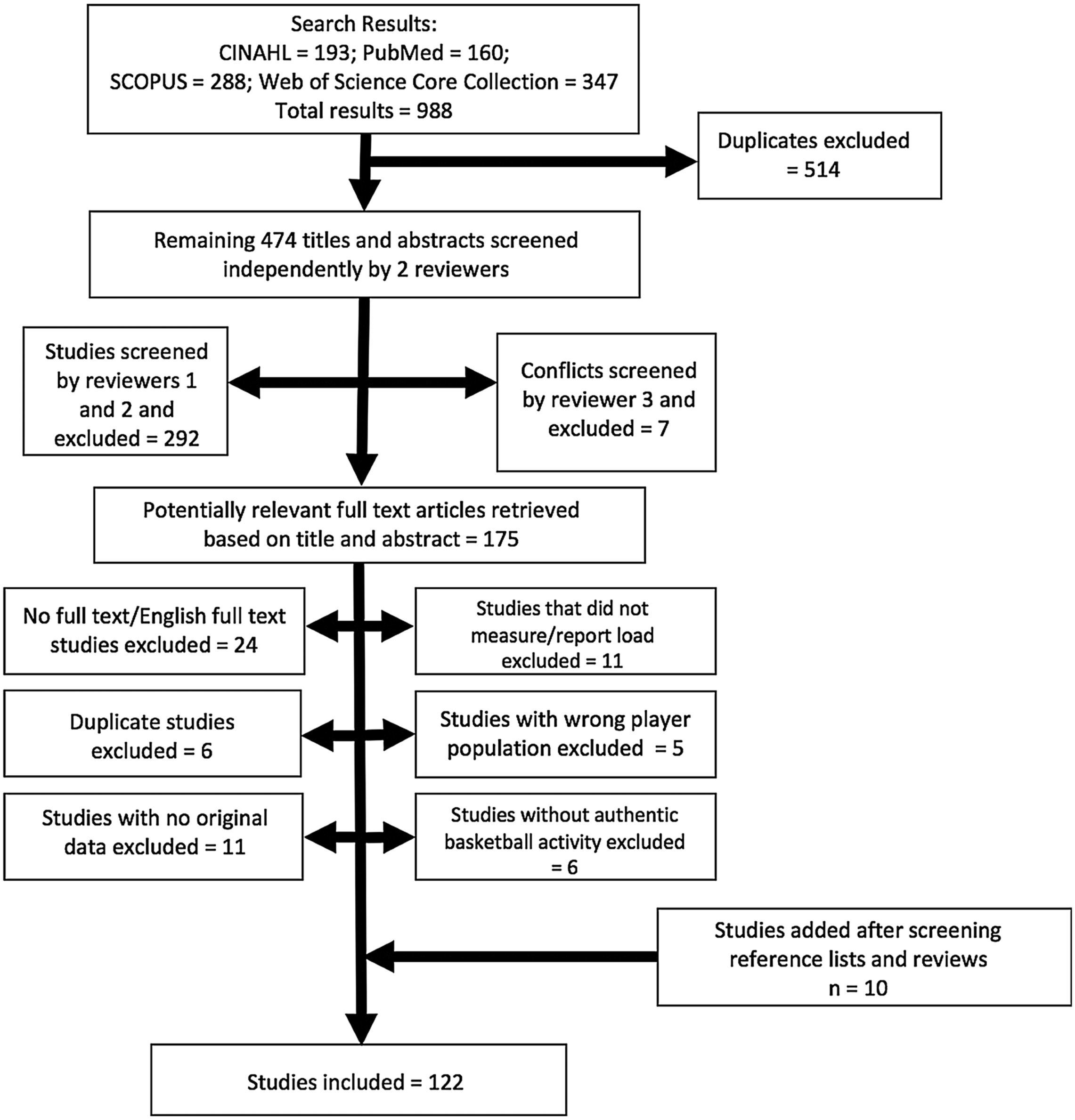

Fig. 1 Flowchart illustrating the search and inclusion/exclusion strategy

load only. Training load measurements included metrics from inertial devices (e.g. accelerometers), positioning systems (e.g. video analysis and GPS), heart rate (HR) derived load, and session rating of perceived exertion (sRPE) measures. A measure of training load was investigated during training and competition in 30 studies, during competition only in 36 studies, and during training only in 56 studies. Of the studies included in this review, 76 investigated training load in male basketball athletes, 34 investigated female athletes, 9 studies investigated both sexes, and 3 studies did not define the sex of the participants. Furthermore, 77 studies investigated competitive basketball athletes over 18 years of age (i.e. adult), 37 studies included participants under 18 years (i.e. youth), 4 studies investigated both adult and youth participants, and 4 studies did not define the age of participants.

3.2.1 Levels of Competition

The description of 'elite' to classify participants was used in 43 studies (33 adult, 10 youth), with large variation in age and sex of participants and geographical location. Additionally, there was no consistent objective criteria in these studies for which to define participants as 'elite'. Further examination revealed a lack of consistent classifications for competition levels among included studies. Therefore, five levels of competition taking into account training type and history, adapted from the work of Depauw et al. [14]

and Decroix et al. [15], were used to define objective classifications for levels of competition in basketball, shown in Table 1.

Using these defining criteria, 13 studies investigated participants competing at Level 2, 53 studies at Level 3, 22 studies at Level 4, 25 studies at Level 5, and 8 studies investigated participants across different competition levels. The descriptive results of the studies that investigated competitive adult athletes are grouped by competition level and displayed in Tables 2, 3 and 4. Studies that included multiple competition levels are listed in the highest level of competition that was reported. The descriptive results of the studies investigating youth athletes are displayed in Table 5.

3.2.2 Duration Methods

To measure physical load, all of the included studies utilized a measure of duration. However, these methods to quantify duration were inconsistent and often poorly described, or not defined at all ($n = 23$). The types of reported duration calculation methods are summarized in Table 6. The range of duration methods used in studies are reported in Tables 2, 3, 4 and 5.

In addition to the methods of quantifying activity duration, the duration of study designs varied considerably across the basketball literature. This review identified study designs ranging from single games to multiple seasons. Methods of reporting study length included number of individual games/training sessions ($n = 46$), days ($n = 4$), weeks ($n = 61$), months ($n = 2$), or seasons ($n = 1$). Eight studies included in this review did not specify length of time for data collection.

3.2.3 Participant Inclusion

Of the 122 included studies, 37 reported excluding some participants based on specific criteria. Participant exclusion was reported in 19 studies based on percentage of participation in training or competition [16–34], 7 studies based on player rotation status during competition (i.e. starter, bench, active in game, not substituted) [35–41], 5 studies based on missed sessions (i.e. poor compliance, injury) [42–46], 3 studies cited equipment limitations [47–49], and 3 studies reported data collection issues (i.e. interference with HR, sRPE, accelerometer data) [50–52]. However, only 28 of the 38 studies that reported excluding participants stated that they analyzed fewer participants than were originally recruited.

4 Discussion

The current review highlights many inconsistencies within the basketball literature, related to methodologies and reporting of physical demands. These inconsistencies create difficulties in comparing findings and definitively determining the most meaningful and informative techniques to quantify physical demands in basketball. This work provides recommendations to establish consistent terminology and technical definitions to be used with currently available training load monitoring solutions in basketball. We also highlight areas that are under-investigated, which represent opportunities to enhance understanding of basketball related physical demands and monitoring strategies.

A recent review of basketball match-play [7] highlighted that there are vast disparities in basketball training load monitoring methodologies, which has contributed to the current wide range of reported physical demands. Making informed decisions about best practices, relating to training plans and monitoring in basketball requires practitioners and researchers to adequately understand and compare/contrast established methods. Methodological differences include training load data characterization, acquisition, and processing [7, 10]; however, the specifics of these methods are often poorly reported. Within the current body of scientific literature, there is a wide variety of tools and analyses used, combined with the lack of methodological transparency, which makes it difficult to establish recommendations for best practices in quantifying the physical demands of basketball.

Table 1 Classification of levels of competition Adapted from De Pauw et al. [14] and Decroix et al. [15]

Competition Level	Description	Examples in this review
Level 1[a]	Untrained or sedentary	N/A
Level 2	Habitually active, physically fit, recreationally trained	(i.e. youth state/regional competition)
Level 3	Trained and competitive	(i.e. youth international competition, NCAA)
Level 4	Highly trained and competitive	(i.e. part-time international competition, semiprofessional)
Level 5	Professional	(i.e. full-time paid athletes in professional competitive leagues)

[a]Did not meet inclusion criteria for this review

NCAA National Collegiate Athletic Association

Table 2 Summary of level 5 (adult) basketball load monitoring studies

References	Participants M or F (recruited: analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Training and competition										
Clemente et al. [28]	M (15:15)	27.1 ± 5.2	Level 5	Regular and congested (42 weeks)	2	Internal	sRPE	RPE scale [111]	[109]	Did not report
Doeven et al. [16]	M (14:11)	26.7 ± 3.8	Level 5	Competition (6 weeks)	4	Internal	sRPE	RPE scale [109]	[38]	Did not report
Ferioli et al. [18]	M (32:32)	24.5 ± 5.4	Levels 4 and 5	Preseason (7 weeks)	1, 5, 8	Internal	sRPE	RPE scale [111]	[109]	Did not report
Ferioli et al. [17]	M (28:28)	24.9 ± 5.7	Levels 4 and 5	Preseason (7 weeks)	1, 5, 8	Internal	sRPE	RPE scale [111]	[109]	Did not report
Leite et al. [171]	M (13:8)	21.9 ± 3.4	Level 5	Pre/regular season (19 weeks)	2	Internal	SPI	RPE scale [109]	[107]	Original work
Manzi et al. [38]	M (8:8)	28 ± 3.6	Level 5	Regular season (12 weeks)	1, 5, 9	Internal	HR, sRPE	Polar Team, RPE scale [108]	[108, 172]	Did not report
Moreira et al. [60]	M (10:10)	26.4 ± 3.8	Level 5	Regular season (4 weeks)	5	Internal	sRPE	RPE scale [107]	[107]	Did not report
Paulauskas et al. [61]	F (75:29)	21 ± 5	Level 5	Regular season (24 weeks)	1, 5, 9	Internal	sRPE	RPE scale [109]	[10, 80, 109]	Did not report
Svilar et al. [41]	M (16:NR)	26.2 ± 4.0	Level 5	Pre/regular season (8 weeks)	3	External	Inertial	Catapult T6	[85, 152, 173–175]	[85, 152, 173–175]
Svilar et al. [68]	M (13:13)	25.7 ± 3.3	Level 5	Season (2 months)	2	Both	Inertial, sRPE	Catapult Optimeye S5, RPE scale	[108, 176–178]	[108, 173, 175–178]
Weiss et al. [119]	M (13:6)	24.7 ± 4.7	Level 5	Regular season (24 weeks)	2	Internal	sRPE	RPE scale [109]	[109]	Did not report
Competition only										
Bishop and Wright [36]	NR (6:6)	–	Level 5	Competitive season (5 games)	3	External	Semi-automated video analysis	Sony Digital camera, Nordulus Observer pro software	–	–
Caparros et al. [93]	M (33:11)	24.9 ± 2.9	Level 5	Regular season (26 weeks)	0	External	Optical tracking	Stats OTS	Did not report	[179–181]

Table 2 (continued)

References	Participants M or F (recruited: analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Conte et al. [59]	F (12:6)	27 ± 4	Level 5	Regular season (5 games)	3, 5	External	Semi-automated video analysis	Sony HD AVCHD HDR-CX115 and Dartfish 6.0	Did not report	Original work
Daniel et al. [67]	M (10:10)	27.6 ± 5.5	Level 5	(6 games)	3, 5	Both	HR, Manual video analysis	Polar Team JVC Everio GZ-HM690	Did not report	Did not report
Galvada et al. [144]	F (10:10)	21.3 ± 2.71	Level 5	Playoff (10 matches over 70 days)	3	Both	Semi-automated video analysis, HR	Suunto Team Pack, JVC GZ620SE, Kinovea 8.15	[96]	Original work
McInnes et al. [47]	M (8:8)	23.5 ± 3.2	Level 5	State competition and practice games	3, 7	Both	Manual video analysis, HR, Blood markers	National M-7 camera, National Editing Controller NV-A960, Sports Tester PE-3000	Did not report	Original work
Montgomery and Maloney [81]	M (361:NR), F (208:NR)	25.7 ± 6.9 (M) 22.9 ± 5.6 (F)	Levels 3, 4 and 5	International competition (252 games)	2	Both	Inertial, HR	Polar T34, Catapult S5	[182]	[182]
Oba and Okuda [169]	F (NR)	–	Levels 3 and 5	Playoff (1 game)	6	External	Optical tracking	PTS-110 camera, Frame-DIAS II 3D analysis software.	–	Original work
Riberio et al. [66]	Did not report	Did not report	Level 5	Did not report	0	External	Semi-automated video analysis	JVC GZ-HD620, Dvideo System	[183]	Did not report
Scanlan et al. [82]	M (22:22)	28.3 ± 4.9 26.1 ± 5.3	Levels 4 and 5	Regular season (2 games)	3, 11	External	Manual video analysis	JVC Everio GZ-HD10 camcorder, Basler A602 FC cameras	Did not report	Original work

Table 2 (continued)

References	Participants M or F (recruited: analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Scanlan et al. [151]	M (22:22)	28.3 ± 4.9, 26.1 ± 5.3	Levels 4 and 5	Regular season (5 games total)	3	External	Manual video analysis	JVC Everio GZ-HD10 camcorder, Basler A602FC cameras	Did not report	Original work
Staunton et al. [40]	F (10:8)	27 ± 5	Level 5	Regular season (18 games)	7	External	Inertial	Link Actigraph	Did not report	Did not report
Vazquez-Guerrero et al. [22]	M (12:12)	25.5 ± 5.2	Level 5	2 days (2 games)	3	External	Inertial	ADXL326 triaxial accelerometers	Original work	Original work
Training only										
Aoki et al. [126]	M (14:9)	27.8 ± 6.4	Level 5	Competitive season (11 weeks)	2	Both	HR, sRPE, Inertial	Zephyr Bioharness, RPE scale [109]	[39, 54, 184, 185]	[186–188]
Scanlan et al. [136]	M (15:15)	20.6 ± 4.5	Levels 4 and 5	Preseason (6–10 sessions)	2, 9	Internal	HR	Polar T31, Catapult Optimeye S5	[129]	Did not report
Schelling and Torres. [62]	M (12:12)	25.0 ± 4.3	Level 5	Regular season (4 weeks)	2, 9	External	Inertial	X8-mini triaxial accelerometer	[159, 189]	[159, 189]
Staunton et al. [153]	F (9:9)	27 ± 5	Level 5	Regular season(6 weeks)	1	External	Inertial	Link Actigraph	Did not report	[190–192]
Svilar et al. [63], [55]	M (13:13)	25.7 ± 3.3	Level 5	Regular season (16 weeks)	1, 8	Both	sRPE, Inertial	RPE scale [109], Catapult S5	[97, 109, 176–178]	[173, 175, 152]
Torres-Ronda et al. [64]	M (14:14)	25.5 ± 4.7	Level 5	Pre/regular season (12 weeks)	3, 6, 9, 11	Both	Semi-automated video analysis, HR	Suunto HR, Lince software	[35, 54, 128, 129, 143]	Did not report
Vazquez-Guerrero et al. [65]	M (12:12)	29.6 ± 4.5	Level 5	Regular season (18 weeks)	2	External	LPS	WIMU Pro	[193]	Original work

M male, *F* female, *NR* not reported, *sRPE* session rating of perceived exertion, *SPI* self-perceived intensity, *HR* heart rate, *LPS* local positioning system, *RPE* rating of perceived exertion, *OTS* optical tracking system

Table 3 Summary of level 4 (adult) basketball load monitoring studies

References	Participants M or F (recruited:analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Training and competition										
Berkelmans et al. [137]	M (12:6)	21.7 ± 4.9	Level 4	Preseason (6 weeks)	2, 9	Internal	HR	Polar T31, Catapult Optimeye S5	[38, 50, 127, 194]	Did not report
Delextrat et al. [37]	F (9:9)	24.3 ± 4.1	Level 4	Regular season (1 week)	2	Both	Manual video analysis, sRPE	RPE Scale [112] JVC × 400 camera	[107]	Did not report
Fox et al. [117]	M (15:15)	20.4 ± 4.5	Level 4	Preseason (6 weeks)	1, 3, 10	Both	Inertial, sRPE, HR [129]	Catapult Optimeye S5, RPE scale [109], Polar T31	[38, 109, 129, 195]	Did not report
Fox et al. [30]	M (8:8)	24.4 ± 3.2	Level 4	Regular season (15 weeks)	2, 9	Both	HR, Inertial	Catapult Optimeye S5, Polar T31	[136, 137]	Did not report
Fox et al. [92]	M (8:8)	24 ± 3, 22 ± 4	Level 4	Regular season (15 weeks)	0	External	Inertial	Catapult Optimeye S5	[117, 196]	[117, 196]
Sansone et al. [20]	F (13:11)	22 ± 3	Level 4	Regular season (14 weeks)	2, 5, 9	Internal	sRPE	RPE scale [109]	[107, 109]	Did not report
Competition only										
Ferioli et al. [58]	M (136:136)	27 ± 5 25 ± 4 26 ± 6 22 ± 5	Level 4	(20 games, only 1 game per subject)	3, 6	External	Manual video analysis	GoPro Hero 4	Did not report	Original work
Puente et al. [32]	M (25:NR)	25.6 ± 5.2	Level 4	Tournament (1 day)	0	Both	GPS, HR, Inertial	Spi Pro X, Polar T34	[197, 198]	[197, 198]
Scanlan et al. [11]	F (12:12)	22.0 ± 3.7	Level 4	Regular season (8 games)	3, 7	Both	HR, Manual video analysis, Blood markers	Polar Team System, Basler A602FC cameras, Accusport Lactate Analyzer	[82]	[82]
Scanlan et al. [21]	M (12:12), F (12:12)	21.2 ± 3.1, 26.2 ± 7.4	Level 4	Regular season (3 games each)	3	External	Manual video analysis	Basler A602FC cameras	[11, 82, 199]	Did not report

Table 3 (continued)

References	Participants M or F (recruited:analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Scanlan et al. [46]	M (5:5)	24 ± 3	Level 4	Regular season (10 games)	5, 7	Both	Inertial, HR, RPE	Catapult Optimeye S5, Polar T31 RPE scale [112]	[136]	[200]
Vaquera et al. [51]	M (8:8)	27.5 ± 11.6	Level 4	Preseason (5 games)	3	Internal	HR	Polar Team	Did not report	Did not report
Vencurik et al. [91]	F (17:17)	17.4 ± 0.9, 20.6 ± 2.9	Levels 3 and 4	1 game	4	Internal	HR	Suunto Memory Belts	[54, 143, 201]	Did not report
Vencurik et al. [99, 106]	F (10:10)	20.4 ± 2.8	Level 4	2 games	0	Internal	HR	Suunto Team	[9]	Did not report
Training only										
Ballesta et al. [102]	NR (11:11)	25.5 ± 5.7	Level 4	Competitive season (15 sessions)	0	Both	Inertial	Polar Team Pro	[152, 175]	[152, 175]
Coyne et al. [42]	F (17:15)	27.8 ± 3.6	Level 4	Not reported	2	Both	Inertial, sRPE	Catapult accelerometers, RPE scale [109]	[159]	Did not report
Freitas et al. [202]	M (20:20)	22 ± 5	Level 4	Competitive season (19 weeks)	2	Internal	sRPE	RPE scale [107]	[107, 203]	Did not report
Messias et al. [204]	F (8:8)	20 ± 1	Level 4	Preseason (7 weeks)	2	Internal	sRPE	RPE scale [109]	[109]	Did not report
Nunes et al. [80]	F (19:19)	26 ± 5	Level 4	Regular season (19 weeks)	2	Internal	sRPE	RPE scale [107]	[205, 206]	Did not report
Sansone et al. [98]	M (12:10)	21 ± 2	Level 4	Regular season (4 weeks)	0	Both	Blood markers, Inertial, HR	ELISA, Catapult Optimeye S5, Polar H7	[75, 129, 152]	Did not report
Scanlan et al. [50]	M (8:8)	26.3 ± 6.7	Level 4	Preseason (2–9 sessions)	2	Both	HR, sRPE, Inertial	Polar Team2 Pro, RPE scale [109], MMA7361L accelerometers	Original work [109, 125, 205]	Original work, [109, 125, 205]

Table 3 (continued)

References	Participants M or F (recruited:analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Scanlan et al. [127]	M (8:8)	26.3 ± 6.7	Level 4	Preseason (10 weeks)	2	Internal	sRPE, HR	Polar Team 2 Pro RPE scale [109]	[109, 112, 125, 129]	Did not report

M male, *F* female, *NR* not reported, *HR* heart rate, *sRPE* session rating of perceived exertion, *GPS* global positioning system, *RPE* rating of perceived exertion, *ELISA* enzyme-linked immunosorbent assay

4.1 Participant Characteristics

Clearly defining and understanding the types of participants involved in basketball research is critical for understanding population specific physical demands, which is necessary to define training targets. To date, there has not been consistent reporting or clear definitions of participant characteristics within the majority of the literature investigating the physical demands of the basketball.

4.1.1 Competition Level

The current review identifies a disparity in participant descriptors (e.g. 'elite'), which has been created by a lack of objective definitions. The inconsistent use of various participant descriptors has created a confusing cycle of methodological justification and direct comparisons across subject groups that may have limited shared characteristics. For example, this review assessed 43 studies that referred to the studied basketball athletes as 'elite'. However, this term was used to categorize participants ranging from youth playing for under-14 club teams, teenagers playing for NCAA teams, and paid adult professional athletes. Additionally, some work describing physical demands for 'elite' athletes used the same cohort for multiple studies [34, 35, 41, 53–56], which contributes to an over-representation of the findings in a limited body of work. Acknowledging this replication of cohorts is important when interpreting the applicability and significance of findings. To assist with this interpretation, we have identified studies that appear to use the same cohort/datasets and grouped these studies in Tables 2, 3, 4 and 5. While many authors justify their methods and compare and contrast their findings based on the 'elite' descriptor, it is clear that large differences exist across the range of studies using this classification, in both age and competition level.

Standardized classification to distinguish between subject groups has been suggested in individualized sports such as cycling and running [15, 14, 57]. Using data related to anthropometrics, physiology, and training status/history has been suggested to differentiate between performance levels. While standardized criteria in basketball are not as easily delineated, it is important to establish a common framework to compare and apply research findings appropriately. This is supported by recent work of Ferioli et al. [58], which found that there are clear differences in physical demands of basketball games based on level of competition. By classifying participants by competition level, as we have defined in Table 1, only 14 of these 43 studies describing 'elite' athletes used participants competing at the highest level (i.e. level 5) [22, 38, 40, 41, 59–68]. In the other 29 studies, the classifications of participants were: youth ($n = 10$) [31, 34, 43, 52, 56, 69–73], adult level 3 ($n = 14$) [26, 28, 33, 35, 42, 53, 54, 60, 74–79], adult level 4 ($n = 2$) [37, 80],

Table 4 Summary of level 3 (adult) basketball load monitoring studies

References	Participants M or F (Recruited: analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Training and competition										
Conte et al. [25]	M (13:10)	20.9 ± 0.9	Level 3	Regular season (10 weeks)	1	Internal	sRPE	RPE scale [109]	[109]	Did not report
Matthew and Delextrat [143]	F (9:9)	25.8 ± 2.5	Level 3	Pre/regular season (~32 weeks)	3, 4	Both	Manual video analysis, HR	Polar S810, JVC-×400 camera	[47, 207]	Original work
Montgomery et al. [75]	M (11:11)	19.1 ± 2.1	Level 3	Competition (2 weeks)	0	Both	Inertial, HR	Suunto Pro Team, MiniMaxX	Original work	Did not report
Moreira et al. [76]	M (15:15)	19 ± 0.6	Level 3	Regular season (4 weeks)	2	Internal	sRPE	RPE scale [107]	[107]	Did not report
Moreira et al. [39]	M (10:10)	19 ± 0.6	Level 3	Regular season (15 weeks)	5	Internal	sRPE	RPE scale [107]	[107]	Did not report
Peterson and Quiggle [77]	F (5:5)	20 ± 1.0	Level 3	Regular season (20 weeks)	2	External	Inertial	Catapult Optimeye S5	[75, 208]	Did not report
Reina et al. [90]	F (10:10)	21.7 ± 3.7	Level 3	(2 months)	2, 6	Both	Inertial, HR	WIMU, Garmin HR band	[32, 79, 209, 210]	Did not report
Sanders et al. [211]	F (13:	19.6 ± 1.3	Level 3	Season	2, 8	Internal	HR	Polar Team Pro	[122, 129]	Did not report
Competition only										
Abdelkrim et al. [54]	M (38:38)	18.2 ± 0.5	Level 3	Competition (6 games)	3, 5, 10	Both	Semi-automated video analysis, HR, Blood markers	Sony DSR-PD170P, Team Sports 4.0, Sport-tester S610	[53]	Did not report
Abdelkrim et al. [212]	M (38:38)	18.2 ± 0.5	Level 3	Competition (6 games)	3, 5, 10	Internal	HR, Blood markers	Polar Electro Oy	Did not report	Did not report
Abdelkrim et al. [35]	M (18:18)	18.2 ± 0.5	Level 3	Competition (6 games)	6	Both	Semi-automated video analysis, HR	Sony DSR-PD170P, Team Sports 4.0, Polar Electro Oy	[4]	[54]
Abdelkrim et al. [53]	M (38:NR)	18.2 ± 0.5	Level 3	Competition (6 games)	7	Both	Semi-automated video analysis, HR, Blood markers	Sony DSR-PD170P, PC foot 4.0, Polar Electro Oy	[127]	Original work

Table 4 (continued)

References	Participants M or F (Recruited: analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Fernandez et al. [29]	M (11:11)	18.82 ± 1.65	Level 3	Competition (6 games)	4, 11	Both	HR, Inertial	WIMU, Garmin HR band	[212, 213]	Original work
Ransdell et al. [33]	F (NR:6)	19.7 ± 1.5	Level 3	Competition (4 seasons)	6	External	Inertial	Catapult Optimeye S5	[158–160, 214]	
Sanders et al. [19]	F (14:10)	19.8 ± 1.3	Level 3	Regular season (5 months, 31 games)	5, 7	Internal	HR	Polar Team Pro	[50, 64, 137, 127]	[74, 191, 194, 204]
Training only										
Anderson et al. [116]	F (12:12)	18 - 22	Level 3	Regular season (20 weeks)	2	Internal	sRPE	RPE scale [107]	[112]	Did not report
Castagna et al. [94]	M (14:14)	18.9 ± 2.3	Level 3	Off season (3 sessions)	0	Internal	HR, Blood markers	COSMED, Lactate-Pro system	[215, 216]	Original work
Foster et al. [109]	M (14:14)	20.2 ± 1.5	Level 3	Did not report	2	Internal	HR	Polar Electro, RPE scale [109]	[107, 108, 110, 217]	Did not report
Heishman et al. [128, 154]	M (10:10)	20.9 ± 1.2	Level 3	Preseason (5 weeks)	1	Both	Inertial, HR	Firstbeat, Catapult Optimeye S5	[50, 152, 159, 160, 214, 132]	[17, 50, 107, 134, 152, 159, 160, 194, 132]
Heishman et al. [78]	M (13:13)	20.2 ± 1.2	Level 3	Off-season (3 sessions)	1	External	Inertial, LPS	Catapult Optimeye T6, ShotTracker LPS	Did not report	[88, 158, 161]
Heishman et al. [88]	M (14:14)	19.7 ± 1.0	Level 3	Preseason (5 weeks)	1	External	Inertial	Catapult Optimeye T6	Did not report	[161]
Klusemann et al. [95]	M & F (16:10)	18.2 ± 0.3, 17.4 ± 0.7	Level 3	Preseason (6 weeks)	0	Both	HR, Semi-automated video analysis	Suunto, Sportscode	[54, 61]	Original work
Kozina et al. [96]	F (75)	20-22 and 12-13	Level 3	Undefined (December–March)	0	Internal	HR	Polar RS300X	Did not report	Did not report
Kraft et al. [134]	M (NR), F (NR)	Did not report	Level 3	Regular season (2–3 weeks)	2	Internal	HR	PolarH7, RPE scale [113]	[113, 129]	Did not report
Legg et al. [26]	F (10:10)	18 ± 2	Level 3	Regular season (10 weeks)	2	Internal	sRPE	RPE scale [111]	[111]	Did not report
Lukonaitiene et al. [44]	F (28:24)	18.0 ± 0.5, 19.6 ± 0.8	Level 3	Training camp (3 weeks)	2, 8, 9	Both	Inertial, HR, sRPE	Catapult Optimeye S5, Polar H10, RPE scale [111]	[25, 61, 109, 117, 119]	Did not report

Table 4 (continued)

References	Participants M or F (Recruited: analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Marcelino et al. [74]	M (12:12)	18.6 ± 0.5	Level 3	Regular season (2 days)	2	Internal	sRPE	RPE scale [107]	[107]	Did not report
Mi [97]	M & F (16:10)	19.2 ± 0.3 (M) 20.4 ± . 0.7 (F)	Level 3	Regular season (19 sessions)	0	Both	HR, RPE, Video analysis	Did not report equipment used	Did not report	Did not report
Narazaki et al. [48]	M & F (12:10)	20.4 ± 1.2	Level 3	Off season (2 sessions)	3, 10	Both	Manual video analysis, HR, Blood markers	VO2000 portable, Canon ZR-20	[151]	Original work

M male, *F* female, *NR* not reported, *sRPE* session rating of perceived exertion, *HR* heart rate, *LPS* local positioning system

and multiple competition levels ($n = 3$) [58, 81, 82]. For the standardized classifications, we dichotomized between youth and adult studies due to physical demand distinctions between participants [83], that otherwise might be lost by grouping by competition level rather than chronological age.

Only one study included in this review evaluated potential physical requirement differences based on training age [84]. Conte et al. examined variations in basketball skills related to physical maturation, training age/playing experience, and physical demands, and reported no relationship between self-assessed maturation/training age and physical demands of basketball [84]. However, this work was completed during training only, with participants from one team playing in the same competitive league [84]. This methodology could bias the results by limiting variation in subject training age or maturation, and introduce single team variables that affect the physical demands, such as playing time and rotational status (e.g. starter, non-starter). Research investigating differences in physical demands based on training age is likely helpful in periodizing training based on age groups, but future work should seek to coordinate research with multiple teams in an effort to increase sample sizes and report potential confounding variables that are specific to basketball/team sport. Currently, the underreporting and lack of analysis regarding age differences in athletes limits informed decision making about prescription based on age-related physical demands.

Using a standardized classification system for the competition level of basketball athletes could help elucidate best practices for monitoring physical demands, as it would encourage a more systematic process of comparing and contrasting research findings and identify considerations unique to age and competition level.

4.1.2 Positional Differences

Identifying the differing physical demands between positions has provided valuable insight into the most appropriate way to prepare team sport athletes [85, 86]. This review identified 16 studies [11, 22, 29, 31, 32, 34, 40, 51, 56, 64, 66, 79, 87–90] which specifically analyzed differences between playing positions in basketball. While individual results from these studies help describe differences between playing groups, methods for position classification varied, thereby limiting the ability to compare findings between studies. For example, three studies [11, 40, 66] compared physical demands across two positions, categorizing participants as either 'frontcourt' or 'backcourt', further explaining that frontcourt consisted of small forwards, power forwards and centers, while backcourt consisted of point guards and shooting guards. The majority of studies ($n = 10$) compared demands across three positions, but with different criteria for each position. The most common three positions used

Table 5 Summary of youth (under 18 years) basketball load monitoring studies

References	Participants M or F (recruited:analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Training and competition										
Arede et al. [49]	M (12:12)	16.02 ± 0.40	Level 3	Preseason (3 weeks)	0	Both	LPS, Inertial, sRPE	WIMUPro, RPE scale [111]	[166]	[166]
Benson et al. [103]	M (27:27), F (19:19)	15.4 ± 1.1	Level 2	(1 day)	0	External	Inertial	Vert Classic Sony HDR-CX430	Did not report	Original work
Brandao et al. [138]	M (13:13)	16.4 ± 0.6	Level 2	(4 training sessions, 1 game)	4	Both	HR, Inertial	Polar Team Pro	[218]	Did not report
Clemente et al. [104]	M (20:20)	12.0 ± 0.8, 14.3 ± 0.5	Level 3	Regular season (5 weeks)	0	Both	Manual video analysis, RPE	GoPro Hero 2, RPE scale [109]	Did not report	Original work
Otaegi and Los Arcos [45]	F (21:18)	14.9 ± 0.6 15.1 ± 0.7	Level 2	Regular season (9 weeks)	2, 9	Internal	sRPE	RPE scale [109]	Did not report	Did not report
Competition only										
Alonso et al. [27]	M (12:12)	17.56 ± 0.67	Level 3	Competition (8 games)	4, 9	External	Inertial	Catapult T6	Did not report	[62, 89, 200, 213, 219, 220]
Aspiroz et al. [221]	M (67:67), F (83:83)	Under 12	Level 2	Post season (1 game)	2	Internal	sRPE	RPE scale [222]		
Hulka et al. [69]	M (32:32)	16.88 ± 0.72	Level 3	Preseason (6 matches)	0	Both	Semi-automated video analysis, HR	Team Polar 2 Pro, Canon HF10, Video Manual Motion Tracker 1.0 software	[36, 47, 54]	
Klusemann et al. [146]	M (8:6)	17.8 ± 0.2	Level 3	13 games	3, 5, 10	Both	HR, Semi-automated video analysis	SportsCode, SuuntoTM	[47, 54]	Original work
Pino Ortega et al. [79]	M (94:NR)	17.6 ± 0.8	Level 3	Tournament (13 games)	4	External	Inertial, LPS	WIMUPro™	[166]	[167]
Portes et al. [31]	M (25:NR), F (48:NR)	17 ± 1 17 ± 1	Level 2	Tournament (4 days)	3	External	Inertial, LPS	WIMUPro™	[166]	[165, 223]
Reina et al. [89]	F (48:48)	Under 18	Level 3	Tournament (3 games)	3, 6, 11	External	LPS	WIMUPro™	Did not report	Did not report
Training only										

Table 5 (continued)

References	Participants M or F (recruited:analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
Abad et al. [100]	F (15:15)	16.92 ± 1.07	Level 3	Preseason (2 weeks)	0	Internal	HR	Team 2 Polar	Did not report	Did not report
Atli et al. [224]	F (12:12)	15.5 ± 0.5	Level 3	Regular season (1 week)	3	Internal	HR	Polar S810	–	–
Brunelli et al. [23]	M (12:12)	12.7 ± 0.6	Level 2	Preseason	2	Internal	sRPE	RPE scale [107]	[217]	
Coe and Pivarnik [162]	M (10:10)	12.8 ± 0.4	Level 2	Regular season	2	Both	HR, Inertial	Polar Cantage XL, CSA Accelerometer	–	–
Conte et al. [115]	M (21:21)	15.4 ± 0.9	Level 3	Regular season (10 weeks)	1	Internal	sRPE, HR	Polar Team System 2, RPE scale [107]		
Conte et al. [133]	M (23:23)	15.5 ± 0.9	Level 3	Preseason (2 weeks)	0	Internal	HR	Polar Team system 2	[129]	
Conte et al. [84]	M (12:12)	13.9 ± 0.7	Level 2	Regular season (2 weeks)	3	Internal	HR, Manual video analysis	Polar Team System 2, Sony and Panasonic cameras, Kinovea software	–	–
Cortis et al. [225]	M (10:10)	15.7 ± 0.2	Level 3	(1 session)	1	Internal	HR	Polar team	–	–
Cruz et al. [114]	F (10:10)	17.2 ± 0.4	Level 3	Regular season (9 weeks)	2	Internal	sRPE	RPE scale [112]	[109]	
Delextrat and Kraiem [87]	M (31:31)	16.6 ± 1.0	Level 3	(6 sessions)	1	Internal	HR	Suunto Pro Team	[35, 53]	
Herran et al. [155]	F (10:10)	15 ± 1	Level 2	(2 weeks)	2, 8	External	Inertial	MinimaxX v 4.0	[152, 226]	[227]
Lastella et al. [43]	F (11:11)	17.3 ± 0.9	Level 3	Training camp (2 weeks)	2	Internal	sRPE	RPE scale [109]	[109]	[109]
Lupo et al. [135]	M (6:6)	16.5 ± 0.5	Level 3	Regular season (5 weeks)	2	Internal	HR, sRPE	Polar H7, RPE scale [110]	[108–110, 129]	–
Lupo et al. [73]	F (15:15)	16.7 ± 0.5	Level 3	Training camp (3 weeks)	2	Internal	HR, sRPE	Polar H7, RPE scale [110]	[109]	Did not report

Table 5 (continued)

References	Participants M or F (recruited:analyzed)	Age (years)	Competition level (Table 1)	Season phase (duration)	Duration method (Table 6)	Internal/external	Measure of physical demands	Equipment used	Validity cited	Reliability reported
McCormick et al. [145]	M (12:12)	15	Level 3	Regular season (1 session)	3	Both	HR, Manual video analysis	Polar E600, Sony Handycam DVD 850	[228, 229]	Original work
Miloski et al. [24]	M (23:16)	15.3 ± 0.7	Level 3	(8 weeks)	2	Internal	sRPE	Did not report	[80, 230]	Did not report
Moraes et al. [70]	M (23:21)	15.8 ± 0.8	Level 3	(8 weeks)	2	Internal	sRPE	RPE scale [107]	[39, 60, 80]	
Moreira et al. [71]	M (48:32)	15.2 ± 1.2	Level 3	(2 weeks)	0	Internal	HR, sRPE	Polar Electro T31, RPE scale [107]	[38], 39, 50, 135]	Original work
Sampaio et al. [170]	M (10:10)	17.4 ± 1.1	Level 3	Regular season (1 session)	2	Both	HR, GPS	Polar Team, SPI Pro GPS	[231]	[231]
Sampaio et al. [105]	M (8:8)	15.5 ± 0.6	Level 3	Did not report	0	Internal	HR, RPE	Polar Team, RPE scale [113]	–	–
Sanchez–Sanchez et al. [101]	F (6:6)	14.3 ± 0.5	Level 2	Regular seaso (3 weeks)	0	Both	HR, Semi-automated video analysis	Polar Team System 2, Borg CR-10, Sony Handycam and Match Vision software	–	Original work
Vacquera et al. [72]	M (12:12)	16 ± 0.4	Level 2	Regular season (6 weeks)	0	Internal	HR, RPE	Suunto Memory Belts, RPE scale [107]	[232]	–
Valvassori et al. [52]	M (23:20)	14.5 ± 0.5	Level 2	Season (2 sessions)	0	Both	Inertial, HR	Team AMS Accelerometer, Polar T31	Did not report	Did not report
Vasquez-Guerrero et al. [34, 56]	M (94:94)	17.4 ± 0.7	Level 2	Tournament (13 games)	4	External	Inertial, LPS	WIMUPro™	[165]	Original work

M male, *F* female, *NR* not reported, *LPS* local positioning system, *sRPE* session rating of perceived exertion, *HR* heart rate, *RPE* rating of perceived exertion, *GPS* global positioning system, *CSA* computer science application, *CR* category ratio, *AMS* athlete management system

Table 6 Definitions of methods for measuring duration

	# in Tables 2, 3, 4 and 5
Primary duration method	
Did not report	0
Total training duration including all stoppages	1
Duration of session	2
Live time (When player on court, ball in play, clock running)	3
Game time when player is on court, excluding quarter/half breaks, including free throws, out of bounds, timeouts	4
Game time including all stops	5
Game time including all stoppages except time outs/quarter/half breaks	6
Game time including all stoppages except quarter/half breaks	7
Accessory duration method	
Included warm up/cool down	8
Excluded warm up/cool down	9
Include rest periods	10
Short periods when clock was stopped but player was active	11

to classify participants were "guards, forwards, or centers" [29, 31, 32, 34, 56, 79, 87–89], while Torres-Ronda et al. [64] classified participants as "point guards, wings (shooting guards and small forwards), and bigs (power forwards and centers)", and Vaquera et al. [51] classified participants as "point guard, forward, or center". Finally, three studies [22, 66, 90] had five classifications for positions, including point guard, shooting guard, small forward, power forward and center.

The variance we identified in position descriptions supports the idea that modern basketball teams may not follow a traditional position classification system. It has also been reported that physical characteristics of basketball athletes and playing styles can differ between geographical areas [11], which may not allow for consistent descriptions of position from team to team. Therefore, findings related to physical demands classified by position should be applied with caution in the field, mainly due to the current inconsistency in categorizing and clarifying playing role, and the potential team-to-team variance within positional roles. Indeed, individual leagues may have technical differences in rules or regulations, and individual teams may have differences in tactical strategies that impact the physical demands of various individuals/positions [11, 91]. Based on the wide range of positional demands in basketball, we recommend that future research investigating position specific differences in training load should dichotomize the types of positions reported to either 'frontcourt' or 'backcourt'. Additionally, the reporting of anthropometric data for those positional groups would assist with application despite differences in age group, level of competition, and league. While positional dichotomization may help in summarizing research findings, the best application of the evidence for practitioners may be to assess physical demands on an individual basis rather than depend on positional criteria to inform training.

4.1.3 Participant Inclusion and Exclusion

Determining best practices for training load monitoring solutions in basketball should encompass and be effective for all members of a basketball team, including a variety of roles within the team (e.g. starter, non-starter). A common finding among the studies included in this review was the inclusion or exclusion of certain participants based on objective participation or data collection criteria. Many studies only reported participants that were included in the final analysis and did not report clear exclusion criteria, or if any participants were excluded from the initial cohort. While inclusion and exclusion criteria are necessary in all research, it is equally important to include information related to originally recruited participants (i.e. members of the team) as well as participants that were eliminated from and retained for final analysis.

Only 31 out of 122 studies included in this review reported recruited versus analyzed participants. Three studies that evaluated physical demands of competition only reported data from starters and/or players that were not substituted for the entire game [35, 36, 76]. While this may give insight into the most strenuous physical demands possible during play, it is not a practical representation of physical demands of games, which always includes substitutions and meaningful contributions from bench players. Similarly, 13 studies [16, 19, 21, 22, 27, 29, 31–34, 37, 40, 92] excluded participants from analysis that did not reach a minimum threshold of game participation, but only 5 of those studies explicitly reported how many participants were originally recruited [16, 19, 31, 34, 40]. The type of exclusions also occurred with participants that did not meet training-based participation and/or data collection thresholds, and there was again a lack of reporting about number of participants excluded or originally recruited.

The elimination of certain team members (e.g. rotation players), coupled with the lack of reporting of recruited versus analyzed participants, does not allow for complete understanding of the physical demands of the whole team. Only including some team members in analysis can create issues by providing incomplete information on which to infer training models and prescriptions. This can create skewed training load descriptions and assessments for certain groups of athletes, leading to misinformed training load prescriptions when programming for an entire team. Additionally, only reporting physical demands for subgroups of teams such as 'starters' or 'rotation players' is counterintuitive to an individualized training load management approach (i.e. for all players on a team), which is essential in high-performance sport. Increasing clarity about number of athletes available in team sport settings, the inclusion criteria, describing the characteristics of excluded participants and how that impacted final data analysis will help elucidate best practices in basketball training load monitoring, and improve decision making/management for entire teams and not only limited subsets of athletes.

4.2 Methodology for Quantifying Duration

Exercise duration is the most fundamental proxy measure of training volume for any sport/modality. Indeed, common training impulse techniques use duration as a base unit, with a specific multiplier (e.g. HR, RPE) used to calculate overall training load for a given duration. While duration is a fundamental, first principles metric, there are many ways to record exercise duration. In basketball games, 'total' duration may be recorded as the entire time on the court, restricted to the time in which the player was actively involved in the play, or only recorded when the game clock was running (i.e. the traditional definition of minutes played). This review identified a wide range of methods used to determine training duration in basketball, and a significant number of studies ($n=24$) that failed to report how duration was defined and calculated [32, 49, 52, 66, 69, 71, 72, 75, 84, 92–106]. A commonly used description of duration methodology in basketball was defined in 1995 by McInnes et al. [47], where total time was calculated as "all of the time that the subject was on the court, including all stoppages in play such as time-outs, free-throws and out-of-bounds, but excluding breaks between quarters, or time that the subject was substituted out of the game" [47]. A further categorization of 'live' time was "only to the time during which the game clock was running and the ball was in play" [47]. Despite the clarity of these descriptions, many papers modified duration reported by including or excluding warm-ups, cool downs, or modifying the types of stoppages in play that would be counted.

Rather than reporting specific methods, many studies ($n=31$) in this review reported only 'session duration' and used multiple references to ambiguously justify and describe their methodology. These approaches often made it difficult to determine the exact duration methodology, as the multiple studies cited used differing descriptions of what 'session duration' entailed. Our analysis identified four different studies by Foster [107] and Foster et al. [108–110] that were commonly cited throughout the basketball literature to justify the methods for calculating session duration. Two of these previous studies defined duration as "total duration of training in minutes" [108, 110], one specifically noted that session duration included "warm up, cooldown, and recovery intervals" [107], and one study did not address duration measurement at all [109]. Additionally, two of these studies [107, 108] had participants self-report duration, noting that "Some subjects preferred to report only the time for high intensity segments while excluding recovery time between exercise or sets. Others preferred to record the total duration." [108].

The importance of consistent methodology for calculating and reporting duration is essential when comparing data between studies. Including or excluding specific periods of training or games would influence intensity measures (i.e. variables reported as a rate) and other derived global training load measures such as sRPE, as these are calculated with duration as one of the base units. Indeed, 43 papers included in this review reported a sRPE-derived training load measure, and within these studies, there were 10 different methods used to calculate duration, which invalidates potential comparisons between these studies.

A review by Stojanovic et al. [7] proposed analyzing physical demands with both live and total duration methods. It was suggested that analyzing physical demands during live time only would help in the development of more precise competition specific training, while analyzing physical demands during total time was important for the development of ecologically valid training plans [7]. Thorough descriptions and justification for duration methods in the literature is imperative for best training load monitoring practices in basketball moving forward. For researchers, we recommend using the previously defined terms of 'live' and 'total' duration as outlined by McInnes et al. [47], while calculating and reporting non basketball specific work (i.e. warm up and cool down) separately. In addition to this, we strongly advise against broadly defining duration as 'session duration', as this does not allow the work to be fully understood or reproduced. For practitioners using a measure of training load that incorporates duration, the first priority should be to have consistency across individuals and teams when measuring duration. When possible, measuring both total and live time would allow for practitioners to more accurately calculate intensity demands of the activity with live duration, as well as volume completed over the total session duration.

The duration of data collection is also a point of concern when interpreting results across studies. The most common method for reporting duration of data collection was to report the number of weeks or individual games/training sessions included in the study. The number of weeks of data collection ranged from 1 to 42 weeks (mean ± SD; 9.7 ± 8.5 weeks), and the number of games/training sessions ranged from 1 to 252 (mean ± SD; 12.2 ± 38.7 games/training sessions). While the duration of data collection may vary based on the research aims, evaluating the demands of basketball over only short durations may produce results that are skewed based on contextual factors (i.e. score, tactics, travel, conditioning, opponent, injury). The duration and timing of data collection in basketball studies are important considerations when comparing findings across studies, and we strongly encourage researchers to clearly describe aims and acknowledge limitations of short periods of data collection when communicating findings.

4.3 Internal Training Load

For the purposes of this review, internal training load was defined as "the psychophysiological responses occurring during the execution of the exercise" [2]. This review included 52 studies that reported internal training load measures only, while an additional 41 studies reported internal training load in conjunction with external training load (i.e. 76% of studies had at least one measure of internal training load). The most common internal training load measures reported included sRPE ($n = 43$) and HR derived measures ($n = 58$).

4.3.1 sRPE

A common working definition of sRPE is "a global rating of the intensity for the entire training session" [109], where intensity is quantified using RPE, and this is widely utilized in training load calculations by multiplying the total duration by this intensity rating [107]. This sRPE-derived training load is considered internal training load as it estimates the perceptual response during the session. In this review, 43 studies utilized sRPE load to evaluate the physical demands of basketball, of which 25 reported sRPE derived load as the only training load measure. The studies in this review that calculated sRPE used different RPE scales, including the category ratio (CR) scales developed by Borg [111, 112] and modified by Foster [107–110], as well as the OMNI pictorial scale [113]. The most common timeframe for collecting sRPE was approximately 30 min post-session, as reported in 29 out of 43 studies. Some studies reported collecting RPE as soon as 10–20 min post [20, 45, 68, 114] or immediately after the training session/game [26, 37, 43, 46, 71, 115], while other studies did not report the timeframe in which sRPE was collected [23, 42, 116, 117]. While sRPE is a common method used to quantify the physical demands of basketball, inconsistencies in the methodology may complicate the comparison of the findings across different studies. Specifically, there is a wide variety of duration calculations and sRPE scales used, making it difficult to reach reliable conclusions about the efficacy of sRPE-derived training load to quantify the physical demands of basketball.

Many of the aforementioned duration inconsistencies are apparent in the sRPE literature. The most commonly reported (26 of 43 studies) duration method was a generic 'session duration', without any specific detail about how this 'session duration' was calculated. An additional five papers reported session duration, but specified that this included all stoppages, while one paper reported total duration that did not include stoppages of play. Although these may seem like small variations in methodology, these differences can have a meaningful impact on duration derived sRPE training load. To put these differences of duration calculation into context, a paper by McInnes et al. [47] reported that excluding stoppages of play during a professional basketball game could be removing up to ~ 39 min from the duration reported. Additionally, NBA games since the 2017 season have averaged over 130 min in total duration [118], but include only 48 min of live time. Researchers that choose to utilize the sRPE method as a measure of training load should be detailed and transparent in their reporting of duration to facilitate a better ability to compare and understand the application of sRPE derived training load in basketball.

Another obstacle to comparing between basketball studies is the reported use of multiple sRPE intensity scales. There is a very circular nature of methodology description and justification among basketball specific papers using sRPE derived load, which needs to be considered when interpreting results and basing future research on previous work. For example, the most commonly used justification for using sRPE in the included studies referred to the training monitoring work of Foster and colleagues [107–109]. Of the 107 participants in these 3 studies by Foster et al. [107–109], only 14 were basketball players, and the rest were individual sport athletes in a variety of sports (e.g. runners, cyclists, speed skaters). It was described that the majority of these participants self-reported training duration over a time span anywhere from 6 months to 3 years [107], with the authors acknowledging that they "were unable to impose a consistent pattern across subjects" [108].

Additionally, these three studies used scales with different sets of verbal anchors across multiple sports, further complicating the comparison between basketball studies utilizing sRPE as a training load measure. The original perceived exertion scale was published by Borg in 1970, followed-up by a CR scale in 1987 that showed sRPE intensity responses closely resembled HR and blood lactate responses during arm cycle ergometry in untrained males [112]. The 1996 study by Foster [108] utilized a modified version of Borg's CR-10 scale, which included nine verbal anchors from 'Rest' to 'Just Like My Hardest Race', and concluded that increases in training load (as measured by sRPE), resulted in a performance improvement in runners, cyclists and speed skaters [108]. However, this study was observational in nature and there was no description of the training history or type of training each athlete underwent, as it was self-reported and dictated by individual coaches/athletes. Foster's 1998 study [107] used Borg's CR scale to measure sRPE intensity in speed skaters, finding that, on an individual basis, sRPE was fairly well correlated to Edwards training impulse (TRIMP) scores (ranging from 0.75 to 0.90) [107]. In Foster's 2001 study [109], another different modified version of the original CR-10 scale was used, this time using eight verbal anchors from 'Rest' to 'Maximal', and stating that sRPE was highly correlated to TRIMP scores in basketball and steady-state cycling, but failed to report any correlation values [109]. Maintaining consistent methodology when using qualitative measures such as sRPE is crucial to preserve the validity of the tool and its measurement properties. There is a systemic pattern of modification of the sRPE process in the basketball literature which is perpetuated by practitioners adjusting the measurement tool (e.g. changing the questionnaire prompt/verbal anchors/duration used) and either not providing any reasoning for the change or justifying the change by citing older studies. For example, Weiss et al. [119] cited Foster's 2001 study to justify their use of sRPE in basketball, but then further described their sRPE methodology by citing Coutts et al.'s 2007 work with triathletes [120] and Impellizzeri et al.'s work with soccer [121], both of which cite Foster's 1995 paper for their methods. Another study by Doeven et al. [16] describes that sRPE is a valid method in elite basketball, but uses a 6–20 point RPE scale with no prior validation in the basketball literature. Researchers in this field need to be thorough in their literature reviews, understanding the works that they are citing and how those relate to their own work, while being diligent in administering measurements and methods validated in the literature, for the purposes being investigated.

4.3.2 Heart Rate (HR)

Measures of HR are commonly used as indicators of exercise intensity and internal training load in athletes [122, 123]. HR monitoring in basketball was first reported in a 1968 study which described position specific HR responses in women's basketball at the collegiate level [124]. In the current review, nearly half of the included studies (58 of 122) measured HR, with 40 out of 58 studies only providing a global description of HR response (e.g. mean HR, maximum HR (HR_{max}), percentage of HR_{max}), while 18 of 58 studies also calculated a HR-derived training load measure. All of the studies in which HR was measured in this review used commercially available HR sensors, including Polar ($n = 39$), Suunto ($n = 10$), FirstBeat ($n = 2$), Garmin ($n = 2$), and Zephyr ($n = 1$), while three studies did not specify the specific HR hardware used [48, 94, 97].

HR responses (e.g. beats per minute) during basketball activity have been used to calculate a TRIMP with a variety of algorithms. The original model proposed by Banister [125] uses mean HR or the summation of every HR data point during exercise to calculate a TRIMP, and three studies included in this review used this method [126–128]. To account for the demands associated with the increased cost of higher intensity activity, additional models were proposed by Edwards [129] and Lucia et al. [130]. These models divide HR responses into intensity zones, with each zone arbitrarily weighted when calculating internal training load to account for the increased metabolic costs of higher intensity exercise [129, 131, 132]. The Edwards' summated HR zones (SHRZ) was the most common method used to derive a training load measure from HR for the studies in this review [19, 44, 52, 64, 98, 109, 115, 133–138]. Although these TRIMP models have been used widely as a measure of internal training load in sports, they have never been validated against gold standard measures of true energy cost [48, 139]. Rather, these TRIMP calculations have been compared to 'criterion measures', such as other TRIMP calculations or sRPE [109, 131]. Additionally, the HR zones and the arbitrary weighting system used in TRIMP scores may not account for the individual nature of acute HR responses [132, 139], psychological or environmental external stressors [140], and HR adaptations over time [139, 141].

Limitations around measuring HR_{max} should also be considered, as this is a key anchor for calculating commonly used internal training load intensity zones and descriptive HR responses in basketball (e.g. $\%HR_{max}$ or %HR reserve). Studies included in this review assessed HR_{max} using a variety of different methods, including the YoYo test ($n = 13$), 20-m shuttle test ($n = 4$), incremental treadmill test ($n = 7$), 30–15 intermittent fitness test ($n = 4$), Leger beep test ($n = 1$), age prediction equations ($n = 5$), HR during basketball sessions ($n = 12$), maximum oxygen uptake test ($n = 1$), or did not report how HR_{max} was determined ($n = 11$). While HR_{max} measures are central to the calculation of exercise intensity (e.g. $\%HR_{max}$) and global training load (e.g. HR_{max} zones), it appears that most studies have used measures of peak HR (HR_{peak}). Whilst the specific effect of each of these HR_{peak} assessments on these calculations has not been described, the effect of imprecise HR_{max} proxy measures is likely to affect both measures of intensity and global training load [142]. Therefore, the derivatives using HRmax as a key anchor (e.g. HR-derived training load) are difficult to compare across studies as the accuracy of the HRmax, peak and intensity zones is unknown.

Despite these methodological issues, HR monitoring is heralded as an advantageous monitoring tool due to its purported ability to reflect exercise intensity [122] and convenience (e.g. non-invasive, continuously recorded) [10]. However, exercise intensity may be underestimated during basketball training and competition when measured by only HR [10], as HR response is delayed or disproportionate during high intensity intermittent activity, which forms the majority of basketball activity [21, 40, 50, 64, 82, 122, 127, 140]. This delay in HR response could pose issues related to the duration methodologies mentioned earlier, as only including 'live' time during basketball could eliminate meaningful HR data [117, 143]. Additionally, HR response can be impacted by environmental effects, psychological arousal, and nutritional/hydration status [47, 140, 143, 144]. These factors can lead to meaningful differences in the interpretation of HR intensities, within and between athletes, and should be considered when using HR as a monitoring tool in basketball.

Modern software has created much more convenient processing of HR data, particularly when monitoring groups/teams. However, this automated download and analysis of HR data skips any required visual/manual inspection of data quality. The majority of studies that included HR measures in this review reported utilizing this automated process, but only two of these specifically acknowledged removal of HR data due to incomplete data [145] and issues 'between monitors' [143]. Other studies investigating HR responses in basketball reported collecting HR data in only 127 out of 240 [127] and 75 out of 109 [146] of the sessions for which they had planned to collect such data. These limitations have been attributed to equipment availability [127], lost data [127], missed sessions [127], as well as interference of upper extremity movements [48] and HR garments falling off [146], but could also be due to user error (e.g. taking monitor off, not appropriately wetting HR strap), or hardware/software malfunctions. While missing data are certainly a common occurrence in the field and limitation in many research studies, the reliability of utilizing HR monitors in basketball specific settings should be considered alongside the previously mentioned convenience. We recommend that practitioners and researchers be diligent in checking for HR data free of interruptions or artifacts and not blindly relying on an automated process of collection, downloading, processing and reporting. Additionally, we advise research including HR monitoring in basketball to consistently report data cleaning procedures and the amount of sessions not included in analysis due to data collection issues. This will allow practitioners to better assess the convenience vs reliability of HR monitoring in basketball.

4.4 External Training Load

Measurements of external training load were reported in 70 studies included in this review and described with a variety of movement characteristics, types, and intensities. In much of the external training load related basketball literature, the term 'Time Motion Analysis' (TMA) is commonly used to describe the use of recorded video footage to gather relevant information from the footage using a variety of techniques. However, this is a very narrow application of the term TMA, which has previously been defined as "the quantification of movement patterns involved in sporting situations, thus providing speeds, durations and distances of various locomotor patterns" [147]. Under this definition, video-based techniques, inertial measurement units (IMU), and local/global positioning systems (LPS/GPS) can all be categorized as TMA methods. In the following sections, we have summarized external training load methods into categories that more clearly identify the method used, including manual techniques (e.g. notational video TMA), semi-automated techniques (e.g. software assisted video TMA) and automated techniques (e.g. IMU, optical tracking) [148]. Our aim is to establish a clear and consistent categorization of methods and align terminology for use in future external training load research and practice.

4.4.1 Manual Techniques

Manual notational analysis has been commonly used to describe basketball movement patterns and assess physical demands, despite the subjectivity of analyses and associated validity and reliability issues [54, 149]. This review included 12 studies that reported using manual video-TMA methods, which would require one or multiple investigators to classify the movement patterns and intensities [47] using only frame by frame playback of video.

One of the first manual video-TMA studies in basketball was conducted by McInnes et al. [47] and in order to describe movement form and intensity, this group utilized eight classification categories: stand/walk, jog, run, stride/sprint, low shuffle, medium shuffle, high shuffle, and jump. Despite these authors acknowledging the difficulty of categorization and low reliability for some intensity categories [47], these categories have been repeatedly adopted for other video-TMA studies [35, 48, 53, 64, 95, 143, 144, 150]. Using these categories to classify basketball specific external training load may be further limited, as dribbling activity is not included/classified according to intensity [11], and movement form is not classified according to direction (i.e. forward, backward, lateral) [11]. Montgomery et al. [75] highlighted that basketball play also includes frequent isometric actions, which have a meaningful associated energy cost, but would fall in the category of 'standing/walking' within commonly used TMA movement classifications [35, 47, 53, 54]. While many TMA studies report counts or frequencies of common basketball specific actions, the absence of a category for isometric activities (e.g. screening, blocking, positioning) limits understanding of the physical demands of basketball. Duration methodology can significantly impact the frequency and total number of activities, and comparing video-TMA-based movement descriptions between studies may be misleading based on the duration used (e.g. total time, live time) [21]. Given the aforementioned limitations of duration methodologies, movement categories and technological differences, we recommend limiting comparisons of video-TMA results between studies.

4.4.2 Semi-Automated Techniques

Technological advancements have allowed for some video-TMA procedures to be semi-automated [10], through the use of software that can auto-detect movements and record duration after the user manually identifies athletes [148]. Although a semi-automated process has the potential of increasing reliability, there are methodological areas that may limit comparing or applying semi-automated video-TMA findings. First, this review identified 13 different software packages that were used to complete video-TMA, ranging from custom Labview analysis [11, 82, 151] to free, publicly available software [144], and less than half of those studies ($n=6$) reported the reliability of their methods. Only six studies identified the software release (e.g. Dartfish 6.0, Kinovea 8.15) that was used, which is important to acknowledge as these different versions may impact the player tracking algorithm and level of manual intervention needed [148]. Second, the camera number, brand, and set-up (e.g. position around court, distance from court), as well as recording frequency varied between studies, with no study reporting the validity of their specific equipment or set up. It is important to consider that the accuracy of vision-based systems has been shown to be affected by distances between cameras and athletes [148], camera angles [148] (e.g. height, distance from floor), and lens type [149] (e.g. wide angle). Therefore, validating equipment and calibrating set up [148, 149], as well as reporting detailed methods, is paramount to understanding how the physical demands were measured and the appropriateness of comparisons across studies.

4.4.3 Automated Techniques

4.4.3.1 Inertial Measurement Units The use of IMUs was first reported in the basketball literature in 2010 [75]. It is suggested that IMUs may improve training load monitoring in team sports, primarily due to objective analysis of data [50, 152, measuring small movements and overcoming some limitations of HR monitoring during intermittent activity [152, 153], and manual/semi-automation of processes for timely data collection. In total, nine different IMUs were used within the studies included in this review (Tables 2, 3, 4, 5), which included using uniaxial accelerometers ($n=1$), triaxial accelerometers ($n=5$), and triaxial accelerometers combined with magnetometers and gyroscopes ($n=11$). The most commonly reported metric in basketball literature was Catapult PlayerLoad™ [41, 50, 62, 63, 77, 81, 98, 117, 128, 154, 155], which is a square root of the sum of the squared instantaneous rate of change in acceleration in each of the three orthogonal planes (i.e. anterior/posterior, lateral and vertical) divided by 100 [156]. The purported ability of these units to measure instantaneous rate of change in acceleration across three planes of motion [75] may be particularly relevant in basketball, given the frequent change of activity and direction within the sport [21, 40, 50, 64, 82, 122, 127, 140]. The intra-unit reliability of commercially available IMUs to measure acceleration in three directions during lab and field based studies has been addressed in the previous literature [152, 157–160], with the PlayerLoad™ metric deemed to have 'acceptable' test–retest reliability within and between participants during physical activity [159, 160] and strong correlations to HR and oxygen consumption within participants during treadmill running [159]. While many manufacturers recommend wearing the IMU posteriorly on the upper thoracic region to enhance the GPS signal (IMUs are commonly paired with GPS technology), criterion placement has been suggested to be closer to the center of mass (COM), e.g. near the navel [159], and studies evaluating the device reliability during human movement have shown that unit placement [159] and fit [161] impact PlayerLoad™. Accelerometer measurements taken from units placed near the scapulae have greater vertical vector motion compared with placements near the COM, which was suggested to be due to upper body movement (e.g. shoulder-girdle sway, arm swing, trunk flexion) [159], 160]. Of the 18 studies in this review that included accelerometer data, eight reported positioning the unit at the upper thoracic region, two reported positioning the unit at the hip (i.e. closer to the COM), two reported having the unit worn on a chest strap, and five did not report where the unit was worn. Due to the high sampling rate of accelerometer devices (e.g. 100 Hz), it has been also been suggested that if the accelerometer is not placed on an athlete in a tightly fitted manner, incidental movement of the unit can occur, causing up to a two-fold increase in accelerometer loads reported during matched activity [161].

These methodological details related to the validity and reliability of IMU data are especially relevant when considering the large number of variables that micro-sensor units can output [63]. For example, the previously mentioned PlayerLoad™ metric has 117 different default output options in the manufacturer's software [156], with more custom options available. Other metrics reported when describing the physical demands of basketball included accelerations [22, 41, 55, 63, 81, 126], decelerations [22, 41, 55, 63, 81], acceleration: deceleration ratios [22, jumps [41, 55, 63, 81], changes of direction (COD) [41, 55, 63, 81], activity counts [162], average net force[40], 153], mechanical load [126], and inertial movement analysis [77]. None of these metrics have been validated against criterion measures in the existing literature, limiting our understanding of true differences within and between studies. Additionally, it has been suggested that the rapid technological advancements of IMUs may account for differences between similar metrics over time [81].

The emergence of IMU use in sport presents a promising new data source for quantifying physical demands, particularly in basketball. However, practitioners and researchers alike should seek to understand the validity of these devices and related metrics, via both independent research [163, 164] as well as encouraging manufacturers to share internal validation work [163] and increase transparency regarding data processing methods. While previous basketball research has called for reporting only the crucial variables related to external training load [63], it is difficult to determine which variables are most meaningful without understanding their role in describing basketball specific physical demands.

4.4.3.2 Positioning Systems Positioning systems (e.g. LPS, optical tracking, GPS) have been advocated for use in basketball over other external load monitoring options due to an improved accuracy [31, 32, 79], comparative ease of data collection and processing [31, 32], and more comprehensive locomotive variables [31] than other external training load monitoring options. This review identified 12 studies that utilized positioning systems to quantify external training load, including the use of LPS ($n=8$), optical tracking ($n=2$), and GPS ($n=2$). LPS and optical tracking technology have emerged as viable replacements for GPS in indoor settings and have been evaluated in the recent basketball literature as systems have become commercially available.

The LPS used in studies covered by this review operated by positioning anchors/antennas around the area of play, which would then triangulate between each other and a sensor worn by the athletes, thus deriving position information [31, 34, 49, 56, 65, 78, 79, 89]. The most commonly used LPS reported in seven of the eight studies was the WIMU PRO system [31, 34, 49, 56, 65, 78, 89]. This system was previously validated using raw data outputs [165–167], but only one study included in this review investigated the application in basketball using raw data [79], while the other seven studies in this review that utilized a LPS reported using the software associated with the system for data analysis [31, 34, 49, 56, 65, 78, 89], indicating a filter had been applied to the data used to estimate positional information [168]. Although this is common practice, the filtering process is usually not disclosed by manufacturers due to the proprietary nature and intellectual property concerns [163], further confounding understanding the validity of measurements. This is an especially relevant topic to address in basketball related research and practice, as LPS accuracy is impacted by fast changes of velocity and changes of direction [168], which are common in the sport. Additionally, because of the impact that fast changes in direction or velocity can have on system accuracy, it has been suggested that error estimations be verified for 'elite' athletes that may be able to produce faster dynamic movements [168]. Therefore, technologies evaluating external training load should seek to validate across an ecological representative range of activities and movements. This further highlights the importance of categorizing athletes based on competition level and physical attributes such as age, as opposed to labels like 'elite', when establishing the credibility of emerging technologies for basketball athletes.

Another emerging technology in basketball is optical tracking systems. These fully automated video-analysis systems can estimate the position of athletes and the ball by converting two-dimensional images to three-dimensional coordinates [169], and through this estimation of position can derive locomotive variables such as distance and speed. While this method is an attractive solution to basketball training load monitoring, based on the non-invasive nature (i.e. athletes do not have to wear units) and time effective data collection and analysis, it has some of the same limitations as semi-automated video techniques, including the validation of hardware. Two studies included in this review utilized optical tracking systems, but neither cited or reported any validation work related to the system [93, 169]. This included one study by Caparros et al. [93] using publicly available data from the NBA, which utilizes a league wide optical tracking system (Second Spectrum, Los Angeles, United States). There is currently no published validity or reliability information on this optical tracking system [163], which should be acknowledged in any studies analyzing publicly available data to describe physical demands. Two studies included in this review also utilized GPS technology to quantify external training load in basketball [138, 170], and while GPS has been widely validated in team sports, it has very limited application for indoor sport. Utilizing GPS for basketball specific studies moving forward will not yield easily comparable results, as this technology is unlikely to be used frequently in a game played primarily indoors.

5 Conclusions

This review provides a holistic appraisal of training load monitoring in basketball, and a detailed discussion of the constantly evolving technology which can be used to quantify a variety of physical demands. Despite this evolution, it is difficult to draw definitive conclusions about the true physical demands of basketball due to small data sets, varying methodologies, and short periods of data collection in the available literature. This review comprehensively evaluated past practices and developed methodological suggestions that we believe future researchers should adopt, as creating alignment on methodologies and terminology is critical to progressing understanding.

This review highlighted a range of methodological inconsistencies in key areas of data collection, processing, and analyses, which held true for objective, subjective and even the most fundamental principles in training load monitoring (i.e. measuring duration of basketball activities). We provided specific guidelines for defining and applying duration measurement methodologies to address this issue, and outline recommendations for classifying competition level to encourage easier identification of cohorts and comparisons between studies. Finally, it is important to reiterate that there are, to date, no gold standards but only proxy measures, to quantify training load in basketball. The validity and suitability of a measure also depends on the variable practitioners are aiming to assess and control during the training process, or for determining the physical demands (i.e. training targets). There are no measurements that are free of limitations, but knowledge of existing limitations allows practitioners to select the best measure for a given purpose, and to avoid erroneous interpretation of the results.

5.1 Practical Applications

- Researchers and practitioners should thoroughly review data collection and analysis procedures to ensure reproducibility of methods. This will allow for the accurate quantification of the physical demands of basketball, as well as an enhanced ability to compare studies.
- We recommend that practitioners clearly define their methods of duration calculation (suggestions provided in Table 6) and apply their chosen construct consistently.
- Due to the rapid advances in player tracking technology, a meticulous approach to vetting the validity and reliability of measurement tools and associated metrics is crucial when interpreting and applying these data. We implore practitioners and researchers alike to raise the validation culture in basketball by utilizing internal validation when appropriate, and applying aggressive critical appraisal of any unsubstantiated emerging methods or technologies. Original validation and reliability research should be conducted and reported related to the specific metrics being evaluated, where possible, to encourage increased understanding of the limitations of those metrics.
- Consistency in data collection and systematic reporting of methods is key to advancing the ability to compare the physical demands of basketball across participant groups and time. We recommend researchers adapt their methodology based on previous research in an effort to compare studies, which may lead to a more robust understanding of the relationship between physical demands and other areas (e.g. injury, performance), better application of findings to specific cohorts of basketball athletes, and identification of best practices regarding training load monitoring in basketball.

Declarations

Funding No sources of funding were used for the preparation of this study.

Conflicts of interest Jennifer Russell, Blake McLean and Donnie Strack are NBA affiliated practitioners/researchers. As such, all methods in this work are required to comply with the NBA Health Related Research Policy and have been reviewed by the NBA, NBA Physicians Association, NBA Players Association. As part of this process, this work was made available for comment from the NBA and NBA research Committee prior to publication (these contributors are not listed as authors). Jennifer Russell, Blake McLean, Franco Impellizzeri, Donnie Strack and Aaron Coutts declare that they have no other conflicts of interest relevant to the content of this review.

Authorship contributions JR, BM, AC and FI created the search strategy and refined the scope of the review. JR, BM, and AC screened the search results. JR extracted and interpreted the data and wrote the first draft of the manuscript. BM, AC, FI and DS revised the original manuscript. All authors read and approved the final manuscript.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Availability of data and material Not applicable.

Code availability Not applicable.

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