ESCUELA INTERNACIONAL DE DOCTORADO
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Murcia, julio de 2021

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AUTHORIZATION OF THE DIRECTORS OF THE THESIS FOR SUBMISSION

Prof. Dr. Pedro E. Alcaraz Ramón, Prof. Dr. Julio Calleja-González and Dr. Tomás T. Freitas as Directors of the Doctoral Thesis "Neuromuscular fluctuations and match-play demands of the collegiate basketball competitive season" by Adam James Romano Petway in the Program de Doctorado en Ciencias del Deporte, **authorize for submission** since it has the conditions necessary for its defense.

Sign to comply with the Royal Decrees 99/2011, 1393/2007, 56/2005 and 778/98, in Murcia.

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The field of basketball performance and sports science is constantly evolving. It is for this reason, similar to the athletes that we study, we as practitioners must constantly be adapting to the environment around us. The empidids of my PhD journey stems from the curiosity of what is best practice to help the athletes that I have the privilege to work with. Embedded within that is also the humbleness to acknowledge that in searching for answers one must have a well-rounded team of people to help guide them. I would like to take this opportunity to recognize the people and places that helped lead me through this process.

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To all, thank you!

“How do you go from where you are to where you wanna be? And I think you have to have an enthusiasm for life. You have to have a dream, a goal. And you have to be willing to work for it.”

Jim Valvano

This thesis is a compendium of 3 international articles already published in peer-reviewed journals. The references for the abovementioned articles are as follows:

Article 1

Petway AJ, Freitas TT, Calleja-González J, Medina Leal D, Alcaraz PE. Training Load and match-play demands in basketball based on competition level: A systematic review. PLoS ONE. 2020;15(3):e0229212.

Article 2

Petway AJ, Freitas TT, Torres-Ronda L, Calleja-González J, Alcaraz PE. Seasonal Variations in Game Activity Profiles and Players' Neuromuscualr Performace in Collegiate Division I Basketball. Front. Sports Act. Living. 2020;2:592705.

Article 3

Petway AJ , Freitas TT, Calleja-González J, Alcaraz PE. Match Day-1 Reative Strength Index and In-Game Peak Speed in Collegiate Division I Basketball. Int. J. Environ. Res. Public Health 2021;18:3259.

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ABBREVIATIONS

The abbreviations of the units from the International System Units are not included in the following list as there are internationally accepted standards for their use. In addition, no abbreviations universally used in statistics are presented in this section.

ACC	Acceleration
ACC_{HI}	High-Intensity Accelerations
ACC_{T}	Total Accelerations
BPM	Beats Per Minute
CMJ	Countermovement jump
COD	Change of direction
CONF	Conference
CT	Contact time
DEC	Deceleration
DEC_{HI}	High-Intensity Decelerations
DEC_{T}	Total Decelerations
D1	Division I
EBC	Elite Back-Court
EFC	Elite Front-Court
HIA	High Intensity Actions
HR	Heart Rate
HR_{ave}	Heart Rate Average
HR_{max}	Heart Rate Max
LIA	Low-Intensity Actions
MPH	Miles Per Hour
MD-1	Match Day-1
N	Newton
NM	Neuromuscular
NON-CONF	Non-Conference
PF	Peak Force

RFD	Rate of Force Development
sRPE	Session Rating of Perceived Exertion
RSI	Reactive Strength Index
SEBC	Sub-Elite Back-Court
SEFC	Sub-Elite Front-Court
S&C	Strength and Conditioning
SSC	Stretch-Shortening Cycle
TRIMP	Training Impulse

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ABSTRACT

Basketball is a court-based team sport that requires a high demand from the neuromuscular system. Within the sporting activity of basketball there have been recent modifications to increase pace and spacing during competition. As a result of this increase in movement variability, coaches and sports scientists must use a model to reflect the evolution of the game. At its origins the goal of the strength & conditioning staff is to optimize performance whilst reducing the risk of potential injury. To obtain these goals the performance staff must have a comprehensive understanding of training and match-play demands, as well as a standardized and repeatable test to evaluate neuromuscular outputs. Due to the nature of the game, it is plausible that practitioners use a jumping evaluation to evaluate the effects that match-play has on the athletes' neuromuscular system throughout the competitive season. Some of the more popular metrics to track from jumping tasks are Jump Height (JH), Peak Force (PF), and Reactive Strength Index (RSI). When evaluating the demands of the sporting activity of basketball evaluation of a rapid stretch reflex and stretch-shortening cycle (SSC) is an indicator of specificity and ecological validity, thus justifying the use of RSI in the domain of basketball performance. However, further understanding of training load and match-play demands has on these reactive strength qualities need to be evaluated. Therefore, the present thesis aims to: (1) systematically review the literature to determine training load and match-play demands in basketball relative to competition level; (2) examine the chronicity of fluctuation in neuromuscular outputs during the competitive basketball season; (3) evaluate the acute effects of neuromuscular potentiation had on in-game physical demands. The results of the present compendium of articles concluding that elite level performers have a unique profile as it relates to physical demands in competition. Moreover, through the systematic review, it was concluded that elite level basketball athletes cover less total distance in competition, however, possess the ability move at the fastest peak speeds. Also, it was found that neuromuscular outputs were sensitive to time of year and density of competitions.

Peak speed was an indicator of neuromuscular reediness for competition. Athletes that had greater ergogenic effects in RSI the day before competition had greater peak speeds relative to their normative values the next day. These results could be helpful to practitioners in gaining insight to match-play demands in elite basketball, programming macro cycle to account for game density, and acute facilitation of reactive strength qualities to optimize neuromuscular readiness.

RESUMEN

El baloncesto es un deporte de equipo basado en la cancha que requiere una gran demanda del sistema neuromuscular. El baloncesto ha habido modificaciones recientes que han aumentado el ritmo y el espaciamiento durante la competición. Como resultado de este aumento de la variabilidad del movimiento, los entrenadores y los científicos del deporte deben utilizar un modelo que refleje la evolución del juego. En sus orígenes, el objetivo de los especialistas de fuerza y acondicionamiento físico es optimizar el rendimiento y reducir el riesgo de posibles lesiones. Para conseguir estos objetivos, los preparadores físicos deben tener un conocimiento exhaustivo de las exigencias del entrenamiento y del juego, así como una prueba estandarizada y repetible para evaluar el rendimiento neuromuscular. Debido a la naturaleza del juego, es plausible que los profesionales utilicen una evaluación de saltos para evaluar los efectos que los partidos tienen en el sistema neuromuscular de los atletas a lo largo de la temporada competitiva. Algunas de las métricas más populares para hacer un seguimiento de las tareas de salto son la altura de salto (JH), la fuerza máxima (PF) y el índice de fuerza reactiva (RSI). Al evaluar las exigencias de la actividad deportiva del baloncesto, la evaluación del reflejo de estiramiento rápido y del ciclo de estiramiento-acortamiento (SSC) es un indicador de especificidad y validez ecológica, lo que justifica el uso del RSI en el ámbito del rendimiento en el baloncesto. Sin embargo, es necesario evaluar la carga de entrenamiento y las exigencias de los partidos sobre estas cualidades de fuerza reactiva. Por lo tanto, la presente tesis tiene como objetivo: (1) revisar sistemáticamente la literatura para determinar la carga de entrenamiento y las demandas de juego en el baloncesto en relación con el nivel de competición; (2) examinar la cronicidad de la fluctuación de los rendimientos neuromusculares durante la temporada de baloncesto competitivo; (3) evaluar los efectos agudos de la potenciación neuromuscular en las demandas físicas durante el partido. Los resultados del presente compendio de artículos concluyen que los jugadores de nivel de élite tienen un perfil único en relación con las demandas físicas en la competición. Además, a través de la revisión sistemática, se concluyó que los atletas de baloncesto de élite cubren menos distancia total en la competición, sin embargo, poseen la capacidad de moverse a mayores velocidades máximas. Asimismo, se halló que el rendimiento neuromuscular es sensible a la época del año y a la

densidad de las competiciones. La velocidad máxima es un indicador de la preparación neuromuscular para la competición. Los atletas que tuvieron mayores efectos ergogénicos en la RSI el día anterior a la competición alcanzaron mayores velocidades máximas en relación con sus valores normativos al día siguiente. Estos resultados podrían ser útiles para los profesionales a la hora de conocer las exigencias de los partidos en el baloncesto de élite, la programación del macrociclo para tener en cuenta la densidad de los partidos y la mejora aguda de las cualidades de la fuerza reactiva para optimizar la preparación neuromuscular..

Términos TESAURO:

NEUROMUSUCLAR

FISIOLOGIA DEL EJERCICIO

BIOMECANICA

I - INTRODUCTION

I. INTRODUCTION

Basketball is a court-based team-sport that requires a vast demand of physical parameters and biomotor abilities (1) and is played within a 94 by 50-foot (28 by 15 m) hardwood court. The ability accelerate, decelerate, change directions, jump, and run are principal components to the sporting activity (2-4). These intermittent boughs of high-intensity actions can determine success in both the technical and tactical aspects of competition. Recently, the physical demands of basketball have been studied from both an internal and external perspective (5,7-11). Internal correspond to the physiological response to stress applied during training and competition whereas external load is the mechanical demands imposed during training and competition (86). These measures can be useful in evaluating the individual dose-repose of loads from training and competition for each individual player, as well as monitoring the effects that fitness and fatigue have on match-play performance.

The most common measure of internal load in basketball is heart rate (HR) response which is measured in beats per minute (BPM) and expressed in both mean and maximal values. Abdelkrim et al. (16) measured inter-quarter HR response from the Tunisian National Team. Of note, the lowest average HR per quarter was at the end of competition in the 4^{th} quarter. This could imply that the tactical aspects of the game become more relevant during crucial moments of competition (i.e. more scripted sets offensively). When mimicking training to reflect the demands of competition, this provides a good road map of HR zones to work within scrimmage. López-Laval et al. (11) examined HR response during competition of elite, sub-elite, and youth athletes. Interestingly, the elite population had a significantly lower mean HR when compared to the youth and amateur group. This is likely due to elite athletes having a greater expression of movement economy contextually relative to demands of the sport. Blood lactate concentration is also a popular measure of internal load (9,18,21). Blood lactate is the buildup of metabolic waste during glycogen depletion. These values are expressed in mmol/L. Abdelkrim et al. (9), observed a peak of blood lactate concentration for the Tunisian National Team in the 4^{th} quarter. This is more than likely due to the buildup of blood metabolites and catabolic hormones later in competition. The mechanism of buffering these substrates has been shown to impact performance during competition and negatively affecting whole-body work rate and decision making in team-sports (87).

Mechanical load has also been studied thoroughly within the context of basketball. Distance and speed may be tracked via accelerometry, GPS, and spatial tracking cameras (4,7,13,16). While distance covered during competition can be a useful metric about pace relative to an individual athlete, caution is warranted when using distance to quantify absolute in-game performance in basketball. Scanlan et al. (13) when comparing activity demands of elite and sub-elite competition, found that the sub-elite group covered more distance during competition that their elite counterparts. Based on distance and time, these technologies calculate velocity, which is typically expressed in meters/second ($m \cdot s^{-1}$) and can be displayed by both peak and mean values. The rates of change of velocity (i.e., accelerations or decelerations) are other common variables used to monitor external loads (5,7,10,13). A positive rate of change velocity is considered an acceleration, which are expressed in $m \cdot s^{-2}$. Conversely, a negative rate of change of velocity is considered to be a deceleration. Sampaio et al. (5) investigated All-Star Players versus Non-All-Star players in the National Basketball Association (NBA) and discovered there was a significant discrepancy in average speed on both (the offensive and defensive ends of the court). All-Star players had an average speed of 4.38 mile per hour (mph) offensively and 3.65 mph defensively, whereas Non-All-Star players, had an average speed of 4.50 mph and 3.86 mph. This suggested that given the same number of minutes played, Non-All-Star players would cover more ground than All-Star players in the world's most competitive basketball league. It is for this reason that examining not only total distance, but speed and rate of change of speed is important in evaluating physical performance in basketball.

Time-motion analysis is also a tool to quantify external load within basketball via tracking frequency and duration of movement during competition and practice (4,9,14,18,22,26,32). Movements that are commonly tracked are stand/walk, jog, run, sprint, and jump for different positional demands as well as level of competition. For example, Ferioli et al. (32) and Scanlan et al. (4) examined time motion analysis among elite and sub-elite populations. Upon review, Ferioli et al. (32) found that there was stark contrast between first and second division players as it relates to time spent and frequency in high-speed running and sprinting. Athletes from the 1st Italian Division had frequency of exposures to high-intensity actions (HIA) of 107 ± 26, compared to an average of 78 ± 35 HIA in the second division players. In an investigation of match-play demands in elite versus sub-elite populations, Scanlan et al. (13) observed that elite backcourt and elite frontcourt athletes had much higher frequency of running compared to sub-elite backcourt and frontcourt. The elite backcourt and frontcourt had mean frequencies of 504 ± 38 and 513 ± 26 exposures to running, respectively, during competition. These number are much greater than the sub-elite backcourt (321 ± 75) and sub-elite frontcourt (352 ± 25). Another application of time-motion analysis can be found in literature in studies that have examined positional differences within basketball. Abdelkrim et al. (18) and Puente et al. (26) compared in-game physical demands of guards, forwards, and centers. Abdelkrim et al. (18) found that guards had a greater frequency of running during competition (103 ± 11), when compared to forwards (88 ± 5) and centers (101 ± 19). Puente et al. (26) found that guards run a longer distance 3.1 ± 1.1 (m. min^1) compared to forwards (2.2 ± 1.9) and centers (1.6 ± 1.6). These findings are sensible when one considers the tactical aspect involved within perimeter players relative to constant motion and ball-screen situations during competition.

Understanding the physical demands of match-play in basketball is extremely vital to create an optimal environment for training and the management of fatigue. Once a practitioner has a comprehension of the load imposed on athletes during competition, it is possible to model out what could be the best practice for training and recovery. There are several factors such as frequency of competition, densities of match-play, and time of year that will affect this training model. According to Sampaio et al. (5), the NBA season is comprised of 82 regular season games, which averages out to 3.5 competitions per calendar week. Likewise, depending on the time of year, the NCAA Division I schedule typically has competitions on average around twice per week (38,67,74). This high congestion of match-play makes it very challenging to maximize training and optimize recovery during the season. Therefore, coaches and sports scientist must be precise in the application and quantification of training loads during this time period to achieve optimal adaptations and decrease the risk of injury or overtraining (83).

Similar to match-play, training load can be quantified via both internal and external measures (38,39,41,42). In this regard, HR is one of the most popular measures of quantifying internal training load. Torres-Ronda et al. (12) examined HR_{max}, HR_{ave}, and $\%HR_{max}$ in games of 5vs5, 4vs4, 3vs3, 2vs2, and 1vs1 and found that drills involving 1vs1 elicited a greater physiological response. This is practical when considering the distance that must be covered in 1vs1 drills and the fact that no low-intensity "off the ball" periods exist in such exercises. Gocentas et al. (23) compared inter-positional demands (between guards and forwards) by measuring HR_{max} in different training sessions and found that guards had a higher HR_{max} response (194 ± 14) than forwards (190 ± 12.7). The authors' findings are logical and expected taking into account the previously mentioned research reporting that guards are exposed to higher frequencies of running in competition (12). This type of information could be pertinent when designing position specific training programs.

External training load is frequently expressed through several metrics, two of which are accelerations (ACC) and decelerations (DEC) (35,37,41). Schelling and Torres (47) found that ACC load in 3vs3 and 5vs5 full-court scrimmage drills was greater than 2vs2 and 4vs4 scrimmage drills which suggests that the manipulation of training drills may have a direct impact on the load imposed on the athletes. Tweaking duration or distance parameters, and number of participants in training drills could be an adequate strategy depending on the desired outcome. Svilar et al. (10) investigated the positional differences among guards, forwards, and centers through accelerometery training data. Interestingly, centers had a higher volume and intensity of ACC load when compared to guards and forwards. In contrast, forwards were shown to have a high volume and intensity of DEC load. This suggests that the activity profiles of training and match-play are different depending on situation and positional role. Since there is no standardized time frame of training, there can be huge degrees of variance from club to club. It is for this reason that it is important for practitioners to understand the demands of match-play and make sure they are reflected in training. Ultimately, the intent of practice is to prepare the athlete for competition loads without exceeding one's capacity for said load. Thus, it is imperative for coaches to assess and quantify the loads imposed during these physical endeavours. These metrics are collected with the intent to increase on-court performance and mitigate the risk of potential injury.

Once a foundational base of knowledge exists in regard to training load and match-play demands in basketball, a critical aspect for practitioners is, then, to evaluate the undulating nature of players' physical qualities chronologically based on time of year (57). Examining density patterns of games throughout the calendar week can provide insight to into optimal times to train and provide recovery for each athlete (68,76). Minutes played during competition could be a guiding factor to delineate groups into high-minute versus low-minute. This, in turn, can be a barometer to determine which athletes need more recovery and which athletes need to supplement fitness menu items on non-game days. González et al. (72) observed that players who played more than 25-min per game across an entire NBA season increased vertical jump power and improved reaction time from pre- to post- season. These finding suggest that athletes that are not exposed to high rate of game demands throughout the training week may need a segregate stimulus of power to maintain game readiness if called upon for competition. For this reason, monitoring training loads throughout the competitive season is paramount in optimizing performance. Different types of training can have a potentiation or derogation effect on the neuromuscular system. Heishman et al. (38) found that, within collegiate basketball, timing of training had an impact in CMJ power outputs, where neuromuscular (NM) outputs were subject to change during afternoon training sessions. These findings would suggest that the application of training loads can be deleterious to performance outputs and result in NM fatigue. Therefore, how sports scientist and strength and conditioning coaches monitor fatigue in-season is paramount to on-court performance.

The fatigue, defined as an exercised-induced impairment on performance (49), can be ambiguous in nature at times given that it is typically multifactorial (78). Within basketball fatigue has shown to have deleterious effects on free throw percentage (6). Proper management of fatigue is vital during the competitive season to optimize performance and mitigate potential risk of injury (83). Due to the chaotic nature of basketball and volume of ACC, DEC, and COD tease out fatigue and know when to prioritize recovery (60,61). Fatigue is a task dependent phenomenon that can be both central and peripheral in nature. Central fatigue refers to the decreased ability to recruit high threshold motor units. A motor unit consists of an alpha motor neuron and articulating muscle fibers (64,65). Motor unit synchronization, rate coding, and size principle all are factors governed by these central properties. The blunting of these functions can decrease outputs and ultimately have maladaptive qualities on performance. Peripheral fatigue, on the other hand, refers to a decrease in force producing capabilities from the contractile proteins (67). Peripheral fatigue is typically caused by a buildup of metabolic waste at the tissue (65).

Measuring readiness and fatigue during the competitive season of basketball is common practice (70,71). Based on the demands of the sporting activity, having a standardized and repeatable test to assess neuromuscular function can provide ecological validity to the effects of training load and match-play demands on basketball athletes (72-74). Schelling and Torres-Ronda (1) found that basketball athletes are exposed to roughly 45 jumps during competition. For this reason, using a jump test in basketball to measure neuromuscular function is logical as it replicates movement patterns that are frequently performed during match-play. Previous research has utilized vertical jumps as a tool to gauge and quantify neuromuscular fatigue in team-sports mainly through the use of the countermovement jump (CMJ) as the primary tool (79-82). However, due to the short ground contact times that characterize jumping in basketball and the reliance on stretch shortening qualities, repeat jump assessment may have a higher level of specificity relative to the tasks of the sport.

In regard to measuring fatigue and readiness within a repeat jump assessment the ratio of flight time to ground contact time can be used as an indicator of neuromuscular outputs (69,74). When time spend on the ground is increased, and flight time is decreased this could be a sign of neuromuscular fatigue (73). Conversely, when flight time is increased, and ground contact time is reduced this could be a sign of high neuromuscular readiness (84,85). Ultimately, the goal of this assessment is to jump as high as possible while spending minimal time on the ground. From an applied perspective, this information could be used to provide more precise prescription of training and recovery strategies and practitioners can use the training calendar to assess how these variables fluctuate from both an acute and chronic standpoint throughout the competitive season.

In fact, within basketball, a standardized and repeatable jumping assessment can have an impact on decision making (89,90,91) which is why practitioners collect and analyze jump data throughout the competitive season (90-92). These measures must be taken with a high rate of frequency (due to the sensitivity of neuromuscular outputs based on environmental factors) and the data collected must be valid and reliable. In this sense, practitioners should take into consideration that, according to the current state of the literature, force platform jump analysis is considered the gold standard. The use of this instrumentation is particularly relevant considering that jump height alone does not always indicate an athlete's state of neuromuscular readiness as movement strategies can be altered to produce similar outputs. Gathercole et al. (95) reported that neuromuscular function alterations 24 h after a fatiguing protocol were not detected using jump height alone and suggested that complementary variables such as the ratio of Flight Time: Contact Time should be assessed. Furthermore, a recent study by Spyrou et al. (117) found that after the COVID lockdown jump height was not affected; however other kinetic variable such as eccentric deceleration impulse, rate of force development, peak power, and landing peak force showed significant declines based on the hiatus. Within this context, assessing variables outside of jump height could be a pragmatic approach to monitor fatigue and neuromuscular readiness within the basketball competitive season.

As previously mentioned, basketball requires reflexive eccentric movements and high contribution from the stretch-shortening cycle (SSC) (1). The mechanical benefits of this rapid pre stretch have been thoroughly studied. For example, in 1963, Verkoshansky (55) used a squat jump, a countermovement jump, and a drop jump to examine which method yielded a greater displacement of the center of mass. In his findings, Verkoshansky wrote that the best jump performances were elicited by the drop jump rather than the CMJ or squat jump. This phenomenon was again replicated in 1979 by Komi et al. (56). Bobbert et al. (111) found that the work done by a muscle shortening at a given velocity was greater if the shortening was proceeded by a stretch during stimulation. These findings suggest that the force generated by the contractile components are greater if the muscle shortens after being stretch as opposed to starting from a static condition. Furthermore, Asmussen and Bonde-Petterson (112) found that when performing two separate jump tasks, one CMJ and one repeat jump, the second jump was higher than the first in the repeated-jump task. This data showed that the height of the second jump of two successive actions was greater than that obtained by a single CMJ. The hypothesis was the stored elastic energy of the rapid downward movement of the second jump allowed for greater takeoff velocity yielding greater outputs.

Following this rationale, although the CMJ has been the most commonly used jump assessment within basketball (87), it is sensible that using a repeat jump and hop task to assess neuromuscular function is more specific to the demands of the sporting activity. How basketball athletes utilize the series elastic components of the tissue is not always reflected within a CMJ. To circumvent this technical issue, repeat jumping and hopping task can be used to facilitate high vertical ground reaction forces in short ground contact times. In fact, the reactive strength index (RSI) (i.e., ratio of jump height/contact time), has been previously used to assess performance and fatigue within athletic populations (69,80, 79). This metric has been shown as a valid and reliable measure of lower body power output. Markwick et al. (113) found high intraday reliability of RSI from varying drop jump heights in professional men's basketball. Flanagan et al. (114) proposed that the use of ground contact times to modulate plyometric training yield superior results based on the reliance of fast rate of eccentric stretching from muscle spindle reflexes. These qualifying measures have also been used to express lower-leg stiffness during running and jumping task. Lloyd et al. (115) found RSI during sub-maximal hopping to be a valid and reliable measure of leg stiffness in youth athletes. Based on the present information, it is plausible that RSI is a valid and reliable way to assess neuromuscular function in basketball with a high degree of specificity.

When trying to understand neuromuscular readiness in basketball, it is worth noting that, along with jumping, running is also a principal component as it relates to basketball performance (57,62, 81,88). Although basketball is played within a 28 by 15-m court, the ability to express high rates of acceleration can provide extreme tactical advantages as it relates to positional demands of the sport (1,4,5,8). The athlete that can produce large amounts of force in minimal time has a distinct advantage over their opponent. Using distance and time can also be of value from an evaluation standpoint (2,10,15,28). If an athlete is taking more time to cover the same distance this may be a sign of residual fatigue (118). Conversely, if an athlete is covering more distance in the same amount of time this maybe an indication status of high neuromuscular readiness. Peak velocity is an instantaneous value to measure one's horizontal displacement of center of mass through time and space. Evaluating this metric throughout the competitive season can give practitioners insight on fluctuations in neuromuscular outputs that could affect recovery and training strategies (97-99). Previous research (95, 102, 103,105) has examined the relationship between jump outputs and sprint performance and found them to be intrinsically associated. Both running and jumping large distances in short amounts of time can put athletes in better positions to make plays during in-game situations. It is for this reason that both vertical and horizontal displacement of one's center of mass should be examined during basketball competition (1,8). Considering this information the question arises: what effect does training and match-play demands have on basketball athletes' neuromuscular system?

In summary, based on the previously exposed, understanding basketball training load and match-play demands, as well as how these affect players' neuromuscular performance during the season is crucial to help strength and conditioning coaches optimize training and recovery strategies. Therefore, the present thesis aims to: 1) systematically review the literature to evaluate training load and match-play demands in basketball; 2) determine whether game demands vary across a competitive season in collegiate basketball; 3) investigate how neuromuscular performance variables chronically fluctuate based on frequency of match-play and density of competition throughout an entire season and 4) examine the acute onset of neuromuscular adaptations as it relates to match-play physical performance of basketball players.

II - HYPOTHESES

II. HYPOTHESES

2.1. GENERAL HYPOTHESES

The general hypotheses of the present study were that a systematic review of the literature would provide clarity of distinct activity profiles as it relates to athletes that are effective in basketball competition. Moreover, from a performance standpoint and based on data from previous investigations, it was hypothesized that external factors (i.e., acute readiness and chronic fatigue) affect these profiles, and that neuromuscular performance fluctuates based on time of year and density of competitions in basketball. Acute readiness being defined as the physiological state at a given movement; whereas chronic preparedness refers to the ability of the athlete to tolerate the totality of loads throughout the entire season. Finally, it was also hypothesized that these fluctuations in neuromuscular outputs manifest themselves in match-day activity profiles.

2.2. SPECIFIC HYPOTHESES

The specific hypotheses outlined for each of the studies included in the present thesis are presented below:

Study 1:

- Basketball match-play demands and activity profiles are different across levels of competition.
- Training age is a factor as it relates to physical demands associated with basketball.
- Distance and peak speed differ across elite, sub-elite, and youth populations.
- Training load imposed in basketball is highly variable based on contextual differences during practice.

Study 2:

- Neuromuscular outputs fluctuate based on time of year and schedule.
- Neuromuscular outputs decrease with an increased density and congestion of match-play.
- Match-play physical demands are consistent regardless of time course in the competitive season.

Study 3:

- Physical demands in competition are affected by the training session the day prior.
- Neuromuscular outputs collected pre- and post-practice may provide meaningful information regarding the athletes' ability to express high physical demands in ensuing competitions.
- Fluctuations in neuromuscular outputs would uniformly rise and fall with higher and lower physical activity profiles in match-play.

III - OBJECTIVES

III. OBJECTIVES

3.1. GENERAL OBJECTIVES

Considering the hypotheses previously outlined, and within the general objectives of this thesis, the present compendium of articles aims to systematically review the state of the literature with regards to basketball training load and match-play demands based on competition level. Moreover, it aims to investigate the seasonal variations in game activity and players' neuromuscular performance in collegiate basketball in order to determine best practice for fatigue management and optimal windows of trainability. Lastly, it aims to determine whether specific neuromuscular outputs assessed before and after training could discriminate superior in-game performances.

3.2. SPECIFIC OBJECTIVES

The specific objectives outlined for each of the studies included in the present thesis are presented below:

Study 1:

- To systematically review the literature on training load and match-play demands in basketball.
- To identify activity profile trends based on competition level and training age.
- To examine training loads and competition from elite, sub-elite, and youth participants.
- To investigate variances in training load versus match-play demands.

Study 2:

- To examine the seasonal variations in neuromuscular outputs and match-play demands.

- To analyze the effects that schedule congestion and density of competition has on the neuromuscular system.
- To investigate the acute effects of a Conference versus Non-Conference schedule on the neuromuscular system in NCAA Division I Basketball.

Study 3:

- To investigate how in-game physical demands are affected by players' neuromuscular readiness assessed on Match Day-1.
- To examine if neuromuscular outcomes collected pre- and post-practice can discriminate the athletes' physical activity profiles in game.
- To investigate the effects that Reactive Strength qualities Match-Day -1 had on speed during competition the following day.

IV – GENERAL OVERVIEW OF THE STUDIES

IV. GENERAL OVERVIEW OF THE STUDIES

STUDY Nº 1:

TRAINING LOAD AND MATCH-PLAY DEMANDS IN BASKETBALL BASED ON COMPETITION LEVEL: A SYSTEMATIC REVIEW

Abstract

The main aim of the present systematic review is to investigate the training and match-play demands of basketball in elite, sub-elite, and youth competition. A search of five electronic databases (PubMed, SportDiscus, Web of Science, SCOPUS, and Cochrane) was conducted until December 20th, 2019. Articles were included if the study: (i) was published in English; (ii) contained internal or external load variables from basketball training and/or competition; and (iii) reported physiological or metabolic demands of competition or practice. Additionally, studies were classified according to the type of study participants into elite (20), sub-elite (9), and youth (6). A total of 35 articles were included in the systematic review. Results indicate that higher-level players seem to be more efficient while moving on-court. When compared to sub-elite and youth, elite players cover less distance at lower average velocities and with lower maximal and average heart rate during competition. However, elite-level players have a greater bandwidth to express higher velocity movements. From the present systematic review, it seems that additional investigation on this topic is warranted before a "clear picture" can be drawn concerning the acceleration and deceleration demands of training and competition. It is necessary to accurately and systematically assess competition demands to provide appropriate training strategies that resemble match-play.

STUDY Nº 2:

SEASONAL VARIATIONS IN GAME ACTIVITY PROFILES AND PLAYERS' NEUROMUSCULAR PERFORMANCE IN COLLEGIATE DIVIDION I BASKETBALL: NON-CONFEREENCE VS. CONFERENCE TOURNAMENT

Abstract

This study aimed to examine the seasonal variations on game demands and players' neuromuscular performance during the Non-Conference (NON-CONF) and Conference (CONF) seasons in NCAA Division I Men's Basketball. Seven NCAA Division I Basketball players' (20±1.2 years, 1.95±0.1 m, and 94 ± 15 kg) match activity profiles were tracked in 17 home games (7 NON-CONF; 10 CONF); furthermore, players performed a repeat hop test on a force platform the day before competition to assess neuromuscular performance. A *t*-test for paired samples was used to analyze the differences between NON-CONF and CONF. Results indicated no significant differences in Total Distance, Peak Speed, Acceleration, and Deceleration loads when comparing NON-CONF and CONF match-play. Regarding neuromuscular performance, Jump Height ($p = 0.03$; ES = 0.43) was negatively affected during CONF. Moreover, a trend toward a decline in Peak Force ($p = 0.06$; ES = 0.38) was found in CONF. Conversely, no differences were obtained regarding Reactive Strength Index and Contact Time. In conclusion, match-play demands remained constant across the season whilst neuromuscular outputs were inhibited during the CONF season.

STUDY Nº 3:

MATCH DAY-1 REACTIVE STRENGTH INDEX AND IN-GAME PEAK SPEED IN COLLEGIATE DIVISION I BASKETBALL

Abstract

The objective of this study was to examine whether repeated jump assessments the day prior to competition (MD-1) could discriminate between fast and slow in-game performances the following day. Seven NCAA Division I Basketball athletes (4 guards and 3 forwards; 20 ±1.2 years, 1.95 ±0.09 m, and 94 ± 15 kg) performed a repeated- hop test on a force platform before and after each practice MD-1 to assess Reactive Strength Index (RSI) and Jump Height (JH). Peak speed was recorded during games via spatial tracking cameras. A median split analysis classified performance into FAST and SLOW relative to individual in-game peak speed. Paired *T*-tests were performed to assess post- to pre-practices differences. An independent sample *T*-test was used to assess the differences between FAST and SLOW performances. Cohen's d effect sizes (ES) were calculated to determine the magnitude of the differences. Statistical significance was set for $p \leq 0.05$. Post-practice RSI and JH were significantly higher than pre-training values prior to the FAST but not the SLOW in-game performances. A significant difference was found for MD-1 RSI when comparing FAST and SLOW conditions ($p = 0.01$; ES = 0.62). No significant between-group differences were obtained in JH ($p = 0.07$; ES = 0.45). These findings could have implications on the facilitation of reactive strength qualities in conjunction with match-play. Practitioners should evaluate the placement of stimuli to potentiate athlete readiness for competition.

V – STUDY 1

V. STUDY 1:

TRAINING LOAD AND MATCH-PLAY DEMANDS IN BASKETBALL BASED ON COMPETITION LEVEL: A SYSTEMATIC REVIEW.

5.1. INTRODUCTION

Basketball is a court-based team-sport that requires proficiency in a vast array of physical parameters and motor abilities (i.e., speed, strength, and endurance) to achieve success from both a technical and tactical standpoint (1). The ability to accelerate, decelerate, change direction, jump, and shuffle are paramount for on-court success, due to the intermittent high- intensity nature of most actions and basketball-specific movements (2,3) as well as the demands of the sporting activity (4,5,6). Importantly, in competition settings, the aforementioned abilities must be expressed in an efficient and economical manner over the course of four quarters with contributions from both aerobic and anaerobic energy pathways (1). In this context, the density of game-related activity (determined by specific work-to-rest ratios) is dictated by action intensity and by the moment of the game (7). This includes medium- to high- intensity actions that last 15 seconds (s) and high- to maximal-intensity actions that last up to 2–5 s (8,9). It is for this reason that practitioners must have a precise overview of match-play demands as well as the load elicited during training (2,3,4,5,6,10, 11,12,13,14,15). In fact, over the past years, there have been several studies documenting match-play demands in basketball (2-7, 9-28). Particularly, a recent review by Stojanovic et al. (29) analyzed the activity demands and physiological responses obtained during basketball competition and found that playing period, playing position, level, geographical location and sex greatly influenced the stress experienced by basketball players. In their article Stojanovic et al. (29) examined HR, blood lactate concentration, total distance, and movement patterns of male and female basketball competitions based on time-motion analysis. However, while the study clearly described the competition characteristics, the authors did not present data on the acceleration/deceleration requirements of the game nor did they examine the demands of training versus match-play. It is for these reasons that the current systematic review is justified.

It is important to note that amongst the several methods used to quantify the demands of play, and regarding internal load quantifications, HR (3,6,11,12,14,20) and blood lactate concentration (4,13,14,16,9,30) were the most frequently used. In fact, internal variables such as average and maximal HR can be extracted to quantify loading parameters during match-play (11,12,21,30,26). Concerning external load, methods such as accelerometery and the use of positional tracking cameras (2,4,7,13,16,17,31) are amongst the most common. Within this frame- work, total or high-intensity accelerations and decelerations, total distance travelled, and top speed reached were the widely used variables to assign a value to the mechanical load imposed. In addition, time-motion analysis (4,9,14,18,22,26,32) measuring time and frequency of movements such as "standing"; "jogging"; "running"; "sprinting"; and "jumping" during competition can be found in the literature. Despite match-play demands based on time-motion analysis having been found to present a high level of variability according to playing position, skill level and training age (29), no robust evidence exists regarding the use of accelerometery. Therefore, a systematic analysis of both approaches to match demands quantification is war- ranted. Collectively, a better understanding of this 'real-time' feedback can give relevant and useful information concerning normative group standards, as well as relative to the individual athlete. Additionally, having a clear "picture" of both internal and external loading parameters can provide a better insight into global stress that the players deal with during training and competition (2,10,26).

In a related topic, tracking training load in this team-sport may be of extreme importance to ensure that the players are physically prepared for competition demands from a fitness standpoint, in order to avoid acute spikes in load from a fatigue and injury prevention perspective (3,7,11,17) and to provide individualized recovery strategies (33,34). With this in mind, a copious amount of research has also been focused on investigating and describing basketball training load parameters over recent years (21,24,35,36,37,38,39,40,41,42,43,44). As previously mentioned for competition, accelerometery is becoming an increasingly popular means of quantifying load during training (21,36,38,40); however, no conclusive data has been reported throughout the different studies. For this reason, a more in-depth and systematic analysis of the literature is warranted. Regarding internal load, HR and session rate of perceived exertion (sRPE) (i.e., the subjective feedback from the player on a 1–10 scale multiplied by duration of training) have been shown to be a cost-effective way of providing valuable information widely used by coaches and sport scientists (35,37,41). Remarkably, an important variability has been reported within basketball training loads based on quantification means of training load, position, perceived exertion, skill level, and training age (36,37,38,39,40,41,43,44), once again identifying the need for a systematic review of the published data.

The current state of the scientific literature is not conclusive regarding to the typical training load experienced by basketball players of different competition levels given that only match-play demands and physiological responses during competition have been previously described (29). To the best of the author's knowledge, no previous investigation has focused on systematically reviewing the literature to identify precise loads during training versus match-play whilst clearly defining different levels of competition. As such, there is an important gap in the available research that does not allow concluding whether basketball training is closely mimicking game demands, hence, adequately preparing players for the stress imposed by competition. Moreover, new technologies that allow quantifying the acceleration/deceleration demands in basketball training and competition have emerged, but no current literature review has addressed this topic. Therefore, the aim of the present systematic review is to analyze the evidence related to the training load and match-play demands of basketball across different levels of competition.

5.2. METHODS

5.2.1. Study design

The present study is a systematic review focused on training load and match-play demands at different levels of competition in basketball. The review was not registered prior to initiation, was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) statement (45) and did not require Institutional Review Board approval.

5.2.2. Search strategy

A structured search was carried out in PubMed, PubMed Central, Web of Science, SportDiscus and Cochrane databases, all high-quality databases which guarantees strong bibliographic sup- port. The electronic database search for the related articles considered all publications prior to December 20th, 2019. The following key words were used to conduct the search "basketball", "training load", "accelerometry", "load monitoring", "internal load", "total distance", "average distance", "top speed", "average speed", "metabolic", "heart rate", "competition demands", "training demands", "training", and "rate of perceived exertion". In addition, the key word "basketball" was present in each search to ensure that the relevant information was catered to articles involving only this sport. The reference sections of all identified articles were also examined (by applying the "snowball methods" strategy (40)). Once the electronic search was conducted, relevant studies were identified and organized in a systematic fashion.

All titles and abstracts from the search were cross-referenced to identify duplicates and any potential missing studies, and then screened for a subsequent full-text review. The search for published studies was independently performed by two authors (AP and TTF) and disagreements were resolved through discussion.

5.2.3. Inclusion and exclusión criteria

This review included cross-sectional and longitudinal studies considering healthy, professional or junior, male basketball players. Study participants were categorized into three groups: elite, sub-elite, and youth. The elite basketball group was defined as teams participating in the NBA, NBA G-League, NCAA Division I, Euro League, FIBA International Competition, ACB, Top Divisions in Europe, South America, Australia, and Asia. Sub-elite was defined as professional or semi-professional that did not meet the elite criteria but were over 19 years old. Youth was considered for studies in which the participants were all 19 years of age or younger. Studies were included in the present review if they met the following criteria: (i) the study was published in English; (ii) the study included internal or external load variables from basketball training and/or competition; and (iii) the study reported physiological or metabolic demands of competition or practice.

Studies were excluded if (i) the study participants were wheelchair basketball players; (ii) the study participants were female; (iii) the data being collected did not describe training load or competition demands; and (iv) the study consisted on a review or a conference proceeding.

5.2.4. Study selection

The initial search was conducted by one researcher (AP). After the removal of duplicates, an intensive review of all of the titles and abstracts obtained were conducted. Following the first screening process, the full-version of the remaining articles was read. Then, on a blind, independent fashion, two reviewers excluded studies not related to the review's topics and deter- mined the studies for inclusion (AP and TTF), according to the criteria previously established. If no agreement was obtained, a third party intervened and settled the dispute. Moreover, PEDro scale was used to evaluate whether the selected randomized controlled trials were scientifically sound (9–10 = excellent, 6–8 = good, 4–5 = fair, and <4 = poor) (46). Papers with poor PEDro score were excluded. Final outcomes of the interventions were extracted independently by two authors (AP and TTF) using a customized spreadsheet (Microsoft Excel 2016, USA). Disagreements were resolved through discussion until a consensus was achieved.

5.3. SEARCH RESULTS

As several databases were scrutinized, the initial database search yielded 18,805 citations. After duplicate removal, 3,282 abstracts and titles were left for review. Upon screening, 165 articles met the inclusion criteria for full-text review. Of the 165 articles reviewed, 35 met the criteria for the systematic review. Of the 35 articles that met the criteria, 12 had participants for elite competition demands (4,5,6,7,9,11-16,30,32), 16 articles had participants for elite training load (2,3,10,12,15,20,25,27,35,37,38,39,41,42,43,47), 6 for sub-elite competition demands (4,11,13,21,26,32), 3 for sub-elite training load (23,44,48), 5 for youth competition demands (9,11,18,22,28) and 1 for youth training load (24). A full view of the search and selection process can be found in the PRISMA flow diagram (45) in Fig 2.

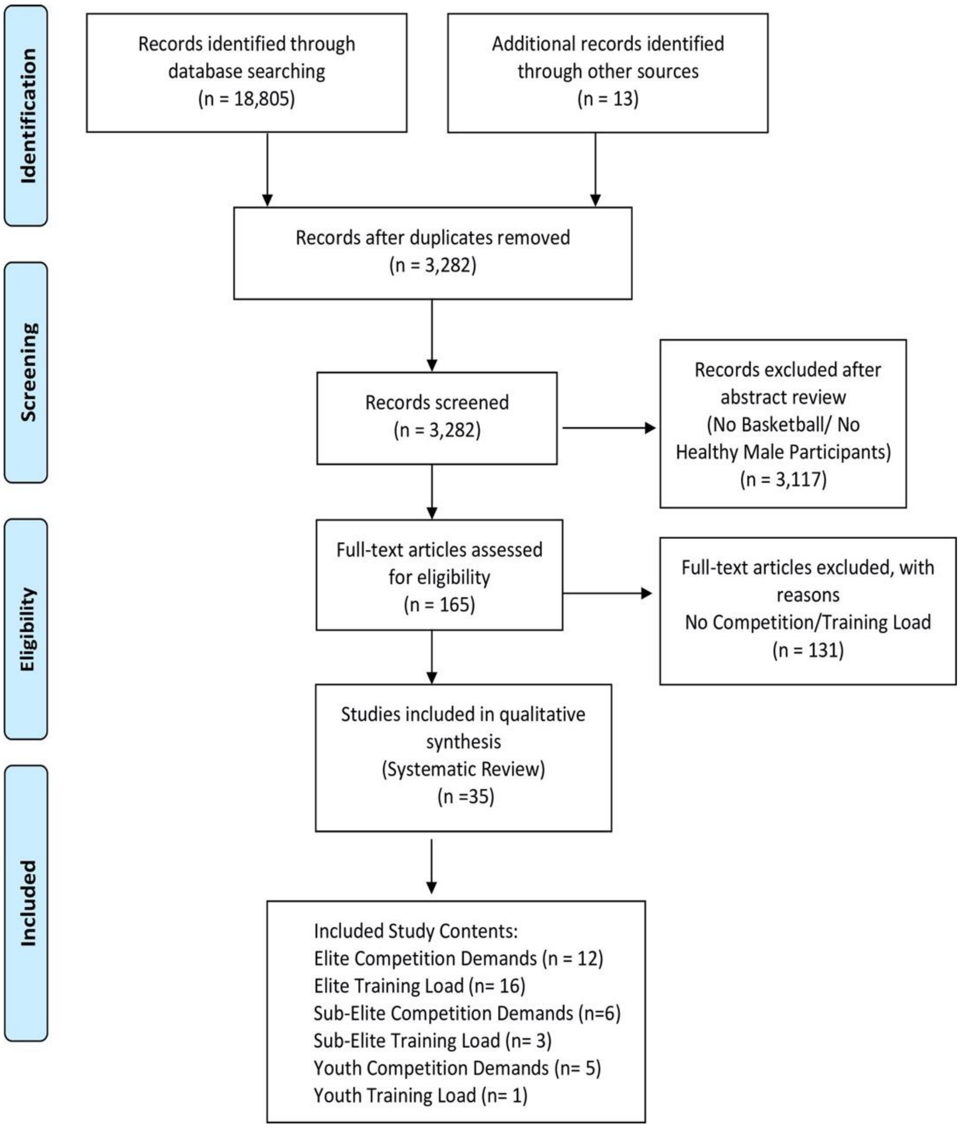

FIGURE 1. PRISMA flow diagram.

5.4. COMPETITION DEMANDS

5.4.1. Internal Competition Demands

Internal load outcomes pertaining to competition demands can be found in Table 1. The variables displayed in the different studies consisted of HR and blood lactate concentration.

Table 1. Internal load during competition.

Study	Competitions (n=)	Participants (Competition Level)	% of HR Lactate Threshold	Mean HR (beats/min)	Max HR%	Max HR (beats/min)	Blood Lactate Concentrate (mmol/l)
Daniel et al. [6]	n = 6	Brazilian Basketball League (Elite)	Defense- 104.2 ± 2.21 Offense- 103.7 ± 1.80 Defense Transition- 104.8 ± 2.44 Offense Transition- 104.3 ± 3.55				
Lopez-Laval et al. [11]	n = 3	SpanishACB League/ABA/Spanish Juniors(Elite/Sub-Elite/Youth)		Elite Adults- 150 ± 11 Amateur Adults- 168 ± 9 Elite Juniors- 167 ± 10	Elite Adults- 79 ± 4 Amateur Adults - 87 ± 3 Elite Juniors- 84 ± 4	Elite Adults- 190 ± 2 Amateur Adults- 193 ± 4 Elite Juniors- 199 ± 3	
Abdelkrim et al. [18]	n = 9	Tunisian U-19 National Team (Youth)		All Positions- Q1-173 ± 4 Q2-173 ± 5 Q3-173 ± 4 Q4-167 ± 4 Guards- Q1- 176 ± 4 Q2- 176 ± 5 Q3- 176 ± 4 Q4- 167 ± 4 Forwards- Q1- 173 ± 5 Q2- 173 ± 5 Q3- 174 ± 4 Q4- 167 ± 4 Center- Q1- 171 ± 3 Q2- 170 ± 3 Q3- 171 ± 4 Q4- 165 ± 4	All Positions- 91 ± 2		Mean-5.49 ± 1.24 mmol/l
Torres-Ronda et al. [12]	n = 7	Spanish ACB League (Elite)		158 ± 10	96.8 ± 2.6	198 ± 9.3	
Abdelkrim et al. [9]	n = 6	Tunisian Junior National Team (Youth)					Mean-5.75 ± 1.25 mmol/L Peak- 6.22 ± 1.34
Abdelkrim et al. [30]	n = 6	Tunisian National Team (Elite)		Q1-176 ± 5 Q2-176 ± 4 Q3-176 ± 4 Q4-172 ± 4			
Narazaki et al. [21]	n = 1	NCAA Division II (Sub- Elite)		169.3 ± 4.5			4.2 ± 1.3mmol/L
Puente et al. [26]	n = 1	Spanish Basketball Federation (Sub-Elite)			Guards- 89.6 ± 4.7 Forwards- 87.8 ± 3.2 Centers- 92.7 ± 4.7 Whole Group- 89.8 ± 4.4		

Heart Rate (HR) expressed in Beats Per Minute (BPM). Blood Lactate Concentrate express in millimoles per liter mmol/L. Q1 is 1st

5.4.1.1. Internal Load During Competition Heart rate

HR during competition (Table 1) was organized into two categories according to the classification used in the included studies: maximal (HR_{max}) and average HR (HR_{ave}). The values of HR_{max} during elite level competition ranged from 187 to 198 beats per minute (BPM) with a mean of 190 BPM (11,12,30). With regards to sub-elite competition, values ranged from 192 to 195 BPM with a mean of 194 BPM (11,21,26). In addition, in youth competition, the HR_{max} held a mean of 199 BPM (11,18). The data extracted indicated that elite competitors presented lower HR_{max} values during competition, which can be interpreted as an indicator of elite players having a higher overall level of fitness and a more efficient work rate compared to sub-elite and youth players (11). Interestingly, according to the results retrieved from the literature, the same pattern occurred with the HR_{ave}. During elite level competition the value ranged from 150 to 175 BPM (11,12,30), in sub-elite competition ranged from 168 to 169 BMP (11,21) and in youth competition the HR_{ave} ranged from 167 to 172 BPM (11,18).

5.4.1.2. Blood lactate concentration

Blood lactate concentration was collected as an internal measurement during select studies of elite level competition. The samples for mean blood lactate post-competition held an average of 5.1 ± 1.3 mmol/L (9,18,21) with a range of 4.2 to 5.7 ± 1.2. Abdelkrim et al. (9) observed a peak of 6.2 ± 1.3 in the fourth quarter for the Tunisian National Team. The fourth quarter peak is likely due to the build-up of blood metabolites and catabolic hormones based on the depletion of muscle glycogen later in competition. The ability to buffer these mechanisms internally may have had a direct impact on mechanical outputs during competition (30) as internal load parameters leading to fatigue have been reported to negatively affect whole-body work rate, physical and technical performance, and even decision making in team-sports (49). It is for such a reason that there is a need for future investigation of blood metabolite accumulation during competition and the effects it has on high-speed running.

Table 2. External load during competition.

Study	Competitions (n=)	League (Level)	Average Speed	Max Speed	Total Distance	Accelerations	Decelerati
Sampaio et al. [5]	n = 1230	NBA (Elite)	Speed in offense (m/s) All-Star 1.95 ± 0.16 Non-All-Star 2.01 ± 0.12 Speed in defense (m/s) All-Star 1.63 ± 0.07 Non-All-Star 1.72 ± 0.08				
Scanlan et al. [13]	n = 5	Australian NBL/ Queensland State Basketball League (Elite/ Sub-Elite)			Professional Quarter 1–1653 ± 38 Quarter 2–1591 ± 24 Quarter3-1531 ± 72 Quarter 4–1504 ± 21 Semiprofessional		
Vázquez-Guerrero et al. [27]	n = 2	Spanish ACB League (Elite)				PGs- Acc. (<3 m/s^{-2}) #/min- 29.6 ± 3.9 Acc. (>3 m/s^{-2}) #/min- 1.4 ± .9 SGs- Acc. (<3 m/s^{-2}) #/min- 32.7 ± 11 Acc. (>3 m/s^{-2}) #/min- 1 ± .4 SFs- Acc. (<3 m/s^{-2}) #/min-26.7 ± 2.6 Acc. (>3 m/s^{-2}) #/min-.8 ± .3 PFs- Acc. (<3 m/s^{-2}) #/min- 28 ± 5 Acc. (>3 m/s^{-2}) #/min- 1.4 ± .5 Cs- Acc. (<3 m/s^{-2}) #/min- 28.3 ± 1.1 Acc. (>3 m/s^{-2}) #/min- 1.5 ± .4	PGs- Dec. (<-3 m/s^{-2}) #/min- 23.8 ± 3.6 Dec. (>-3 m/s^{-2}) #/min- 4.5 ± 1.4 SGs- Dec. (<-3 m/s^{-2}) #/min-25.7 ± 10 Dec. (>3 m/s^{-2}) #/min- 4.5 ± 1.4 SFs- Dec. (<-3 m/s^{-2}) #/min- 21.7 ± 2.2 Dec. (>-3 m/s^{-2}) #/min- 3.2 ± .7 PFs- Dec. (<-3 m/s^{-2}) #/min- 24 ± 4.6 Dec. (>-3 m/s^{-2}) #/min- 3.5 ± .7 Cs- Dec. (<-3 m/s^{-2}) #/min- 23.4 ± 1.3 Dec. (>-3 m/s^{-2}) #/min- 3.7 ± .8
Svilar et al. [15]	n = 11	Spanish ACB League (Elite)				tACCmin- 2.19 ± 0.84 (2.07–2.31) hACCmin- 0.38 ± 0.25 (0.34–0.42)	tDECmin- 2.38 ± 0.63 (2.28–2.47) hDECmin- 0.25 ± 0.19 (0.22–0.28)
Caparrós et al. [7]	n = 87	NBA (Elite)		Average- 8.09 ± 0.44 (m/s) Minimum- 6.79 (m/s) Maximum- 8.76 (m/s)		Acceleration- .5 (m/s^{-2})- 262.5 ± 97.9 1 (m/s^{-2})- 90.2 ± 34 2 (m/s^{-2})- 12.8 ± 34 4 (m/s^{-2})- 0.7 ± 1.0	Deceleration- -.5 (m/s^{-2})- 172.7 ± 62.7 -1 (m/s^{-2})- 112.3 ± 39.1 -2 (m/s^{-2})- 6.6 ± 3.6 -4 (m/s^{-2})- 0.3 ± 0.6

(Table 2 Continued)

Abdelkrim et al. [16]	n = 6	Tunisian National Team (Elite)		Peak Speed- (m/s) PG- 5.2 ± .52 (4.02–5.76) SG4.60 ± 0.42 (4.02–5.29) SF- 4.69 ± 0.63 (4.02–5.76) PF- 4.72 ± 0.61 (4.02–5.76) C- 4.10 ± 0.35 (3.78–4.79)	PG- 2,724 ± 711 (1,120–3,480) SG- 1,907 ± 577 (1,120–2,840) SF- 2,031 ± 867 (1,120–3,480) PF- 2,067 ± 837 (1,120–3,480) C- 1,227 ± 484 (800–2,160)		
Puente et al. [26]	n = 1	Spanish Basketball Federation (Sub- Elite)		Max Speed (m/s) Guards- 6.6 ± 0.4 (5.9–7.3) Forwards- Max Speed- 6.2 ± 1.1 (5.1–8.5) Center- Max Speed- 5.9 ± 0.4 (5.1–6.3) Whole group- Max Speed- 6.2 ± 0.7 (5.0–8.5)			
Abdelkrim et al. [9]	n = 6	Tunisian National Team (Elite)			Total Distance 7,558 ± 575 (6,338–8,397). 1st half- 3,742 ± 304 2nd Half- 3,816 ± 299 m		
Vázquez-Guerrero et al. [28]	n = 13	Euro League U- 18 (Youth)		Peak Speed (km/h^{-1}) Guards- Q1- 19.57 ± 0.9 Q2- 19.56 ± 1.3 Q3- 19.64 ± 0.8 Q4- 19.36 ± 1.0 Forwards- Q1- 19.35 ± 1.0 Q2- 39.34 ± 1.0 Q3- 18.92 ± 0.3 Q4- 19.15 ± 1.0 Center- Q1- 19.16 ± 0.8 Q2- 18.82 ± 1.0 Q3- 18.75 ± 1.0 Q4- 19.07 ± 0.9	Total Distance/Playing Duration Guards- Q1- 80.46 ± 7.5 Q2- 73.91 ± 8.9 Q3- 76.81 ± 8.4 Q4- 70.00 ± 9.8 Forwards- Q1- 78.91 ± 10.0 Q2- 71.90 ± 9.0 Q3- 71.98 ± 11.2 Q4- 69.15 ± 13.8 Centers- Q1- 73.45 ± 12.9 Q2- 69.10 ± 7.9 Q3- 68.95 ± 9.4 Q4- 64.24 ± 8.5	Acc. > 2 (m/s^{-1}) Guards- Q1- 2.20 ± 0.6 Q2- 1.99 ± 0.6 Q3- 1.95 ± 0.5 Q4- 1.72 ± 0.4 Forwards- Q1- 2.04 ± 0.6 Q2- 1.83 ± 0.5 Q3- 1.72 ± 0.5 Q4- 1.66 ± 0.6 Centers- Q1- 1.76 ± 0.6 Q2- 1.64 ± 0.4 Q3- 1.44 ± 0.3 Q4- 1.26 ± 0.4	Dec. > -2 (m/s^{-1}) Guards- Q1- 2.04 ± 0.4 Q2- 1.79 ± 0.5 Q3- 1.82 ± 0.5 Q4- 1.52 ± 0.4 Forwards- Q1- 1.70 ± 0.5 Q2- 1.47 ± 0.5 Q3- 1.39 ± 0.5 Q4- 1.28 ± 0.5 Centers- Q1- 1.25 ± 0.4 Q2- 1.20 ± 0.4 Q3- 1.04 ± 0.3 Q4- 0.99 ± 0.4

(m/s) = meters per second. (km/h) = kilometers per hour PG- Point Guard, SG-Shooting Guard, SF- Small Forward, C- Center. Acc. = accelerations. Dec. = decelerations. tACC = total accelerations. hACC = high-intensity accelerations. tDEC = total decelerations. hDEC = high-intensity decertations. #/min = number per minute. Q1 = 1st Quarter. Q2 = 2nd Quarter. Q3 = 3rd Quarter. Q4 = 4th Quarter.

5.4.2. External competition load

Table 2, displays the external load variables retrieved from the different studies. Total distance, ACC and DEC efforts during basketball competition, average and top speed reached, and time motion analysis movement frequency and duration were the out- comes extracted.

5.4.2.1. Total Distance

In elite competition, distance traveled ranged from 1,991 to 6,310 m (9,13,16). The total distance covered during sub-elite competition ranged from 3,722 to 6,208 m (13,48). Finally, considering youth competition, only one study tracked the distance traveled during competition and reported a value of 7,558 m (9). Remarkably, there was a discrepancy in distance covered between elite, sub-elite, and youth athletes. Upon review, the elite level basketball athletes covered, on average, less distance (4,369 m) (4,7,13,16), compared to sub-elite (5,377 m) (4,13,48) and youth players (7,558 m) (9). This seemingly paradoxical finding suggests that the total distance covered may be a poor indicator of in-game performance. In fact, one could infer that the observed phenomenon is a product of technical mastery relative to the demands of competition, as well as elite level players having a higher level of economy in relation to the tactical aspects of basketball (1,5,6). Based on the present results and as it occurs in other team-sports (50), the key aspect here appears to be not "how much" distance a player covers (i.e., quantity) but "how" and at "what intensity" that distance is covered (i.e., quality). In fact, in support of the previous, Sampaio et al., (5) suggested that better players tend to make fewer mistakes when deciding when and where to run which may result in shorter paths to reach their destination. This is more than likely due to a high degree of technical and tactical discipline based on training age and experience, more hours of professional supervised practices, and higher level of coaching.

5.4.2.2. Accelerations and decelerations

Accelerometry in basketball is tracked via inertial units containing accelerometer, gyroscope, and magnetometer sensors (7,15,27). These sensors allowed inertial movement analysis by recording accelerations, decelerations, jumps, and COD. As it can be seen in Table 2, when considering the accelerometry data collected during elite level competition, most research breaks it down into two important categories: ACC and DEC (7,15,27,28). Additionally, two sub- sections of these categories can be found: total (T), and high intensity (HI) (15,27). For the purpose of this review, total accelerations (ACC_T) were classified as total forward acceleration, whereas high-intensity accelerations (ACC_{HI}) were classified as the total forward acceleration within the high band (>3.5 $m{\cdot}s^{-2}$) (15), and (>3 $m{\cdot}s^{-2}$) (27). Total decelerations (DEC_T) consisted of the total number of decelerations and high-intensity decelerations (DEC_{HI}) were classified as total deceleration within the high band (>-3.5 $m{\cdot}s^{-2}$), and (>-3 $m{\cdot}s^{-2}$) (27).

During elite level match-play, the ACC_T ranged from 43 to 145, and the total number of ACC_{HI} ranged from 1 to 15 per match. Remarkably, a substantial variability can be found within the included studies, considering the ACC values. This occurrence makes it difficult to draw precise conclusions regarding the ACC demands of elite basketball competition. In fact, a similar pattern can be observed for DEC_T as values ranging from 24 to 95 per match were found. Regarding the total number of DEC_{HI} per match, data extracted ranged from 4 to 40. It seems evident that additional investigations on this topic are warranted before a "clear picture" can be drawn concerning the ACC and DEC demands. Moreover, researchers and sports scientists are encouraged to follow a standardized approach to ACC and DEC quantifications (e.g., determining the same HI bands) so that comparisons between studies and data sets can be conducted. None of the sub-elite or youth teams in the included studies collected accelerometry data during competition.

5.4.2.3. Average and top speed

Studies evaluating NBA competition (5,7) recorded average speed in miles per hour (mph), but values were converted by the authors to the global unit measurement of meters per second ($m{\cdot}s^{-1}$). The speed recorded by using spatial tracking cam- eras (Sport VU1; Chicago, USA) can be seen in Table 2. Sport VU1 cameras were installed in all 30 NBA arenas from the 2012–2013 season until the 2016–2017 season and McLean et al. (51) collected data from the entire 82 games plus the playoffs. This technology uses computer vision systems designed with algorithms to measure player positions at a sampling rate of 25 frames per second (5). Top speed was also measured by Puente (26) via SPI PRO X (GPSports1, Australia) and Abdelkrim et al. (16), as well as Vázquez-Guerrero et al. (28) via WIMU PRO Local Positioning System (Realtrack System, Almeria, Spain).

Similar to accelerometry data, positional tracking cameras have only been used to track match demands in elite level basketball, most likely due to the financial limitations on the sub- elite and youth levels. Importantly, when examining normative data points related to movements associated with basketball, it seems that the best performers on an elite level expressed certain performance characteristics. For example, Sampaio et al. (5), when examining All-Star Players versus Non-All-Star players in the NBA, found that there was a significant difference in average speed on both the offensive and defensive ends of the court. All-Star players had an average speed of 4.38 ± 0.36 mph (2.0 ± 0.2 $m \cdot s^{-1}$) offensively and 3.65 ± 0.16 mph (1.6 ± 0.1 $m \cdot s^{-1}$) defensively, whereas Non-All-Star players had an average speed of 4.50 ± 0.28 mph (2.0 ± 0.1 $m \cdot s^{-1}$) offensively and 3.86 ± 0.20 mph (1.7±0.1 $m \cdot s^{-1}$) defensively. Within the most prestigious level of basketball, the evidence suggests that the most efficient players tend to exert the least amount of energy to achieve the most productive results (5,7). With regards to top speed, there was also variability among levels. Puente et al. (26) showed that the average top speed in sub-elite Spanish basketball competition was 6.2 $m \cdot s^{-1}$, which is lower than the 8.09 $m \cdot s^{-1}$average top speed by NBA players identified in the work of Caparró´s et al. (7). However, the former study (26) only analyzed one single sub-elite game and, therefore, caution is warranted when directly comparing the results. For this reason, future research is needed in this area. Taken together, the distance and speed data extracted from the literature hint that higher level basketball players seem to cover less distance but achieve greater top speeds during competition, which is in line with what has been reported in other team-sports (52,50).

5.4.2.4. Time motion analysis

Time motion analysis has been widely used to track frequency and duration of movements during competition (4,9,14,18,26,22,32). Movements such as stand/walk, jog, run, sprint, and jump are commonly recorded among different levels of competition as well as different positions. Within this research, and based on the published literature, stand/walk was defined as movements performed at a velocity of 0–1 $m \cdot s^{-1}$ (1,14,18,22,32) and jogging was defined as intensities greater than walking but without urgency performed at 1.1–3.0 $m \cdot s^{-1}$ (4,9,18,26). Running was defined as sagittal plane movement at a greater intensity than jogging and with a moderate degree of urgency at 3.1–7.0 $m \cdot s^{-1}$ (18,22,33). Finally, sprinting was defined as forward movements characterized as effort close to maximum >7.0 $m \cdot s^{-1}$ (4,9,14,18,26,32). Ferioli et al. (32) and Scanlan et al. (4) examined time motion analysis among elite and sub-elite populations. Upon review, Ferioli et al. (32) found that there was a stark difference between time spent and frequency in high-speed running and sprinting versus jogging in the first division compared to the second division. The 1st Italian Division had frequency of exposures to high-intensity actions (HIA) of 107 ± 26, compared to an average of 78 ± 35 HIA in the second division. Scanlan et al. (4) found that elite backcourt (EBC) and elite frontcourt (EFC) had a much higher frequency of running compared to sub-elite backcourt (SEBC) and sub-elite front court (SEFC) during match-play. EBC had a mean frequency of 504 ± 38 and EFC had a mean frequency of 513 ± 26 of exposures to running during competition. These figures for running during competition are much higher than the SEBC (321 ± 75) and SEFC (352 ± 25), respectively. Again, these results would suggest that top-level basketball players spend more time at high-intensity activities compared to their sub-elite counterparts. In addition, elite players tend to display greater control over the most appropriate time and situations to express high-intensity actions relative to the total distance covered whilst on the court. Abdelkrim et al. (18) and Puente et al. (26) examined the positional differences using time motion variables during competition. Both studies showed that guards spend more time running compared to forwards and centers. Abdelkrim et al. (18) found that guards had a greater frequency of running during competition (103 ± 11), compared to forwards (88 ± 5) and centers (101 ± 19). Puente et al. (26) found that guards run a longer distance of 3.1 ± 1.1 (m.min-1) compared to forwards (2.2 ± 1.9) and centers (1.6 ± 1.6). This information, seen in Table 3, is useful and may have important implications when prescribing high-intensity running relative to each position in basketball. Based on these results, individual conditioning programs should be adapted to the specific physical requirements of guards, forwards, and centers, keeping in mind that the latter have been found to have a lower proportion of high-intensity running, acceleration, decelerations, and COD.

Table 3. Frequency, duration, and distance of time-motion analysis during competition.

Study	Participants (Competition Level)n = # of comp.	Stand/Walk	Jog	Run	Sprint	Jump	All Movements
Scanlan et al. [4]	Australian NBL/ Queensland State Basketball League (Elite/ Sub-Elite) n = 5	Mean Frequency — EBC- 764 ± 86 SEBC- 462 ± 74 EFC- 815 ± 45 SEFC- 532 ± 38 Duration—mean/total EBC- 0.91± 0.09/691 ±35 SEBC- 2.13 ± 0.11/ 981 ± 81 EFC- 1.02 ± 0.10/ 829 ± 8 SEFC- 2.16 ± 0.07 /1150 ± 68 Distance— EBC- 0.48 ± .06/ 363 ± 4 SEBC- 1.08 ±. 07/495 ± 28 EFC- 0.54 ± .06/ 435 ± 23 SEFC- 1.10 ± .05/586 ± 45	Mean Frequency— EBC- 911 ± 65 SEBC- 586 ± 77 EFC- 955 ± 33 SEFC- 664 ± 59 Duration–mean/total EBC- 1.27 ± 0.07/ 1153 ± 6 SEBC- 1.66 ± .18/961 ± 45 EFC- 1.25 ± .05/ 1192 ± 24 SEFC- 1.57 ± .07/1039 ± 53 Distance— EBC- 2.36 ± .09/ 2142 ± 70 SEBC- 2.97 ± .32/1723 ± 87 EFC- 2.31 ± .06/ 2208 ± 15 SEFC- 2.73 ± .13/1804 ± 89	Mean Frequency— EBC- 504 ± 38 SEBC- 321 ± 75 EFC- 513 ± 26 SEFC- 352 ± 25 Duration—mean/total EBC- 1.34 ± .10/ 673 ± 9 SEBC- 1.38 ± .16/436 ± 60 EFC- 1.43 ± .09/ 730 ± 3 SEFC- 1.33 ± .03/467 ± 11 Distance— EBC- 5.67 ± .46/ 2845 ± 16 SEBC- 6.11 ± .67/1926 ± 268 EFC- 6.11 ± .42/ 3125 ± 57 SEFC- 6.02 ± 0.64/ 2112 ± 73	Mean Frequency— EBC- 18 ± 7 SEBC- 105 ± 31 EFC- 24 ± 1 SEFC- 140 ± 14 Duration–mean/total EBC- 0.51 ± .01/9 ± 1 SEBC-0.93 ± .03/ 97 ± 29 EFC-0.51 ± .03/12 ± 3 SEFC-0.98 ± .02/ 136 ± 15 Distance— EBC- 3.85 ± .01/70 ± 26 SEBC- 9.08 ± .38/952 ± 321 EFC- 3.92 ± .25/94 ± 9 SEFC- 9.48 ± .72/ 1329 ± 235		Mean Frequency—EBC-2733 ± 142 SEBC- 1911 ± 283 EFC- 2749 ± 137 SEFC- 2014 ± 131

Table 3. (Continued)

Study	Participants (Competition Level)n = # of comp.	Stand/Walk	Jog	Run	Sprint	Jump	All Movements
McInnes et al. [14]	Australian NBL (Elite)n = 15	Frequency- 295 ± 54 Duration- 2.5 ± .5	Frequency- 99 ± 36 Duration- 2.5 ± 4	Frequency- 107 ± 27 Duration- 2.3 ± 4	Frequency- 105 ± 52 Duration- 1.7 ± .2	Frequency- 46 ± 12 Duration- .9 ± .1	Frequency- 997 ± 183
Abdelkrim et al. [9]	Tunisian National Team (Elite) n = 6	Distance-(meters) 1720 ± 143	Distance-(meters) 1870 ± 322		Distance-(meters) 763 ± 169		Distance (meters)-7558 ± 575
Ferioli et al. [32]	Italian 1st/2nd Division (Elite/Sub-Elite) n = 20	REC Frequency- (n) Division I- 184 ± 57 Division II- 184 ± 52 Duration- (s) Division I- 1599 ± 468 Divisin II- 1757 ± 502	LIA Frequency—(n) Division I- 306 ± 92 Division II- 296 ± 77 Duration- (s) Division I- 698 ± 213 Division II- 748 ± 200	MIA Frequency- (n) Division I- 106 ± 31 Division II- 82 ± 34 Duration- (s) Division I- 184 ± 53 Division II- 143 ± 62	HIA Frequency- (n) Division I- 107 ± 26 Division II- 78 ± 35 Duration- (s) Division I- 164 ± 48 Divison II- 116 ± 69		

EBC = elite back-court. EFC = elite front-court. SEBC = sub-elite back-court. SEFC = sub-elite front-court. REC = recovery. LIA = low-intensity activity.MIA = medium-intensity activity. HIA = high-intensity activity. m*min = meters per minute.

(Table 3 Continued)

Abdelkrim et al. [18]	Tunisian U-19 National Team (Youth) n = 6	Frequency- All Positions- 129 ± 10 Guards-130 ± 8 Forwards- 126 ± 15 Centers- 130 ± 8 Duration- (s) All Players- 2.4 ± 0.3 Guards-2.3 ± 0.2 Forwards- 2.4 ± 0.3 Centers- 2.6 ± 0.1	Frequency- All Positions- 113 ± 8 Guards-113 ± 8 Forwards- 110 ± 10 Centers- 117 ± 6 Duration-(s) All Players- 2.2 ± 0.2 Guards-2.1 ± 0.1 Forwards- 2.2 ± 0.2 Centers- 2.3 ± 0.1	Frequency- All Positions- 97 ± 14 Guards-103 ± 11 Forwards-88 ± 5 Centers- 101 ± 19 Duration-(s) All Players- 2.3 ± 0.3 Guards-2.1 ± 0.4 Forwards- 2.4 ± 0.2 Centers- 2.4 ± 0.4	Frequency- All Positions- 55 ± 11 Guards-67 ± 5 Forwards-56 ± 5 Centers- 43 ± 4 Duration-(s) All Players-2.1 ± 0.2 Guards- 1.9 ± 0.2 Forwards-2.1 ± 0.1 Centers-2.2 ± 0.1	Frequency-All Positions- 44 ± 7 Guards-41 ± 7 Forwards- 41 ± 6 Centers-49 ± 3	Frequency- All Positions-1050 ± 51 Guards-1103 ± 32 Forwards-1022 ± 45 Centers- 1026 ± 27
Puente et al. [26]	Spanish Basketball Federation (Sub-Elite)n = 1	Distance- (m*min) All Players-36.4 ± 3.7 Guards- 37.7 ± 2.9 Forwards-37.2 ± 4.6 Centers- 34.6 ± .6	Distance- (m*min) All Players-30.9 ± 5.9 Guards- 31.5 ± 6.9 Forwards-32.0 ± 5.3 Centers- 29.5 ± 5.8	Distance- (m*min) All Players-2.3 ± 1.6 Guards-3.1 ± 1.1 Forwards- 2.2 ± 1.9 Centers- 1.6 ± 1.6	Distance- (m*min) All Players- 0.2 ± 0.7 Guards- 0.1 ± 0.2 Forwards- 0.5 ± 1.3 Centers- 0.0 ± 0.0		Distance-(m*min) All Players- 82.6 ± 7.8 Guards-85.3 ± 7.3 Forwards-86.8 ± 6.2 Centers- 76.6 ± 6.0
Klusemann et al. [22]	Elite Australian Juniors (Youth) n = 13	Frequency- Season- 255 ± 32 Tournament- 252 ± 34	Frequency- Season-102 ± 23 Tournament- 99 ± 28	Frequency- Season- 90 ± 17 Tournament- 82 ± 15	Frequency- Season- 33 ± 7 Tournament- 28 ± 8		Frequency-Season- 809 ± 80 Tournament-758 ± 106

5.5. TRAINING DEMANDS

5.5.1. Internal training demands

Internal Training Load, displayed in Table 4, considered the following variables: s-RPE, Weekly Training Load, HR_{max}, HR_{ave}, % HR_{max}, and Training Impulse (TRIMP).

5.5.1.1. Heart rate

HR in training was used to quantify the cardiovascular demands imposed on the athletes (3,12,35,20,23,24). Torres-Ronda et al. (12) examined HR_{max}, HR_{ave}, and %HRmax in 5vs5, 4vs4, 3vs3, 2vs2, and 1vs1 games and found the 1vs1 situations had elicited the largest physiological response. Gocentas et al. (23) compared the HR_{max} between guards and forwards in different training sessions and found that on average guards had a higher HR response (194 ± 14) than forwards (190 ± 12.7). More investigation is needed in the future as it relates to the HR demands of varying training programs.

5.5.1.2. Session RPE and total weekly training load

A fairly common strategy to monitor players' load is to track the total weekly load via the sRPE (RPE multiplied by session duration), collected throughout the training week. In basketball, this method has been widely used to assess Training Load (35, 37, 41) and has been shown to provide good insight on the energy cost of different movement patterns, particularly when coupled with external load data (2,10,39). Briefly, it involves players reporting their RPE score using the Borg 10-point scale thirty minutes after the completion of each training session, multiplying the value by the number of minutes of the session (41) and then calculating the sum of the values of each training session during the week.

Table 4. Internal training load.

Study	Training Sessions (n=)	Participants (Competition Level)	s-RPE	Weekly TL (AU)	HR Max (BPM)	HR Average (BPM)	Max HR%	TRIMP (AU)
Svilar et al. [2]	n = 12	Spanish ACB League (Elite)	390.2±135.6					
Svilar et al. [10]	n = 12	Spanish ACB League (Elite)	Guards- 402.9 ± 151.8 Forwards- 385.5 ± 137.3 Centers- 385.1± 121.6					
Ramos-Campo et al. [3]	n = 24	Spanish ACB League (Elite)			187.3 ± 10.9			
Torres-Ronda et al. [12]	n = 15	Spanish ACB League (Elite)			5v5- 172 ± 19 4v4- 176 ± 18 3v3- 177 ± 12 2v2- 174 ± 14	5v5- 144 ± 17 4v4- 142 ± 15 3v3- 142 ± 15 2v2- 141 ± 15	5v5- 83 ± 9 4v4- 85 ± 7 3v3- 86 ± 5 2v2- 84 ± 5	
Angyan et al. [25]	n = 7	Hungarian Pro League (Elite)			169 ± 5.3			
Conte et al. [35]	n = 41	NCAA Division I (Elite)		Starters- 1666.2 ± 148.6 Bench- 1505.5 ± 220.8 1-game week- 1647.7 ± 251.3. 2-game week- 1423.2 ± 163.1				
Manzi et al. [37]	n = 200	Italian 1st Division (Elite)		No Game- 3334 1 Game- 2928 2 Games- 2791				

Table 4. (Continued)

Study	Training Sessions (n=)	Participants (Competition Level)	s-RPE	Weekly TL (AU)	HR Max (BPM)	HR Average (BPM)	Max HR%	TRIMP (AU)
Scanlan et al. [44]	n = 44	Australian State Level (Sub-Elite)	47.0 ± 15.7 65.0 ± 17.8 65.0 ± 24.2 74.0 ± 22.7					31.6 ± 5.0 30.3 ± 6.4 28.8 ± 4.9 29.9 ± 5.4
Vaquera et al. [24]	n = 26	U-18 Spanish Juniors (Youth)					5v5 condition (91.2 ± 4.7%. HRmax) Max HR 2v2 92.7 ± 3.3%	
Manzi et al. [37]	n = 200	Italian 1st Division (Elite)		No Game- 3334 1 Game- 2928 2 Games- 2791				
Heishman et al. [38]	n = 16	NCAA Division I (Elite)						High PL- 135.1 ±35.9 Low PL- 65.6±20.0 High Readiness- 85.3 ±19.6 Low Readiness- 104.4 ±20.1 Pre- 100.3±8.6 Post- 81.9±11
Aoki et al. [39]	n = 45	National Brazilian League (Elite)	Preseason- 442.9 ± 89.2 In-Season- 377.1 ± 68.3					Preseason- 27.1 ± 2.1 In-Season- 21.5 ± 1.6
Ferioli et al. [41]	n = 360	Italian 1st Division/ semiprofessional (Elite/Sub-Elite)		Pro- 5058 ± 1849 Simi-Pro- 2373 ± 488				
Gocentas et al. [23]	n = 42	Semiprofessional (Sub-Elite)			Guards- 194 ±14 Post- 190 ± 12.7			
Chatzinikolaoet al. [20]	n = 2	Greek League (Elite)			195 ± 6			

s-RPE = session rate of perceived exertion. (AU) = arbitrary units. 5v5 = 5 players versus 5 players. 4v4 = 4 players versus 4 players. 3v3 = 3 players versus 3 players. 2v2 = 2 players versus 2 players.

As noted in Table 4, the Total Weekly Training Loads in the studies analyzed ranged from 2255 to 5058 AU in elite level teams (35,37,41). The large range observed is likely due to the high variability on the number of training sessions or practice duration based on the loads pro- vided by the technical staff. Since sRPE is obtained by multiplying RPE by session duration, the accumulative amount of weekly training load is dependent on the duration of each training session, which can vary based on style of play, level of competition, or moment of the season (36,42,44). In addition, Svilar et al. (2) found that sRPE showed a very strong correlation with DEC_T and COD_T. According to the authors, the rapid eccentric actions involved in decelerations, cuts, and COD may explain the abovementioned relationship (1,2). Nevertheless, the mechanical stress imposed on the athletes during these movements, as well as the effects of eccentric training in

basketball athletes are areas that need additional investigation in upcoming studies. A key aspect to consider when utilizing this method to monitor training loads and demands is that in the examination of coach and player perception of recovery and exertion, research has shown that coaches tend to overestimate recovery when compared to the athletes' perception (17). Therefore, when designing appropriate training sessions, a combination of internal and external load variables is recommended (2,10,39).

5.5.2. External training load

Regarding External Training Load (Table 5), the variables retrieved from the studies were the number of ACC, DEC, and COD, tracked with inertial units through accelerometry.

5.5.2.1. Accelerations and decelerations

In elite level basketball, ACC_T in training varied from 16.9 to 59.5 (2,10,15,26,47). The ACC_{HI} in elite training, classified as the total forward acceleration within the high band (>3.5 $m \cdot s^{-2}$), ranged from 1.9 to 7.2 with a mean of 5.56 per training session. The DEC_T in elite basketball training ranged from 16.4 to 93.2 with a mean of 64.6 per training session whereas the DEC_{HI} (n), which were classified as the total number of decelerations within the high band (>-3.5 $m \cdot s^{-2}$), ranged from 1.6 to 12. When interpreting this data, it is important to acknowledge that ACC_T and DEC_T are qualified measures to quantify training volume, whereas ACC_{HI} and DEC_{HI} are quality measures of training intensity (2,10,15,43).

Remarkably, the number of ACC_T, ACC_{HI}, DEC_T, and DEC_{HI} reported during training were considerably lower than the data found in competition settings (15,7,27). The total volume of ACC in competition was 81 per match on average, as opposed to a mean of 38 accelerations per training session (36,40,43,47). The total number of ACC_{HI} was moderately less in training (5.6) opposed to (7.3) during match-play. This was also the case with DEC. DEC_T in competition was 73.1 and the DEC_{HI} 16.4, which is slightly greater than the 64.6 (DEC_T) and 7.4 (DEC_{HI}) in elite level training. The present data supports the notion that training, and match demands seem to be considerably different, at least considering the number of ACC and DEC (15). Matching the volume and intensity of competition via training is important during certain times of the preparatory and competitive season to adequately prepare the athletes for competition. As a consequence, the data reported herein may be extremely pertinent for practitioners in regard to training reflecting the demands of match-playing, as well as modulating training load based on outputs of these variables during competition. In this context, to try and achieve similar or even greater ACC demands in training with respect to match- play, manipulating constraints such as the number of players, the duration of drills or court dimension may be a potential strategy (12,15,47). Within this framework, Schelling and Torres (47) found that ACC load in 3vs3 and 5vs5 full court scrimmage drills was greater than 2vs2 and 4vs4 full court scrimmage drills, indeed suggesting that manipulating training variables may greatly affect the total load imposed to the players.

A study by Svilar et al. (10) reported interpositional differences in training load accelerometry data among guards, forwards, and centers. Interestingly, the authors examined load parameters according to positional on-court roles and found that centers had a higher volume of ACC_T (59.5 ± 27.1) and ACC_{HI} (7.2 ± 4.8) opposed to forwards (42 ± 21.5; 5.8 ± 4.3, respectively) and guards (43.5 ± 17.5; 6.4 ± 4.4, respectively). Also, noteworthy, forwards were shown to have a high volume of DEC_T (93.2 ± 35.0) and DEC_{HI} (12.7 ± 8.3) compared to guard (84.7 ± 30.1; 11.9 ± 5.7) and centers (88.5 ± 30.3; 6.8 ± 4). It appears that the profiles of activity are quite different amongst positions and further research is necessary to better understand each individual profile. Still, the number of exposures to cuts, COD, or screening actions, as well as the typical movement area of each positional role may conceivably explain such findings (6,10,12,16,27,53).

Table 5. External training load.

Study	Training Sessions (n=)	Participants (Competition Level)	Acceleration	Deceleration	COD
Svilar et al. [2]	n = 300	Spanish ACB League (Elite)	tACC- 49.1 ± 24.2 hACC- 6.5 ± 4.6	tDEC-89.1 ± 32.2 hDEC-10.2 ± 6.8	tCOD- 324.1 ± 116 hCOD- 21.4 ± 12.5
Svilar et al. [10]	n = 208	Spanish ACB League (Elite)	tACC- Guards- 43.5 ± 17.5 Forwards- 42 ± 21.5 Centers- 59.5 ± 27.1 hACC- Guards- 6.4 ± 4.4 Forwards- 5.8 ± 4.3 Centers- 7.2 ± 4.8	tDEC- Guards- 84.7 ± 30.1 Forwards- 93.2 ± 35.4 Centers- 88.5 ± 30.3 hACC- Guards- 11.9 ± 57 Forwards- 12.7 ± 8.3 Centers- 6.8 ± 4.0	tCOD- Guards- 324.8 ± 110.2 Forwards- 336.8 ± 121.4 Centers- 312.1 ± 114.8 hCOD- Guards- 23.5 ±1 2.5 Forwards- 24.7 ±1 4.5 Centers- 16.8 ± 8.6
Svilar et al. [15]	n = 16	Spanish ACB League (Elite)	tACCmin RSG- 1.92 ± 0.97 (1.78–2.06) NSG- 2.20 ± 0.76 (1.88–2.52) hACCmin RSG- 0.33 ± 0.26 (0.29–0.37). NSG- 0.25 ± 0.20 (0.17–0.34)	tDECmin RSG- 2.40 ± 1.08 (2.24–2.55) NSG- 2.95 ± 0.88 (2.58–3.23) hDECmin RSG- 0.24 ± 0.22 (0.21–0.28) NSG- 0.36 ± 0.27 (0.25–0.48)	tCODmin RSG- 10.61 ± 4.40 (9.97–11.25) NSG- 13.25 ± 3.69 (11.70–14.81) hCODmin RSG- 0.73 ± 0.46 (0.66–0.80) NSG- 0.95 ± 0.58 (0.71–1.20)

Vazquez-Guerrero et al. [43]	n = 33	Spanish ACB League (Elite)	Accelerations(counts)- 1/2 court- 18.0 ± 2.4 (16.6–19.4) 1/2 court w/transition- 18.3 ± 2.8 (16.7–19.8) Full court- 16.9 ± 0.4 (16.2–17.6) hACC (counts)- 1/2 court- 1.4 ± 0.3 (1.2–1.6) 1/2 court w/transition- 1.6 ± 0.2 (1.5–1.7) Full court- 1.9 ± 0.4 (1.3–2.6) Peak Speed (m/s)- 1/2 court- 4.2 ± 0.2 (4.0–4.3) 1/2 court w/transition- 5.5 ± 0.3 (5.3–5.7) Full court- 5.0 + 0.3 (4.5–5.5)	Decelerations (counts)- 1/2 court- 17.6 ± 2.2 (16.3–18.9) 1/2 court w/transition- 17.9 ± 2.6 (16.4–19.3) Full court- 16.4 ± 0.5 (15.6–17.2) hDEC (counts)- 1/2 court- 1.1 ± 0.3 (1.0–1.3) 1/2 court w/transition- 1.4 ± 0.2 (1.3–1.5) Full court- 1. ± 0.3 (1.1–2.1)	
Aoki et al. [39]	n = 10	National Brazilian League (Elite)	Peak Acceleration (m·s^{-2})- Preseason- 2.2 ± 0.2 In-Season- 2.4 ± 0.2		
Scanlan et al. [44]	n = 10	Australian State League (Sub-Elite)	Mean sprint speed (m/s) 3.77 ± 0.38 3.59 ± 0.29 3.62 ± 0.23 3.58 ± 0.30		
Schelling et al. [47]	n = 16	Spanish ACB League (Elite)	2v2 = 14.6 ± 2.8 3v3 = 18.7 ± 4.1 4v4 = 13.8 ± 2.5 5v5 = 17.9 ± 4.6		

hACC = high-intensity acceleration. hDEC = high-intensity deceleration. tACC = total acceleration. tDEC = total deceleration. tCOD = total change of directions. hCOD = high-intensity change of directions. RSG- regular stoppage games. NSG- non-stoppage games.

Despite the aforementioned, one must consider the limitations of accelerometry when measuring external load. Even though such technology is extremely useful, accelerometers fail to measure the metabolic demands of isometric muscle contractions during player-on-player contact due to the low velocity outputs. While these actions have very low acceleration, they potentially have very high energy demands (1,19,54). Therefore, the physical cost of player-on-player contact loading is a component of basketball that must be examined more thoroughly in future research to more accurately quantify training and competition load.

5.6. LIMITATIONS

Some limitations should be addressed when considering the present research on training load and competition demands among different levels of basketball. Firstly, several elite leagues (e.g., NBA or ACB) do not allow for wearable technology to be used during competition which creates a gap in the literature as far as linking demands placed on the players during elite com- petition and how that compares to training. Secondly, when trying to investigate these variables, most sub-elite and youth teams do not have the financial means to invest in equipment to accurately quantify load during training. Finally, the limited number and sample size of youth and sub-elite studies made it difficult to conclude the precise demands of training and competition at these levels. As such, more resources need to be invested in these areas.

5.7. CONCLUSIONS AND PRACTICAL APPLICATIONS

Basketball is a highly competitive team-sport that requires a cascade and flow of various movement patterns relative to the technical and tactical aspects of the sport. Examining the internal and external loads imposed on the players from both training and competition provides con- text for the practitioner to create an optimal training environment. Having the knowledge of the stress demands on the player during competition will help to dictate the volume and dos- age of load for desirable adaptations in the player's training regimen. From the results of the present systematic review, it appears that higher-level players seem to be more efficient while moving on-court. Elite level players cover less distance, at lower average velocities, and with lower HR_{max} and HR_{ave} during competition. However, they seem to have greater capacities to move at higher speed. This is likely due to a heightened sense of awareness based on the schematics of the game. Such information may provide insight into personalized testing protocols as well as training recovery strategies based on each player's response and considering mechanical and physiological loading parameters relative to competition level. Examining this holistic approach creates an ideal training environment that facilitates both technical and tactical development as it relates to the game of basketball. Future research must be dedicated to this area to provide more precise insight into the physical and interpositional demands of the sport. It is necessary to accurately and systematically assess competition demands to help determine valid training strategies that resemble match-play, considering training age, physical characteristics, and in-game role of guards, forwards, and centers. Reviewing these principals will allow priming and preparing basketball players for the rigorous of match-play demands.

VI – STUDY 2

VI. STUDY 2:

SEASONAL VARIATIONS IN GAME ACTIVITY PROFILES AND PLAYERS' NEUROMUSCULAR PERFORMANCE IN COLLEGIATE DIVISION I BASKETBALL: NON-CONFERENCE VS. CONFERENCE TOURNAMENT

6.1. INTRODUCTION

Basketball is an intermittent sport in which repeated high-intensity explosive actions (i.e., jumps, ACC, DEC, and changes of direction) are performed during match-play (18,33,34,60). Due to the force-velocity features that characterize these actions of the game, an adequate development of the neuromuscular system capabilities (i.e., strength and power) is required (15,17). In fact, it has been suggested that the ability to produce high levels of force in short amounts of time is paramount and may differentiate basketballers from superior competition levels (85). For this reason, coaches and sport scientists have long been interested in the study of basketball game demands (5,7,18,19) and the players' neuromuscular profile (62, 72, 73). A deeper knowledge on these topics could have huge implications on the global responses relative to stress imposed by competition on, for example, players' jumping or reactive strength capabilities. This is especially relevant in contexts where the season lasts for long periods and the competitive calendars are schedule-congested, as in the NBA or college basketball competitions.

In the particular case of the National Collegiate Athletic Association (NCAA) Division I Basketball, the competitive season (where the players have to practice, compete and study) begins in November and potentially lasts up until April. There are typically 3 phases to the season: (i) the Non-Conference (NON- CONF) season, which lasts from November until December and has an inconsistent schedule and variability in competition density patterns; (ii) the Conference (CONF) schedule, held from January until early March, which is consistent in nature and has at least two competitions every calendar week; (iii) the NCAA Tournament which is played in March for teams that qualify. Despite the abundance of literature describing the demands of basketball in different levels of competition (74,87,88), no study has focused on analysing changes in game demands throughout the

NCAA college season and the implications this could have on neuromuscular outputs.

Due to the demands and chaotic schedule of competition, it is common practice for strength and conditioning coaches and sports scientist to track and monitor neuromuscular performance outputs and fatigue throughout the competitive season (67,68). Understanding how these values fluctuate across the season may provide insight on how athletes are adapting to the stress imposed by the sporting activity and have a direct impact on the training loads prescribed to each athlete. In this context, previous studies from basketball and other team-sports have shown that long competitive calendars may have a detrimental effect (i.e., decreased outputs) on selected neuromuscular variables such as maximum dynamic strength, vertical jump height, or sprinting speed (62). Conversely, Gonzalez et al. (72) observed that players who played more than ~25 min per game across an entire NBA season increased vertical jump power and improved their reaction time from pre- to post- season. Given these inconsistencies, more research is needed to better understand the fluctuation of neuromuscular performance parameters throughout the basketball season as it may provide valuable information regarding players' recovery needs and readiness to compete (18,73,81).

Considering the previous, having standardized and repeatable assessments that allow gathering information about the function of the neuromuscular system, as well as specific external load variables to the game of basketball, might be extremely relevant for trainers and staff (60,61,62). Vertical jumps, for example, have been proposed as simple monitoring tools that can be used to quantify neuromuscular fatigue, particularly through force plate evaluations (70,71). Notably, most research utilizes the countermovement jump (CMJ) as the main tool for neuromuscular fatigue evaluation in team-sports (amongst the different types of vertical jump) (84,85,87,96). However, based on the need for rapid stretch shortening cycle actions in basketball, it may be interesting to explore a repeated-hop test to assess players readiness and fatigue levels during the competitive phase of the season (24). Variables obtained from this type of evaluation (e.g., peak force or reactive strength index (RSI) can provide important information in sports that require the production of large amounts of vertical force in a short amount of time; moreover, they can reflect potential neuromuscular fatigue elicited by basketball competition (57,62,73,74,90).

To the best of authors' knowledge, no previous study has simultaneously investigated the match-play demands of NCAA Division I basketball and examined how players' neuromuscular performance, assessed through a repeated-hop test, fluctuates throughout the competitive collegiate season. From an applied standpoint, this investigation may help coaches and sport scientists design more effective training and recovery strategies (60,61) by providing insight on the effects of a basketball season on performance. Therefore, the purpose of this study was twofold: (1) to examine and compare the match demands in both a NON-CONF and CONF tournament of the NCAA Division I Men's Basketball Championship; (2) to investigate how neuromuscular performance outputs and neuromuscular fatigue levels change throughout the course of the complete collegiate basketball season.

6.2. METHODS

6.2.1. Experimental Design

This descriptive longitudinal study was performed during the competitive phase of the 2017/2018 NCAA Division I collegiate basketball season. Match-play data was recorded during home games in both the NON-CONF and CONF seasons. NON- CONF occurred in the months of November and December 2017 and was classified as playing teams outside of the conference in a randomized format with a total of 12 matches (8 home and 4 away). CONF occurred during the months of January and February and was classified as playing teams within the conference with a frequency of 2 competitions per week for a total of 19 competitions (10 home and 9 away). Players' neuromuscular performance and fatigue were continuously assessed throughout the season on a weekly basis, particularly in the day before competition (i.e., Match-day−1) via a repeated- hop test. Data on each player was collected by the strength and conditioning staff as routine for the daily assessment of fatigue and player loads.

6.2.2. Participants

Seven NCAA Division I male collegiate basketball athletes (4 guards and 3 forwards; 20 ± 1.2 years, 1.95 ± 0.09 m, and 94 ±15 kg) from the same team were included in this study. The University Institutional Review Board (IRB) approved this study and researchers were provided de-identified data to analyse. By enrolling in the university's basketball program, student- athletes provided individual consent for study participation as part of their requirements as a team member. All participants were medically cleared and presented no musculoskeletal injuries or cardiovascular, respiratory, neurological, metabolic, haematological endocrine exercise disorders that might impair their performance during training or match. Additionally, no participants were using illegal drugs or taking medications, which affected body mass.

6.3. PROCEDURES

6.3.1. Match-Play Demands

Match-play activity profiles were tracked throughout the competitive season via spatial tracking cameras (Sport VU ; Chicago, USA) (77). A total of 17 home games were analyzed during the competitive season (7 NON-CONF and 10 CONF). Six cameras were set up within the competition arena to track in-game payer loads. The primary performance variables used to track game load were Total Distance (m), Peak Speed (km·h−1), ACC and DEC loads expressed in arbitrary units (AU) (14,18). Data was collected via Stats Sports Sport VU ®software and exported to a customized spreadsheet (Microsoft Excel 2016, USA). All seven participants competed in each of the 17 matches.

6.3.2. Neuromuscular Testing

Each player's neuromuscular performance and fatigue were assessed on the Match-Day−1 of the 17 competitive home matches via a repeated-hop test (69). The hop test was preceded by a standardized warm up consisting of a series of squats, lunges, and free arm swing CMJ. Three repeated-hops were performed on a triaxial force plate (9260 AA—Kistler, Switzerland) (66). The repeat hop test was performed with the athlete's hands on their hips and after the athlete was still for a 3 s period on the force platform to stabilize body mass Athletes were instructed to jump as high and as fast as possible 3 times with minimal ground contact time and without resetting between jumps. All tests were completed 15 min prior to practice. If the athletes did not complete the standardized warm up or the test did not fall within the 15-min window pre-practice, results were not considered (76). All jumps were recorded via a data acquisition system (DAQ System Type 5691 A- Kistler, Switzerland). Each trial was exported to a text file and then imported and analyzed with the ForceDecks Software (Vald Performance, Brisbane, Australia). The primary variables examined of the 3 jumps were best Jump Height (JH) in cm, Peak force (PF) in Newtons (N), mean Contact Time (CT) of the 3 jumps in ms and best RSI (calculated by dividing JH/CT) in $m \cdot s^{-1}$.

6.4. Statistical Analysis

All data was reported in mean ± SD with 95% confidence intervals. Normality and homogeneity of variance were checked via the Shapiro-Wilk test (<50), revealing parametric data and Levene test to check the homocesdaticity. Therefore, differences in performance between NON- CONF and CONF metrics were assessed by a t-test for paired samples. Effect sizes were calculated as Cohen's d (parametric data), and interpreted as trivial, < 0.2; small, 0.2-0.6; moderate, 0.6-1.2 or large, 1.2-2.0 (75). The P values below 0.05 were considered statistically significant (63). The data was analyzed using the SPSS statistical package (version 23.0; SPSS, Inc., Chicago, IL).

6.5. Results

Match-play activity profiles can be found in Table 1. There were no significant differences in Total Distance covered and Peak Speed achieved in competition between NON-CONF and CONF games ($p > 0.05$). Furthermore, no significant between- tournament differences were found with regards to Acceleration and Deceleration loads ($p > 0.05$). Table 2 and Figure 1 display the neuromuscular performance outcomes. Significantly lower JH ($p = 0.03$; ES = 0.43) were observed in CONF with respect to NON-CONF. Furthermore, a trend toward a small decline in PF ($p = 0.06$; ES = 0.38) was found. Finally, no significant differences between NON-CONF and CONF were obtained for CT and RSI ($p > 0.05$).

TABLE 1 | Comparison of the match-play outcomes between the non-conference and conference tournaments.

	Non-CONF	CONF	p-*value*	ES (95% CL)
Distance (m)	1590 ± 535	1560 ± 659	0.77	0.05 (−0.35; 0.45)
Peak Speed (km·h^{-1})	15.5 ± 1.1	15.3 ±1.4	0.53	0.13 (−0.27; 0.53)
Acceleration Load (AU)	349 ± 110	331 ± 126	0.46	0.15 (−0.25; 0.55)
Decelerations Load (AU)	643 ± 201	603 ± 235	0.31	0.18 (−0.22; 0.58)

NON-CONF, Non-conference tournament; CONF, Conference tournament; ES, effect sizes; CL, confidence limits; AU, arbitrary units.

Table 2 | Comparison of the neuromuscular performance outcomes between Non-conference and Conference tournament.

	Non-CONF	CONF	p-*value*	ES (95% CL)
Jump Hieght (cm)	22.7 ± 6.7	19.9 ± 6.3	0.03	0.43 (0.05; 0.84)
Peak Force (N)	2957 ± 651	2719 ± 596	0.06	0.38 (−0.02; 0.79)
Contact Time (s)	0.50 ± 0.16	0.46 ± 0.13	0.14	0.28 (−0.12; 0.68)
RSI (m.s^{-1})	52.8 ± 23.1	48.0 ± 28.5	0.37	0.18 (−0.22; 0.58)

*NON-CONF, Non-conference tournament; CONF, Conference tournament; ES, effect sizes; CL, confidence limits; RSI, Reactive Strength Index. *P < 0.05.*

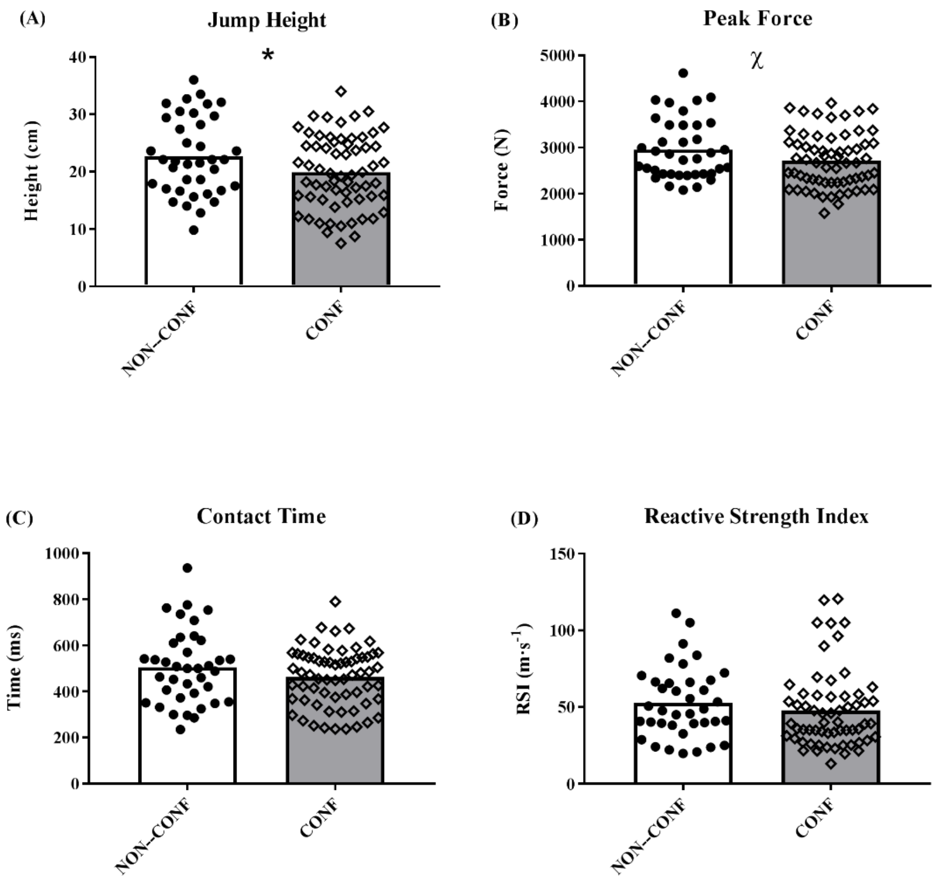

FIGURE 2 | (A) Jump Height, (B) Peak Force, (C) Contact Time, and (D) Reactive Strength Index obtained on the repeated-hop test during the Non-Conference (NON-CONF) and Conference (CONF) seasons. Bars indicate mean values. The black circles and white squares represent individual data points from all the players' Match-Day−1 assessments. * Significant decrease in Jump Height. χ Trend toward decreased Peak Force.

6.6. DISCUSSION

The main purpose of the present study was to examine and compare the game demands in both NON-CONF and CONF match- play of NCAA Division I Men's Basketball, as well as to investigate how neuromuscular performance outputs change throughout the course of the competitive collegiate basketball season (November and December 2017). The main findings from this study indicated that: (1) no difference were found in match- play demands when comparing NON-CONF to CONF seasons and (2) neuromuscular performance (i.e., JH and PF), assessed with a repeated-hop test, was negatively impacted during the CONF season. The results show that game demands appear to be constant across both competitions; nevertheless, the higher density patterns and travel characteristics of the CONF season (i.e., 19 games in ~8 weeks) may result in higher levels of residual fatigue that ultimately affect performance (78).

Previous research has examined game demands of basketball based on regular season vs. tournament competitions (22), different competition levels (16,18) and playing position (2,9,10). However, to the authors' knowledge, no previous study has investigated the game activity profiles in elite level collegiate basketball or whether meaningful changes occur throughout the season. For example, Klusemann et al. (22) found that the frequency of running, sprinting, and shuffling movements in seasonal games was higher than in tournament games by 8–15%, but investigated a sample U-18 youth basketball players. Conversely, the present data regarding match-play demands identified no significant fluctuations in any of the variables analyzed (i.e., Total Distance, Peak Speed, Acceleration, and Deceleration loads) when contrasting the NON-CONF and CONF seasons. These findings suggest that the activity profiles remain constant regardless of the schedule and competition characteristics in collegiate basketball format. From a practical perspective, as game loads appear to be stable throughout the competitive season, practitioners can manipulate variables outside of competition to influence performance and use this information to program typical weeks that mimic loads imposed during match-play. For example, coaches can modulate training to reflect game demands during times of the year where frequency of competition is less (i.e., NON-CONF). On the contrary, when congestion of games is high (i.e., CONF tournament) coaches may wish to limit high volumes of court transitions, ACC, and DEC during training to allow for an adequate recovery between consecutive matches (15,16).

As it relates to neuromuscular performance, a distinctive aspect of the present study is that not only JH, but also other outcomes from the repeated-hop test (i.e., PF, CT and RSI) were investigated. Notably, there was a significant decrease in JH during the CONF season (Figure 1A) and a trend ($p = 0.06$) toward a decline in PF (Figure 1B). No differences were found in CT or RSI. Previous research has shown that loads imposed during training can elicit neuromuscular fatigue resulting in decreased JH and increased ground CT in elite basketball athletes (73,74), as well as top level Australian Football (64,65) and Rugby League (78) using a CMJ. Despite the CMJ being the jump test most frequently found in the scientific literature (67,68,73,74), the repeated-hop test was used herein and, hence, direct comparisons between studies must be performed with caution. However, the rebounding aspect of a repeat-hop test has an extremely high level of specificity as it relates to the sporting activity of basketball and that is the reason why the coaching staff opted to use this assessment throughout the season. There are several potential factors that could influence the observed changes in neuromuscular performance within this present study, the first being density of games in CONF compared to NON-CONF play. In the 8-week NON-CONF season, the team was exposed to 12 games during the months of November and December (i.e., average of ~1.5 games·week−1). In contrast, during the 8-week cycle of the CONF season in January and February, the team completed 19 games (i.e., average of 2.4 games·week−1). Based on this fact, it appears that the increased frequency of games might ha a negative impact on some of the neuromuscular outputs assessed.

Further to the previous, one must also consider the travel required during different times of the year. In NON-CONF, the players only traveled via plane and stay overnight in a hotel twice. In contrast, the team had to travel 9 times during the CONF season. In this context, previous investigations have showed the detrimental effects that travel can have on performance in basketball (83). Steenland and Deddens (83) found that less travel and more time in between competitions resulted in an improved performance in the NBA. These findings provide insight on how teams should prioritize training or recovery based on density patterns of games and travel during the competitive season. During times of less dense competitions, practitioners might want to prescribe greater volumes of resistance and strength-power related training (e.g., gym-based sessions and court-based sessions with high incidence of jumps, cuts, changes of direction) to avoid/minimize declines in neuromuscular performance later in the season. However, in match-congested moments of the season it may be more adequate to focus on more restorative training sessions to increase on- court performance (26). Based on the present research it is evident that when frequency of competition and travel demands increase practitioners should have more of an emphasis on recovery.

Notably, both peak and temporal kinetic values during jumping tasks can be useful to gain insight on the neuromuscular strategies employed for each individual athlete. RSI, assessed as a ratio of JH:CT, has been shown to be an extremely useful evaluation tool for coaches during the course of a competitive season (79,80). When CT increases and JH decreases, it could potentially be a sign of neuromuscular fatigue; however, when JH increases, and CT decreases this may indicate a high level of training readiness (69). In the present study, no significant differences were found in RSI, despite the decreases observed in JH. This outcome is most probably due to the small non-significant decline in CT observed. Regarding PF, this variable is another valuable force platform outcome for coaches (70,71) since it has been recently recommended to be used in conjunction with JH to assess subtle differences in vertical jump performance (82). In fact, both peak and time course force plate variables have been used to assess neuromuscular fatigue in athletes (81,84). Interestingly, a trend toward a small decline was found in PF when comparing CONF to NON-CONF (Figure 1B), hence supporting the notion that fatigue (or insufficient recovery) was present and vertical jump ability was affected during the more congested phase of the season. Future research is needed to gain better insight on how different metrics oscillate throughout a basketball season.

Discussion is warranted on the limitations of the present study. First, the limited sample size may have impacted the statistical analysis of the results. However, all players involved in the present research are currently in professional basketball rosters in North America and Europe, highlighting the exceptionality of the sample studied. Furthermore, it is worth emphasizing that this investigation was conducted during 16 consecutive weeks in which players were continuously assessed on a weekly basis. This is extremely difficult to accomplish in top level collegiate basketball within the constraints of limited time and resources, characteristic of applied research (58,59). Second, match-play activity profiles were monitored only during home games due to the fact tracking system was not available at other arenas. As a consequence, potential discrepancies between the demands imposed at home vs. away games were not depicted in the present research. Finally, neuromuscular outputs may have been affected by factors other than the game and training demands in this sample of college student-athletes (i.e., academic stress, poor sleep quality, dehydration). Therefore, future research warrants the investigation of these global stressors that could have a potentially impact on performance

6.7. CONCLUSIONS AND PRACTICAL APPLICATIONS

The NCAA Division I Basketball schedule is demanding on student-athletes. It is imperative for practitioners working with these athletes to monitor game demands and neuromuscular outputs (and fatigue) that can blunt performance throughout the season. Having a wholistic approach allows coaches to manipulate variables outside of training to garner specific adaptations and facilitate recovery when needed. Based on the present data, no differences were found in match-play demands when comparing NON-CONF vs. CONF seasons. In contrast, neuromuscular performance (i.e., jump height and peak force) was impacted during the CONF season, when the density of games and travel requirements were higher. Understanding how these variables fluctuate during different periods of the season can have direct implications on how coaches and sports scientists' program for peak performance. From a practical perspective, when frequency of match-play is low, greater volumes of strength- and power-oriented training and on-court sessions that replicate game loads may help maintain high levels of physiological readiness. Conversely, when densities increase, the emphasis should be placed on practices that enhance and optimize recovery between games.

Congestion of match-play demands can have a detrimental impact on neuromuscular outputs and impede performance. Although game demands were constant throughout the competitive season, neuromuscular profiling showed a deleterious effect based on time of year. The data highlighted the importance of load tolerance and robustness when density patterns of games are at their highest rate. These findings could potentially affect how practitioners have selective menu items to facilitate recovery vs. potentiation effects based on time of year and competition schedule.

VII – STUDY 3

VII. STUDY 3:

MATCH DAY-1 REACTIVE STRENGTH INDEX AND IN-GAME PEAK SPEED IN COLLEGIATE DIVISION I BASKETBALL

7.1. INTRODUCTION

Basketball is a court-based team-sport that requires contributions from various physical parameters and bio-motor abilities (1). These broad arrays of skills are principal components of in-game performance (2). Particularly, basketball requires large expressions of speed and power qualities for match-play success. The technical and tactical aspects of the game put a high demand on the neuromuscular system relative to the sporting activity (3). Therefore, the process of monitoring changes in these qualities for each individual player becomes paramount during the season (in view of the various stressors encountered by the players) (4,5), as it allows for evaluating longitudinal fluctuations over time (7) and provides insight on speed- and power-related performances.

Within basketball, standardized and repeatable jumping assessments are amongst the most popular to assess neuromuscular function (38,67,68,72,73,74). The ability to produce substantial amounts of force onto the ground to vertically displace the center of mass is an important skill contextually within the game, since basketball athletes execute around 45 jumps per game (1). Thus, it is logical that practitioners collect and analyze jump data throughout the competitive season (90,91) to allow for a more in-depth neuromuscular function assessment (92-94,96). This is particularly important since JH alone does not always indicate athlete readiness as individuals may change movement strategies to achieve similar outputs (99). In this context, the assessment of variables other than height in various jump tasks could be a suitable approach to monitor fatigue and readiness in the in-season period (100).

Previous research has examined jumping ability in basketball, with most studies utilizing the CMJ to assess neuromuscular function (89–93). However, basketball mainly requires rapid stretch-shortening cycle (SSC) actions as well as the activation of H-reflex responses (94,98,99,104,106) that are not always reflected within the CMJ. To overcome this issue, repeated jumping and hopping tasks can be used, as they permit evaluating the ability to produce high vertical ground reaction forces in short ground contact times. In fact, RSI (i.e., ratio of JH/contact time) has been previously used to measure both performance and fatigue within athletes (69,79).

Along with jumping, running speed is also an important characteristic in basketball (23,24,26,101). Although the sport is played in a 28 by 15-m court, the ability to reach high top speeds and rates of acceleration can be extremely advantageous within the context of the game (1). Whether it is via jumping- or running-based actions, athletes that can produce large amounts of force is a short amount of time are more likely to be in optimal positions on the court to garner competitive advantages (e.g., grab a rebound or intercept a pass) (95). Conversely, if an athlete is producing less force and having longer ground contact times relative to their normative datapoint, this may be a potential sign of fatigue (107,108). It is for this reason that examining the effects that fluctuations in reactive strength qualities have on the mechanical demands of in-game performance can provide informative decision-making on readiness to compete and recovery needs.

To the best of the authors' knowledge, no previous research has investigated whether a repeated-hop test performed the day before basketball competition can provide meaningful information regarding match-play mechanical demands. Therefore, the main purpose of this study was to investigate if fluctuations in reactive strength qualities could be used as an indicator to discriminate between faster and slower physical in-game performance the following day. This research may help coaches and sports scientists to make more informed decisions on both training and recovery.

7.2. METHODS

7.2.1. Study design

A prospective comparative study was conducted. Neuromuscular performance was assessed on the training day before competition (i.e., Match-day-1 [MD-1]) via a repeated- hop test. Match-play data was recorded during all 17 matches at the team's home arena. All data was collected between the months of November 2017 and February 2018 by the strength and conditioning staff as routine for the daily assessment of fatigue and player loads.

To evaluate neuromuscular performance (i.e., RSI and JH) on MD-1 for all 17 games, a repeated-hop test (76) was performed. The test was performed both pre-practice and post-practice to account for any of the acute effects imposed by the training session the day before the competition. A standardized warm-up of squats, lunges, and free arm swing CMJ preceded the assessment. Three repeated-hops were performed on a triaxial force platform (9260 AA-Kistler, Kistler Group, Winterhur, Switzerland) with the athletes' hands on their hips. Players were instructed to jump as high and as fast as possible while spending minimal time on the plate without resetting between jumps. All tests were completed 15-min prior to, and after practice. The tests were disregarded if the athlete did not complete the standardized warm-up or did not fall within the 15-min windows. Likewise, data was not considered if the player did not test both pre- and post-practice. All jumps were recorded via a data acquisition system (DAQ System Type 5691 A- Kistler, Kistler Group, Winterhur, Switzerland). Each trial was exported to a TXT file and analyzed with the ForceDecks Software (Vald Performance, Brisbane, Australia) (109). For each athlete season, the difference between post- and pre-practice values were calculated (i.e., delta [Δ]). A positive or a negative integer would indicate an increase or decrease in neuromuscular performance, respectively. The mean of the 3 jumps RSI (calculated by dividing JH/contact time) in m s^{-1}, and JH, in cm, were considered for analysis.

Match-play activity profiles were tracked for each of the 17 home games throughout the 2017–2018 season via spatial tracking cameras (Sport VU®, Stats Perform, Chicago, IL, USA). This six-camera system was set up in the home gymnasium during competitions to track distance and speed of each athlete. The activity profile data was collected via Stats Sports VU software and exported to a customized spreadsheet (Microsoft Excel 2016, Microsoft Corporation, Redmond, WA, USA). The primary performance metric examined was peak speed (km h^{-1}), given that it is an intensity-related variable that can provide a good gauge of neuromuscular readiness. A median split relative to individual's peak speed was used to determine fast versus slow in-game performances. All 7 players competed in every home match.

7.2.2. Participants

Seven NCAA Division I male collegiate basketball athletes (4 guards and 3 forwards; 20 ± 1.2 years; 1.95 ± 0.09 m, and 94 ±15 kg) from the same team were included in this study. The University Institutional Review Board (IRB) approved this study and researchers were provided and identified data to analyze. By enrolling in the university's basketball program, student- athletes provided individual consent for study participation as part of their requirements as a team member. All participants were medically cleared and presented no musculoskeletal injuries or cardiovascular, respiratory, neurological, metabolic, hematological endocrine exercise disorders that might impair their performance during training.

7.2.3. Statistical analysis

Data is presented as means and standard deviation. Data normality was tested using the Shapiro-Wilk test ($n < 30$). For every player, in-game performances ($n = 17$) were divided using a median split analysis into two groups (i.e., FAST: above the individual's median value, and SLOW: below the player's median) according to the peak speed achieved by each athlete during competition. Paired T-tests were performed to assess post- to pre- practices differences. An independent Sample T-test was used to assess the differences between FAST and SLOW performances. Cohen's d effect sizes (ES) (63) were calculated to determine the magnitude of the differences and classified as: trivial (<0.2), small (>0.2–0.6), moderate (>0.6–1.2), large (>1.2–2.0), and very large (>2.0–4.0). Statistical significance was set for $p \leq 0.05$ (110).

7.3. Results

Table 1, shows the descriptive data and the comparison between FAST and SLOW performances. Post-practice RSI and JH were significantly higher than pre-training values prior to the FAST but not the SLOW in-game performances. Moreover, when considering the ergogenic response from before to after training (i.e., Δ), a significant difference was found for MD-1 RSI when comparing FAST and SLOW conditions (p = 0.01; ES = 0.62). No significant between-group differences were obtained in JH (p = 0.07; ES = 0.45).

Table 1. Repeated-hop descriptive data from Match-Day -1 and comparison between FAST and SLOW in-game performances

	In-game Performance			
	FAST	**SLOW**	***p***	**ES (95% CI)**
Jump Height (cm)				
Pre-Practice	19.1 ± 5.7	20.9 ± 4.0	0.16	-0.37 (-0.9 - 0.16)
Post-Practice	23.5 ± 8.7**	22.1 ± 4.5	0.45	0.20 (-0.32 - 0.73)
Δ	4.4 ± 8.1	1.2 ± 4.7	0.07	0.49 (-0.05 - 1.03)
RSI ($m \cdot s^{-1}$)				
Pre-Practice	42.6 ± 20.1	45.1 ± 16.1	0.54	-0.13 (-0.66 - 0.39)
Post-Practice	57.5 ± 27.2**	47.1 ± 17.4	0.16	0.45 (-0.09 - 0.98)
Δ	16.4 ± 27.1	2.0 ± 18.3	0.01	0.62 (0.06 - 1.17)

** Significant increase with respect to pre-practice ($p \leq 0.01$) **Δ**: delta, change from pre- to post-practice; CI: confidence interval; ES: effect size; RSI: reactive strength index.

7.4. Discussion

The main aim of the present study was 1) to examine MD-1 pre- to post-practice differences (i.e., Δ) in repeated jump outputs and 2) determine whether potentiation or degradation of neuromuscular performance in training could discriminate between faster and slower in-game physical performance. The main findings indicated that large gains in RSI (from before to after training) were observed the day prior to competitions in which higher peak speed values were reached during match-play. These preliminary results are novel and suggest that testing athletes' repeated jump ability both prior to and after practice MD-1 (to account for any potential acute onset of fatigue or potentiation) could provide meaningful information regarding neuromuscular readiness to compete. This study is also unique in that it evaluated elite level basketball players throughout the entire competitive season.

Of note, vertical jump has been previously found to be highly related to running speed (95) and a predictor of repeated-sprint ability in elite basketball players (96). How- ever, the present study is the first to identify what seemed to be a positive influence of gains in RSI MD-1 in peak speed of subsequent basketball competition. This finding could be extremely useful to practitioners considering that neuromuscular performance usually fluctuates during a typical in-season week (97). Knowing that speed is a primary component in basketball (1,3), coaches can, therefore, optimize training strategies with the aim of maximizing reactive strength qualities prior to competition. This may, in turn, translate into superior neuromuscular status of the athletes that can place them at an optimal position for in-game success.

Remarkably, Δ JH MD-1 was not able to discriminate between FAST and SLOW in-game performances. Gathercole et al. (95) reported that neuromuscular function alternations 24 h after a fatiguing protocol were not detected when using JH alone (i.e., in both CMJ and drop jump tasks) and suggested that complementary variables such as Flight Time: Contact Time ratio should be assessed. Likewise, it appears that in the repeated-hop test herein, Δ RSI was more sensible than JH to determine neuromuscular readiness the following day. Based on the previous, it appears that an athlete’s ability to express high- force outputs in reduced contact times may better discriminate between FAST and SLOW games when compared to how high he can jump in a repeated-hop task. From a practical perspective, coaches are recommended to utilize the RSI metric obtained from a high rate of frequency test to assess their players on MD-1.

The limitations of the present study should be addressed. Firstly, the small sample size limits the generalization of the current findings to other athletic populations. Nevertheless, since 17 games were analyzed here, the preliminary results obtained open a new perspective and should be investigated more in-depth. Secondly, it is important to keep in mind that peak speed is only one of many in-game physical parameters (e.g., accelerations, decelerations, or jumps); hence, further research should consider a more complete set of metrics to provide a clearer picture regarding match-play performance. Finally, variables other than RSI alone may influence subsequent in-game physical performance (e.g., MD-1 training load, recovery protocols, priming strategies). Thus, the reader should interpret the present results cautiously.

In summary, MD-1 sessions that resulted in greater post-practice increases in RSI were observed prior to faster in-game performances when examining peak speed in elite collegiate basketball players. However, larger JH gains were not able to discriminate between faster and slower performances. These finding could impact stimuli provided to athletes prior to competition. Exposures to menu items that promote maximal high force outputs applied in reduced contact times may be most appropriate close to competition.

7.5. Conclusions and practical applications

Athletes with greater gains (i.e., Δ) in RSI from pre- to post-practice were found to achieve greater peak speeds in match-play the following day. Conversely, no differences were found between FAST or SLOW performances when JH was the variable analysed. It is for this reason that professionals should closely examine acute adaptations to MD-1 as it may influence player selection or training strategies that place their athletes in the best position to succeed on the court. Having a critical thought process in regard to the sequencing of menu items is vital in the appreciation of the heterochronicity and different time courses of adaptive processes for varying stimuli. Specifically, actions that foster reactive strength and short ground contacts should be placed as close to the competition as possible within a training week. Further research on these topics is needed to gain a more robust insight into how to best create an environment for optimal neuromuscular outputs around match-play. The proper application of stimulus relative to match-play could have a direct impact on the optimization of neuromuscular status for in-game performance.

VIII – SUMMARY AND DISCUSSION OF RESULTS

VIII. SUMMARY AND DISCUSSION OF RESULTS

The main objective of the present compendium of studies was to conduct a systematic review on the physical demands of basketball training and competition and to investigate neuromuscular fluctuations and match-play activity profiles in basketball players during the in-season period. Results indicated that (I) the elite level performers across various levels of competition cover the least amount of distance yet have the capacity to move at the highest velocities; (II) neuromuscular outputs were compromised by time of year and match-play congestion and (III) greater effects of RSI MD-1 resulted in faster in-game peak speeds the following day.

In Study 1 (86) the main objective was to systematically review the literature for training load and match-play demands in basketball based on competition level. These groups were classified into elite, non-elite, and youth levels. Based on the data extracted from the scientific literature, it was concluded that elite level performers were more economical during competition (i.e., covering less total distance during competition but exhibiting the capacity to reach high velocities). This finding is important to both sports scientist and tactical coaches in that it creates a technical model to adhere to when evaluating training load in relation to match play. This also allows practitioners to identify what is optimal as it pertains to distance and velocity in game.

Of note, the degrees of variance within training loads made it difficult to examine trends. This is likely based on different coach methodologies and styles of play and suggests that a more standardized format of training throughout the basketball playing world would be needed for conclusive assertions. Technical and tactical coaches should be focused on creating awareness of where athletes should be on-court to allow for a high degree of economy relative to the demands of the sporting activity resulting in less distance covered to yield optimal results (2-5,9-16, 18-24).

According to the results of Study 1 (86), elite basketball athletes have a very distinct profile compared to their sub-elite and youth counterparts during competition. Such information will allow for technical models to adhere to when creating physical profiles for basketball athletes. However, the results from the examination of training load were inconclusive when investigating trends among different levels of competition. This highlights the need for a common means of quantification and distribution of training load among varying levels of basketball and the importance to consider other factors such as the moment of the season (e.g., pre-season or playoffs) when analyzing the demands of the game.

Based on this premise, in Study 2 (91), the objective was to examine seasonal variations in match-play demands and neuromuscular outputs based on CONF versus NON-CONF schedule. As expected, neuromuscular outputs in JH and PF were negatively affected during the CONF season. Conversely, match-play demands were consistent regardless of time of year as it relates to peak speed, total distance, ACC, and DEC. Of note, this study highlights the need to examine how the demands imposed, and density of competition impact outputs from the neuromuscular system.

From an applied perspective, understanding the effects of density of match-play and residual fatigue is important for basketball S&C professionals and sports scientists because this will allow for accurate prescriptions as it relates to both training and recovery. Findings by Calleja-González et al. (61) support the need for adequate recovery to induce optimal adaptations. In order for professional to do this, it is necessary to know the type of induced fatigue and its underlying mechanisms. For example, causes of fatigue can be multifactorial stemming from competition load and complementary training programs. Identifying the primary driver of fatigue is essential in prescribing a recovery protocol (61). The experimental design and methodological approach employed in Study 2 allowed to identify potential markers of central fatigue from the neuromuscular system. It was hypothesized that the fatigue induced by the NM system was chronic in nature and was the byproduct of a long competition season and increased schedule congestion later in the year. In the mentioned investigation, the resultant decrease of outputs during the CONF season leads one to believe that fatigue levels are highly dependent on the competitive schedule. Therefore, these findings would suggest that decrements in JH and PF later in the season manifested accordingly during onsets of high frequency match-play. Considering that this fatigue mechanism is also associated with intermittent-sprint exercise (32,34) or repeated COD tasks in basketballers (22), training load and recovery should be leveraged in a way to optimize performance later in the competitive schedule. Fitness will not be a limiting factor for athletes that play high minutes during this time of year (118). It is for this reason that training should be briefed in nature once baseline levels of fitness are achieved. This decrease of mechanical training loading will allow the ability of high capacities for outputs during match-play.

Remarkably, a novel finding from Study 2 (91) was that match-play demands did not differ from NON-CONF to CONF seasons. This lack of variability would suggest that the games are a physical constant throughout the season. According to the investigation, the aggregate of different time points will be consistent as far as distance, speed, and the rate of change of speed. Having this information is extremely valuable as it has important practical applications. Firstly, when projecting out training microcycles, coaches should be aware of the frequency of match-play. Knowing that these match-play demands are constants through the season (91), practitioners should allow for menu items that facilitate recovery during non-game days during times of high congestion of match-play (33,34). Secondly, coaches should mimic game demands during training on weeks where match-play is not frequent to ensure high levels of readiness for match-play. This qualifying statement is made with the carveout that, based on the findings, these measures could have a more sensitive fatigue response later in the year. Therefore, coaches should be cautious when applying voluminous and intense training sessions towards the end of the competitive season. Moreover, how training loads are distributed across the training week is another aspect worth considering as a proper planning may potentially reduce the effects of fatigue and optimize in-game performances from a physical performance perspective.

Considering the previous idea, in Study 3 (116) the objective was to investigate the ergogenic effects on basketball players' neuromuscular performance pre- versus post-practice MD-1 in relationship to their physical outputs in competition the next day. The main discovery indicated that greater potentiation of RSI MD-1 yielded greater in-game peak speed the following day. This is very relevant for sport scientists and practitioners as it highlights the need to maximize reactive strength qualities close to match-play to optimize outputs during competition. Previous research has supported the positive effects that potentiation has on performance (119,120). These findings support that garnering a general physical quality during training can lead to specific transference relative to the demands of the sporting activity. Knowing this information gives practitioners a guiding influence to potentially increase speed during competition, ultimately increasing the capacity to perform at a high level.

There are several key takeaways from the present information. Firstly, as previously mentioned, peak speed in a principal component in elite basketball (1,4,8). Thus, having a means to facilitate this physical quality is of importance in this sport. Secondly, the training done in anticipation for match-play has a direct effect on outputs and physical demands of competition. Previous research has emphasized the importance of microcycle planning within team-sports (121,122). According to Lyakh et al. (121), during the competitive season thematic days of mental and physical recovery should be programmed in the training week for optimal performance. Tthe temporal component of RSI is a good indicator of neuromuscular readiness. If ground contact time decreases, and jump height increase vertically during repeat jumps, there is a high likelihood this will also be true horizontally during acceleration tasks. In fact, short ground contact times have been shown to be determining factors of several movement patterns such as linear sprints and COD (123,124). Spiteri et al. (123) found that in, the 505 COD test, athletes that produced shorter ground contact times had greater strength capacity to enable greater mechanical adjustment through force production. It is for this reason professionals should adhere to the principle of producing greater amounts of force in less amount of time in different athletic performance tasks (55,56).

In summary, from a practical and applied perspective based on the results of the present compendium of studies, basketball S&C coaches and sport scientists should be aware that elite basketball athletes elicit unique neuromuscular outputs and in-game physical profiles. These outputs are sensitive to fatigue during times of high match congestion. From a chronic perspective, JH and PF were found to be compromised during CONF play, particularly later in the season when frequency of competition was increased. Finally, to try and counteract the effects of fatigue, and from an acute reference point, training schemes that led to increases in RSI -pre to -post practice MD-1 resulted in greater peak speeds in-game the following day. These findings would indicate the heterochronicity of transient adaptations of the neuromuscular system. As such, when forecasting the competitive season in basketball recovery should be prioritized from a macro perspective. However, practitioners should find windows of opportunity to facilitate reactive strength qualities to try and optimize the capacity to produce higher peak speeds in competition.

IX – CONCLUSIONS

IX. CONCLUSIONS

9.1. General conclusions

The results of the present compendium of articles allowed concluding that elite basketball athletes have unique physical profiles as it relates to speed and distance in competition, hence highlighting the need to develop training programs that mimic these characteristics. Moreover, NM outputs can be compromised during times of high schedule congestion. Finally, it was concluded that higher ergogenic effects in RSI MD-1 resulted in greater peak speeds the following day.

9.2. Specific conclusions

The specific conclusions of the studies comprising the present thesis are displayed below. Importantly, the following conclusions are only applicable to athletes with similar characteristics to those presented in each investigation.

Study 1:

- The systematic review of the scientific literature concluded that there are differences in match-play demands based on level of competition.
- Training load had a much greater degree of variability based on the lack of standardization and repeatability of training.
- Elite players covered the least amount of distance during competition when compared to their sub-elite and youth counterparts.
- Elite Players had the bandwidth to move at a greater peak speed when compared to lower division competition.

Study 2:

- NM outputs (particularly JH and PF) were compromised during the CONF season of NCAA Division I Basketball.
- Match-Play demands were consistent throughout the competitive season.

- Total Distance, Peak Speed, ACC, and DEC were stable metrics in both CONF and NON-CONF play.

Study 3:

- Athletes that had greater increases in RSI from -pre to -post practice MD-1 also generated greater peak speed the following day during competition.
- Throughout the 16-week competitive season, RSI was a valid qualifying measure for neuromuscular readiness in relation to match-play.
- Absolute measures such as PF and JH were not indicators of neuromuscular readiness when delineating FAST versus SLOW performances in competition.

X – LIMITATIONS

X. LIMITATIONS

Some limitations of the studies composing the present thesis must be addressed:

- In Study 1, there was no standardization of training load. This made the data form the studies difficult to interpret due to the variance in training styles as well the use of different technologies to quantify training load.

- The varying technologies used to determine match-play demands in Study 1 may create some discrepancy in reporting as it relates to determining internal and external demands .

- The small sample sizes in Study 2 and Study 3 may have prevented the identification of significant and meaningful differences between FAST versus SLOW groups, and CONF versus NON-CONF play in variables such as JH or PF .

- In study 2 and 3, the only physical demands that were recorded were from the home gymnasium. Physical profiles may have been different in road versus home matches.

- The homogenous population in studies 2 and 3 made it difficult to determine what role training age, gender, and playing experience had on the physical characteristics studied.

XI – PRACTICAL APPLICATIONS

XI. PRACTICAL APPLICATIONS

From an applied and practical perspective, according to the results from the studies in the present thesis, basketball S&C coaches and sport scientists should consider that:

- Elite basketball athletes have distinct physical profiles. Therefore, when considering the present, results coaches should model their training to allow for their athletes to be economical in their environment relative to the demands of competition.

- In alternative, from a fatigue-management perspective, neuromuscular performance is compromised during times of high schedule congestion. This would indicate the need to promote recovery during these times of the competitive season. From a chronic standpoint, once a baseline qualifying measure of fitness is achieved, a minimal effective dose of training should be applied to ensure neuromuscular preparedness.

- RSI was found to be a valid measure of acute neuromuscular readiness. Short term adaptations of short ground contacts should be facilitated as close to match-play as possible to yield capacity for high speed-power outputs .

- Chronically, the neuromuscular system is exposed to fatigue more so later in the competitive season. From an acute standpoint, it was found necessary to foster reactive strength qualities in relation to competition to allow higher in-game peak speeds.

XII – FUTURE RESEARCH LINES

XII. FUTURE RESEARCH LINES

After the completion of the present thesis, future research lines arise from the results obtained. In this regard, potential future investigations that could bring further understanding on the topics studied herein are presented below:

- To investigate the effects that different training units (i.e., varying volume and intensity) have on neuromuscular outputs.

- To investigate the time course of adaptations in systems other the NM system (i.e. cardiopulmonary, musculoskeletal) and how said systems effect in-game demands.

- To research the effects training age has on the ability to recover and the repeatability of game demands in competitive basketball.

- To determine optimal loads of training relative to in-game performance in basketball.

- To investigate the individual dose-repose relationship that effects neuromuscular fatigue and match-play demands in basketball. In the present thesis, the effects on a group of NCAA Division I basketball players was examined but no evidence was obtained regarding the effects of that chronological age, high versus low responders, sex, and playing experience has on these factors.

XIII – REFERENCES

XIV. REFERENCES

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XIV. APPENDICES

APPENDIX 1. Study 1: TRAINING LOAD AND MATCH-PLAY DEMANDS IN BASKETBALL BASED ON COMPETITION LEVEL: A SYSTEMATIC REVIEW

Reference:

Petway AJ, Freitas TT, Calleja-González J, Medina Leal D, Alcaraz PE. Training Load and Match-Play demands in basketball based on competition level: A systematic review. PLoS One. 2020;15(3): e0229212.

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RESEARCH ARTICLE

Training load and match-play demands in basketball based on competition level: A systematic review

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Abstract

Basketball is a court-based team-sport that requires a broad array of demands (physiological, mechanical, technical, tactical) in training and competition which makes it important for practitioners to understand the stress imposed on the basketball player during practice and match-play. Therefore, the main aim of the present systematic review is to investigate the training and match-play demands of basketball in elite, sub-elite, and youth competition. A search of five electronic databases (PubMed, SportDiscus, Web of Science, SCOPUS, and Cochrane) was conducted until December 20th, 2019. Articles were included if the study: (i) was published in English; (ii) contained internal or external load variables from basketball training and/or competition; and (iii) reported physiological or metabolic demands of competition or practice. Additionally, studies were classified according to the type of study participants into elite (20), sub-elite (9), and youth (6). A total of 35 articles were included in the systematic review. Results indicate that higher-level players seem to be more efficient while moving on-court. When compared to sub-elite and youth, elite players cover less distance at lower average velocities and with lower maximal and average heart rate during competition. However, elite-level players have a greater bandwidth to express higher velocity movements. From the present systematic review, it seems that additional investigation on this topic is warranted before a "clear picture" can be drawn concerning the acceleration and deceleration demands of training and competition. It is necessary to accurately and systematically assess competition demands to provide appropriate training strategies that resemble match-play.

1. Introduction

Basketball is a court-based team sport that requires proficiency in a vast array of physical parameters and motor abilities (i.e., speed, strength, and endurance) to achieve success from both a technical and tactical standpoint [1]. The ability to accelerate, decelerate, change direction, jump, and shuffle are paramount for on-court success, due to the intermittent high-

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intensity nature of most actions and basketball-specific movements [2,3] as well as the demands of the sporting activity [4,5,6]. Importantly, in competition settings, the aforementioned abilities must be expressed in an efficient and economical manner over the course of four quarters with contributions from both aerobic and anaerobic energy pathways [1]. In this context, the density of game-related activity (determined by specific work-to-rest ratios) is dictated by action intensity and by the moment of the game [7]. This includes medium- to high-intensity actions that last 15 seconds (s) and high- to maximal-intensity actions that last up to 2–5 s [8,9]. It is for this reason that practitioners must have a precise overview of match-play demands as well as the load elicited during training [4,5,2,6,10,3,11,12,13,14,15]. In fact, over the past years, there have been several studies documenting match-play demands in basketball [4,5,2,6,10,3,11,12,13,14,15,16,7,17,18,19,20,21,22,23,24,9,25,26,27,28]. Particularly, a recent review by Stojanovic et al. [29] analyzed the activity demands and physiological responses obtained during basketball competition and found that playing period, playing position, level, geographical location and sex greatly influenced the stress experienced by basketball players. In their article Stojanovic et al. [29] examined heart rate (HR), blood lactate concentration, total distance, and movement patterns of male and female basketball competitions based on time-motion analysis. However, while the study clearly described the competition characteristics, the authors did not present data on the acceleration/deceleration requirements of the game nor did they examine the demands of training versus match-play. It is for these reasons that the current systematic review is justified.

It is important to note that amongst the several methods used to quantify the demands of play, and regarding internal load quantifications, HR [6,3,11,12,14,20] and blood lactate concentration [4,13,14,16,9,30] were the most frequently used. In fact, internal variables such as average and maximal HR can be extracted to quantify loading parameters during match-play [11,12,21,30,26]. Concerning external load, methods such as accelerometry and the use of positional tracking cameras [4,2,13,16,7,17,31] are amongst the most common. Within this framework, total or high-intensity accelerations and decelerations, total distance traveled, and top speed reached were the widely used variables to assign a value to the mechanical load imposed. In addition, time-motion analysis [4,14,18,22,9,26,32] measuring time and frequency of movements such as "standing"; "jogging"; "running"; "sprinting"; and "jumping" during competition can be found in the literature. Despite match-play demands based on time-motion analysis having been found to present a high level of variability according to playing position, skill level and training age [29], no robust evidence exists regarding the use of accelerometry. Therefore, a systematic analysis of both approaches to match demands quantification is warranted. Collectively, a better understanding of this 'real-time' feedback can give relevant and useful information concerning normative group standards, as well as relative to the individual athlete. Additionally, having a clear "picture" of both internal and external loading parameters can provide a better insight into global stress that the players deal with during training and competition [2,10,26].

In a related topic, tracking training load in this team-sport may be of extreme importance to ensure that the players are physically prepared for competition demands from a fitness standpoint, in order to avoid acute spikes in load from a fatigue and injury prevention perspective [3,11,7,17] and to provide individualized recovery strategies [33,34]. With this in mind, a copious amount of research has also been focused on investigating and describing basketball training load parameters over recent years [35,36,37,38,39,40,41,21,42,24,43,44]. As previously mentioned for competition, accelerometry is becoming an increasingly popular means of quantifying load during training [36,38,40,21]; however, no conclusive data has been reported throughout the different studies. For this reason, a more in-depth and systematic analysis of the literature is warranted. Regarding internal load, HR and session rate of perceived exertion (sRPE) (i.e., the subjective feedback from the player on a 1–10 scale multiplied by duration of training) have been shown to be a cost-effective way of providing valuable information widely used by coaches and sport scientists [35,37,41]. Remarkably, an important variability has been reported within basketball training loads based on quantification means of training load, position, perceived exertion, skill level, and training age [36,37,38,39,40,41,43,44], once again identifying the need for a systematic review of the published data.

The current state of the literature is not conclusive regarding the typical training load experienced by basketball players of different competition levels given that only match-play demands and physiological responses during competition have been previously described [29]. To our knowledge, no previous investigation has focused on systematically reviewing the literature to identify precise loads during training versus match-play whilst clearly defining different levels of competition. As such, there is an important gap in the available research that does not allow concluding whether basketball training is closely mimicking game demands, hence, adequately preparing players for the stress imposed by competition. Moreover, new technologies that allow quantifying the acceleration/deceleration demands in basketball training and competition have emerged, but no current literature review has addressed this topic. Therefore, the aim of the present systematic review is to analyze the evidence related to the training load and match-play demands of basketball across different levels of competition.

2. Materials and methods

2.1 Study design

The present study is a systematic review focused on training load and match-play demands at different levels of competition in basketball. The review was not registered prior to initiation, was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) statement [45] and did not require Institutional Review Board approval.

2.2 Search strategy

A structured search was carried out in PubMed, PubMed Central, Web of Science, SportDiscus and Cochrane databases, all high quality databases which guarantees strong bibliographic support. The electronic database search for the related articles considered all publications prior to December 20^{th,} 2019. The following key words were used to conduct the search "basketball", "training load", "accelerometry", "load monitoring", "internal load", "total distance", "average distance", "top speed", "average speed", "metabolic", "heart rate", "competition demands", "training demands", "training", and "rate of perceived exertion". In addition, the key word "basketball" was present in each search to ensure that the relevant information was catered to articles involving only this sport. The reference sections of all identified articles were also examined (by applying the "snowball methods" strategy [40]). Once the electronic search was conducted, relevant studies were identified and organized in a systematic fashion.

All titles and abstracts from the search were cross-referenced to identify duplicates and any potential missing studies, and then screened for a subsequent full-text review. The search for published studies was independently performed by two authors (AP and TTF) and disagreements were resolved through discussion.

2.3 Inclusion and exclusion criteria

This review included cross-sectional and longitudinal studies considering healthy, professional or junior, male basketball players. Study participants were categorized into three groups: elite, sub-elite, and youth. The elite basketball group was defined as teams participating in the NBA, NBA G-League, NCAA Division I, Euro League, FIBA International Competition, ACB, Top Divisions in Europe, South America, Australia, and Asia. Sub-elite was defined as professional or semi-professional that did not meet the elite criteria but were over 19 years old. Youth was considered for studies in which the participants were all 19 years of age or younger. Studies were included in the present review if they met the following criteria: (i) the study was published in English; (ii) the study included internal or external load variables from basketball training and/or competition; and (iii) the study reported physiological or metabolic demands of competition or practice.

Studies were excluded if (i) the study participants were wheelchair basketball players; (ii) the study participants were female; (iii) the data being collected did not describe training load or competition demands; and (iv) the study consisted on a review or a conference proceeding.

2.4 Study selection

The initial search was conducted by one researcher (AP). After the removal of duplicates, an intensive review of all of the titles and abstracts obtained were conducted. Following the first screening process, the full-version of the remaining articles was read. Then, on a blind, independent fashion, two reviewers excluded studies not related to the review's topics and determined the studies for inclusion (AP and TTF), according to the criteria previously established. If no agreement was obtained, a third party intervened and settled the dispute. Moreover, PEDro scale (Fig 1) was used to evaluate whether the selected randomized controlled trials were scientifically sound (9–10 = excellent, 6–8 = good, 4–5 = fair, and <4 = poor) [46]. Papers with poor PEDro score were excluded. Final outcomes of the interventions were extracted independently by two authors (AP and TTF) using a customized spreadsheet (Microsoft Excel 2016, USA). Disagreements were resolved through discussion until a consensus was achieved.

3. Search results

As several databases were scrutinized, the initial database search yielded 18,805 citations. After duplicate removal, 3,282 abstracts and titles were left for review. Upon screening, 165 articles met the inclusion criteria for full-text review. Of the 165 articles reviewed, 35 met the criteria for the systematic review. Of the 35 articles that met the criteria, 12 had participants for elite competition demands [4,5,6,11,12,13,14,15,16,7,9,30,32], 16 articles had participants for elite training load [2,10,3,12,15,35,37,38,39,41,20,42,25,27,43,47], 6 for sub-elite competition demands [4,11,13,21,26,32], 3 for sub-elite training load [23,44,48], 5 for youth competition demands [11,18,22,9,28] and 1 for youth training load [24]. A full view of the search and selection process can be found in the PRISMA flow diagram [45] in Fig 2.

4. Competition demands

4.1 Internal competition load

Internal load outcomes pertaining to competition demands can be found in Table 1. The variables displayed in the different studies consisted of HR and blood lactate concentration.

4.1.1 Heart rate. Heart Rate (HR) during competition (Table 1) was organized into two categories according to the classification used in the included studies: maximal (HR_{max}) and average HR (HR_{ave}). The values of HR_{max} during elite level competition ranged from 187 to 198 beats per minute (BPM) with a mean of 190 BPM [11,12,30]. With regards to sub-elite competition, values ranged from 192 to 195 BPM with a mean of 194 BPM [11,21,26]. In addition, in youth competition, the HR_{max} held a mean of 199 BPM [11,18]. The data extracted

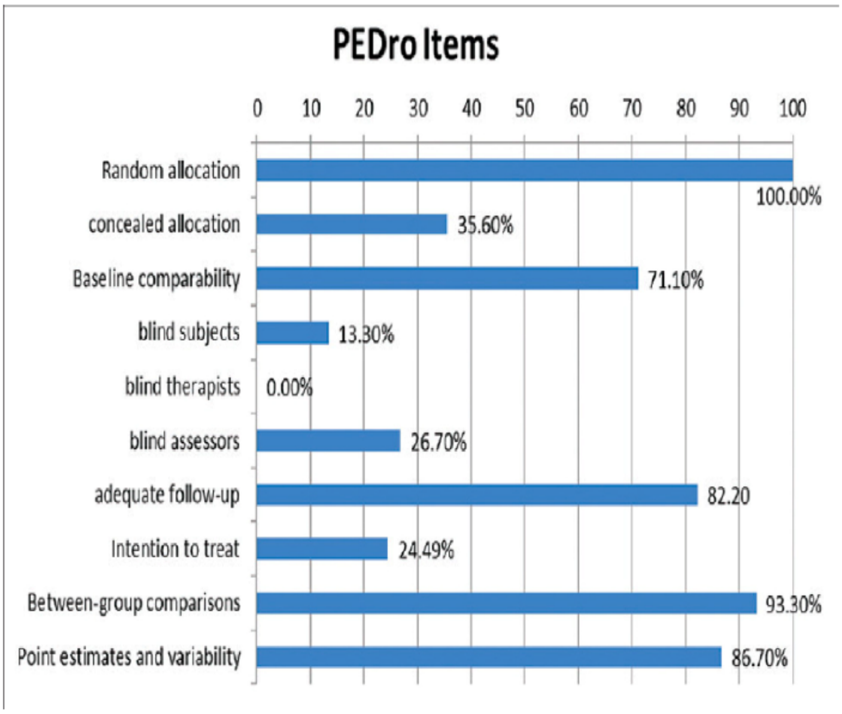

Fig 1. PEDro scale.

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indicated that elite competitors presented lower HR_{max} values during competition, which can be interpreted as an indicator of elite players having a higher overall level of fitness and a more efficient work rate compared to sub-elite and youth players [11]. Interestingly, according to the results retrieved from the literature, the same pattern occurred with the $HR_{ave.}$ During elite level competition the value ranged from 150 to 175 BPM [11,12,30], in sub-elite competition ranged from 168 to 169 BMP [11,21] and in youth competition the HR_{ave} ranged from 167 to 172 BPM [11,18].

4.1.2 Blood lactate concentration. Blood lactate concentration was collected as an internal measurement during select studies of elite level competition. The samples for mean blood lactate post-competition held an average of 5.1 ± 1.3 mmol/L [18,21,9] with a range of 4.2 to 5.7 ± 1.2. Abdelkrim et al. [9] observed a peak of 6.2 ± 1.3 in the fourth quarter for the Tunisian National Team. The fourth quarter peak is likely due to the build-up of blood metabolites and catabolic hormones based on the depletion of muscle glycogen later in competition. The ability to buffer these mechanisms internally may have had a direct impact on mechanical outputs during competition [30] as internal load parameters leading to fatigue have been reported to

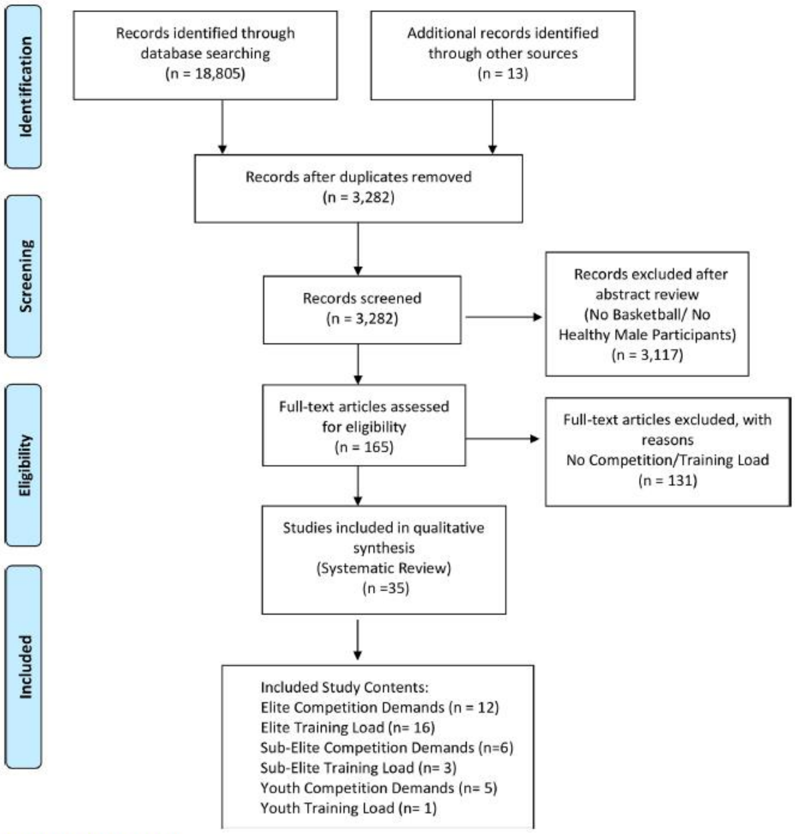

Fig 2. PRISMA flow diagram.

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negatively affect whole-body work rate, physical and technical performance, and even decision making in team-sports [49]. It is for such a reason that there is a need for future investigation of blood metabolite accumulation during competition and the effects it has on high-speed movement.

4.2 External competition load

Table 2 displays the external load variables retrieved from the different studies. Total distance, acceleration (ACC) and deceleration (DEC) efforts during basketball competition, average and top speed reached, and time motion analysis movement frequency and duration were the outcomes extracted.

Table 1. Internal load during competition.

Study	Competitions (n=)	Participants (Competition Level)	% of HR Lactate Threshold	Mean HR (beats/min)	Max HR%	Max HR (beats/min)	Blood Lactate Concentrate (mmol/l)
Daniel et al. [6]	n = 6	Brazilian Basketball League (Elite)	Defense- 104.2 ± 2.21 Offense- 103.7 ± 1.80 Defense Transition- 104.8 ± 2.44 Offense Transition- 104.3 ± 3.55				
Lopez-Laval et al. [11]	n = 3	Spanish ACB League/ABA/ Spanish Juniors (Elite/Sub-Elite/Youth)		Elite Adults- 150 ± 11 Amateur Adults- 168 ± 9 Elite Juniors- 167 ± 10	Elite Adults- 79 ± 4 Amateur Adults- 87 ± 3 Elite Juniors- 84 ± 4	Elite Adults- 190 ± 2 Amateur Adults- 193 ± 4 Elite Juniors- 199 ± 3	
Abdelkrim et al. [18]	n = 9	Tunisian U-19 National Team (Youth)		All Positions- Q1-173 ± 4 Q2-173 ± 5 Q3-173 ± 4 Q4-167 ± 4 Guards- Q1- 176 ± 4 Q2- 176 ± 5 Q3- 176 ± 4 Q4- 167 ± 4 Forwards- Q1- 173 ± 5 Q2- 173 ± 5 Q3- 174 ± 4 Q4- 167 ± 4 Center- Q1- 171 ± 3 Q2- 170 ± 3 Q3- 171 ± 4 Q4- 165 ± 4	All Positions- 91 ± 2		Mean-5.49 ± 1.24 mmol/l
Torres-Ronda et al. [12]	n = 7	Spanish ACB League (Elite)		158 ± 10	96.8 ± 2.6	198 ± 9.3	
Abdelkrim et al. [9]	n = 6	Tunisian Junior National Team (Youth)					Mean-5.75 ± 1.25 mmol/L Peak- 6.22 ± 1.34
Abdelkrim et al. [30]	n = 6	Tunisian National Team (Elite)		Q1-176 ± 5 Q2-176 ± 4 Q3-176 ± 4 Q4-172 ± 4			
Narazaki et al. [21]	n = 1	NCAA Division II (Sub-Elite)		169.3 ± 4.5			4.2 ± 1.3mmol/L
Puente et al. [26]	n = 1	Spanish Basketball Federation (Sub-Elite)			Guards- 89.6 ± 4.7 Forwards- 87.8 ± 3.2 Centers- 92.7 ± 4.7 Whole Group- 89.8 ± 4.4		

Heart Rate (HR) expressed in Beats Per Minute (BPM). Blood Lactate Concentrate express in millimoles per liter mmol/L. Q1 is 1st quarter, Q2 is 2nd quarter, Q3 is 3rd quarter, and Q4 is 4th quarter of match-play.

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Table 2. External load during competition.

Study	Competitions (n=)	League (Level)	Average Speed	Max Speed	Total Distance	Accelerations	Decelerations
Sampaio et al. [5]	n = 1230	NBA (Elite)	Speed in offense (m·s) All-Star 1.95 ± 0.16 Non-All-Star 2.01 ± 0.12 Speed in defense (m·s) All-Star 1.63 ± 0.07 Non-All-Star 1.72 ± 0.08				
Scanlan et al. [13]	n = 5	Australian NBL/ Queensland State Basketball League (Elite/ Sub-Elite)			Professional Quarter 1–1653 ± 38 Quarter 2–1591 ± 24 Quarter3-1531 ± 72 Quarter 4–1504 ± 21 Semiprofessional Quarter 1–1549 ± 81 Quarter 2–1601 ± 88 Quarter 3–1501 ± 166 Quarter 4–1557 ± 238		
Vázquez-Guerrero et al. [27]	n = 2	Spanish ACB League (Elite)				PGs- Acc. (<3 m·s^{-2}) #/min- 29.6 ± 3.9 Acc. (>3 m·s^{-2}) #/min- 1.4 ± .9 SGs- Acc. (<3 m·s^{-2}) #/min- 32.7 ± 11 Acc. (>3 m·s^{-2}) #/min- 1 ± .4 SFs- Acc. (<3 m·s^{-2}) #/min-26.7 ± 2.6 Acc. (>3 m·s^{-2}) #/min-.8 ± .3 PFs- Acc. (<3 m·s^{-2}) #/min- 28 ± 5 Acc. (>3 m·s^{-2}) #/min- 1.4 ± .5 Cs- Acc. (<3 m·s^{-2}) #/min- 28.3 ± 1.1 Acc. (>3 m·s^{-2}) #/min- 1.5 ± .4	PGs- Dec. (<-3 m·s^{-2}) #/min- 23.8 ± 3.6 Dec. (>-3 m·s^{-2}) #/min- 4.5 ± 1.4 SGs- Dec. (<-3 m·s^{-2}) #/min-25.7 ± 10 Dec. (>3 m·s^{-2}) #/min- 4.5 ± 1.4 SFs- Dec. (<-3 m·s^{-2}) #/min- 21.7 ± 2.2 Dec. (>-3 m·s^{-2}) #/min- 3.2 ± .7 PFs- Dec. (<-3 m·s^{-2}) #/min- 24 ± 4.6 Dec. (>-3 m·s^{-2}) #/min- 3.5 ± .7 Cs- Dec. (<-3 m·s^{-2}) #/min- 23.4 ± 1.3 Dec. (>-3 m·s^{-2}) #/min- 3.7 ± .8
Svilar et al. [15]	n = 11	Spanish ACB League (Elite)				tACCmin- 2.19 ± 0.84 (2.07–2.31) hACCmin- 0.38 ± 0.25 (0.34–0.42)	tDECmin- 2.38 ± 0.63 (2.28–2.47) hDECmin- 0.25 ± 0.19 (0.22–0.28)
Caparrós et al. [7]	n = 87	NBA (Elite)		Average- 8.09 ± 0.44 (m·s) Minimum-6.79 (m·s) Maximum-8.76 (m·s)		Acceleration- .5 (m·s^{-2})-262.5 ± 97.9 1 (m·s^{-2})- 90.2 ± 34 2 (m·s^{-2})- 12.8 ± 34 4 (m·s^{-2})- 0.7 ± 1.0	Deceleration- -.5 (m·s^{-2})- 172.7 ± 62.7 -1 (m·s^{-2})- 112.3 ± 39.1 -2 (m·s^{-2})- 6.6 ± 3.6 -4 (m·s^{-2})- 0.3 ± 0.6

(Continued)

Table 2. (Continued)

Study	Competitions (n=)	League (Level)	Average Speed	Max Speed	Total Distance	Accelerations	Decelerations
Abdelkrim et al. [16]	n = 6	Tunisian National Team (Elite)		Peak Speed- (m·s) PG- 5.2 ± .52 (4.02–5.76) SG4.60 ± 0.42 (4.02–5.29) SF- 4.69 ± 0.63 (4.02–5.76) PF- 4.72 ± 0.61 (4.02–5.76) C- 4.10 ± 0.35 (3.78–4.79)	PG- 2,724 ± 711 (1,120–3,480) SG- 1,907 ± 577 (1,120–2,840) SF- 2,031 ± 867 (1,120–3,480) PF- 2,067 ± 837 (1,120–3,480) C- 1,227 ± 484 (800–2,160)		
Puente et al. [26]	n = 1	Spanish Basketball Federation (Sub-Elite)		Max Speed (m·s) Guards- 6.6 ± 0.4 (5.9–7.3) Forwards- Max Speed- 6.2 ± 1.1 (5.1–8.5) Center- Max Speed- 5.9 ± 0.4 (5.1–6.3) Whole group- Max Speed- 6.2 ± 0.7 (5.0–8.5)			
Abdelkrim et al. [9]	n = 6	Tunisian National Team (Elite)			Total Distance 7,558 ± 575 (6,338–8,397). 1st half- 3,742 ± 304 2nd Half- 3,816 ± 299 m		
Vázquez-Guerrero et al. [28]	n = 13	Euro League U-18 (Youth)		Peak Speed ($km \cdot h^{-1}$) Guards- Q1- 19.57 ± 0.9 Q2- 19.56 ± 1.3 Q3- 19.64 ± 0.8 Q4- 19.36 ± 1.0 Forwards- Q1- 19.35 ± 1.0 Q2- 39.34 ± 1.0 Q3- 18.92 ± 0.3 Q4- 19.15 ± 1.0 Center- Q1- 19.16 ± 0.8 Q2- 18.82 ± 1.0 Q3- 18.75 ± 1.0 Q4- 19.07 ± 0.9	Total Distance/Playing Duration Guards- Q1- 80.46 ± 7.5 Q2- 73.91 ± 8.9 Q3- 76.81 ± 8.4 Q4- 70.00 ± 9.8 Forwards- Q1- 78.91 ± 10.0 Q2- 71.90 ± 9.0 Q3- 71.98 ± 11.2 Q4- 69.15 ± 13.8 Centers- Q1- 73.45 ± 12.9 Q2- 69.10 ± 7.9 Q3- 68.95 ± 9.4 Q4- 64.24 ± 8.5	Acc. > 2 ($m \cdot s^{-1}$) Guards- Q1- 2.20 ± 0.4 Q2- 1.99 ± 0.6 Q3- 1.95 ± 0.5 Q4- 1.72 ± 0.4 Forwards- Q1- 2.04 ± 0.6 Q2- 1.83 ± 0.5 Q3- 1.72 ± 0.5 Q4- 1.66 ± 0.6 Centers- Q1- 1.76 ± 0.6 Q2- 1.64 ± 0.4 Q3- 1.44 ± 0.3 Q4- 1.26 ± 0.4	Dec. > -2 ($m \cdot s^{-1}$) Guards- Q1- 2.04 ± 0.4 Q2- 1.79 ± 0.5 Q3- 1.82 ± 0.5 Q4- 1.52 ± 0.4 Forwards- Q1- 1.70 ± 0.5 Q2- 1.47 ± 0.5 Q3- 1.39 ± 0.5 Q4- 1.28 ± 0.5 Centers- Q1- 1.25 ± 0.4 Q2- 1.20 ± 0.4 Q3- 1.04 ± 0.3 Q4- 0.99 ± 0.4

(m·s) = meters per second. (km·h) = kilometers per hour PG- Point Guard, SG-Shooting Guard, SF- Small Forward, C- Center. Acc. = accelerations. Dec. = decelerations. tACC = total accelerations. hACC = high-intensity accelerations. tDEC = total decelerations. hDEC = high-intensity decertations. #/min = number per minute. Q1 = 1st Quarter. Q2 = 2nd Quarter. Q3 = 3rd Quarter. Q4 = 4th Quarter.

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4.2.1 Total distance. In elite competition, distance traveled ranged from 1,991 to 6,310 m [13,16,9]. The total distance covered during sub-elite competition ranged from 3,722 to 6,208 m [48,13]. Finally, considering youth competition, only one study tracked the distance traveled during competition and reported a value of 7,558 m [9]. Remarkably, there was a discrepancy in distance covered between elite, sub-elite, and youth athletes. Upon review, the elite level basketball athletes covered, on average, less distance (4,369 m) [4,13,16,7], compared to sub-elite

(5,377 m) [4,13,48] and youth players (7,558 m) [9]. This seemingly paradoxical finding suggests that the total distance covered may be a poor indicator of in-game performance. In fact, one could infer that the observed phenomenon is a product of technical mastery relative to the demands of competition, as well as elite level players having a higher level of economy in relation to the tactical aspects of basketball [1,5,6]. Based on the present results and as it occurs in other team-sports [50], the key aspect here appears to be not "*how much*" distance a player covers (i.e., quantity) but "*how*" and at "*what intensity*" that distance is covered (i.e., quality). In fact, in support of the previous, Sampaio et al., [5] suggested that better players tend to make fewer mistakes when deciding when and where to run which may result in shorter paths to reach their destination. This is more than likely due to a high degree of technical and tactical discipline based on training age and experience, more hours of professional supervised practices, and higher level of coaching.

4.2.2 Accelerations and decelerations. Accelerometry in basketball is tracked via inertial units containing accelerometer, gyroscope, and magnetometer sensors [15,7,27]. These sensors allowed inertial movement analysis by recording accelerations, decelerations, jumps, and changes of direction (COD). As it can be seen in Table 2, when considering the accelerometry data collected during elite level competition, most research breaks it down into two important categories: accelerations (ACC) and decelerations (DEC) [15,7,27,28]. Additionally, two subsections of these categories can be found: total (T), and high-intensity (HI) [15,27]. For the purpose of this review, total accelerations (ACC_T) were classified as total forward acceleration, whereas high-intensity accelerations (ACC_{HI}) were classified as the total forward acceleration within the high band (>3.5 $m{\cdot}s^{-2}$) [15], and (>3 $m{\cdot}s^{-2}$) [27]. Total decelerations (DEC_T) consisted of the total number of decelerations and high-intensity decelerations (DEC_{HI}) were classified as total deceleration within the high band (>-3.5 $m{\cdot}s^{-2}$), and (>-3 $m{\cdot}s^{-2}$) [27].

During elite level match-play, the ACC_T ranged from 43 to 145, and the total number of ACC_{HI} ranged from 1 to 15 per match. Remarkably, a substantial variability can be found within the included studies, considering the ACC values. This occurrence makes it difficult to draw precise conclusions regarding the ACC demands of elite basketball competition. In fact, a similar pattern can be observed for DEC_T as values ranging from 24 to 95 per match were found. Regarding the total number of DEC_{HI} per match, data extracted ranged from 4 to 40. It seems evident that additional investigations on this topic are warranted before a "clear picture" can be drawn concerning the ACC and DEC demands. Moreover, researchers and sports scientists are encouraged to follow a standardized approach to ACC and DEC quantifications (e.g., determining the same HI bands) so that comparisons between studies and data sets can be conducted. None of the sub-elite or youth teams in the included studies collected accelerometry data during competition.

4.2.3 Average and top speed. Studies evaluating NBA competition [5,7] recorded average speed in miles per hour (mph), but values were converted by the authors to the global unit measurement of meters per second ($m{\cdot}s^{-1}$). The speed recorded by using spatial tracking cameras (Sport VU®; Chicago, USA) can be seen in Table 2. Sport VU® cameras were installed in all 30 NBA arenas from the 2012–2013 season until the 2016–2017 season and McLean et al. [51] collected data from the entire 82 games plus the playoffs. This technology uses computer vision systems designed with algorithms to measure player positions at a sampling rate of 25 frames per second [5]. Top speed was also measured by Puente [26] via SPI PRO X (GPSports®, Australia) and Abdelkrim et al. [16], as well as Vázquez-Guerrero et al. [28] via WIMU PRO Local Positioning System (Realtrack System, Almeria, Spain).

Similar to accelerometry data, positional tracking cameras have only been used to track match demands in elite level basketball, most likely due to the financial limitations on the sub-elite and youth levels. Importantly, when examining normative data points related to movements associated with basketball, it seems that the best performers on an elite level expressed certain performance characteristics. For example, Sampaio et al. [5], when examining All-Star Players versus Non-All-Star players in the NBA, found that there was a significant difference in average speed on both the offensive and defensive ends of the court. All-Star players had an average speed of 4.38 ± 0.36 mph (2.0 ± 0.2 $m{\cdot}s^{-1}$) offensively and 3.65 ± 0.16 mph (1.6 ± 0.1 $m{\cdot}s^{-1}$) defensively, whereas Non-All-Star players had an average speed of 4.50 ± 0.28 mph (2.0 ± 0.1 $m{\cdot}s^{-1}$) offensively and 3.86 ± 0.20 mph (1.7±0.1 $m{\cdot}s^{-1}$) defensively. Within the most prestigious level of basketball, the evidence suggests that the most efficient players tend to exert the least amount of energy to achieve the most productive results [5,7]. With regards to top speed, there was also variability among levels. Puente et al. [26] showed that the average top speed in sub-elite Spanish basketball competition was 6.2 $m{\cdot}s^{-1}$, which is lower than the 8.09 $m{\cdot}s^{-1}$ average top speed by NBA players identified in the work of Caparrós et al. [7]. However, the former study [26] only analyzed one single sub-elite game and, therefore, caution is warranted when directly comparing the results. For this reason, future research is needed in this area. Taken together, the distance and speed data extracted from the literature hint that higher level basketball players seem to cover less distance but achieve greater top speeds during competition, which is in line with what has been reported in other team sports [52,50].

4.2.4 Time motion analysis. Time motion analysis has been widely used to track frequency and duration of movements during competition [4,18,26,22,14,9,32]. Movements such as stand/walk, jog, run, sprint, and jump are commonly recorded among different levels of competition as well as different positions. Within this research, and based on the published literature, stand/walk was defined as movements performed at a velocity of 0–1 $m{\cdot}s^{-1}$ [1,14,18,22,32] and jogging was defined as intensities greater than walking but without urgency performed at 1.1–3.0 $m{\cdot}s^{-1}$ [4,18,26,9]. Running was defined as sagittal plane movement at a greater intensity than jogging and with a moderate degree of urgency at 3.1–7.0 $m{\cdot}s^{-1}$ [18,22,33]. Finally, sprinting was defined as forward movements characterized as effort close to maximum >7.0 $m{\cdot}s^{-1}$ [4,14,18,9,26,32].

Ferioli et al. [32] and Scanlan et al. [4] examined time motion analysis among elite and sub-elite populations. Upon review, Ferioli et al. [32] found that there was a stark difference between time spent and frequency in high-speed running and sprinting versus jogging in the first division compared to the second division. The 1st Italian Division had frequency of exposures to high-intensity actions (HIA) of 107 ± 26, compared to an average of 78 ± 35 HIA in the second division. Scanlan et al. [4] found that elite backcourt (EBC) and elite frontcourt (EFC) had a much higher frequency of running compared to sub-elite backcourt (SEBC) and sub-elite front court (SEFC) during match-play. EBC had a mean frequency of 504 ± 38 and EFC had a mean frequency of 513 ± 26 of exposures to running during competition. These figures for running during competition are much higher than the SEBC (321 ± 75) and SEFC (352 ± 25), respectively. Again, these results would suggest that top-level basketball players spend more time at high-intensity activities compared to their sub-elite counterparts. In addition, elite players tend to display greater control over the most appropriate time and situations to express high-intensity actions relative to the total distance covered whilst on the court.

Abdelkrim et al. [18] and Puente et al. [26] examined the positional differences using time motion variables during competition. Both studies showed that guards spend more time running compared to forwards and centers. Abdelkrim et al. [18] found that guards had a greater frequency of running during competition (103 ± 11), compared to forwards (88 ± 5) and centers (101 ± 19). Puente et al. [26] found that guards run a longer distance of 3.1 ± 1.1 ($m.min^{-1}$) compared to forwards (2.2 ± 1.9) and centers (1.6 ± 1.6). This information, seen in Table 3, is useful and may have important implications when prescribing high-intensity running relative to each position in basketball. Based on these results, individual conditioning programs should be adapted to the specific physical requirements of guards, forwards, and centers, keeping in mind that the latter have been found to have a lower proportion of high-intensity running, acceleration, decelerations, and COD.

5. Training demands

5.1 Internal training demands

Internal Training Load, displayed in Table 4, considered the following variables: s-RPE, Weekly Training Load, HR_{max}, HR_{ave}, % HR_{max}, and Training Impulse (TRIMP).

5.1.1 Heart rate. Heart rate in training was used to quantify the cardiovascular demands imposed on the athletes [3,12,35,20,23,24]. Torres-Ronda et al. [12] examined HR_{max}, HR_{ave}, and %HR_{max} in 5vs5, 4vs4, 3vs3, 2vs2, and 1vs1 games and found the 1vs1 situations had elicited the largest physiological response. Gocentas et al. [23] compared the HR_{max} between guards and forwards in different training sessions and found that on average guards had a higher HR response (194 ± 14) than forwards (190 ± 12.7). More investigation is needed in the future as it relates to the HR demands of varying training programs.

5.1.2 Session RPE and total weekly training load. A fairly common strategy to monitor players' load is to track the total weekly load via the sRPE (RPE multiplied by session duration), collected throughout the training week. In basketball, this method has been widely used to assess Training Load [35, 37, 41] and has been shown to provide good insight on the energy cost of different movement patterns, particularly when coupled with external load data [2,10,39]. Briefly, it involves players reporting their RPE score using the Borg 10-point scale thirty minutes after the completion of each training session, multiplying the value by the number of minutes of the session [41] and then calculating the sum of the values of each training session during the week.

As noted in Table 4, the Total Weekly Training Loads in the studies analyzed ranged from 2255 to 5058 AU in elite level teams [35,37,41]. The large range observed is likely due to the high variability on the number of training sessions or practice duration based on the loads provided by the technical staff. Since sRPE is obtained by multiplying RPE by session duration, the accumulative amount of weekly training load is dependent on the duration of each training session, which can vary based on style of play, level of competition, or moment of the season [36,42,44]. In addition, Svilar et al. [2] found that sRPE showed a very strong correlation with DEC_T and COD_T. According to the authors, the rapid eccentric actions involved in decelerations, cuts, and COD may explain the abovementioned relationship [1,2]. Nevertheless, the mechanical stress imposed on the athletes during these movements, as well as the effects of eccentric training in basketball athletes, are areas that need additional investigation in upcoming studies. A key aspect to consider when utilizing this method to monitor training loads and demands is that in the examination of coach and player perception of recovery and exertion, research has shown that coaches tend to overestimate recovery when compared to the athletes' perception [17]. Therefore, when designing appropriate training sessions, a combination of internal and external load variables is recommended [2,10,39].

5.2 External training load

Regarding External Training Load (Table 5), the variables retrieved from the studies were the number of ACC, DEC, and COD, tracked with inertial units through accelerometry.

5.2.1 Accelerations and decelerations. In elite level basketball, ACC_T in training varied from 16.9 to 59.5 [2,10,15,26,47]. The ACC_{HI} in elite training, classified as the total forward acceleration within the high band (>3.5 $m \cdot s^{-2}$), ranged from 1.9 to 7.2 with a mean of 5.56 per training session. The DEC_T in elite basketball training ranged from 16.4 to 93.2 with a mean of

Table 3. Frequency, duration, and distance of time-motion analysis during competition.

Study	Participants (Competition Level)n = # of comp.	Stand/Walk	Jog	Run	Sprint	Jump	All Movements
Scanlan et al. [4]	Australian NBL/ Queensland State Basketball League (Elite/ Sub-Elite) n = 5	Mean Frequency— EBC- 764 ± 86 SEBC- 462 ± 74 EFC- 815 ± 45 SEFC- 532 ± 38 Duration—mean/total EBC- 0.91± 0.09/691 ±35 SEBC- 2.13 ± 0.11/ 981 ± 81 EFC- 1.02 ± 0.10/ 829 ± 8 SEFC- 2.16 ± 0.07 /1150 ± 68 Distance— EBC- 0.48 ± .06/ 363 ± 4 SEBC- 1.08 ±. 07/495 ± 28 EFC- 0.54 ± .06/ 435 ± 23 SEFC- 1.10 ± .05/586 ± 45	Mean Frequency— EBC- 911 ± 65 SEBC- 586 ± 77 EFC- 955 ± 33 SEFC- 664 ± 59 Duration–mean/total EBC- 1.27 ± 0.07/ 1153 ± 6 SEBC- 1.66 ± .18/961 ± 45 EFC- 1.25 ± .05/ 1192 ± 24 SEFC- 1.57 ± .07/1039 ± 53 Distance— EBC- 2.36 ± .09/ 2142 ± 70 SEBC- 2.97 ± .32/1723 ± 87 EFC- 2.31 ± .06/ 2208 ± 15 SEFC- 2.73 ± .13/1804 ± 89	Mean Frequency— EBC- 504 ± 38 SEBC- 321 ± 75 EFC- 513 ± 26 SEFC- 352 ± 25 Duration—mean/total EBC- 1.34 ± .10/ 673 ± 9 SEBC- 1.38 ± .16/436 ± 60 EFC- 1.43 ± .09/ 730 ± 3 SEFC- 1.33 ± .03/467 ± 11 Distance— EBC- 5.67 ± .46/ 2845 ± 16 SEBC- 6.11 ± .67/1926 ± 268 EFC- 6.11 ± .42/ 3125 ± 57 SEFC- 6.02 ± 0.64/ 2112 ± 73	Mean Frequency— EBC- 18 ± 7 SEBC- 105 ± 31 EFC- 24 ± 1 SEFC- 140 ± 14 Duration–mean/total EBC- 0.51 ± .01/ 9 ± 1 SEBC-0.93 ± .03/ 97 ± 29 EFC-0.51 ± .03/12 ± 3 SEFC-0.98 ± .02/ 136 ± 15 Distance— EBC- 3.85 ± .01/ 70 ± 26 SEBC- 9.08 ± .38/ 952 ± 321 EFC- 3.92 ± .25/ 94 ± 9 SEFC- 9.48 ± .72/ 1329 ± 235		Mean Frequency—EBC- 2733 ± 142 SEBC- 1911 ± 283 EFC- 2749 ± 137 SEFC- 2014 ± 131
Abdelkrim et al. [18]	Tunisian U-19 National Team (Youth) n = 6	Frequency- All Positions- 129 ± 10 Guards-130 ± 8 Forwards- 126 ± 15 Centers- 130 ± 8 Duration- (s) All Players- 2.4 ± 0.3 Guards- 2.3 ± 0.2 Forwards- 2.4 ± 0.3 Centers- 2.6 ± 0.1	Frequency- All Positions- 113 ± 8 Guards-113 ± 8 Forwards- 110 ± 10 Centers- 117 ± 6 Duration-(s) All Players- 2.2 ± 0.2 Guards- 2.1 ± 0.1 Forwards- 2.2 ± 0.2 Centers- 2.3 ± 0.1	Frequency- All Positions- 97 ± 14 Guards-103 ± 11 Forwards-88 ± 5 Centers- 101 ± 19 Duration-(s) All Players- 2.3 ± 0.3 Guards- 2.1 ± 0.4 Forwards- 2.4 ± 0.2 Centers- 2.4 ± 0.4	Frequency- All Positions- 55 ± 11 Guards-67 ± 5 Forwards-56 ± 5 Centers- 43 ± 4 Duration-(s) All Players-2.1 ± 0.2 Guards- 1.9 ± 0.2 Forwards-2.1 ± 0.1 Centers-2.2 ± 0.1	Frequency-All Positions- 44 ± 7 Guards-41 ± 7 Forwards- 41 ± 6 Centers- 49 ± 3	Frequency- All Positions-1050 ± 51 Guards-1103 ± 32 Forwards-1022 ± 45 Centers- 1026 ± 27
Puente et al. [26]	Spanish Basketball Federation (Sub-Elite) n = 1	Distance- (m*min) All Players- 36.4 ± 3.7 Guards- 37.7 ± 2.9 Forwards- 37.2 ± 4.6 Centers- 34.6 ± .6	Distance- (m*min) All Players- 30.9 ± 5.9 Guards- 31.5 ± 6.9 Forwards- 32.0 ± 5.3 Centers- 29.5 ± 5.8	Distance- (m*min) All Players- 2.3 ± 1.6 Guards- 3.1 ± 1.1 Forwards- 2.2 ± 1.9 Centers- 1.6 ± 1.6	Distance- (m*min) All Players- 0.2 ± 0.7 Guards- 0.1 ± 0.2 Forwards- 0.5 ± 1.3 Centers- 0.0 ± 0.0		Distance-(m*min) All Players- 82.6 ± 7.8 Guards-85.3 ± 7.3 Forwards-86.8 ± 6.2 Centers- 76.6 ± 6.0
Klusemann et al. [22]	Elite Australian Juniors (Youth) n = 13	Frequency- Season- 255 ± 32 Tournament- 252 ± 34	Frequency- Season-102 ± 23 Tournament- 99 ± 28	Frequency- Season- 90 ± 17 Tournament- 82 ± 15	Frequency- Season- 33 ± 7 Tournament- 28 ± 8		Frequency-Season- 809 ± 80 Tournament-758 ± 106

(Continued)

Table 3. (Continued)

Study	Participants (Competition Level)n = # of comp.	Stand/Walk	Jog	Run	Sprint	Jump	All Movements
McInnes et al. [14]	Australian NBL (Elite) n = 15	Frequency- 295 ± 54 Duration- 2.5 ± .5	Frequency- 99 ± 36 Duration- 2.5 ± 4	Frequency- 107 ± 27 Duration- 2.3 ± 4	Frequency- 105 ± 52 Duration- 1.7 ± .2	Frequency- 46 ± 12 Duration- .9 ± .1	Frequency- 997 ± 183
Abdelkrim et al. [9]	Tunisian National Team (Elite) n = 6	Distance- (meters) 1720 ± 143	Distance- (meters) 1870 ± 322		Distance- (meters) 763 ± 169		Distance (meters)- 7558 ± 575
Ferioli et al. [32]	Italian 1st/2nd Division (Elite/Sub-Elite) n = 20	REC Frequency- (n) Division I- 184 ± 57 Division II- 184 ± 52 Duration- (s) Division I- 1599 ± 468 Divisin II- 1757 ± 502	LIA Frequency—(n) Division I- 306 ± 92 Division II- 296 ± 77 Duration- (s) Division I- 698 ± 213 Division II- 748 ± 200	MIA Frequency- (n) Division I- 106 ± 31 Division II- 82 ± 34 Duration- (s) Division I- 184 ± 53 Division II- 143 ± 62	HIA Frequency- (n) Division I- 107 ± 26 Division II- 78 ± 35 Duration- (s) Division I- 164 ± 48 Divison II- 116 ± 69		

EBC = elite back-court. EFC = elite front-court. SEBC = sub-elite back-court. SEFC = sub-elite front-court. REC = recovery. LIA = low-intensity activity. MIA = medium-intensity activity. HIA = high-intensity activity. m*min = meters per minute.

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64.6 per training session whereas the DEC_{HI} (n), which were classified as the total number of decelerations within the high band (>-3.5 m·s^{-2}), ranged from 1.6 to 12. When interpreting this data, it is important to acknowledge that ACC_T and DEC_T are qualified measures to quantify training volume, whereas ACC_{HI} and DEC_{HI} are quality measures of training intensity [2,10,15,43].

Remarkably, the number of ACC_T, ACC_{HI}, DEC_T, and DEC_{HI} reported during training were considerably lower than the data found in competition settings [15,7,27]. The total volume of ACC in competition was 81 per match on average, as opposed to a mean of 38 accelerations per training session [36,40,43,47]. The total number of ACC_{HI} was moderately less in training (5.6) opposed to (7.3) during match-play. This was also the case with DEC. DEC_T in competition was 73.1 and the DEC_{HI} 16.4, which is slightly greater than the 64.6 (DEC_T) and 7.4 (DEC_{HI}) in elite level training. The present data supports the notion that training, and match demands seem to be considerably different, at least considering the number of ACC and DEC [15]. Matching the volume and intensity of competition via training is important during certain times of the preparatory and competitive season to adequately prepare the athletes for competition. As a consequence, the data reported herein may be extremely pertinent for practitioners in regard to training reflecting the demands of match-playing, as well as modulating training load based on outputs of these variables during competition. In this context, to try and achieve similar or even greater ACC demands in training with respect to match-play, manipulating constraints such as the number of players, the duration of drills or court dimension may be a potential strategy [12,15,47]. Within this framework, Schelling and Torres [47] found that ACC load in 3vs3 and 5vs5 full court scrimmage drills was greater than 2vs2 and 4vs4 full court scrimmage drills, indeed suggesting that manipulating training variables may greatly affect the total load imposed to the players.

A study by Svilar et al. [10] reported interpositional differences in training load accelerometry data among guards, forwards, and centers. Interestingly, the authors examined load

Table 4. Internal training load.

Study	Training Sessions (n=)	Participants (Competition Level)	s-RPE	Weekly TL (AU)	HR Max (BPM)	HR Average (BPM)	Max HR%	TRIMP (AU)
Svilar et al. [2]	n = 12	Spanish ACB League (Elite)	390.2±135.6					
Svilar et al. [10]	n = 12	Spanish ACB League (Elite)	Guards- 402.9 ± 151.8 Forwards- 385.5 ± 137.3 Centers- 385.1± 121.6					
Ramos-Campo et al. [3]	n = 24	Spanish ACB League (Elite)			187.3 ± 10.9			
Torres-Ronda et al. [12]	n = 15	Spanish ACB League (Elite)			5v5- 172 ± 19 4v4- 176 ± 18 3v3- 177 ± 12 2v2- 174 ± 14	5v5- 144 ± 17 4v4- 142 ± 15 3v3- 142 ± 15 2v2- 141 ± 15	5v5- 83 ± 9 4v4- 85 ± 7 3v3- 86 ± 5 2v2- 84 ± 5	
Angyan et al. [25]	n = 7	Hungarian Pro League (Elite)			169 ± 5.3			
Conte et al. [35]	n = 41	NCAA Division I (Elite)		Starters- 1666.2 ± 148.6 Bench- 1505.5 ± 220.8 1-game week- 1647.7 ± 251.3. 2-game week- 1423.2 ± 163.1				
Manzi et al. [37]	n = 200	Italian 1st Division (Elite)		No Game- 3334 1 Game- 2928 2 Games- 2791				
Heishman et al. [38]	n = 16	NCAA Division I (Elite)						High PL- 135.1 ±35.9 Low PL- 65.6±20.0 High Readiness- 85.3 ±19.6 Low Readiness- 104.4 ±20.1 Pre- 100.3±8.6 Post- 81.9±11
Aoki et al. [39]	n = 45	National Brazilian League (Elite)	Preseason- 442.9 ± 89.2 In-Season- 377.1 ± 68.3					Preseason- 27.1 ± 2.1 In-Season- 21.5 ± 1.6
Ferioli et al. [41]	n = 360	Italian 1st Division/ semiprofessional (Elite/Sub-Elite)		Pro- 5058 ± 1849 Simi-Pro- 2373 ± 488				
Gocentas et al. [23]	n = 42	Semiprofessional (Sub-Elite)			Guards- 194 ±14 Post- 190 ± 12.7			
Chatzinikolaoet al. [20]	n = 2	Greek League (Elite)			195 ± 6			

(*Continued*)

Table 4. (Continued)

Study	Training Sessions (n=)	Participants (Competition Level)	s-RPE	Weekly TL (AU)	HR Max (BPM)	HR Average (BPM)	Max HR%	TRIMP (AU)
Scanlan et al. [44]	n = 44	Australian State Level (Sub-Elite)	47.0 ± 15.7 65.0 ± 17.8 65.0 ± 24.2 74.0 ± 22.7					31.6 ± 5.0 30.3 ± 6.4 28.8 ± 4.9 29.9 ± 5.4
Vaquera et al. [24]	n = 26	U-18 Spanish Juniors (Youth)					5v5 condition (91.2 ± 4.7%. HRmax) Max HR 2v2 92.7 ± 3.3%	

s-RPE = session rate of perceived exertion. (AU) = arbitrary units. 5v5 = 5 players versus 5 players. 4v4 = 4 players versus 4 players. 3v3 = 3 players versus 3 players. 2v2 = 2 players versus 2 players.

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parameters according to positional on-court roles and found that centers had a higher volume of ACC_T (59.5 ± 27.1) and ACC_{HI} (7.2 ± 4.8) opposed to forwards (42 ± 21.5, 5.8 ± 4.3, respectively) and guards (43.5 ± 17.5, 6.4 ± 4.4, respectively). Also, noteworthy, forwards were shown to have a high volume of DEC_T (93.2 ± 35.0) and DEC_{HI} (12.7 ± 8.3) compared to guards (84.7 ± 30.1, 11.9 ± 5.7) and centers (88.5 ± 30.3, 6.8 ± 4). It appears that the profiles of activity are quite different amongst positions and further research is necessary to better understand each individual profile. Still, the amount of exposures to cuts, COD, or screening actions, as well as the typical movement area of each positional role may conceivably explain such findings [6,10,12,16,27,53].

Despite the aforementioned, one must consider the limitations of accelerometry when measuring external load. Even though such technology is extremely useful, accelerometers fail to measure the metabolic demands of isometric muscle contractions during player-on-player contact due to the low velocity outputs. While these actions have very low acceleration, they potentially have very high energy demands [1,19,54]. Therefore, the physical cost of player-on-player contact loading is a component of basketball that must be examined more thoroughly in future research to more accurately quantify training and competition load.

6. Limitations

Some limitations should be addressed when considering the present research on training load and competition demands among different levels of basketball. Firstly, several elite leagues (e.g., NBA or ACB) do not allow for wearable technology to be used during competition which creates a gap in the literature as far as linking demands placed on the players during elite competition and how that compares to training. Secondly, when trying to investigate these variables, most sub-elite and youth teams do not have the financial means to invest in equipment to accurately quantify load during training. Finally, the limited number and sample size of youth and sub-elite studies made it difficult to conclude the precise demands of training and competition at these levels. As such, more resources need to be invested in these areas.

7. Conclusion

Basketball is a highly competitive team-sport that requires a cascade and flow of various movement patterns relative to the technical and tactical aspects of the sport. Examining the internal and external loads imposed on the players from both training and competition provides context for the practitioner to create an optimal training environment. Having the knowledge of

Table 5. External training load.

Study	Training Sessions (n=)	Participants (Competition Level)	Acceleration	Deceleration	COD
Svilar et al. [2]	n = 300	Spanish ACB League (Elite)	tACC- 49.1 ± 24.2 hACC- 6.5 ± 4.6	tDEC-89.1 ± 32.2 hDEC- 10.2 ± 6.8	tCOD- 324.1 ± 116 hCOD- 21.4 ± 12.5
Svilar et al. [10]	n = 208	Spanish ACB League (Elite)	tACC- Guards- 43.5 ± 17.5 Forwards- 42 ± 21.5 Centers- 59.5 ± 27.1 hACC- Guards- 6.4 ± 4.4 Forwards- 5.8 ± 4.3 Centers- 7.2 ± 4.8	tDEC- Guards- 84.7 ± 30.1 Forwards- 93.2 ± 35.4 Centers- 88.5 ± 30.3 hACC- Guards- 11.9 ± 57 Forwards- 12.7 ± 8.3 Centers- 6.8 ± 4.0	tCOD- Guards- 324.8 ± 110.2 Forwards- 336.8 ± 121.4 Centers- 312.1 ± 114.8 hCOD- Guards- 23.5 ±1 2.5 Forwards- 24.7 ±1 4.5 Centers- 16.8 ± 8.6
Svilar et al. [15]	n = 16	Spanish ACB League (Elite)	tACCmin RSG- 1.92 ± 0.97 (1.78–2.06) NSG- 2.20 ± 0.76 (1.88–2.52) hACCmin RSG- 0.33 ± 0.26 (0.29–0.37). NSG- 0.25 ± 0.20 (0.17–0.34)	tDECmin RSG- 2.40 ± 1.08 (2.24–2.55) NSG- 2.95 ± 0.88 (2.58–3.23) hDECmin RSG- 0.24 ± 0.22 (0.21–0.28) NSG- 0.36 ± 0.27 (0.25–0.48)	tCODmin RSG- 10.61 ± 4.40 (9.97–11.25) NSG- 13.25 ± 3.69 (11.70–14.81) hCODmin RSG- 0.73 ± 0.46 (0.66–0.80) NSG- 0.95 ± 0.58 (0.71–1.20)
Vazquez-Guerrero et al. [43]	n = 33	Spanish ACB League (Elite)	Accelerations(counts)- 1/2 court- 18.0 ± 2.4 (16.6–19.4) 1/2 court w/transition- 18.3 ± 2.8 (16.7–19.8) Full court- 16.9 ± 0.4 (16.2–17.6) hACC (counts)- 1/2 court- 1.4 ± 0.3 (1.2–1.6) 1/2 court w/transition- 1.6 ± 0.2 (1.5–1.7) Full court- 1.9 ± 0.4 (1.3–2.6) Peak Speed (m·s)- 1/2 court- 4.2 ± 0.2 (4.0–4.3) 1/2 court w/transition- 5.5 ± 0.3 (5.3–5.7) Full court- 5.0 + 0.3 (4.5–5.5)	Decelerations (counts)- 1/2 court- 17.6 ± 2.2 (16.3–18.9) 1/2 court w/transition- 17.9 ± 2.6 (16.4–19.3) Full court- 16.4 ± 0.5 (15.6–17.2) hDEC (counts)- 1/2 court- 1.1 ± 0.3 (1.0–1.3) 1/2 court w/transition- 1.4 ± 0.2 (1.3–1.5) Full court- 1. ± 0.3 (1.1–2.1)	
Aoki et al. [39]	n = 10	National Brazilian League (Elite)	Peak Acceleration ($m{\cdot}s^{-2}$)- Preseason- 2.2 ± 0.2 In-Season- 2.4 ± 0.2		
Scanlan et al. [44]	n = 10	Australian State League (Sub-Elite)	Mean sprint speed (m·s) 3.77 ± 0.38 3.59 ± 0.29 3.62 ± 0.23 3.58 ± 0.30		
Schelling et al. [47]	n = 16	Spanish ACB League (Elite)	2v2 = 14.6 ± 2.8 3v3 = 18.7 ± 4.1 4v4 = 13.8 ± 2.5 5v5 = 17.9 ± 4.6		

hACC = high-intensity acceleration. hDEC = high-intensity deceleration. tACC = total acceleration. tDEC = total deceleration. tCOD = total change of directions. hCOD = high-intensity change of directions. RSG- regular stoppage games. NSG- non-stoppage games.

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the stress demands on the player during competition will help to dictate the volume and dosage of load for desirable adaptations in the player's training regimen. From the results of the present systematic review, it appears that higher-level players seem to be more efficient while moving on-court. Elite level players cover less distance, at lower average velocities, and with lower HR_{max} and HR_{ave} during competition. However, they seem to have greater capacities to move at higher speed. This is likely due to a heightened sense of awareness based on the schematics of the game. Such information may provide insight into personalized testing protocols as well as training recovery strategies based on each player's response and considering mechanical and physiological loading parameters relative to competition level. Examining this holistic approach creates an ideal training environment that facilitates both technical and tactical development as it relates to the game of basketball. Future research must be dedicated to this area to provide more precise insight into the physical and interpositional demands of the sport. It is necessary to accurately and systematically assess competition demands to help determine valid training strategies that resemble match-play, considering training age, physical characteristics, and in-game role of guards, forwards, and centers. Reviewing these principals will allow priming and preparing basketball players for the rigorous of match-play demands.

Supporting information

S1 Checklist. PRISMA 2009 Checklist.
(DOC)

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APPENDIX 2. Study 2: SEASONAL VARIATIONS IN GAME ACTIVITY PROFILES AND PLAYERS' NEUROMUSCUALAR PERFORMANCE IN COLLEGIATE DIVISION I BASKETBALL: NON-CONFERENCE VS. CONFERENCE TOURNAMENT

Reference:

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Seasonal Variations in Game Activity Profiles and Players' Neuromuscular Performance in Collegiate Division I Basketball: Non-conference vs. Conference Tournament

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Basketball has a high demand on a player's neuromuscular system due to a high volume of explosive high-intensity actions. This study aimed to examine the seasonal variations on game demands and players' neuromuscular performance during the Non-Conference (NON-CONF) and Conference (CONF) seasons in NCAA Division I Men's Basketball. Seven NCAA Division I Basketball players' (20 ± 1.2 years, 1.95 ± 0.1 m, and 94 ± 15 kg) match activity profiles were tracked in 17 home games (7 NON-CONF; 10 CONF); furthermore, players performed a repeat hop test on a force platform the day before competition to assess neuromuscular performance. A *t*-test for paired samples was used to analyze the differences between NON-CONF and CONF. Results indicated no significant differences in Total Distance, Peak Speed, Acceleration, and Deceleration loads when comparing NON-CONF and CONF match-play. Regarding neuromuscular performance, Jump Height ($p = 0.03$; ES = 0.43) was negatively affected during CONF. Moreover, a trend toward a decline in Peak Force ($p = 0.06$; ES = 0.38) was found in CONF. Conversely, no differences were obtained regarding Reactive Strength Index and Contact Time. In conclusion, match-play demands remained constant across the season whilst neuromuscular outputs were inhibited during the CONF season.

Keywords: vertical jump, RSI, game demands, fatigue, neuromuscular outputs

INTRODUCTION

Basketball is an intermittent sport in which repeated high-intensity explosive actions (i.e., jumps, accelerations, decelerations, and changes of direction) are performed during match-play (Steenland and Deddens, 1997; Calleja-González et al., 2016a,b; Svilar et al., 2018; Vázquez-Guerrero et al., 2019). Due to the force-velocity features that characterize these actions of the game, an adequate development of the neuromuscular system capabilities (i.e., strength and power) is required (Aoki et al., 2017; Edwards et al., 2018a; Ferioli et al., 2018). In fact, it has been suggested that the ability to produce high levels of force in short amounts of time is paramount and may differentiate basketballers from superior competition levels (Ziv and Lidor, 2010). For this reason, coaches and sport scientists have long been interested in the study of basketball game demands (McInnes et al., 1995; Abdelkrim et al., 2010a,b; Sampaio et al., 2015; Puente et al., 2017; Ferioli et al., 2018; Svilar et al., 2018, 2019; Vázquez-Guerrero et al., 2018, 2019) and the players' neuromuscular profile (Caterisano et al., 1997; Gonzalez et al., 2013; Edwards et al., 2018a,b; Heishman et al., 2019, 2020). A deeper knowledge on these topics could have huge implications on the global responses relative to stress imposed by competition on, for example, players' jumping or reactive strength capabilities. This is especially relevant in contexts where the season lasts for long periods and the competitive calendars are schedule-congested, as in the National Basketball Association (NBA) or college basketball competitions.

In the particular case of the National Collegiate Athletic Association (NCAA) Division I Basketball, the competitive season (where the players have to practice, compete and study) begins in November and potentially lasts up until April. There are typically 3 phases to the season: (i) the Non-Conference (NON-CONF) season, which lasts from November until December and has an inconsistent schedule and variability in competition density patterns; (ii) the Conference (CONF) schedule, held from January until early March, which is consistent in nature and has at least two competitions every calendar week; (iii) the NCAA Tournament which is played in March for teams that qualify. Despite the abundance of literature describing the demands of basketball in different levels of competition (Caterisano et al., 1997; Abdelkrim et al., 2010a; Aoki et al., 2017; McMahon et al., 2019; Souza et al., 2020), no study has focused on analyzing changes in game demands throughout the NCAA college season and the implications this could have on neuromuscular outputs.

Due to the demands and chaotic schedule of competition, it is common practice for strength and conditioning coaches and sports scientist to track and monitor neuromuscular performance outputs and fatigue throughout the competitive season (Edwards et al., 2018a,b). Understanding how these values fluctuate across the season may provide insight on how athletes are adapting to the stress imposed by the sporting activity and have a direct impact on the training loads prescribed to each athlete. In this context, previous studies from basketball and other team-sports have shown that long competitive calendars may have a detrimental effect (i.e., decreased outputs) on selected neuromuscular variables such as maximum dynamic strength, vertical jump height, or sprinting speed (Caterisano et al., 1997; Edwards et al., 2018a,b; Ferioli et al., 2018). Conversely, Gonzalez et al. (2013) observed that players who played more than ∼25 min per game across an entire NBA season increased vertical jump power and improved their reaction time from pre- to post-season. Given these inconsistencies, more research is needed to better understand the fluctuation of neuromuscular performance parameters throughout the basketball season as it may provide valuable information regarding players' recovery needs and readiness to compete (McInnes et al., 1995; Abdelkrim et al., 2010b; Puente et al., 2017; Neal et al., 2018; Vázquez-Guerrero et al., 2018; Heishman et al., 2019, 2020; Svilar et al., 2019).

Considering the previous, having standardized and repeatable assessments that allow gathering information about the function of the neuromuscular system, as well as specific external load variables to the game of basketball, might be extremely relevant for trainers and staff (Cormack et al., 2008, 2013; Bishop et al., 2018). Vertical jumps, for example, have been proposed as simple monitoring tools that can be used to quantify neuromuscular fatigue, particularly through force plate evaluations (Gerodimos et al., 2008; Gathercole et al., 2015; McMahon et al., 2018). Notably, most research utilizes the countermovement jump (CMJ) as the main tool for neuromuscular fatigue evaluation in team-sports (amongst the different types of vertical jump) (Ziv and Lidor, 2010; Gonzalez et al., 2013; Gathercole et al., 2015; Suchomel et al., 2016; Edwards et al., 2018b; Neal et al., 2018). However, based on the need for rapid stretch shortening cycle actions in basketball, it may be interesting to explore a repeated-hop test to assess players readiness and fatigue levels during the competitive phase of the season (Klusemann et al., 2013). Variables obtained from this type of evaluation (e.g., peak force or reactive strength index [RSI]) can provide important information in sports that require the production of large amounts of vertical force in a short amount of time; moreover, they can reflect potential neuromuscular fatigue elicited by basketball competition (Cormack et al., 2008, 2013; Gerodimos et al., 2008; McMahon et al., 2018; Heishman et al., 2019, 2020).

To the best of authors' knowledge, no previous study has simultaneously investigated the match-play demands of NCAA Division I basketball and examined how players' neuromuscular performance, assessed through a repeated-hop test, fluctuates throughout the competitive collegiate season. From an applied standpoint, this investigation may help coaches and sport scientists design more effective training and recovery strategies (Calleja-González et al., 2016a,b) by providing insight on the effects of a basketball season on performance. Therefore, the purpose of this study was two fold: (1) to examine and compare the match demands in both a NON-CONF and CONF tournament of the NCAA Division I Men's Basketball Championship; (2) to investigate how neuromuscular performance outputs and neuromuscular fatigue levels change throughout the course of the complete collegiate basketball season.

MATERIALS AND METHODS

Experimental Design

This descriptive longitudinal study was performed during the competitive phase of the 2017/2018 NCAA Division I collegiate basketball season. Match-play data was recorded during home games in both the NON-CONF and CONF seasons. NON-CONF occurred in the months of November and December 2017 and was classified as playing teams outside of the conference in a randomized format with a total of 12 matches (8 home and 4 away). CONF occurred during the months of January and February and was classified as playing teams within the conference with a frequency of 2 competitions per week for a total of 19 competitions (10 home and 9 away). Players' neuromuscular performance and fatigue were continuously assessed throughout the season on a weekly basis, particularly in the day before competition (i.e., Match-day−1) via a repeated-hop test. Data on each player was collected by the strength and conditioning staff as routine for the daily assessment of fatigue and player loads.

Subjects

Seven NCAA Division I male collegiate basketball athletes (4 guards and 3 forwards; 20 ± 1.2 years, 1.95 ± 0.09 m, and 94 ±15 kg) from the same team were included in this study. The University Institutional Review Board (IRB) approved this study and researchers were provided de-identified data to analyze. By enrolling in the university's basketball program, student-athletes provided individual consent for study participation as part of their requirements as a team member. All participants were medically cleared and presented no musculoskeletal injuries or cardiovascular, respiratory, neurological, metabolic, hematological endocrine exercise disorders that might impair their performance during training or match. Additionally, no participants were using illegal drugs or taking medications, which affected body mass.

Procedures

Match-Play Demands

Match-play activity profiles were tracked throughout the competitive season via spatial tracking cameras (Sport VU®; Chicago, USA) (Sampaio et al., 2015; Linke et al., 2018). A total of 17 home games were analyzed during the competitive season (7 NON-CONF, 10 CONF). Six cameras were set up within the competition arena to track in-game payer loads. The primary performance variables used to track game load were Total Distance (m), Peak Speed (km·h^{-1}), Acceleration and Decelerations loads expressed in arbitrary units (AU) (Vázquez-Guerrero et al., 2018; Svilar et al., 2019). Data was collected via Stats Sports Sport VU software and exported to a customized spreadsheet (Microsoft Excel 2016, USA). All seven subjects competed in each of the 17 matches.

Neuromuscular Testing

Each player's neuromuscular performance and fatigue were assessed on the Match-Day−1 of the 17 competitive home matches via a repeated-hop test (Flanagan and Comyns, 2008). The hop test was preceded by a standardized warm up consisting of a series of squats, lunges, and free arm swing CMJ. Three repeated-hops were performed on a triaxial force plate (9260 AA—Kistler, Switzerland) (Crewther et al., 2011). The repeat hop test was performed with the athlete's hands on their hips and after the athlete was still for a 3 s period on the force platform to stabilize body weight. Athletes were instructed to jump as high and as fast as possible 3 times with minimal ground contact time and without resetting between jumps. All tests were completed 15 min prior to practice. If the athletes did not complete the standardized warm up or the test did not fall within the 15-min window pre-practice, results were not considered (Kamonseki et al., 2018). All jumps were recorded via a data acquisition system (DAQ System Type 5691 A- Kistler, Switzerland). Each trial was exported to a text file and then imported and analyzed with the ForceDecks Software (Vald Performance, Brisbane, Australia). The primary variables examined of the 3 jumps were best Jump Height (JH) in cm, Peak force (PF) in Newtons (N), mean Contact Time (CT) of the 3 jumps in ms and best RSI (calculated by dividing JH/CT) in m·s^{-1}.

TABLE 1 | Comparison of the match-play outcomes between the non-conference and conference tournaments.

	NON-CONF	CONF	*p*-value	ES (95% CL)
Distance (m)	1590 ± 535	1560 ± 659	0.77	0.05 (−0.35; 0.45)
Peak Speed (km·h^{-1})	15.5 ± 1.1	15.3 ±1.4	0.53	0.13 (−0.27; 0.53)
Acceleration Load (AU)	349 ± 110	331 ± 126	0.46	0.15 (−0.25; 0.55)
Decelerations Load (AU)	643 ± 201	603 ± 235	0.31	0.18 (−0.22; 0.58)

NON-CONF, Non-conference tournament; CONF, Conference tournament; ES, effect sizes; CL, confidence limits; AU, arbitrary units.

TABLE 2 | Comparison of the neuromuscular performance outcomes between Non-conference and Conference tournament.

	NON-CONF	CONF	*p*-value	ES (95% CL)
Jump Height (cm)	22.7 ± 6.7	19.9 ± 6.3*	0.03	0.43 (0.03; 0.84)
Peak Force (N)	2957 ± 651	2719 ± 596	0.06	0.38 (-0.02; 0.79)
Contact time (s)	0.50 ± 0.16	0.46 ± 0.13	0.14	0.28 (-0.12; 0.68)
RSI (m·s^{-1})	52.8 ± 23.1	48.0 ± 28.5	0.37	0.18 (-0.22; 0.58)

*NON-CONF, Non-conference tournament; CONF, Conference tournament; ES, effect sizes; CL, confidence limits; RSI, Reactive Strength Index. *P < 0.05.*

Statistical Analysis

All data was reported in mean ± SD with 95% confidence intervals (95%). Normality and homogeneity of variance were checked via the Shapiro-Wilk test (<50), revealing parametric data. Therefore, differences in performance between NON-CONF and CONF metrics were assessed by a *t*-test for paired samples. Effect sizes were calculated as Cohen's *d* (parametric data), and interpreted as trivial, < 0.2; small, 0.2-0.6; moderate, 0.6-1.2 or large, 1.2-2.0 (Hopkins et al., 2009). *P* values below 0.05 were considered statistically significant (Cohen, 1988). The data was analyzed using the SPSS statistical package (version 23.0; SPSS, Inc., Chicago, IL).

RESULTS

Match-play activity profiles can be found in **Table 1**. There were no significant differences in Total Distance covered and Peak Speed achieved in competition between NON-CONF and CONF games ($p > 0.05$). Furthermore, no significant between-tournament differences were found with regards to Acceleration and Deceleration loads ($p > 0.05$).

Table 2 and **Figure 1** display the neuromuscular performance outcomes. Significantly lower JH ($p = 0.03$; ES = 0.43) were observed in CONF with respect to NON-CONF. Furthermore, a trend toward a small decline in PF ($p = 0.06$; ES = 0.38) was found. Finally, no significant differences between NON-CONF and CONF were obtained for CT and RSI ($p > 0.05$).

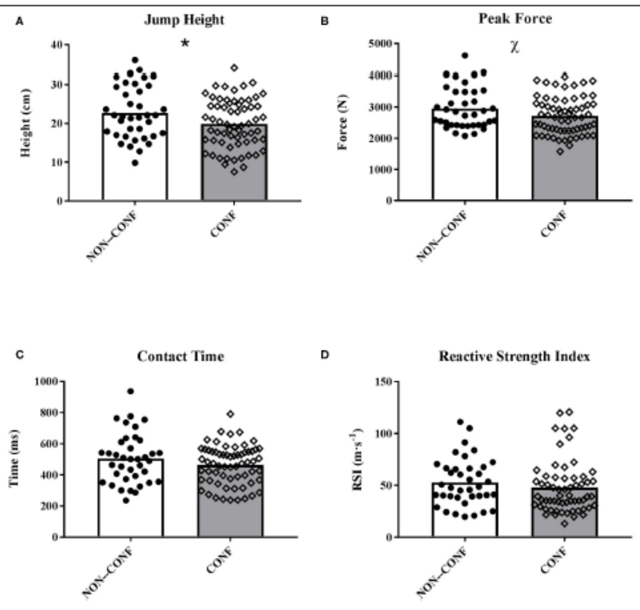

FIGURE 1 | (A) Jump Height, **(B)** Peak Force, **(C)** Contact Time, and **(D)** Reactive Strength Index obtained on the repeated-hop test during the Non-Conference (NON-CONF) and Conference (CONF) seasons. Bars indicate mean values. The black circles and white squares represent individual data points from all the players' Match-Day−1 assessments. * Significant decrease in Jump Height. $^{\chi}$ Trend toward decreased Peak Force.

DISCUSSION

The purpose of the present study was to examine and compare the game demands in both NON-CONF and CONF match-play of NCAA Division I Men's Basketball, as well as to investigate how neuromuscular performance outputs change throughout the course of the competitive collegiate basketball season (November and December 2017). The main findings from this study indicated that: (1) no difference were found in match-play demands when comparing NON-CONF to CONF seasons and (2) neuromuscular performance (i.e., JH and PF), assessed with a repeated-hop test, was negatively impacted during the CONF season. The results show that game demands appear to be constant across both competitions; nevertheless, the higher density patterns and travel characteristics of the CONF season (i.e., 19 games in ∼8 weeks) may result in higher levels of residual fatigue that ultimately affect performance (McLean et al., 2010).

Previous research has examined game demands of basketball based on regular season vs. tournament competitions (Klusemann et al., 2013), different competition levels (Abdelkrim et al., 2010b; Aoki et al., 2017; Ferioli et al., 2018; Svilar et al., 2018) and playing position (Abdelkrim et al., 2010a; Puente et al., 2017; Svilar et al., 2019). However, to the authors' knowledge, no previous study has investigated the game activity profiles in elite level collegiate basketball or whether meaningful changes occur throughout the season. For example, Klusemann et al. (2013) found that the frequency of running, sprinting, and shuffling movements in seasonal games was higher than in tournament games by 8–15%, but investigated a sample U-18 youth basketball players. Conversely, the present data regarding match-play demands identified no significant fluctuations in any of the variables analyzed (i.e., Total Distance, Peak Speed, Acceleration, and Deceleration loads) when contrasting the NON-CONF and CONF seasons. These findings suggest that the activity profiles remain constant regardless of the schedule and competition characteristics in collegiate basketball format. From a practical perspective, as game loads appear to be stable throughout the competitive season, practitioners can manipulate variables outside of competition to influence performance and use this information to program typical weeks that mimic loads imposed during match-play. For example, coaches can modulate training to reflect game demands during times of the year where frequency of competition is less (i.e., NON-CONF). On the contrary, when congestion of games is high (i.e., CONF tournament) coaches may wish to limit high volumes of court transitions, accelerations, and decelerations during training to allow for an adequate recovery between consecutive matches (Abdelkrim et al., 2010a; Calleja-González et al., 2016b).

As it relates to neuromuscular performance, a distinctive aspect of the present study is that not only JH, but also other outcomes from the repeated-hop test (i.e., PF, CT and RSI) were investigated. Notably, there was a significant decrease in JH during the CONF season (**Figure 1A**) and a trend ($p = 0.06$) toward a decline in PF (**Figure 1B**). No differences were found in CT or RSI. Previous research has shown that loads imposed during training can elicit neuromuscular fatigue resulting in decreased JH and increased ground CT in elite basketball athletes (Edwards et al., 2018a,b; Heishman et al., 2019, 2020), as well as top level Australian Football (Cormack et al., 2008, 2013) and Rugby League (McLean et al., 2010) using a CMJ. Despite the CMJ being the jump test most frequently found in the scientific literature (Edwards et al., 2018a,b; Heishman et al., 2019, 2020), the repeated-hop test was used herein and, hence, direct comparisons between studies must be performed with caution. However, the rebounding aspect of a repeat-hop test has an extremely high level of specificity as it relates to the sporting activity of basketball and that is the reason why the coaching staff opted to use this assessment throughout the season. There are several potential factors that influenced the observed changes in neuromuscular performance within this present study, the first being density of games in CONF compared to NON-CONF play. In the 8-week NON-CONF season, the team was exposed to 12 games during the months of November and December (i.e., average of ~1.5 games·week^{-1}). In contrast, during the 8-week cycle of the CONF season in January and February, the team completed 19 games (i.e., average of 2.4 games·week^{-1}). Based on this fact, it appears that the increased frequency of games might have had a negative impact on some of the neuromuscular outputs assessed.

Further to the previous, one must also consider the travel required during different times of the year. In NON-CONF, the players only traveled via plane and stay overnight in a hotel twice. In contrast, the team had to travel 9 times during the CONF season. In this context, previous investigations have showed the detrimental effects that travel can have on performance in basketball (Steenland and Deddens, 1997). Steenland and Deddens (1997) found that less travel and more time in between competitions resulted in an improved performance in the NBA. These findings provide insight on how teams should prioritize training or recovery based on density patterns of games and travel during the competitive season. During times of less dense competitions, practitioners might want to prescribe greater volumes of resistance and strength-power related training (e.g., gym-based sessions and court-based sessions with high incidence of jumps, cuts, changes of direction) to avoid/minimize declines in neuromuscular performance later in the season. However, in match-congested moments of the season it may be more adequate to focus on more restorative training sessions to increase on-court performance (Puente et al., 2017). Based on the present research it is evident that when frequency of competition and travel demands increase practitioners should have more of an emphasis on recovery.

Notably, both peak and temporal kinetic values during jumping tasks can be useful to gain insight on the neuromuscular strategies employed for each individual athlete. RSI, assessed as a ratio of JH:CT, has been shown to be an extremely useful evaluation tool for coaches during the course of a competitive season (McMahon et al., 2018; Heishman et al., 2019). When CT increases and JH decreases, it could potentially be a sign of neuromuscular fatigue; however, when JH increases, and CT decreases this may indicate a high level of training readiness (Flanagan and Comyns, 2008; Cormack et al., 2013). In the present study, no significant differences were found in RSI, despite the decreases observed in JH. This outcome is most probably due to the small non-significant decline in CT observed. Regarding PF, this variable is another valuable force platform outcome for coaches (Gerodimos et al., 2008; Bishop et al., 2018; McMahon et al., 2018) since it has been recently recommended to be used in conjunction with JH to assess subtle differences in vertical jump performance (McMahon et al., 2019; Souza et al., 2020). In fact, both peak and time course force plate variables have been used to assess neuromuscular fatigue in athletes (Cormack et al., 2008, 2013; Gonzalez et al., 2013; Gathercole et al., 2015; Suchomel et al., 2016; Edwards et al., 2018a; McMahon et al., 2018, 2019; Neal et al., 2018; Heishman et al., 2020). Interestingly, a trend toward a small decline was found in PF when comparing CONF to NON-CONF (**Figure 1B**), hence supporting the notion that fatigue (or insufficient recovery) was present and vertical jump ability was affected during the more congested phase of the season. Future research is needed to gain better insight on how different metrics oscillate throughout a basketball season.

Discussion is warranted on the limitations of the present study. First, the limited sample size may have impacted the statistical analysis of the results. However, all players involved in the present research are currently in professional basketball rosters in North America and Europe, highlighting the exceptionality of the sample studied. Furthermore, it is worth emphasizing that this investigation was conducted during 16 consecutive weeks in which players were continuously assessed on a weekly basis. This is extremely difficult to accomplish in top level collegiate basketball within the constraints of limited time and resources, characteristic of applied research (Bishop, 2008). Second, match-play activity profiles were monitored only during home games due to the fact tracking system was not available at other arenas. As a consequence, potential discrepancies between the demands imposed at home vs. away games were not depicted in the present research. Finally, neuromuscular outputs may have been affected by factors other than the game and training demands in this sample of college student-athletes (i.e., academic stress, poor sleep quality, dehydration). Therefore, future research warrants the investigation of these global stressors that could have a potentially detrimental impact on performance.

PRACTICAL APPLICATIONS

The NCAA Division I Basketball schedule is demanding on student-athletes. It is imperative for practitioners working with these athletes to monitor game demands and neuromuscular outputs (and fatigue) that can blunt performance throughout the season. Having a wholistic approach allows coaches to manipulate variables outside of training to garner specific adaptations and facilitate recovery when needed. Based on the present data, no differences were found in match-play demands when comparing NON-CONF vs. CONF seasons. In contrast, neuromuscular performance (i.e., jump height and peak force) was impacted during the CONF season, when the density of games and travel requirements were higher. Understanding how these variables fluctuate during different periods of the season can have direct implications on how coaches and sports scientists' program for peak performance. From a practical perspective, when frequency of match-play is low, greater volumes of strength- and power-oriented training and on-court sessions that replicate game loads may help maintain high levels of physiological readiness. Conversely, when densities increase, the emphasis should be placed on practices that enhance and maximize recovery between games.

CONCLUSION

Congestion of match-play demands can have a detrimental impact on neuromuscular outputs and impede performance. Although game demands were constant throughout the competitive season, neuromuscular profiling showed a deleterious effect based on time of year. The data highlighted the importance of load tolerance and robustness when density patterns of games are at their highest rate. These findings could potentially affect how practitioners have selective menu items to facilitate recovery vs. potentiation effects based on time of year and competition schedule.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The University of Arkansas. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

AP is corresponding author and conducted the data collection. TF, PA, and JC-G all contributed to the design of the study as well as the manuscript. TF conducted the statistical analysis. LT-R was a contributing author on the manuscript. All authors contributed to the article and approved the submitted version.

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APPENDIX 3. Study 3: MATCH DAY-1 REACTIVE STRENGTH INDEX AND IN-GAME PEAK SPEED IN COLLEGIATE DIVISION I BASKETBALL

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Match Day-1 Reactive Strength Index and In-Game Peak Speed in Collegiate Division I Basketball

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Abstract: Basketball is a game of repeated jumps and sprints. The objective of this study was to examine whether repeated jump assessments the day prior to competition (MD-1) could discriminate between fast and slow in-game performances the following day. Seven NCAA Division I Basketball athletes (4 guards and 3 forwards; 20 ± 1.2 years, 1.95 ± 0.09 m, and 94 ± 15 kg) performed a repeated-hop test on a force platform before and after each practice MD-1 to assess Reactive Strength Index (RSI) and Jump Height (JH). Peak speed was recorded during games via spatial tracking cameras. A median split analysis classified performance into FAST and SLOW relative to individual in-game peak speed. Paired *T*-tests were performed to assess post- to pre-practices differences. An independent sample *T*-test was used to assess the differences between FAST and SLOW performances. Cohen's d effect sizes (ES) were calculated to determine the magnitude of the differences. Statistical significance was set for $p \leq 0.05$. Post-practice RSI and JH were significantly higher than pre-training values prior to the FAST but not the SLOW in-game performances. A significant difference was found for MD-1 RSI when comparing FAST and SLOW conditions ($p = 0.01$; ES = 0.62). No significant between-group differences were obtained in JH ($p = 0.07$; ES = 0.45). These findings could have implications on the facilitation of reactive strength qualities in conjunction with match-play. Practitioners should evaluate the placement of stimuli to potentiate athlete readiness for competition.

Keywords: neuromuscular; repeated jump; max speed

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1. Introduction

Basketball is a court-based team sport that requires contributions from various physical parameters and bio-motor abilities [1]. These broad arrays of skills are principal components of in-game performance [2]. Particularly, basketball requires large expressions of speed and power qualities for match-play success. The technical and tactical aspects of the game put a high demand on the neuromuscular system relative to the sporting activity [3]. Therefore, the process of monitoring changes in these qualities for each individual player becomes paramount during the season (in view of the various stressors encountered by the players) [4–6], as it allows for evaluating longitudinal fluctuations over time [7] and provides insight on speed- and power-related performances.

Within basketball, standardized and repeatable jumping assessments are amongst the most popular to assess neuromuscular function [8–12]. The ability to produce substantial amounts of force onto the ground to vertically displace the center of mass is an important skill contextually within the game, since basketball athletes execute around 45 jumps per game [3]. Thus, it is logical that practitioners collect and analyze jump data throughout the competitive season [13] to allow for a more in-depth neuromuscular function assessment [14–16]. This is particularly important since jump height (JH) alone does not always indicate athlete readiness as individuals may change movement strategies to achieve similar outputs [17]. In this context, the assessment of variables other than height in various jump tasks could be a suitable approach to monitor fatigue and readiness in the in-season period [18].

Previous research has examined jumping ability in basketball, with most studies utilizing the countermovement jump (CMJ) to assess neuromuscular function [18–22]. However, basketball mainly requires rapid stretch-shortening cycle (SSC) actions as well as the activation of H-reflex responses [23] that are not always reflected within the CMJ. To overcome this issue, repeated jumping and hopping tasks can be used, as they permit evaluating the ability to produce high vertical ground reaction forces in short ground contact times. In fact, the reactive strength index (RSI) (i.e., ratio of JH/contact time) has been previously used to measure both performance and fatigue within athletes [8,22].

Along with jumping, running speed is also an important characteristic in basketball [24]. Although the sport is played in a 28 by 15-m court, the ability to reach high top speeds and rates of acceleration can be extremely advantageous within the context of the game [1]. Whether it is via jumping- or running-based actions, athletes that can produce large amounts of force is a short amount of time are more likely to be in optimal positions on the court to garner competitive advantages (e.g., grab a rebound or intercept a pass) [25]. Conversely, if an athlete is producing less force and having longer ground contact times relative to their normative datapoint, this may be a potential sign of fatigue [26,27]. It is for this reason that examining the effects that fluctuations in reactive strength qualities have on the mechanical demands of in-game performance can provide informative decision-making on readiness to compete and recovery needs.

To the best of the authors' knowledge, no previous research has investigated whether a repeated-hop test performed the day before basketball competition can provide meaningful information regarding match-play mechanical demands. Therefore, the main purpose of this study was to investigate if fluctuations in reactive strength qualities could be used as an indicator to discriminate between faster and slower physical in-game performance the following day. This research may help coaches and sports scientists to make more informed decisions on both training and recovery.

2. Materials and Methods

A prospective comparative study was conducted. Neuromuscular performance was assessed on the training day before competition (i.e., Match-day-1 [MD-1]) via a repeated-hop test. Match-play data was recorded during all 17 matches at the team's home arena. All data was collected between the months of November 2017 and February 2018 by the strength and conditioning staff as routine for the daily assessment of fatigue and player loads.

To evaluate neuromuscular performance (i.e., RSI and JH) on MD-1 for all 17 games, a repeated-hop test [28] was performed. The test was performed both pre-practice and post-practice to account for any of the acute effects imposed by the training session the day before the competition. A standardized warm-up of squats, lunges, and free arm swing CMJ preceded the assessment. Three repeated-hops were performed on a triaxial force platform (9260 AA-Kistler, Kistler Group, Winterhur, Switzerland) with the athletes' hands on their hips. Players were instructed to jump as high and as fast as possible while spending minimal time on the plate without resetting between jumps. All tests were completed 15-min prior to, and after practice. The tests were disregarded if the athlete did not complete the standardized warm-up or did not fall within the 15-min windows. Likewise, data was not considered if the player did not test both pre- and post-practice. All jumps were recorded via a data acquisition system (DAQ System Type 5691 A- Kistler, Kistler Group, Winterhur, Switzerland). Each trial was exported to a TXT file and analyzed with the ForceDecks Software (Vald Performance, Brisbane, Australia) [29]. For each athlete, the difference between post- and pre-practice values were calculated (i.e., delta [Δ]). A positive or a negative integer would indicate an increase or decrease in neuromuscular performance, respectively. The mean of the 3 jumps RSI (calculated by dividing JH/contact time) in m·s^{-1}, and JH, in cm, were considered for analysis.

Match-play activity profiles were tracked for each of the 17 home games throughout the 2017–2018 season via spatial tracking cameras (Sport VU®, Stats Perform, Chicago, IL, USA). This six-camera system was set up in the home gymnasium during competitions to track distance and speed of each athlete. The activity profile data was collected via Stats Sports VU software and exported to a customized spreadsheet (Microsoft Excel 2016, Microsoft Corporation, Redmond, WA, USA). The primary performance metric examined was peak speed (km·h^{-1}), given that it is an intensity-related variable that can provide a good gauge of neuromuscular readiness. A median split relative to individual's peak speed was used to determine fast versus slow in-game performances. All 7 players competed in every home match.

Data is presented as means and standard deviation. Data normality was tested using the Shapiro-Wilk test ($n < 30$). For every player, in-game performances ($n = 17$) were divided using a median split analysis into two groups (i.e., FAST: above the individual's median value, and SLOW: below the player's median) according to the peak speed achieved by each athlete during competition. Paired *T*-tests were performed to assess post- to pre-practices differences. An independent Sample *T*-test was used to assess the differences between FAST and SLOW performances. Cohen's d effect sizes (ES) [30] were calculated to determine the magnitude of the differences and classified as: trivial (<0.2), small (>0.2–0.6), moderate (>0.6–1.2), large (>1.2–2.0), and very large (>2.0–4.0). Statistical significance was set for $p \leq 0.05$.

3. Results

Table 1 shows the descriptive data and the comparison between FAST and SLOW performances. Post-practice RSI and JH were significantly higher than pre-training values prior to the FAST but not the SLOW in-game performances. Moreover, when considering the ergogenic response from before to after training (i.e., Δ), a significant difference was found for MD-1 RSI when comparing FAST and SLOW conditions ($p = 0.01$; ES = 0.62). No significant between-group differences were obtained in JH ($p = 0.07$; ES = 0.45).

Table 1. Repeated-hop descriptive data from Match-Day -1 and comparison between FAST and SLOW in-game performances.

	In-Game Performance			
	FAST	**SLOW**	***p***	**ES (95% CI)**
Jump Height (cm)				
Pre-Practice	19.1 ± 5.7	20.9 ± 4.0	0.16	−0.37 (−0.9–0.16)
Post-Practice	23.5 ± 8.7 **	22.1 ± 4.5	0.45	0.20 (−0.32–0.73)
Δ	4.4 ± 8.1	1.2 ± 4.7	0.07	0.49 (−0.05–1.03)
RSI (m·s^{-1})				
Pre-Practice	42.6 ± 20.1	45.1 ± 16.1	0.54	−0.13 (−0.66–0.39)
Post-Practice	57.5 ± 27.2 **	47.1 ± 17.4	0.16	0.45 (−0.09–0.98)
Δ	16.4 ± 27.1	2.0 ± 18.3	0.01	0.62 (0.06–1.17)

** Significant increase with respect to pre-practice ($p \leq 0.01$). **Δ**: delta, change from pre- to post-practice; CI: confidence interval; ES: effect size; RSI: reactive strength index.

4. Discussion

The aim of the present study was to examine MD-1 pre- to post-practice differences (i.e., Δ) in repeated jump outputs and determine whether potentiation or degradation of neuromuscular performance in training could discriminate between faster and slower in-game physical performance. The main findings indicated that large gains in RSI (from before to after training) were observed the day prior to competitions in which higher peak speed values were reached during match-play. These preliminary results are novel and suggest that testing athletes' repeated jump ability both prior to and after practice MD-1 (to account for any potential acute onset of fatigue or potentiation) can provide meaningful information regarding neuromuscular readiness to compete. This study is also unique in that it evaluated elite level basketball players throughout the entire competitive season.

Of note, vertical jump has been previously found to be highly related to running speed [24] and a predictor of repeated-sprint ability in elite basketball players [25]. However, the present study is the first to identify what seemed to be a positive influence of gains in RSI MD-1 in peak speed of subsequent basketball competition. This finding could be extremely useful to practitioners considering that neuromuscular performance usually fluctuates during a typical in-season week [26]. Knowing that speed is a primary component in basketball [1,3], coaches can, therefore, optimize training strategies with the aim of maximizing reactive strength qualities prior to competition. This may, in turn, translate into superior neuromuscular status of the athletes that can place them at an optimal position for in-game success.

Remarkably, Δ JH MD-1 was not able to discriminate between FAST and SLOW in-game performances. Gathercole et al. [11] reported that neuromuscular function alternations 24 h after a fatiguing protocol were not detected when using JH alone (i.e., in both CMJ and drop jump tasks) and suggested that complementary variables such as Flight Time:Contact Time ratio should be assessed. Likewise, it appears that in the repeated-hop test herein, Δ RSI was more sensible than JH to determine neuromuscular readiness the following day. Based on the previous, it appears that an athlete's ability to express high-force outputs in reduced contact times may better discriminate between FAST and SLOW games when compared to how high he can jump in a repeated-hop task. From a practical perspective, coaches are recommended to utilize the RSI metric obtained from a high rate of frequency test to assess their players on MD-1.

The limitations of the present study should be addressed. Firstly, the small sample size limits the generalization of the current findings to other athletic populations. Nevertheless, since 17 games were analyzed here, the preliminary results obtained open a new perspective and should be investigated more in-depth. Secondly, it is important to keep in mind that peak speed is only one of many in-game physical parameters (e.g., accelerations, decelerations, or jumps); hence, further research should consider a more complete set of metrics to provide a clearer picture regarding match-play performance. Finally, variables other than RSI alone may influence subsequent in-game physical performance (e.g., MD-1 training load, recovery protocols, priming strategies). Thus, the reader should interpret the present results cautiously.

In summary, MD-1 sessions that resulted in greater post-practice increases in RSI were observed prior to faster in-game performances when examining peak speed in elite collegiate basketball players. However, larger JH gains were not able to discriminate between faster and slower performances. These finding could impact stimuli provided to athletes prior to competition. Exposures to menu items that promote maximal high force outputs applied in reduced contact times may be most appropriate close to competition.

5. Conclusions

Athletes with greater gains (i.e., Δ) in RSI from pre- to post-practice were found to achieve greater peak speeds in match-play the following day. Conversely, no differences were found between FAST or SLOW performances when JH was the variable analyzed. It is for this reason that professionals should closely examine acute adaptations to MD-1 as it may influence player selection or training strategies that place their athletes in the best position to succeed on the court. Having a critical thought process in regard to the sequencing of menu items is vital in the appreciation of the heterochronicity and different time courses of adaptive processes for varying stimuli. Specifically, actions that foster reactive strength and short ground contacts should be placed as close to the competition as possible within a training week. Further research on these topics is needed to gain a more robust insight into how to best create an environment for optimal neuromuscular outputs around match-play. The proper application of stimulus relative to match-play could have a direct impact on the optimization of neuromuscular status for in-game performance.

Author Contributions: For this present study A.J.P. was responsible for data collection and writing. T.T.F. was responsible for data curation, formal analysis, and editing. J.C.-G. and P.E.A. were responsible for methodologies, editing, and supervision. All authors have read and agreed to the published version of the manuscript.

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

Data Availability Statement: The data presented in this study are available within the article.

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