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Physiological Determinants and Physical Match Activities in Basketball

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DEDICATION

A Giancarla e Vittorio, i miei genitori,

i migliori che potessi desiderare, sempre disponibili e pronti a sostenermi nelle mie scelte di vita.

A Cristina, la mia dolce metà,

sempre al mio fianco in questi anni, incoraggiandomi e seguendomi in tutto e per tutto.

Grazie,

questo traguardo non sarebbe stato possibile senza di voi.

ATTESTATION OF AUTHORSHIP

I hereby declare that the work contained in this thesis has not been previously submitted either in whole or in part to qualify for any other academic award. I also certify that the thesis is my own work carried out during my candidature and that any assistance that I have received in my research work and in the preparation of this thesis has been acknowledged.

Davide Ferioli

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STATEMENT OF CANDIDATE CONTRIBUTION

The contribution of each author to the manuscripts prepared or submitted as part of the thesis is outlined in Table A below.

Table A: Percentage contribution (%) of each author to the manuscripts prepared or submitted during the candidature.

Author	Study 1	Study 2	Study 3	Study 4	Study 5	Study 6
Ferioli D.	65%	60%	60%	65%	70%	65%
Azzolini M.	2%					
Bilsborough JC.			3%			
Bosio A.	5%	10%	10%	7%	7%	3%
Carlomagno D.		3%				
Connolly DR.		2%				
Coutts AJ.	8%					
La Torre A.	5%	5%	5%	5%	5%	3%
Manfredi MM.						7%
Maffiuletti NA.				8%		
Rampinini E.	15%	20%	20%	15%	18%	15%
Rucco D.						7%
Tornaghi M.			2%			

ABSTRACT

Introduction: Players' anthropometrical and physiological characteristics play a key role for basketball success. Despite several studies investigating the physical profile of basketball players of different competitive levels, geographical locations, gender and ages, the studies comparing anthropometrical and physiological characteristics, and their seasonal changes, among male adult players competing at different playing levels are still limited. In addition, data regarding activity demands of European adult basketball competitions at various competitive levels is yet unknown. The aims of this thesis are 1) to describe the physical profile of Italian adult male basketball players of different competitive levels across an entire basketball season and 2) to examine the differences in the activity demands of basketball games between different competitive levels.

Study 1: This investigation examined the anthropometrical and physiological differences in adult male basketball players of different competitive levels (from elite to amateur) and playing roles (Guards, Forwards and Centres) during the competitive phase of the season. Results revealed that a high force and power production and the ability to sustain high-intensity intermittent exercises should be considered as important characteristics for success in basketball and to compete at higher level. In addition, this study provided normative data of anthropometric and physiological characteristics of basketball players according to their playing positions.

Study 2: This study compared the training load indices and the changes in physical fitness between professional and semi-professional adult male basketball players during the preparation period. In addition, the relationships between training load indices and changes in physical fitness level were investigated. Professional players underwent a greater training load compared to semi-professional players, however, in some extent, similar physical fitness improvements were observed between the two groups. The results raise doubts on the

effectiveness of using high training load and training volume during the preparation period to improve the physical fitness level of players.

Study 3: This study investigated the changes induced by the preparation period on selected neuromuscular variables (i.e. vertical jump and change of direction (COD) ability) among professional and semi-professional adult male basketball players. In addition, this research investigated the relationships between training load indices and changes in neuromuscular physical performance during the preparation period. The preparation period induced minimal changes in the CMJ, while the ability to sustain repeated COD efforts was improved. Reaching high training loads might partially and negatively affect the ability to produce strength and power.

Study 4: This investigation examined the differences among adult male basketball players of different competitive levels (from elite to amateur) and the changes over an entire basketball season of peripheral neuromuscular functions (PNF) of knee extensor muscles (KE) measured following a standardized repeated CODs exercises. Results demonstrate how elite and professional basketball players are characterized by better PNF and by less fatigue levels following repeated CODs runs compared to lower level counterparts. The majority of changes in PNF following CODs exercises occurs after the preparation period, when the KEs appear to be less fatigable.

Study 5: This study examined the changes in several physical fitness parameters of adult male basketball players of different competitive levels (from elite to semi-professional) over an entire basketball season. In general, the preparation period appears to minimally affect variables measured during vertical jump test but enhance the aerobic fitness and the ability to sustain high-intensity intermittent exercise. The changes in physical performance during the competitive phase of the season seem to be affected by the competitive level of play.

Study 6: This investigation examined the differences in the activity demands of official basketball games between different competitive levels (from elite to amateur) among a large sample of adult male players. The main results demonstrated different intermittent profiles among competitive levels, with elite players performing at increased high and moderate intensities and amateur players utilising longer recovery periods during competition. The game activity demands of professional and semi-professional players were similar. This study provided normative match activity data for Italian basketball tournaments.

Conclusion: This thesis provides insight into the activity demands of Italian basketball tournaments and the anthropometrical and physiological characteristics of basketball players across an entire basketball season, highlighting the differences among the various competitive levels of play. In addition, this thesis provides novel insight into the relationships between training load and changes in physical fitness in basketball.

KEYWORDS

Basketball

Competitive level

Playing position

Session RPE

Seasonal variations

Change of direction

Intermittent exercise

Neuromuscular functions

Vertical jump

Yo-Yo test

Time-motion analysis

LIST OF ABBREVIATIONS

abs	Absolute
AU	Arbitrary Units
bpm	Beats per minute
Bas	Baseline
BEST	Basketball Exercise Simulation Test
BUSA	British Universities Sports Association
CI	Confidence Interval
CL	Confidence limits
Cm	Centimetre
CMJ	Counter-movement jump
CMJ_h	Counter-movement jump height
COD	Change of direction
CV	Coefficient of Variation
ES	Effect Size
FIBA	International Basketball Federation
$[H^+]$	Blood hydrogen ion concentration
$[HCO3^-]$	Blood bicarbonate concentration
HIA	High-intensity activity
HIT	High-intensity intermittent test
HR	Heart rate
Hz	Hertz
ICC	Intraclass Correlation Coefficient
Int	International
KE	Knee extensor muscles
$[La^-]$	Blood lactate concentration

LIA	Low-intensity activity
LT	Live time
Kg	Kilogram
$km \cdot h^{-1}$	Kilometres per hour
mA	Milliampere
MBI	Magnitude-based inference
MIA	Moderate-intensity activity
min	Minute
MOG	Mognoni's test
$mmol \cdot L^{-1}$	Millimoles per litre
MP	Metabolic power
MP Max	Metabolic power corresponding to PT Max
N	Newton
n	Sample size
Nat	National
NCAA	National Collegiate Athletic Association
Nm	Newton metre
N/A	Data not available
$N \cdot kg^{-1}$	Newton per kilogram
PF	Peak force
pH	Potential of hydrogen
PNF	Peripheral neuromuscular functions
PPO	Peak power output
PRO	Professional players
PT	Peak torque
PT Dec	PT decrement from PT Max to PT4

PT Max	The highest value of PT
REC	Recovery
Reg	Regional
Rel	Relative
s	Second
SD	Standard deviation
SEMI-PRO	Semi-professional players
SM	Specific movement
SNR	Signal to noise ratio
SPSS	Statistical Package for Social Sciences
sRPE-TL	Session rating of perceived exertion
SWC	Smallest worthwhile changes
TL	Training load
TMA	Time-motion analysis
TT	Total time
TV	Training volume
T1	Before the preparation period
T2	After the preparation period
T3	During the competitive period
US	United States
V	Volt
vs	Versus
Vo_{2max}	Maximal oxygen consumption
W	Watts
$W \cdot kg^{-1}$	Watts kilogram
Yo-Yo IR1	Yo-Yo Intermittent Recovery test (level 1)

r_s	Spearman's rank correlation coefficients
μL	Microlitre
μs	Microsecond

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CHAPTER ONE

Introduction

Background and research problem

Basketball is a physically demanding team sport characterized by frequent high-intensity periods of play and changes of activity type every 2-3 s (Ben Abdelkrim et al. 2007, McInnes et al. 1995, Scanlan et al. 2011). Neuromuscular abilities (i.e. power, strength, speed) are heavily taxed during basketball matches. Specifically, the jumping performance and the ability to quickly accelerate, decelerate and change direction appear to be key components of competitions (McInnes et al. 1995, Scanlan et al. 2011, Ziv and Lidor 2010). Due to these demands, both aerobic and anaerobic mechanisms are heavily activated to provide energy during basketball (Ziv and Lidor 2009).

Anthropometrical and physiological characteristics of players have been shown to play a key role for basketball success (Drinkwater et al. 2008, Ziv and Lidor 2009). Thus, an increasing number of research has described the physical profile of basketball players of different competitive levels, geographical locations, gender and ages (Drinkwater et al. 2008, Ziv and Lidor 2009). Although these studies have provided important insights into the topic, the research comparing anthropometrical and physiological characteristics of male adult players competing at different playing levels are limited (Ben Abdelkrim et al. 2010a, Delextrat and Cohen 2008, Koklu et al. 2011, Metaxas et al. 2009, Sallet et al. 2005). In addition, most of the studies on the topic involved a limited number of individuals (i.e. 16 to ~60), compared only two groups of players (e.g. Division I vs Division II or Professional vs. Semi-professional players) or were conducted during the preseason phase of training when these characteristics may not have been fully developed. Thus, further studies on the topic are needed to better describe the physiological characteristics of adult male basketball players competing in the Italian league.

The assessment of players' physical fitness across an entire basketball season allows to monitor the effectiveness of conditioning programs and to quantify the changes in the fitness status of players over the different phases of season (Drinkwater et al. 2008). The greatest improvement in athletes' physical fitness usually occurs during the preparation period, when players begin performing physical activity after a prolonged period of complete or nearly complete rest (Hoffman 2000). Despite the preparation period representing a crucial phase to optimize athletes' performance, information regarding the correct level of training load and training volume to be performed during this period is limited. In addition, the relationships between training load indices and changes in players' fitness levels have not yet been investigated in basketball. During the competitive phase of the season, strength and conditioning programs aim to maintain players' physical fitness, although realistically fitness may slightly increase or decrease (Drinkwater et al. 2008). Several studies have investigated the seasonal changes in physical fitness of junior and collegiate (NCAA) basketball players (Tavino et al. 1995), but only few studies have focused on adult male professional basketball players (Aoki et al. 2017, Gonzalez et al. 2013, Laplaud et al. 2004). Therefore, information regarding the seasonal changes in physical fitness and the training load sustained by adult male basketball players of different competition levels are still limited. This lack of knowledge is likely due to the difficulties of involving professional athletes in longitudinal studies. Considering that changes in fitness status may be affected by the competitive level of play (Drinkwater et al. 2007, Drinkwater et al. 2008), thorough knowledge of seasonal fitness variations at different playing levels might provide useful information for physical preparation.

To date, several studies have assessed the physiological responses to basketball competition (Beam and Merrill 1994, Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2009, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, Klusemann et al. 2013, Matthew and Delextrat 2009, McInnes et al. 1995, Montgomery et al. 2010, Moreira et al. 2012, Narazaki et al. 2009, Torres-Ronda et al. 2016, Vaquera et al. 2008), while an increasing number of studies have recently focused on the physical activity demands across games (Ben Abdelkrim et al.

2010b, Ben Abdelkrim et al. 2010c, Ben Abdelkrim et al. 2007, Bishop and Wright 2006, Conte et al. 2016, Hulka et al. 2014, Klusemann et al. 2013, Matthew and Delextrat 2009, McInnes et al. 1995, Montgomery et al. 2010, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Taylor et al. 2017, Torres-Ronda et al. 2016). Due to the high-cost and/or the limited effectiveness of the available micro-technologies (e.g. global positioning systems and micro-sensors), time-motion analysis (TMA) has been widely used for measuring the activity demands within male basketball competitions (Fox et al. 2017, Stojanovic et al. 2017). TMA studies demonstrated the intermittent nature of basketball games and provided useful information into the frequency and duration of the movement activities carried out during games. However, most of these studies analysed collegiate or junior teams, players from the same club, a limited number of athletes (i.e. 6 to 14) and/or non-official competitive game, using different methodologies to classify the movement patterns. Thus, these results cannot be considered representative of overall adult male basketball games. Studies that assess the activity demands of a large sample of adult basketball players during official competitions are required. The comparison of match activity demands at different playing levels would provide important insight for the identification of the key physical elements of the game and for the development of more specific training programs. However, only three studies have compared the game activity demands between different competitive levels in basketball (Ben Abdelkrim et al. 2010a, Scanlan et al. 2011, Scanlan et al. 2015b), and these researches included a limited number of junior Tunisian and adult Australian basketball players. These studies provide preliminary insights into game activity demands at different levels. However, these data are only indicative of the few teams and competitions investigated. Data regarding activity demands of European basketball competitions is still limited.

Study objectives

The primary objective of this thesis is to describe the anthropometrical and physiological characteristics of Italian adult male basketball players of different competitive levels during an entire basketball season. Study 1 examines the anthropometrical and physiological differences in basketball players, from elite to amateur level, during the competitive phase of the season. Study 2 and 3 compare the training load indices and the changes in several physical characteristics between professional and semi-professional basketball players during the preparation period. In addition, the relationships between training load indices and changes in physical fitness level are investigated. Study 4 examines the differences among basketball players, from elite to amateur levels, and the changes over an entire basketball season of peripheral neuromuscular functions (PNF) following a repeated changes of direction (COD) exercises. Study 5 describes the changes in several physical fitness parameters of basketball players, from elite to semi-professional levels, over an entire basketball season.

A secondary object of this thesis is to examine the differences in the activity demands of official basketball games between different competitive levels (from elite to amateur levels), providing normative data for Italian basketball competitions (study 6).

CHAPTER TWO

Review of literature

Introduction

The present review firstly aims to describe the anthropometrical and physiological characteristics of adult male basketball players that play a key role for basketball success. Secondly, this review will discuss the seasonal changes in physical performance previously reported among collegiate and open-age adult basketball players. Thirdly, the physiological responses and the activity demands of adult male competitions will be explored to provide insight into the basketball game demands.

Anthropometric and physiological characteristics of male basketball players

The anthropometrical and physiological characteristics of basketball players have been widely investigated in basketball literature (Drinkwater et al. 2008, Ziv and Lidor 2009). Various batteries of physical tests have been used to assess anthropometrics and fitness status of male basketball players (Ben Abdelkrim et al. 2010c, Berg and Latin 1995, Boone and Bourgois 2013, Cormery et al. 2008, Delextrat and Cohen 2008, Groves and Gayle 1993, Hoffman et al. 1991, Hoffman and Kaminsky 2000, Hoffman et al. 1996, Hunter et al. 1993, Koklu et al. 2011, Latin et al. 1994, Metaxas et al. 2009, Ostojic et al. 2006, Pojskic et al. 2015, Sallet et al. 2005, Shalfawi et al. 2011, Tavino et al. 1995). Results of these studies revealed aerobic and anaerobic capacities and the ability to produce force and power to be key components of basketball performance.

Anthropometric data

Several studies examined the anthropometrical profile of basketball players from various competitive levels. Results revealed a wide range of anthropometrical characteristics (i.e.

stature, body mass and body composition) due to the playing roles and competitive levels of players assessed. Table 2.1 presents a summary of existing studies reporting anthropometric data of adult male basketball players of the last 20 years (i.e. from 1997). Anthropometric characteristics are considered a fundamental prerequisite to compete at professional levels and a key determining factor in the selection process (Hoare 2000, Vaquera et al. 2015, Ziv and Lidor 2009). Higher level competitive players are usually taller and heavier compared to lower levels counterparts; however, stature and body mass appear to fail to discriminate between top and moderate-level professional players (Delextrat and Cohen 2008, Koklu et al. 2011, Metaxas et al. 2009, Sallet et al. 2005). Anthropometrical characteristics play a key role in the determination of playing position of basketball players. Traditionally, Forwards are generally shorter and lighter compared to Centres, but taller and heavier compared to Guards (Ziv and Lidor 2009).

Table 2.1. A summary of existing studies reporting anthropometric data of adult male basketball players of the last 20 years (i.e. from 1997)

Study	Participants	Competitive level	Position	Age (years)	Stature (cm)	Body mass (kg)	Body fat (%)
Aoki et al. (2016)	Senior Brazilian	Division I (n=9)	N/A	27.8±6.4	199±6	101.3±12.1	N/A
Apostolidis et al. (2004)	Junior Greece	Int	Guards (n=6)	18.3±0.5	194±4	88.0±4.8	9.1±1.7
			Forwards (n=4)	18.5±0.6	203±4	99.8±4.8	11.8±1.2
			Centres (n=3)	18.7±0.6	206±2	104.9±5.1	13.8±2.8
			All (n=13)	18.5±0.5	200±6	95.5±8.8	11.0±2.5
Ben Abdelkrim et al. (2010a)	Junior Tunisian	Int (n=17)	N/A	18.3±0.4	188±6	81.2±7.4	6.4±4.6
		Nat (n=22)		18.2±0.5	189±4	79.6±6.3	9.6±5.9
Ben Abdelkrim et al. (2010c)	U20 Tunisian	Int (n=15)	N/A	19.5±4.0	199±7	91.4±8.3	10.2±2.4
	Senior Tunisian	Int (n=15)		25.4±3.0	198±6	91.5±7.2	9.8±2.5
Ben Abdelkrim et al. (2007)	Junior Tunisian	Nat	Guards (n=8)	18.2±0.2	183±4	76.2±3.4	6.1±3.7
			Forwards (n=18)	18.2±0.5	188±4	77.4±5.1	7.8±4.1
			Centres (n=12)	18.2±0.5	193±3	87.2±5.3	10.4±7.8
			All (n=38)	18.2±0.5	189±5	80.3±6.7	8.2±5.6
Boone et al. (2013)	Senior Belgian	Division I	Point guards (n=30)	N/A	188±3	83.2±5.3	11.2±2.8
			Shooting guards (n=29)		194±5	89.6±6.6	12.0±4.9
			Small forwards (n=31)		196±3	96.6±4.9	13.1±3.4
			Power forwards (n=30)		200±3	103.8±9.1	14.7±3.7
			Centres (n=24)		207±3	111.2±8.3	15.2±4.0
Castagna et al. (2011)	Junior Italian	Reg	N/A	18.9±2.3	185±6	74.4±5.1	N/A
Castagna et al. (2009)	Senior Italian	Division VI (n=11)	N/A	24.5±3.5	192±9	84.4±11.4	10.0±1.2
Caterisano et al. (1997)	Collegiate US	NCAA Division I (n=9)	N/A	21.0±0.7	N/A	92.2±8.2	5.9±3.1
Chaouachi et al. (2009)	Senior Tunisian	Nat (n=14)	N/A	23.3±2.7	196±8	94.2±10.2	14.0±3.7
Conte et al. (2016)	Collegiate US	NCAA Division I (n=9)	N/A	21±1	196±9	92.6±14.0	N/A
Cormery et al. (2008)	Senior French	Nat	Guards (n=26)	25±1.2 [a]	185±0.01 [a]	83.2±1.66 [a]	13.7±0.51 [a]
			Forwards (n=51)	25±0.8 [a]	200±0.01 [a]	95.9±1.15 [a]	13.5±0.35 [a]
			Centres (n=22)	23±1.7 [a]	207±0.02 [a]	111.0±2.42 [a]	14.1±0.74 [a]
Delextrat & Cohen (2008)	University British	BUSA Division I (n=8)	N/A	25.4±2.4	192±9	90.6±8.1	12.0±5.0
		BUSA Division III (n=8)		21.9±2.1	187±6	86.0±11.9	12.5±4.7

Study	Participants	Competitive level	Position	Age (years)	Stature (cm)	Body mass (kg)	Body fat (%)
Delextrat et al. (2013)	University British	BUSA Division II (n=9)	N/A	22.8±2.2	191±6	88.0±10.3	12.3±4.6
Gocentas et al. (2011)	Senior	Professional	Perimeter (n=24) Post (n=18)	24.1±3.7 25.7±3.2	191±6 206±4	88.4±8.2 107.0±7.5	N/A
Gonzalez et al. (2013)	Senior US	NBA (n=7)	N/A	28.2±3.4	201±9	104.7±13.9	7.2±1.9
Gonzalez et al. (2015)	Senior Spanish	Division I	Guards (n=4) Forwards (n=4) Centres (n=4 All (n=12)	24.1±7.3 24.4±5.6 23.7±1.7 24.1±4.9	187±4 196±7 207±6 196±10	83.2±4.9 90.4±8.2 101.7±9.6 91.8±10.6	10.9±0.7 10.3±1.2 9.5±0.6 10.3±1.0
Hoffman et al. (1999)	Senior Israeli	Nat (n=20)	N/A	19.0±1.7	194±6	88.4±8.0	12.9±3.1
Kalinski et al. (2002)	Senior Polish	Division I (n=54)	N/A	24.2±3.3	197±8	91.0±10.5	N/A
Köklü et al. (2011)	Senior Turkish	Division I (n=22) Division II (n=23)	N/A	24.0±3.8 22.7±4.0	198±8 196±7	98.4±12.3 94.7±14.4	10.9±5.2 12.0±3.5
Laplaud et al. (2004)	Senior French	Division I (n=8)	N/A	24±4	198±8	96±10	N/A
Lockie et al. (2015)	Senior Australian	Semi-professional (n=10) Amateur (n=10)	N/A	21.4±3.1 23.2±4.7	188±10 181±8	86.0±11.9 83.5±13.0	N/A
Manzi et al. (2010)	Senior Italian	Division I	N/A	28±3.6	202±8	102±11.3	11.0±1.4
Metaxas et al. (2009)	Senior Greek	Division I (n=14) Division II (n=15) Division III (n=17) Division IV (n=15)	N/A	23.6±3.1 22.0±3.3 23.8±4.0 20.8±3.4	193±8 191±10 191±6 190±6	95.8±11.5 92.0±15.1 91.4±12.8 94.6±11.5	11.0±1.6 11.9±2.3 12.7±2.0 14.3±3.4
Montgomery et al. (2008a)	Junior Australian	Elite (n=29)	N/A	19.1±2.1	184±3	88.5±14.7	N/A
Montgomery et al. (2010)	Junior Australian	Elite (n=11)	N/A	19.1±2.1	191±9	87.9±15.1	N/A
Moreira et al. (2012)	Senior Brazilian	Elite	N/A	26.4±3.8	196±10	100±14	N/A
Narazaki et al. (2008)	Collegiate US	NCAA Division II (n=6)	N/A	20.8±1.0	192±12	91.9±17.5	9.7±5.9
Ostojic et al. (2006)	Senior Serbian	Division I	Guards (n=20) Forwards (n=20) Centres (n=20) All (n=60)	25.6±3.2 21.4±2.8 23.2±3.2 23.4±3.5	191±6 200±3 208±3 200±8	88.6±8.1 95.7±7.1 105.1±11.5 96.5±11.2	9.9±3.1 10.1±3.2 14.4±5.6 11.5±4.6

Study	Participants	Competitive level	Position	Age (years)	Stature (cm)	Body mass (kg)	Body fat (%)
Pojskić et al. (2015)	Senior Bosnian	Division I	Guards (n=22)	19.4±3.5	183±6	77.4±11.4	12.4±4.2
			Forwards (n=19)	18.2±2.7	190±7	81.5±9.3	12.3±3.1
			Centres (n=14)	19.9±3.0	198±4	95.6±9.6	15.0±4.6
Sallet et al. (2005)	Senior French	Division I (n=33)	N/A	24.2±5.0	197±9	93.9±13	12.7±2.7
		Division II (n=25)		24.2±4.6	196±10	92.1±13.6	12.4±3.7
Scanlan et al. (2011)	Senior Australian	Elite (n=10)	N/A	28.3±4.9	197±8	97.0±13.9	N/A
		Sub-elite (n=12)		26.1±5.3	191±8	85.9±13.2	
Scanlan et al. (2015b)	Senior Australian	Professional (n=10)	N/A	28.3±4.9	197±8	97.0±13.9	N/A
		Semi-professional (n=12)		26.1±5.3	191±8	85.9±13.2	
Scanlan et al. (2015a)	Senior Australian	Semi-professional	Backcourt (n=5)	26.2±7.4	187±4	79.7±9.3	8.7±1.5
			Frontcourt (n=7)	26.0±3.9	197±6	92.2±13.6	14.2±3.5
			All (n=12)	26.1±5.3	191±8	85.9±13.2	11.5±4.1
Scanlan et al. (2012)	Senior Australian	Semi-professional (n=10)	N/A	22.7±6.1	190±10	86.5±18.7	14.7±3.5
		Amateur (n=10)	N/A	26.6±4.0	186±8	92.6±8.4	23.8±6.3
Scanlan et al. (2014b)	Senior Australian	Semi-professional (n=8)	N/A	26.3±6.7	188±6	92.0±13.8	N/A
Sekulic et al. (2017)	Senior Bosnian	Division I (n=25)	N/A	N/A	190±4	84.8±4.9	7.1±2.6
		Division II (n=24)			187±7	78.1±6.0	9.4±2.6
Shalfawi et al. (2011)	Senior	Professional (n=33)	N/A	27.4±3.3	192±8	89.8±11.1	N/A
Torres-Ronda et al. (2016)	Senior Spanish	Division I (n=14)	N/A	25.5±4.7	199±9	93.3±12.8	N/A
Vaquera et al. (2015)	Senior Spanish	Division I (n=24)	N/A	28±1.16 [a]	195±2.69 [a]	98.0±3.52 [a]	N/A
		Division II (n=20)		29±0.99 [a]	198±2.05 [a]	96.5±2.37 [a]	
		Division IV (n=22)		20±0.78 [a]	194±2.04 [a]	89.7±2.86 [a]	
	U20 Spanish	Int (n=24)		19±0.10 [a]	197±1.93 [a]	93.4±3.02 [a]	
Vaquera et al. (2008)	Senior Spanish	Division II (n=8)	N/A	27.5±11.6	195±15	91.3±19.3	9.7±6.4
Weiss et al. (2017)	Senior New Zaeland	Professional (n=13)	N/A	24.4±4.7	195±8	96.3±11.6	N/A

Abbreviations: a, mean ± standard errors; All, all players; BUSA, British Universities Sports Association; Int, International; Nat, National; NCAA, national collegiate athletic association; N/A, data not available; Reg, regional; US, United States.

Physiological characteristics

The identification of physiological characteristics contributing to success in basketball competitions represents a key point in literature. The evaluation of physical fitness of basketball players provide useful information for the development of individualized and role specific training programs. Several studies, mainly involving a small cohort of athletes, have described the physiological determinants of basketball players, while only few studies have compared the characteristics of male adult players competing at different playing levels (Delextrat and Cohen 2008, Drinkwater et al. 2008, Ferioli et al. 2017, Koklu et al. 2011, Metaxas et al. 2009, Sallet et al. 2005, Ziv and Lidor 2009). Numerous batteries of physical tests have been used to assess the fitness status of adult male basketball players; the most investigated fitness characteristics include aerobic and anaerobic capacities and vertical jump and changing of direction ability. Table 2.2 presents a summary of existing studies reporting physiological characteristics data of adult male basketball players of the last 20 years (i.e. from 1997).

Table 2.2. A summary of existing studies reporting physiological characteristics data of adult male basketball players of the last 20 years (i.e. from 1997)

Study	Participants	Competitive level	Position	Aerobic and anaeobic capacity		Vertical jump and COD ability	
				Test	Result	Test	Result
Aoki et al. (2016)	Senior Brazilian	Division I (n=9)	N/A	Submax running		SJ	40.7±3.6 cm
				HR (%HR peak)	82.5±5.5 %	CMJ	41.9±4.1 cm
				Yo-Yo IR1	1737±515 m		
Apostolidis et al. (2004)	Junior Greece	Int (n=13)	N/A	28 m sprint	4.2±0.2	SJ	39.8±3.7 cm
				Wingate		CMJ	40.1±4.0 cm
				Peak power	10.7±1.3 W·kg^{-1}		
				Mean power	8.0±0.7 W·kg^{-1}		
				Fatigue Index	49.5±20.4 %		
Ben Abdelkrim et al. (2010a)	Junior Tunisian	Int (n=17)	N/A	Vo_{2max}	54.4±1.9 ml·kg·min^{-1}		
		Nat (n=22)			51.6±2.0 ml·kg·min^{-1}		
Ben Abdelkrim et al. (2010c)	U20 Tunisian	Int (n=15)	N/A	Yo-Yo IR1	2000±642 m	CMJ	
				Vo_{2max}	55.4±4.6 ml·kg·min^{-1}	*Height*	49.1±5.9 cm
				5 m sprint	1.00±0.10 s	*Peak power*	4656±81 W
				10 m sprint	1.84±0.10 s	Agility T-test	10.45±0.44 s
				30 m sprint	4.13±0.17 s		
	Senior Tunisian	Int (n=15)		Yo-Yo IR1	2619±731 m	CMJ	
				Vo_{2max}	59.9±5.3 ml·kg·min^{-1}	*Height*	49.7±5.8
				5 m sprint	1.04±0.16 s	*Peak power*	4665±116 W
				10 m sprint	1.88±0.15 s	Agility T-test	9.99±0.40 s
				30 m sprint	4.10±0.14 s		
Ben Abdelkrim et al. (2007)	Junior Tunisian	Nat	Guards (n=8)	Vo_{2max}	53.8±1.9 ml·kg·min^{-1}		
			Forwards (n=18)	Vo_{2max}	53.4±2.3 ml·kg·min^{-1}		
			Centres (n=12)	Vo_{2max}	51.4±2.4 ml·kg·min^{-1}		
			All (n=38)	Vo_{2max}	52.8±2.4 ml·kg·min^{-1}		
Boone et al. (2013)	Senior Belgian	Division I	Point guards (n=30)	5 m sprint	1.40±0.03 s	COD test	11.93±0.31 s
				10 m sprint	2.16±0.09 s	SJ	
				Vo_{2max}	57.4±4.8 ml·kg·min^{-1}	*Height*	41.0±3.8 cm
						Peak power	4203±371 W
						CMJ	
						Height	42.7±3.8 cm
						Peak power	4306±373 W
			Shooting guards (n=29)	5 m sprint	1.40±0.09 s	COD test	11.92±0.28 s

Study	Participants	Competitive level	Position	Aerobic and anaeobic capacity		Vertical jump and COD ability	
				Test	Result	Test	Result
				10 m sprint	2.19±0.08 s	SJ	
				Vo_{2max}	55.3±3.6 ml·kg·min^{-1}	*Height*	39.5±3.6 cm
						Peak power	4402±358 W
						CMJ	
						Height	41.3±3.2 cm
						Peak power	4510±322 W
			Small forwards (n=31)	5 m sprint	1.45±0.09 s	COD test	12.25±0.24 s
				10 m sprint	2.23±0.09 s	SJ	
				Vo_{2max}	52.9±5.6 ml·kg·min^{-1}	*Height*	40.2±3.7 cm
						Peak power	4761±381 W
						CMJ	
						Height	42.5±3.8 cm
						Peak power	4901±387 W
			Power forwards (n=30)	5 m sprint	1.47±0.08 s	COD test	12.29±0.27 s
				10 m sprint	2.25±0.08 s	SJ	
				Vo_{2max}	50.4±5.2 ml·kg·min^{-1}	*Height*	39.1±4.2 cm
						Peak power	5021±423 W
						CMJ	
						Height	42.4±3.7 cm
						Peak power	5221±364 W
			Centres (n=24)	5 m sprint	1.51±0.07 s	COD test	12.71±0.29 s
				10 m sprint	2.34±0.11 s	SJ	
				Vo_{2max}	50.9±5.2 ml·kg·min^{-1}	*Height*	35.7±3.2 cm
						Peak power	5149±399 W
						CMJ	
						Height	36.2±4.1 cm
						Peak power	5180±451 W
Castagna et al. (2011)	Junior Italian	Reg	N/A	Vo_{2max}	56.6±8.6 ml·kg·min^{-1}		
Castagna et al. (2009)	Senior Italian	Division VI (n=11)	N/A	Vo_{2max}	50.3±4.0 ml·kg·min^{-1}	SJ	39.9±5.0 cm
						CMJ	47.0±5.8 cm
Caterisano et al. (1997)	Collegiate US	NCAA Division I (n=9)	N/A	Vo_{2max}	53.0±4.7 ml·kg·min^{-1}		
Chaouachi et al. (2009)	Senior Tunisian	Nat (n=14)	N/A	Vo_{2max}	59.1±6.2 ml·kg·min^{-1}	SJ	49.5±4.8 cm
				5 m sprint	0.82±0.05 s	CMJ	61.9±6.2 cm
				10 m sprint	1.70±0.06 s	Agility T-test	9.7±0.2 s

Study	Participants	Competitive level	Position	Aerobic and anaeobic capacity		Vertical jump and COD ability	
				Test	Result	Test	Result
				30 m sprint	4.16±0.11 s		
Cormery et al. (2008)	Senior French	Nat	Guards (n=26)	Vo_{2max} [a]	54.0±1.6 ml·kg·min^{-1}		
			Forwards (n=51)	Vo_{2max} [a]	45.5±0.7 ml·kg·min^{-1}		
			Centres (n=22)	Vo_{2max} [a]	41.7±0.1 ml·kg·min^{-1}		
Delextrat & Cohen (2008)	University British	BUSA Division I (n=8)	N/A	20 m sprint	3.29±0.12 s	CMJ	56.6±4.4 cm
						Suicide run	28.97±0.88 s
						Agility T-test	9.21±0.24 s
		BUSA Division III (n=8)		20 m sprint	3.36±0.36 s	CMJ	51.6±3.3 cm
						Suicide run	29.03±1.1 s
						Agility T-test	9.78±0.59 s
Gocentas et al. (2011)	Senior	Professional	Perimeter (n=24)	Vo_{2max}	52.2±8.7 ml·kg·min^{-1}		
			Post (n=18)	Vo_{2max}	46.2±5.6 ml·kg·min^{-1}		
Gonzalez et al. (2015)	Senior Spanish	Division I	Guards (n=4)	Vo_{2max}	58.0±5.0 ml·kg·min^{-1}	SJ	30.1±5.7 cm
						CMJ	37.7±3.8 cm
			Forwards (n=4)	Vo_{2max}	57.5±4.6 ml·kg·min^{-1}	SJ	28.5±3.2 cm
						CMJ	35.6±4.6 cm
			Centres (n=4	Vo_{2max}	57.5±8.7 ml·kg·min^{-1}	SJ	33.2±7.3 cm
						CMJ	37.2±4.9 cm
			All (n=12)	Vo_{2max}	57.7±5.5 ml·kg·min^{-1}	SJ	30.6±5.5 cm
						CMJ	36.8±4.1 cm
Hoffman et al. (1999)	Senior Israeli	Nat (n=20)	N/A	Vo_{2max}	50.2±3.8 ml·kg·min^{-1}		
				Wingate			
				Peak power	14.4±1.7 W·kg^{-1}		
				Mean power	9.1±1.2 W·kg^{-1}		
				Fatigue Index	59.5±7.6 %		
Kalinski et al. (2002)	Senior Polish	Division I (n=54)	N/A	Wingate			
				Peak power	11.1±0.8 W·kg^{-1}		
				Mean power	8.7±0.6 W·kg^{-1}		
Köklü et al. (2011)	Senior Turkish	Division I (n=22)	N/A	10 m sprint	1.78±0.8 s	SJ	37.8±5.7 cm
				30 m sprint	4.37±0.21 s	CMJ	40.6±4.7 cm
				Vo_{2max}	42.5±8.6 ml·kg·min^{-1}	Agility T-test	9.49±0.61 s
		Division II (n=23)		10 m sprint	1.72±0.8 s	SJ	34.7±5.7 cm
				30 m sprint	4.35±0.25 s	CMJ	36.0±5.0 cm

Study	Participants	Competitive level	Position	Aerobic and anaeobic capacity		Vertical jump and COD ability	
				Test	Result	Test	Result
				Vo_{2max}	44.5±7.0 ml·kg·min^{-1}	Agility T-test	9.76±0.57 s
Laplaud et al. (2004)	Senior French	Division I (n=8)	N/A	Vo_{2max}	44.1±6.5 ml·kg·min^{-1}	CMJ	62±8 cm
Lockie et al. (2015)	Senior Australian	Semi-professional (n=10)	N/A	10 m sprint	1.81±0.09 s	Y Agility test	1.89±0.14 s
		Amateur (n=10)		10 m sprint	1.88±0.07 s	Y Agility test	1.96±0.14 s
Manzi et al. (2010)	Senior Italian	Division I	N/A	Yo-Yo IR1	1945±144 m		
Metaxas et al. (2009)	Senior Greek	Division I (n=14)	N/A	Vo_{2max}	51.3±4.1 ml·kg·min^{-1}		
		Division II (n=15)		Vo_{2max}	50.4±5.4 ml·kg·min^{-1}		
		Division III (n=17)		Vo_{2max}	47.8±5.3 ml·kg·min^{-1}		
		Division IV (n=15)		Vo_{2max}	49.1±5.6 ml·kg·min^{-1}		
Montgomery et al. (2008a)	Junior Australian	Elite (n=29)	N/A	Yo-Yo IR1	1592±629 m	CMJ	61.9±14.6 cm
				20 m sprint	3.09±0.10 s	Suicide run	27.5±1.2 s
						Agility test	6.5±0.2 s
Narazaki et al. (2008)	Collegiate US	NCAA Division II (n=6)	N/A	Vo_{2max}	57.5±8.2 ml·kg·min^{-1}		
Ostojic et al. (2006)	Senior Serbian	Division I	Guards (n=20)	Vo_{2max}	52.5±4.8 ml·kg·min^{-1}	CMJ	
						Height	59.7±9.6 cm
						Power	1485±200 W
			Forwards (n=20)	Vo_{2max}	50.7±2.3 ml·kg·min^{-1}	CMJ	
						Height	57.8±6.5 cm
						Power	1579±138 W
			Centres (n=20)	Vo_{2max}	56.3±4.9 ml·kg·min^{-1}	CMJ	
						Height	54.6±6.9 cm
						Power	1683±192 W
			All (n=60)	Vo_{2max}	49.8±4.9 ml·kg·min^{-1}	CMJ	
						Height	57.4±7.7 cm
						Power	1582±194 W
Pojskić et al. (2015)	Senior Bosnian	Division I	Guards (n=22)	Vo_{2max}	64.4±7.1 ml·kg·min^{-1}	CMJ	
						Height	40.4±5.0 cm
						Peak power	3874±639 W
			Forwards (n=19)	Vo_{2max}	62.4±6.1 ml·kg·min^{-1}	CMJ	
						Height	37.6±6.8 cm
						Peak power	3930±604 W
			Centres (n=14)	Vo_{2max}	57.9±7.2 ml·kg·min^{-1}	CMJ	

Study	Participants	Competitive level	Position	Aerobic and anaeobic capacity		Vertical jump and COD ability	
				Test	Result	Test	Result
						Height	36.0±3.8 cm
						Peak power	4536±458 W
Sallet et al. (2005)	Senior French	Division I (n=33)	N/A	Vo_{2max}	53.7±6.7 ml·kg·min^{-1}		
				30s all out test			
				Peak power	12.5±3 W·kg^{-1}		
				Fatigue index	63.3±13.8%		
		Division II (n=25)		Vo_{2max}	56.5±7.7 ml·kg·min^{-1}		
				30s all out test			
				Peak power	11.9±2.4 W·kg^{-1}		
				Fatigue index	54.1±11.1%		
Scanlan et al. (2015a)	Senior Australian	Semi-professional	Backcourt (n=5)	Vo_{2max}	53.4±3.1 ml·kg·min^{-1}		
			Frontcourt (n=7)	Vo_{2max}	47.5±4.1 ml·kg·min^{-1}		
			All (n=12)	Vo_{2max}	50.8±5.2 ml·kg·min^{-1}		
Scanlan et al (2012)	Senior Australian	Semi-professional (n=10)	N/A	Yo-Yo IR1	1283±362 m		
				BEST			
				Total distance	1670±116		
				Sprint decrement	8.54±0.15 %		
		Amateur (n=10)		Yo-Yo IR1	636±297 m		
				BEST			
				Total distance	1585±152		
				Sprint decrement	15.38±0.27 %		
Sekulic et al. (2017)	Senior Bosnian	Division I (n=25)	N/A			Agility T-test	9.02±0.49 s
						COD test	1.66±0.13 s
		Division II (n=24)				Agility T-test	9.14±0.43 s
						COD test	1.74±0.17 s
Shalfawi et al. (2011)	Senior	Professional (n=33)	N/A			SJ	
						Height	43.1±7.2 cm
						Power	4609±419 W
						CMJ	
						Height	52.0±7.5 cm
						Power	5167±419 W

Abbreviations: a, mean ± standard errors; All, all players; BEST, basketball exercise simulation test; BUSA, British Universities Sports Association; CMJ, counter-movement jump; COD, changes of direction; Int, International; Nat, National; NCAA, national collegiate athletic association; N/A, data not available; Reg, regional; SJ, squat jump; US, United States; Yo-Yo IR1, Yo-Yo intermittent recovery test.

The highly intermittent nature of basketball competitions and the numerous high-intensity actions performed during a game highlight the importance to develop the players' ability to sustain high-intensity intermittent efforts and to quickly recover from high-intensity phases of the competitions. To assess these qualities among basketball players, researchers have typically employed the Yo-Yo Intermittent Recovery test (Yo-Yo IR1) (Aoki et al. 2017, Ben Abdelkrim et al. 2010c, Castagna et al. 2008, Manzi et al. 2010, Montgomery et al. 2008a, Scanlan et al. 2012, Vernillo et al. 2012). Yo-Yo IR1 consist of 20-m shuttle runs performed at increasing velocities (beginning speed of 10 $Km \cdot h^{-1}$) with 10 s of active recovery (consisting of 2x5-m of jogging) between runs until exhaustion. The total distance covered during Yo-Yo IR1 is considered as the test "score" (Krustrup et al. 2003). Previous studies reported Yo-Yo IR1 to highlight differences in performance between senior, under 20 and under 18 basketball players, who covered 2619±731, 2000±642 and 1355±609 m, respectively (Ben Abdelkrim et al. 2010c). In addition, among young basketball players (from under 14 to under 17), Yo-Yo IR1 distance appears to differ between elite and sub-elite athletes (Vernillo et al. 2012). Yo-Yo IR1 could be expected to discriminate adult basketball players of different competitive levels, yet this aspect has not been investigated in basketball literature. In addition, it should be considered that the high-physically demanding nature of Yo-Yo IR1 (i.e. maximal effort) might represent a limit to the use of this test with adult elite basketball players. Previous investigations reported differences in the ability to sustain high-intensity intermittent exercises between players of different playing positions (Ben Abdelkrim et al. 2010c). Guards are usually characterized by the highest intermittent performance, while Centres by the lowest. These differences have been attributed to the higher physiological load imposed on Guards during basketball games (Ben Abdelkrim et al. 2007).

As several studies reported the change of direction (COD) ability to be a main determinant for successful participation in modern team sports, numerous tests have been developed to assess

COD performance (e.g. Illinois agility test, T-test, 505 agility test) (Brughelli et al. 2008). These tests are usually characterized by several different variables (e.g. number of COD, total distance covered, type of force application), but most of them quantify the total running time as test score (Brughelli et al. 2008). Traditionally, a lower total running time to complete these tests is considered as a better ability to rapidly decelerate, change direction and reaccelerate in a new direction. The studies comparing the COD ability between adult players competing at different playing levels revealed contrasting results (Delextrat and Cohen 2008, Koklu et al. 2011, Lockie et al. 2014, Sekulic et al. 2017, Spiteri et al. 2017). T-test and the reactive Y-shaped agility test were found to discriminate COD performance between professional male basketball players compared to lower competitive level counterparts (Delextrat and Cohen 2008, Koklu et al. 2011, Lockie et al. 2014, Sekulic et al. 2017). Furthermore, different COD performance in the 505 agility test were found across three different female basketball leagues (Spiteri et al. 2017). In addition, a faster performance in the T-test was found among Senior and Under 20 compared with under 18 Tunisian national players (Ben Abdelkrim et al. 2010c). On the contrary, Koklu et al. (2011) and Sekulic et al. (2017) found no significant differences among Division I and Division II players in the T-test. However, it should be considered that these contrasting results may be a consequence of the different types/characteristics of tests used to evaluate the COD ability of players.

Jumping movements are frequently performed during basketball competitions. Most of the TMA studies reported male players to complete more than 40 jumps during matches (range: from 17 to 56 jumps) (Stojanovic et al. 2017). In addition, Hoffman et al. (1996) found vertical jumping ability to be significantly related (r=0.68) to playing time in NCAA basketball players. Therefore, vertical jumping ability represents a key component of basketball performance. Counter-movement jumps (CMJ) and Squat jumps (SJ) are the typical techniques used to investigate the vertical jumping ability (Ziv and Lidor 2010). During CMJ, players are usually asked to perform a quick downward movement reaching about 90° knee flexion, promptly followed by a fast-upward movement with the aim to jump as high as possible. In contrast, during SJ athletes are asked to jump from a bent-knee squat position (~90° knee flexion). Due to the greater elastic energy stored within the leg musculature during the eccentric and concentric phases of the CMJ compared to SJ, athletes can reach higher height (CMJ_h) and produce greater peak power output (PPO) and peak force (PF) (Ziv and Lidor 2010). Because of the various tests used to assess the vertical jumping ability, a wide range of values of vertical jump height (from 28.5 to 68.1 cm) have been reported in literature (see Table 2.2). Some, but not all, studies have shown vertical jump performance to be greater in higher level adult basketball players (Ben Abdelkrim et al. 2010c, Delextrat and Cohen 2008, Koklu et al. 2011). Delextrat et al. (2008) reported Division I British university players to reach greater CMJ_h than lower level counterparts (56.6±4.04 vs 51.6±3.3 cm). Similarly, Köklü et al. (2011) showed a greater performance among Division I Turkish players during CMJs when compared with Division II players (40.6±4.7 vs 36.0±5.0 cm); however, no significant differences were reported in SJ performance between these two groups (37.8±5.7 vs 34.7±5.7 cm, respectively). In addition, Ben Abdelkrim et al. (2010c) found CMJ variables (i.e. height and PPO) to discriminate between U18 Tunisian basketball players and older groups (i.e. U20 and Senior teams). However, U20 and Senior Tunisian basketball players were reported to possess similar jumping ability (CMJ_h: 49.1±5.9 vs 49.7±5.8 cm: PPO: 4656±81 vs 4665vs±116 W, respectively). When comparing vertical jumping ability among the different playing positions, Guards and Forwards generally jump higher than Centres, who are usually characterized by greater PPO (Ben Abdelkrim et al. 2010c, Boone and Bourgois 2013, Ostojic et al. 2006).

Seasonal changes in physical fitness

The evaluation of the physiological characteristics of basketball players across the different phases of a season allows strength and conditioning coaches to monitor the effectiveness of conditioning programs and to quantify the changes in the fitness status of players across the season (Drinkwater et al. 2008). Typically, the greatest improvement in athletes' physical fitness occurs during the preparation period, when players begin performing physical activity after a prolonged period of complete or nearly complete rest (Drinkwater et al. 2008, Hoffman 2000). During the competitive phase of the season, coaches typically devote most of their time to improve technical and tactical aspects of the game and players technical skills. Thus, strength and conditioning coaches aim to preserve the players' physical fitness, although realistically, fitness may slightly increase or decrease during these prolonged phase (i.e. > 5 months) (Drinkwater et al. 2008).

Several studies have investigated the seasonal changes in physical fitness of collegiate NCAA male basketball players (Bolonchuk et al. 1991, Caterisano et al. 1997, Drinkwater et al. 2005, Drinkwater et al. 2008, Groves and Gayle 1993, Hoffman et al. 1991, Hunter et al. 1993, Tavino et al. 1995). Tavino etl al. (1995) reported NCAA Division I basketball players to increase their anaerobic capacity and to decrease their body fat by 26% after 5 weeks of preseason. However, body fat increased within the competitive phase by 17%. No changes in Vo_{2max} and body mass were reported during the entire season in this study. Similarly, Bolonchuk et al. (1991) reported a non-significant improvement (1.6%) in Vo_{2max} between pre- and post-season among 8 NCAA basketball players. Hoffmann et al. (1991) showed NCAA Division I players to decrease vertical jump height and sprint performance after 10 weeks from the beginning of the season, without observing any change in body mass and aerobic capacity (i.e. 2414 m run time). On the contrary, no variations in vertical jumping ability were reported by Groves & Gayle (1993) in 8 university players during the different phase of the season. In addition, these authors also reported body mass to be reduced after the preparation period and to be increased during the competitive phase of the season. Caterisano et al. (1997) investigated the effect of a basketball season among starting and reserve players. The former were reported not to change their body mass, body fat and Vo_{2max} during the entire season, while the latter were found to significantly decrease their Vo_{2max} by 10%. Taken together, these studies indicate that the aerobic fitness might be slightly increased after the preparation period, while it usually remains stable or returns to off-season level during the in-season phase. In addition, the anaerobic fitness appears to be improved after the preparation period and to be preserved or slightly increased during the in-season phase. However, no final conclusions can be drawn on the seasonal variations in anthropometric characteristics and in vertical jumping performance because of the contrasting results observed among NCAA basketball players.

Despite the importance of monitoring physical fitness of athletes, only few studies have investigated differences in adult professional basketball players (Aoki et al. 2017, Gonzalez et al. 2013, Laplaud et al. 2004), likely because of the difficulty of involving this cohort of athletes in longitudinal studies. Recently, Gonzalez et al. (2013) investigated physical performance variations among 7 NBA basketball players (4 starters and 3 non-starters) from the beginning to the end of the regular season. Authors reported improvements in lower limb power production during squat exercise; however, lower limb power produced during repeated vertical jumps was increased only among starters. Furthermore, starters maintained their body mass and percentage of body fat during the regular season, while non-starters lost their body mass. Aoki et al. (2017) reported small-to-large improvements in vertical jumping performance (i.e. CMJ and SJ) and moderate-to-large greater distances covered during the Yo-Yo IR1 among professional Brazilian players after 4 and 9 weeks from the beginning of the season. In addition, small improvements were found in repeated-sprint ability (i.e. best sprint time and mean sprint time) after 4 weeks from the start of the preparation period. On the contrary, Laplaud et al.

(2004) did not observe any change in body mass, CMJ_h and VO_{2max} among 8 Division I French players after ~5 months from the beginning of the training period.

These studies provide preliminary useful information on the effect of basketball seasonal phases on physical fitness level of professional and NCAA male players; however, there are some noteworthy considerations. Test-retest reliability has been rarely reported in these studies. In addition, by not accounting for test-retest variation as a source of error, an inferential statistical test (e.g. t-test, ANOVA) may indicate that no significant variation has occurred despite the clinical change being real and meaningful (type I error) (Drinkwater et al. 2008). Furthermore, it should be considered that a physiological test may not accurately reflect the physiological characteristics of players if not performed after a sufficient recovery period from heavy training sessions or competitions.

Demands of basketball competitions

The identification of basketball competition demands is essential to developing specific team-based trainings, to analyse players' physical performance and to design rehabilitation and return-to-play programs. Thus, physiological responses to basketball competitions have been widely reported in literature (Beam and Merrill 1994, Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2009, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, Klusemann et al. 2013, Matthew and Delextrat 2009, McInnes et al. 1995, Montgomery et al. 2010, Moreira et al. 2012, Narazaki et al. 2009, Torres-Ronda et al. 2016, Vaquera et al. 2008), while an increasing number of studies have recently focused on the activity demands across games (Stojanovic et al. 2017).

Physiological responses

The investigation of the physiological responses to competitions provides useful information into the overall stress imposed on basketball players. Most of the studies have measured the internal responses to basketball games in terms of blood lactate concentration ($[La^-]$) and heart rate (HR). The measurement of $[La^-]$ can give an indication of the glycolysis' contribution to players' energy requirements, while the measurement of HR provide an indirect indication of exercise intensity (McInnes et al. 1995).

Existing studies on adult male basketball players reported mean $[La^-]$ values to range from 4.2 to 6.8 $mmol \cdot L^{-1}$ during competitions (Stojanovic et al. 2017). The highest mean $[La^-]$ (6.8±2.8 $mmol \cdot L^{-1}$) was found by McInnes et al. (1995) within elite Australian basketball competitions. The lowest mean $[La^-]$ (4.2±1.3 $mmol \cdot L^{-1}$) was reported during 20-min practice game among NCAA Division II players. However, the variation between these studies may be due to the type of competition being investigated. Indeed, Montgomery et al. (2010) reported that the physiological demands of 5on5 basketball practice are substantially lower than the actual match activity. In addition, Ben Abdelkrim et al. (2007) observed higher $[La^-]$ values in the first half compared to the second half of the game. When comparing athletes of different competitive levels, higher level players were observed to reach higher $[La^-]$ levels than lower level athletes (Stojanovic et al. 2017). In addition, a higher $[La^-]$ was reported for Tunisian players competing at International level compared to National level counterparts (6.1±1.1 vs 5.0±1.1 $mmol \cdot L^{-1}$) (Ben Abdelkrim et al. 2010a). When comparing athletes of different playing roles, Guards were found to work at intensities that elicit higher $[La^-]$ levels compared to Centres (6.4±1.2 vs 4.9±1.2 $mmol \cdot L^{-1}$) (Ben Abdelkrim et al. 2007). Altogether, these studies highlight the considerable contribution of glycolytic pathways to energy production during basketball competitions. However, when interpreting blood lactate values, it should be considered that $[La^-]$ is only a surrogate indicator of anaerobic metabolism, thus it is not possible to directly calculate what percentage of energy comes from aerobic and anaerobic pathways (Ziv and Lidor 2009). In addition, the intensity of exercises carried out immediately before sample collection may influence [La^-] results.

The analysis of HR during adult male basketball competitions showed HR absolute values range between 162-175 bpm or 83.9-94.4 %HR_{max} (Stojanovic et al. 2017). HR was found to be higher during the first half and the first quarter compared to second half and last quarter, respectively (Ben Abdelkrim et al. 2009, Ben Abdelkrim et al. 2007, Janeira and Maia 1998). In addition, most of the studies reported players to spend ~75% of live time during competition at HR responses >85% HR_{max} (Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2010b, McInnes et al. 1995, Stojanovic et al. 2017). Considering that 85% HR_{max} is traditionally considered as an indicator of high-intensity activity (Stojanovic et al. 2017), altogether these studies highlight the considerable demands imposed on the cardiovascular system of basketball players. However, previous studies reported basketball players to spent only ~11-20% of live time performing high-intensity activities (HIA) (Stojanovic et al. 2017). This discrepancy may be due to a prolonged elevation of HR in response to the high physiological cost of HIA (McInnes et al. 1995). Furthermore, it has been reported that the additional upper body activities and the physiological requirements associated with prolonged intensity phases characterized by acceleration, deceleration and change of directions might increase the HR response (Stojanovic et al. 2017). When comparing basketball games of different competitive levels, it appears that elite players are characterized by slightly greater HR_{max} values than lower level counterparts (Stojanovic et al. 2017). Ben Abdelkrim et al. (2010a) reported Under 19 Tunisian basketball players competing at International level to spend more time performing at 85% HR_{max} (76.9 vs 69.6%) and to reach greater HR mean values during competition compared to National level counterparts (94.4±1.7 vs 91.8±2.2 %HR_{max}). When comparing athletes of different playing roles, the highest HR responses have been recorded in Guards, while no differences has been reported in HR values between Forward and Centres (Stojanovic et al. 2017). The measurement of HR during basketball competition provides useful information for the development of specific training programs; however, some considerations are worth noting. HR may be affected by external factors such as nutritional status of player, stress and environmental temperature (Rodriguez-Alonso et al. 2003); thus, it provides an indirect estimation of the game intensity.

Activity demands and Time-motion analysis

In the last 10 years, many studies have focused on the activity demands of basketball competition, with the aim to better understand the movement patterns and external load placed on players (Stojanovic et al. 2017). Due to the high-cost and/or the limited effectiveness of the available micro-technologies (e.g. global positioning systems and micro-sensors), time-motion analysis (TMA) has been widely used for measuring the activity demands within male basketball competitions (Fox et al. 2017). Originally, TMA in basketball has been performed using a cartographical method, during which the technician first drew the position of players on a coordinate map of the court and then measured the estimated distance covered during the game (Hulka et al. 2014). Recently, most of the studies performing TMA of basketball games have used a video-based methodology. Typically, this technique consists of first recording the match and then analysing players' movements on the court using a computer software. As such, when performing video-based TMA, one or more cameras are usually positioned around the basketball court in a position that permits to record all players involved in the game during the entire competition. Typically, the software employed for TMA are manual or semi-automatic (meaning that the players can be automatically detected on the court) and allow the calculation of movement frequency, durations and distances (Fox et al. 2017, Stojanovic et al. 2017). The individual movement patterns are usually classified into 8 movement categories as follows: (a) standing/walking; (b) jogging; (c) running; (d) sprinting; (e) low-; (f) moderate-; (g) high-specific movements and (h) jumping (Ben Abdelkrim et al. 2007, McInnes et al. 1995, Stojanovic et al. 2017). The movements differing from ordinary walking or running are typically classified as “specific movements”, which mainly included shuffling, rolling, reversing and cross-over running activities.

Table 2.3 and 2.4 presents a summary of the existing studies examining the activity demands of basketball players evaluated using TMA (retrieved from Stojanovic et al. 2017).

The TMA studies demonstrated the intermittent nature of basketball games, during which adult male basketball players perform on average from 758 to 2749 movements lasting up to 2-3 s (Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, McInnes et al. 1995, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Torres-Ronda et al. 2016). In addition, relative activity frequencies have been reported to vary between 21.2 and 56.9 movements per minute (Stojanovic et al. 2017). Previous studies found various proportion of playing time spent performing the different type of movement patterns during competitions (standing/walking: 23.4-66.3%; jogging: 5.6-36.3%; running: 4.5-33.2%; sprinting:0.3-8.5%; low- specific movements: 2.1-14.7%; moderate- specific movements: 6.5-19.8%; high- specific movements: 0.4-9.3% and jumping: 0.6-2.3%) (Stojanovic et al. 2017). When considering movement patterns grouped according to their relative intensity, adult male players were found to spend ~28-63% recovering (REC) and ~14-40%, ~11-28% and ~11-20% performing Low-intensity activities (LIA), Moderate-intensity activities (MIA) and High-intensity activities (HIA) respectively during playing time (Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, McInnes et al. 1995, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Torres-Ronda et al. 2016). The wide ranges observed in these results may be attributed to the different game rules applied (e.g. match duration) and methodologies used to classify movement patterns. TMA studies have provided important insights on the topic; however, some limitation should be acknowledged. Most of the TMA studies analysed collegiate or junior teams (Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, Conte et al. 2016, Montgomery et al. 2010, Narazaki et al. 2009), players from the same club (Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, Bishop and Wright 2006, Conte et al. 2016, McInnes et al. 1995, Montgomery et al. 2010, Narazaki et al. 2009, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Torres-Ronda et al. 2016), a limited number of athletes (i.e. 6 to 14) (Bishop and Wright 2006, McInnes et al. 1995, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Torres-Ronda et al. 2016), and/or non-official competitive games (Torres-Ronda et al. 2016). Thus, studies that assess the activity demands of a large sample of senior basketball players during official competitions are still required.

A limited number of studies have compared the game activity demands between different competitive levels in basketball (Ben Abdelkrim et al. 2010a, Scanlan et al. 2011, Scanlan et al. 2015b). These studies reported higher level players to undergo greater intermittent workloads during competition. Ben Abdelkrim et al. (2010a) compared the game activity requirements between international and national junior Tunisian male basketball players. The former were found to complete a greater number of HIA (280±54 vs 198±25) and total movements (1105±74 vs 1004±27) and to spend significantly more live time in HIA (20.3±2.1% vs 16.2±1.2%) and REC (28.1±2.9% vs 24.9±3.2%). On the contrary, the latter were found to perform a significantly greater proportion of MIA (31.0±3.9% vs 24.4±3.6%) during matches. Similarly, Scanlan et al. (2011) have reported open-age Australian male elite players to complete more total activities compared with semi-professional counterparts (backcourt: 2733±142 vs 1911±283; frontcourt: 2749±137 vs 2014±131). However, these authors found Australian elite players to perform more activities at moderate to high intensities compared to sub-elite counterparts, who complete more maximal efforts interspersed by longer periods at low-intensities during games. These partially contrasting results have been attributed to the different TMA methodologies used (e.g. movements classification, software employed) and to the different age group of players involved (i.e. junior vs senior) in these two studies. The differences between game activity demands among various competitive levels are not clear, thus more studies on the topic are required.

These studies provided important insight into the activity demands of basketball competitions; however, some considerations are worth noting. Most of TMA studies involved a limited number of players, mainly belonging to one or two basketball teams. As a consequence, the reported game activity demands data are only indicative of the teams and competitions investigated and cannot be interpreted as normative data. In addition, despite TMA represents a valid and reliable technique to determine the activity demands of players in basketball (Ben Abdelkrim et al. 2007, McInnes et al. 1995), some limitations associated with TMA should be acknowledged. Data analysis and interpretation are time- and resource-intensive. Furthermore, TMA should be performed by appropriate expertise technicians, to identify and categorise movement patterns correctly (Fox et al. 2017).

Table 2.3. Activity frequencies for various types of activities according to playing position, playing level, geographical location, and sex during basketball match-play (retrieved from Stojanovic et al. 2017).

Study	Playing level/location/sex/*n*	Comparison groups	Activity category (*n*)										Total	
			Stand/walk	Jog	Run	Sprint	Low shuffle	Moderate shuffle	High shuffle	Jump	Dribble	Upper body	Absolute (*n*)	Relative ($\cdot min^{-1}$)
McInnes et al. [2]	National Basketball League/Australia/M/8	All players	295 ± 54	99 ± 36	107 ± 27	105 ± 52	168 ± 33	114 ± 44	63 ± 33	46 ± 12			997 ± 183	27.4
Ben Abdelkrim et al. [3]	National Championship U19/Tunis/M/38	PG, SG	271 ± 18	113 ± 8	103 ± 11	67 ± 5[a]	176 ± 14	230 ± 37[a,b]	104 ± 19	41 ± 7			1103 ± 32[a,b]	31.5
		SF, PF	275 ± 23	110 ± 10	88 ± 5	56 ± 5[b]	173 ± 6	186 ± 13	94 ± 13	41 ± 6			1022 ± 45	29.1
		C	280 ± 3	117 ± 6	101 ± 19	43 ± 4	175 ± 11	176 ± 9	85 ± 8	49 ± 3			1026 ± 27	28.6
		All players	275 ± 16	113 ± 8	97 ± 14	55 ± 11	175 ± 10	197 ± 33	94 ± 16	44 ± 7			1050 ± 51	29.7
Matthew and Delextrat [10]	University Sports Association/UK/F/9	All players	151 ± 26	67 ± 17	52 ± 19	49 ± 17	117 ± 14	123 ± 45	58 ± 19	35 ± 11			652 ± 128	21.2
Narazaki et al. [11]	Collegiate Championship Division II/USA/M and F/6 and 6	F	23 ± 13/112 ± 5		89 ± 10					16 ± 6				
		M	23 ± 6/105 ± 12		78 ± 15					17 ± 8				
		All players	23 ± 10/109 ± 9		84 ± 13					17 ± 7				
Ben Abdelkrim et al. [6]	National Championship U19/Tunisia/M/38	International	294 ± 20	114 ± 7	78 ± 11	63 ± 17[c]	164 ± 12	175 ± 37	94 ± 14[c]	42 ± 7			1105 ± 74[c]	31.7
		National	255 ± 12	112 ± 10	96 ± 17[c]	41 ± 22	163 ± 10	180 ± 12	74 ± 19	45 ± 7			1004 ± 27	28.0
		Man-to-man	274 ± 25	110 ± 10	84 ± 18	67 ± 13[c]	163 ± 13	169 ± 14	73 ± 20	46 ± 6			1053 ± 64	30.0
		Zone games	276 ± 28	117 ± 5	90 ± 15	37 ± 19	164 ± 8	185 ± 35	95 ± 11	42 ± 7			1056 ± 89	29.6
Scanlan et al. [4]	National Basketball League and State Basketball League/Australia/M/10	PG, SG (pro)	764 ± 86[c]	911 ± 65[c]	504 ± 38[c]	18 ± 7[c]	75 ± 5[c]		70 ± 5	42 ± 6	60 ± 4	289 ± 15[c]	2733 ± 142[c]	56.9
		PG, SG (semi-pro)	462 ± 47	586 ± 77	321 ± 75	105 ± 31	45 ± 9		46 ± 29	41 ± 3	72 ± 3	233 ± 6	1911 ± 283	39.8
		SF, PF, C (pro)	815 ± 45[c]	955 ± 33[c]	513 ± 26	24 ± 1	58 ± 12[c]		59 ± 14	56 ± 2	23 ± 1	246 ± 3[c]	2749 ± 137[c]	57.3
		SF, PF, C (semi-pro)	532 ± 38	664 ± 59	352 ± 25	140 ± 14	30 ± 3		17 ± 3	49 ± 3	19 ± 2	211 ± 9	2014 ± 131	42.0
Scanlan et al. [5]	State Basketball League/Australia/F/12	PG, SG	412 ± 31	547 ± 49	295 ± 33	97 ± 21	48 ± 1		25 ± 4	43 ± 5	59 ± 4[c]	223 ± 31	1749 ± 158	43.7
		SF, PF, C	452 ± 54	553 ± 82	297 ± 52	117 ± 22	37 ± 9		20 ± 7	41 ± 6	18 ± 5	217 ± 10	1752 ± 212	43.8
		All players	436 ± 44	551 ± 67	295 ± 41	108 ± 20	41 ± 5		22 ± 5	43 ± 6	34 ± 2	220 ± 18	1750 ± 186	43.7
Caprino et al. [29]	U17 Regional Championship/NR/M/10	PG, SG												26.7
		SF, PF												24.2
		C												20.3
Klusemann et al. [9]	National Championship U19/Australia/M/8	Season	255 ± 32	102 ± 23	90 ± 17[c]	33 ± 7[c]	94 ± 15[c]	193 ± 33[c]	26 ± 9[c]	19 ± 6			809 ± 80	27.0
		Tournament	252 ± 34	99 ± 28	82 ± 15	28 ± 8	80 ± 24	175 ± 41	24 ± 9	19 ± 5			758 ± 106	25.3
Delextrat et al. [28]	National Championship Division II/English/M/9	All players	228 ± 14	77 ± 27	66 ± 15	71 ± 20	131 ± 31 (low, moderate and high)			52 ± 14				19.1

Study	Playing level/location/sex/*n*	Comparison groups	Activity category (*n*)										Total	
			Stand/walk	Jog	Run	Sprint	Low shuffle	Moderate shuffle	High shuffle	Jump	Dribble	Upper body	Absolute (*n*)	Relative ($\cdot min^{-1}$)
Scanlan et al. [13]	State Basketball League/Australia/M and F/12 and 12	PG, SG (M)	380 ± 24	480 ± 36	264 ± 48	84 ± 20	36 ± 4[c]		36 ± 20	32 ± 4[c]	60 ± 4	192 ± 12	1580 ± 124	39.5
		PG, SG (F)	404 ± 32	540 ± 48	292 ± 32	96 ± 20	48 ± 0		24 ± 4	44 ± 4	60 ± 4	220 ± 36	1748 ± 19	43.7
		SF, PF,C (M)	440 ± 20	548 ± 28	292 ± 8	116 ± 8	24 ± 4		12 ± 4	40 ± 4	16 ± 0	176 ± 12[c]	1680 ± 72	42.0
		SF, PF, C (F)	444 ± 36	544 ± 60	292 ± 40	116 ± 16	36 ± 12		20 ± 8	40 ± 4	16 ± 4	216 ± 16	1776 ± 232	44.4
		All players (M)	416 ± 20	520 ± 28	280 ± 24	104 ± 12	32 ± 4		24 ± 8	36 ± 4	32 ± 4	184 ± 12	1628 ± 68	40.7
		All players(F)	428 ± 36	544 ± 52	292 ± 36	108 ± 20	40 ± 8		20 ± 4	40 ± 4	32 ± 0	216 ± 24	1764 ± 212	44.1
Conte et al. [26]	National Championship Division I/Italy/F/12	All players	205 ± 42	73 ± 20	63 ± 16	44 ± 15	91 ± 23	56 ± 20	25 ± 10	19 ± 10			576 ± 110	23.4
Delextrat et al. [27]	National Championship Division I/Spain/F/42	PG	195/78	126	39	11	120	61	22	20			753	
		SG	161/47[b]	114	39	6	122	33	8	28			626	
		SF	172/46	97	38	5	118	38	10	26			614	
		PF	198/60	115	20[d]	3[e]	155	20[e]	3	34[e]			698	
		C	166/65	115	25	3[e]	121	20[e]	3	42[e,f,d]			663	
		All players												24.1

PG point guard, *SG* shooting guard, *SF* small forward, *PF* power forward, *C* center, *M* male, *F* female, *pro* professional players, *semi-pro* semi-professional players, *NR* not reported, *U* under

[a]Significantly ($p < 0.05$) different from forwards

[b]Significantly ($p < 0.05$) different from centers

[c]Significant ($p < 0.05$) difference between comparison groups

[d]Significantly ($p < 0.05$) different from SF

[e]Significantly ($p < 0.05$) different from PG

[f]Significantly ($p < 0.05$) different from SG

Table 2.4. Duration (%) spent performing various types of activity according to playing position, playing level, geographical location, and sex during basketball match-play (retrieved from Stojanovic et al. 2017).

Study	Playing level/location/sex/*n*	Comparison groups	Activity category (% of live playing time)										
			Stand/ walk	Jog	Run	Sprint	Sideways/ stride	Low shuffle	Moderate shuffle	High shuffle	Jump	Dribble	Static actions
McInnes et al. [2]	National Basketball League/ Australia/M/8	All players	35.2	11.8	11.7	8.5		14.4	10.3	6.0	2.0		
Ben Abdelkrim et al. [3]	National Championship U19/ Tunisia/M/38	PG, SG	28.4[a]	11.0[a]	10.2	5.9[a]		13.4[a]	19.8[a]	9.3[b]	2.0		
		SF, PF	29.6[a]	11.4[a]	10.1	5.4[a]		14.4	17.9	9.2[a]	2.0		
		C	31.8	12.4	10.8	4.5		14.7	15.5	7.9	2.3		
		All players	29.9	11.6	10.4	5.3		14.2	17.7	8.8	2.1		
Narazaki et al. [11]	Collegiate Championship Division II/USA/M and F/6 and 6	F	65.3		33.2						1.6		
		M	66.3		32.0						1.7		
		All players	65.7		32.6						1.6		
Ben Abdelkrim et al. [6]	National Championship U19/ Tunisia/M/38	International	28.1[c]	11.3	10.2[c]	6.0[c]		13.6	14.2[c]	9.3[c]	2.0		4.1[c]
		National	24.9	12.0	11.2	4.9		14.2	19.8	8.1	2.1		1.5
		Man-to-man	24.9[c]	11.7	11.0	6.2[c]		14.3	15.8	8.1[c]	2.1		3.2
		Zone games	28.0	11.6	10.4	4.6		13.4	18.1	9.3	2.0		2.4
Ben Abdelkrim et al. [7]	National Championship/ Tunisia/M/18	All players	63.3	5.6	4.5	2.8	1.9/2.4	8.5	6.5	3.1	1.3		
Scanlan et al. [4]	National Basketball League and State Basketball League/ Australia/M/10	PG, SG (pro)	23.4[c]	39.1[c]	22.8[c]	0.3[c]		3.6		1.8		9.0	
		PG, SG (semi-pro)	33.7	33.0	15.0	3.3		2.7		1.6		10.6	
		SF, PF, C (pro)	28.4[c]	40.9[c]	25.0[c]	0.4[c]		2.7		1.2		1.3	
		SF, PF, C (semi-pro)	39.6	35.8	16.1	4.7		2.1		0.4		1.3	
Scanlan et al. [5]	State Basketball League/ Australia/F/12	PG, SG	31.0[c]	36.2	16.0[c]	3.7		3.6		0.9		8.6[c]	
		F, PF, C	38.8	35.1	17.2	4.3		2.8		0.7		1.1	
		All players	35.7	35.6	16.7	4.1		3.1		0.7		4.1	
Scanlan et al. [13]	State Basketball League/ Australia/M and F/12 and 12	PG, SG (M)	33.7	33.1	15.0	3.3		2.7		1.7		10.6	
		PG, SG (F)	30.9	36.3[c]	16.0	3.7		3.7		0.8		8.7	
		SF, PF, C (M)	39.5	35.7	16.1	4.7		2.2		0.5		1.3	
		SF, PF, C (F)	38.8	34.9	17.3	4.3		2.8		0.7		1.2	
		All players (M)	37.3	34.6	15.6	4.2		2.3		1.0		5.0[c]	
		All players (F)	35.7	35.5	16.8	4.0		3.2		0.7		4.2	
Conte et al. [26]	National Championship Division I/Italy/F/12	All players	50.2	11.7	13.1	5.2		10.0	6.5	2.7	0.6		

Study	Playing level/location/sex/*n*	Comparison groups	Activity category (% of live playing time)										
			Stand/ walk	Jog	Run	Sprint	Sideways/ stride	Low shuffle	Moderate shuffle	High shuffle	Jump	Dribble	Static actions
Delextrat et al. [27]	National Championship Division I/Spain/F/42	PG	38.8	25.1	5.4	1.3		15.5	5.0	1.9	1.1		1.7
		SG	38.2	24.0	5.7	0.8		19.6	2.8	0.5	2.0		2.1
		SF	41.6	23.9	6.4	0.6		15.4	3.6	0.8	1.9		3.4
		PF	41.2	23.5	3.0[d]	0.2[e]		19.0	1.6	0.2	3.0[e]		4.8[e,f]
		C	38.1	24.1	4.1	0.3[e]		14.6	1.4	0.2	3.1[e,d]		7.1[e,f,d]

PG point guard, *SG* shooting guard, *SF* small forward, *PF* power forward, *C* center, *M* male, *F* female, *pro* professional players, *semi-pro* semi-professional players, *U* under

[a]Significantly ($p < 0.05$) different from centers

[b]Significantly ($p < 0.05$) different from forwards

[c]Significant ($p < 0.05$) difference between comparison groups

[d]Significantly ($p < 0.05$) different from SF

[e]Significantly ($p < 0.05$) different from PG

[f]Significantly ($p < 0.05$) different from SG

CHAPTER THREE

Anthropometrical and physiological characteristics of basketball players according to competitive level and playing role.

Ferioli D, Rampinini E, Bosio A, La Torre A, Azzolini M, Coutts AJ. (*Under Review*). "Anthropometrical and physiological characteristics of basketball. " *Journal of Sports Sciences*.

Abstract

Purpose: 1) to examine the anthropometrical and physiological differences in basketball players of different competitive levels using a large sample size 2) to test whether athletes of different playing roles are characterized by physiological differences.

Methods: During the competitive phase of the season, 129 male adult basketball players (Division I, n=39; Division II, n=28; Division III, n=34 and Division VI, n=28) were assessed on two separate test days. On day 1 the athletes underwent Yo-Yo IR1, while on day 2 they performed a standardized 6-min continuous running test (Mognoni's test), a Counter-movement jump (CMJ) test and a standardized 5-min High-intensity Intermittent running test (HIT).

Results: Qualitative statistical analysis revealed that differences in HIT were very likely moderate between Division I and Division II and likely small between Division II and Division III. The absolute peak power and force produced during CMJs by Division II were possibly lower compared to Division I and possibly-to-likely greater compared to Division III. Professional and semi-professional athletes performed better in Yo-Yo IR1 and Mognoni's test compared to amateur players. Forwards resulted shorter and lighter compared to Centres, but taller and heavier compared to Guards. Differences in HIT and Mognoni's test were likely-to-very likely small between Guards and Forwards, while unclear differences were found between Forwards and Centres. The absolute peak power and force produced during CMJs by Forwards was almost certain greater compared to Guards.

Conclusions: The present study clearly shows that basketball players of different competitive levels and playing positions are characterized by different anthropometrical and physiological characteristics.

Key Words: Competitive level; Intermittent exercise; Playing position; Vertical jump; Yo-Yo test

Introduction

Basketball is an intermittent team sport characterized by frequent high-intensity periods of play, often requiring frequent changes of direction, a variety of specific technical skills and well-developed jumping ability (Stojanovic et al. 2017, Ziv and Lidor 2010). Accordingly, the ability to produce strength, power and speed are important physical performance characteristics for basketball players (Ziv and Lidor 2009). Due to these demands, both aerobic and anaerobic mechanisms are heavily activated to provide energy during basketball (Ziv and Lidor 2009). Basketball game demands also vary according to the competitive playing level (Ben Abdelkrim et al. 2007, Scanlan et al. 2011), with professional players performing more activities at moderate to high intensities compared to semi-professional athletes, who compete more maximal efforts interspersed by longer periods at low-intensities during games (Scanlan et al. 2011).

Whilst the anthropometric and physiological characteristics of basketball players have previously been described (Drinkwater et al. 2008), only few studies compared the characteristics of male adult players competing at different playing levels (Delextrat and Cohen 2008, Ferioli et al. 2017, Koklu et al. 2011, Metaxas et al. 2009, Sallet et al. 2005). Anthropometric characteristics are considered a fundamental prerequisite to compete at professional level (Drinkwater et al. 2008); however, stature and body mass fail to discriminate between top and moderate-level professional players (Delextrat and Cohen 2008, Koklu et al. 2011, Metaxas et al. 2009, Sallet et al. 2005). Similarly, although the aerobic metabolism is heavily taxed during games (Ziv and Lidor 2009), aerobic fitness level also does not discriminate between adult male professional and semi-professional players (Ferioli et al. 2017, Koklu et al. 2011, Sallet et al. 2005).

The ability to sustain high-intensity intermittent efforts and to produce greater leg strength / power are generally considered important physical characteristics for high level basketball players. Indeed, both a better Yo-Yo Intermittent Recovery test (Yo-Yo IR1) performance (Ben Abdelkrim et al. 2010c, Vernillo et al. 2012) and lower physiological responses to high-intensity exercise (Ferioli et al. 2017) have been reported in higher level basketball players. However, the studies comparing strength characteristics and vertical jump ability of basketball players of different competitive level have shown conflicting results (Ben Abdelkrim et al. 2010c, Koklu et al. 2011, Metaxas et al. 2009).

Some limitations should be acknowledged when interpreting the results of previous research on the topic. Only few studies have assessed the anthropometric and physiological characteristics among a large cohort (i.e. sample size >100) of adult players (Boone and Bourgois 2013, Vaquera et al. 2015), during the competitive phase of the season (Ben Abdelkrim et al. 2010c, Cormery et al. 2008, Delextrat and Cohen 2008, Manzi et al. 2010, Vaquera et al. 2015) and/or involving athletes from various (i.e. more than two) divisions (Metaxas et al. 2009, Vaquera et al. 2015). Thus, to overcome these limitations and to draw final conclusions, a study that assess the qualities during the competition phase using a larger cohort of adult male basketball players from various playing levels is still required. This information is needed to develop more appropriate training programs.

Similarly, coaches should consider the different anthropometric and physiological profile of players according to their playing position when developing training programs. Forwards are generally shorter and lighter compared to Centres, but taller and heavier compared to Guards (Ziv and Lidor 2009), whilst aerobic fitness is generally higher in Guards compared to the other playing positions when assessed using both field tests (i.e. Yo-Yo IR1 and multistage 20 m shuttle run test) (Ben Abdelkrim et al. 2010c, Ostojic et al. 2006) and laboratory tests (i.e. incremental running or cycling exercise) (Boone and Bourgois 2013, Cormery et al. 2008). Guards also have higher vertical jump compared to Centres, who are characterized by higher level of muscle strength and power (Ben Abdelkrim et al. 2010c, Boone and Bourgois 2013, Ostojic et al. 2006). Most of the studies investigating the characteristics of players according to their playing position tested a limited number of players (n<60) (Ben Abdelkrim et al. 2010c, Koklu et al. 2011, Pojskic et al. 2015, Sallet et al. 2005) or were conducted during the preseason phase of training (Boone and Bourgois 2013, Cormery et al. 2008, Ostojic et al. 2006). Only a limited number of studies assessed these qualities including a great cohort of players (Boone and Bourgois 2013, Vaquera et al. 2015) or were conducted during the regular season (Ben Abdelkrim et al. 2010c, Cormery et al. 2008, Vaquera et al. 2015). Considering these limits and the importance to develop specific training programs, the findings of previous studies should be further confirmed.

Accordingly, the aim of this study was to examine the physical and physiological differences in basketball players of different competitive levels (from professional to amateur levels) using a large cohort size and measuring these characteristics during the competitive phase of the season. Additionally, this study aimed to test whether athletes of different playing roles are characterized by physical and physiological differences.

Methods

Participants

Data were collected from 129 male basketball players competing in the Italian Serie A (Division I, n=39), Serie A2 (Division II, n=28), Serie B (Division III, n=34) and Serie D (Division VI, n=28). Players were selected from a total of 14 basketball teams (i.e. 3 or 4 teams for each division) during the competitive seasons 2014-15, 2015-16 and 2016-17. All the basketball players included in this study completed the standard training program of their respective team and were free of injury during the testing period. Playing positions were equally represented in all Division groups to avoid potential bias effects of playing position on the outcomes variables.

In Division I and Division II, athletes trained 6 to 10 times a week, while in Division III and Division VI teams performed on average 4 to 7 and 2 to 3 training sessions a week, respectively. On average, Division I, II and III performed strength sessions two times per week and conditioning trainings once per week. Division VI perform only technical/tactical trainings. Training sessions lasted 60-120 min, excluding cool down and/or stretching exercises. All the teams in the lower Divisions (i.e. Division II – VI) completed one game per week and the Division I teams played 1-2 games per week. The athletes, with the exception of Division VI players, were divided according to playing positions into Guards, Forwards and Centres. After verbal and written explanation of the experimental design and potential risk and benefits of the study, written informed consent was signed by all players or their respective parents/guardians if underage. The study was approved by the Independent Institutional Review Board of Mapei Sport Research Centre in accordance with the Helsinki Declaration.

Design and Methodology

This observational study was conducted in the middle of the competitive phase of the season (i.e. from December to March) and the players were assessed in the morning (from 9.30 am to 12.30 am) on two separate test days. On day 1 the athletes underwent Yo-Yo IR1, while on day 2 they performed a continuous running test (Mognoni's test), followed firstly by a counter-movement jump (CMJ) test and by a High-intensity Intermittent running test (HIT). The second test day was carried out between 3 to 8 days after the Yo-Yo IR1. The Division I athletes did not carry out the Yo-Yo IR1 due to restrictions made by technical coaches. To avoid potential confounding effects of prior exercise fatigue on the outcomes variables, no training sessions were performed the day preceding the assessments. No stretching exercises were allowed prior to the tests. All the players were familiar with the tests performed in the present study.

Yo-Yo Intermittent Recovery Test – level 1

Athletes performed the Yo-Yo IR1, according to previously described procedures in basketball (Castagna et al. 2008). Yo-Yo IR1 consisted of 20-m shuttle runs performed at increasing velocities (beginning speed of 10 $km \cdot h^{-1}$) with 10 s of active recovery (consisting of 2x5-m of jogging) between runs until exhaustion. The test concluded when participants failed to complete the distance in time twice (objective evaluation) or due to volitional fatigue (subjective evaluation). The total distance covered during Yo-Yo IR1 was considered as the test "score" (Krustrup et al. 2003). Heart rate was continuously monitored using Team^2 Pro System (Polar, Kempele, Finland) and all the athletes achieved at least the 90% of the predicted maximal heart rate, estimated as 220 – age (Fox III et al. 1971).

Antropometrics

Before the commencement of physical test session, stature (stadiometer Wall Mounted, mod206 Seca, Birmingham UK), body mass (portable scale mod762 Seca, Birmingham UK) and body fat percentage (Harpenden skinfold caliper, Lanzoni srl, Bologna, Italy) were determined. The estimation of the body density was determined through the skin-fold (i.e. chest, abdomen and thigh) technique using the equation eight as described by Jackson and Pollock (1978) which was then transformed to body fat percentage using the Siri's equation (Siri, 1961).

Continuous Running Test (Mognoni's)

Mognoni's test (Sirtori et al. 1993) consisted of a 6-min continuous run at a constant speed of 13.5 $km \cdot h^{-1}$ on a motorized treadmill (HP Cosmos, Nussdorf – Traunstein,Germany). Capillary blood lactate concentration ($MOG_{[La-]}$) was measured from the earlobe immediately after the completion of the test using a portable amperometric microvolume lactate analyser (Lactate

Plus, Nova Biomedical, Waltham, MA, USA). Heart rate was continuously monitored using Team^2 Pro System (Polar, Kempele, Finland) and the mean heart rate (MOG_{HR}) of the last minute of running was considered for analysis. Athletes were instructed to abstain from any kind of warm-up prior to the test to avoid potential confounding effects on the physiological responses to the Mognoni's test.

Counter-Movement Jump Test

One minute before the CMJ test, athletes carried out 2 submaximal CMJs. The CMJ test was performed using a portable force platform (Quattro Jump, Kistler, Winterthur, Switzerland) 10 minutes after the Mognoni's test. Each athlete performed 5 bilateral single CMJs, separated by 30 s of passive rest, from a standing position with hands placed on the hips to minimize any influence of the arms. Players were instructed to perform a quick downward movement reaching about 90° knee flexion, promptly followed by a fast-upward movement with the aim to jump as high as possible. During the concentric phase of each CMJ, peak power output (PPO), peak force (PF) and jump height (CMJ_h) were measured. The average of the best 3 values was used for analysis.

High-intensity Intermittent Test

The HIT protocol (Rampinini et al. 2010), comprising 10 x 10 s shuttle runs over a 25+25 m course with a 180° change of direction and 20 s of passive recovery between each bout, was performed 10 minutes after the end of the CMJ test. The players were required to run at 18 $km \cdot h^{-1}$, following a sequence of audio signals. Immediately after the HIT protocol, a 100 µL capillary blood sample was drawn from an earlobe into a heparinised capillary tube and analysed for blood hydrogen ion concentration ($HIT_{[H+]}$) and bicarbonate concentration

($HIT_{[HCO3-]}$) using a calibrated blood-gas analyser (GEM Premier 3000, Instrumentation Laboratory, Milan, Italy) with an Intelligent Quality Management System cartridge. Capillary blood samples (5 µL) taken from the earlobe were also analysed for blood lactate concentration ($HIT_{[La-]}$) using a portable amperometric microvolume lactate analyser (Lactate Plus, Nova Biomedical, Waltham, MA, USA). Heart rate was continuously monitored using Team[2] Pro System (Polar, Kempele, Finland) and the mean heart rate of the test (HIT_{HR}) was considered for the statistical analysis.

Statistical analysis

The participants' descriptive results are reported as means ± standard deviations (SD). The magnitude-based inference approach was used to analyse the data according to Hopkins et al. (2009) All data were first log-transformed to reduce bias arising from non-uniformity of effects or errors (Hopkins et al. 2009). Practical significance of differences was also assessed by calculating the effect size (ES) and the signal to noise ratio (SNR). ES were considered as follow: ≤0.02, trivial; >0.2-0.6, small; >0.6-1.2, moderate; >1,2-2.0, large; >2.0-4.0, very large (Hopkins et al. 2009). The SNR was calculated for each variable as the percentage mean difference of the results between two divisions/role positions (signal) divided by the typical error of measurement (absolute reliability as the noise) (Amann et al. 2008). For this purpose, the typical error of measurement expressed as coefficient of variation (CV) was established (test-retest reliability). CVs were determined in our laboratory in 15 Division VI basketball players on 2 trials, resulting as follow: Body mass, 0.7%; Body fat percentage, 3.4%; $MOG_{[La-]}$, 8.0%; MOG_{HR}, 0.8%; $HIT_{[La-]}$, 12.4%; $HIT_{[H+]}$, 5.3%; $HIT_{[HCO3-]}$, 7.2%; HIT_{HR}, 2.3%; CMJ_h, 3.8%; absolute PPO, 2.5%; relative PPO, 2.9%; absolute and relative PF, 3.8%. The CV of the Yo-Yo IR1 has been described previously (Krustrup et al. 2003). Probabilities were also calculated to compare the true (unknown) differences and the smallest worthwhile changes

(SWC). SWC was obtained multiplying the between-subject SD by 0.2. Quantitative chances of positive, trivial or negative differences between Division groups and playing roles were evaluated qualitatively according to established criteria: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain (Hopkins et al. 2009). When the probability of having higher or lower values than the SWC was less than 5%, the true difference was assessed as unclear. Customized spreadsheets and SPSS statistical software (version 24.0, IBM SPSS Statistics, Chicago, IL, USA) were utilised to perform data analysis.

Results

Competitive level of play

Anthropometric characteristics and data of physical tests according to competitive level of play are presented in Table 3.1, while standardized differences between groups are reported in Table 3.2. Differences in physiological responses to HIT (i.e. $HIT_{[La-]}$, $HIT_{[H+]}$, $HIT_{[HCO3-]}$) were very likely moderate between Division I and Division II and likely small between Division II and Division III. The PPO and the absolute PF produced during the CMJ test by Division II players was possibly lower compared to Division I athletes and possibly-to-likely greater compared to Division III players. Very likely to almost certain differences were observed in several parameters of the tests between Division III and Division VI groups.

Playing position

Anthropometric characteristics and data of physical tests relative to playing position are presented in Table 3.3, while standardized differences between groups are reported in Table 3.4. Forwards were shorter and lighter compared to Centres, but taller and heavier compared to Guards. Differences in physiological responses to HIT (i.e. $HIT_{[La-]}$, $HIT_{[H+]}$, $HIT_{[HCO3-]}$) and Mognoni's test (i.e. $MOG_{[La-]}$, and MOG_{HR}) were likely-to-very likely small between Guards and Forwards, while no clear differences were found between Forwards and Centres, except for $MOG_{[La-]}$ which was likely higher in Centres. The absolute PPO and the absolute PF produced during the CMJ test by Forwards was almost certain greater compared to Guards. No clear and small differences were found in absolute PPO and absolute PF respectively between Forwards and Centres.

Table 3.1. Anthropometric characteristics and physical tests results relative to competitive levels of play.

	DIVISION I	DIVISION II	DIVISION III	DIVISION VI
		Anthropometric Characteristics		
	n=39 (17-14-8)	*n=28 (13-9-6)*	*n=34 (15-12-7)*	*n=28 (13-10-5)*
Age (years)	26.5 ± 5.0	24.1 ± 4.1	24.4 ± 5.8	21.7 ± 5.3
Stature (cm)	198 ± 9	197 ± 8	193 ± 8	187 ± 8
Body mass (kg)	96.0 ± 11.1	92.7 ± 11.6	90.5 ± 12.8	80.0 ± 10.2
Body fat (%)	11.2 ± 3.1	11.4 ± 3.6	11.5 ± 3.9	11.5 ± 4.3
		Mognoni's Test		
	n=34 (16-11-7)	*n=25 (11-8-6)*	*n=34 (15-12-7)*	*n=28 (13-10-5)*
$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	3.7 ± 1.1	3.8 ± 1.2	4.0 ± 1.9	5.8 ± 2.3
MOG_{HR} (bpm)	160 ± 9	161 ± 8	164 ± 11	174 ± 12
		High-intensity Intermittent Test		
	n=31 (14-10-7)	*n=27 (13-8-6)*	*n=34 (15-12-7)*	*n=28 (13-10-5)*
$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	4.0 ± 1.6	5.0 ± 1.5	6.5 ± 2.6	9.9 ± 3.1
$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	44.3 ± 4.4	47.0 ± 3.3	51.6 ± 8.9	57.7 ± 7.9
$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	22.3 ± 2.3	20.4 ± 2.0	18.9 ± 3.2	15.4 ± 2.7
HIT_{HR} (bpm)	151 ± 9	156 ± 10	159 ± 11	168 ± 12
		Yo-Yo Intermittent Recovery Test – level 1		
	-	*n=29 (13-10-6)*	*n=30 (14-10-6)*	*n=28 (13-10-5)*
Distance (m)	-	2135 ± 356	2265 ± 578	1671 ± 370
		Counter-Movement Jump test		
	n=36 (16-12-8)	*n=25 (11-8-6)*	*n=34 (15-12-7)*	*n=28 (13-10-5)*
CMJ_h (cm)	47.8 ± 5.7	49.2 ± 4.9	48.0 ± 6.1	51.8 ± 4.1
PPO ($W \cdot kg^{-1}$)	57.2 ± 5.9	55.8 ± 5.8	54.1 ± 6.5	60.7 ± 5.3
PF ($N \cdot kg^{-1}$)	27.0 ± 2.6	26.5 ± 3.5	26.0 ± 2.5	28.2 ± 3.4
PPO (W)	5468 ± 820	5177 ± 629	4865 ± 723	4800 ± 536
PF (N)	2573 ± 325	2459 ± 317	2345 ± 316	2231 ± 323

Abbreviations: CMJ_h, Counter-movement jump height; MOG, Mognoni's test; HIT, High-intensity Intermittent Test; HR, heart rate; n, sample size (Guards, Forwards, Centres); PPO, peak power output; PF, peak force; [H+], blood hydrogen ion concentration; [HCO3-], blood bicarbonates concentration; [La-], blood lactate concentration.

Table 3.2. Comparison of anthropometrical and physical tests results between competitive levels of play.

		MBI (%)	Rating	ES (90% CL)		SNR (90% CL)	
		DIVISION I VS DIVISION II					
Anthropometrics	Stature (cm)	40/52/9	Unclear	0.16	±0.45	-	
	Body mass (kg)	65/32/3	Possibly small	0.27	±0.40	5.21	±7.48
	Body fat (%)	14/54/31	Unclear	-0.07	±0.38	-0.07	±0.38
Mognoni's Test	$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	13/49/38	Unclear	-0.10	±0.42	-0.40	±1.67
	MOG_{HR} (bpm)	8/46/46	Unclear	-0.17	±0.46	-1.18	±3.23
HIT	$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	0/0/98	Very likely moderate	-0.66	±0.44	-1.84	±1.22
	$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	0/2/98	Very likely moderate	-0.83	±0.51	-1.18	±0.74
	$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	99/1/0	Very likely moderate	0.92	±0.47	1.31	±0.68
	HIT_{HR} (bpm)	1/13/87	Likely small	-0.47	±0.42	-1.36	±1.19
Yo-Yo IR1 Test	Distance (m)	-	-	-		-	
CMJ test	CMJ_h (cm)	3/33/64	Possibly small	-0.29	±0.45	-0.84	±1.34
	PPO ($W \cdot kg^{-1}$)	56/39/5	Possibly small	0.23	±0.43	0.86	±1.57
	PF ($N \cdot kg^{-1}$)	46/45/9	Unclear	0.12	±0.39	0.51	±1.54
	PPO (W)	73/25/2	Possibly small	0.45	±0.48	2.10	±2.35
	PF (N)	72/26/2	Possibly small	0.35	±0.43	1.22	±1.49
		DIVISION II VS DIVISION III					
Anthropometrics	Stature (cm)	89/11/0	Likely small	0.50	±0.41	-	
	Body mass (kg)	49/44/7	Unclear	0.17	±0.40	3.79	±8.97
	Body fat (%)	19/56/24	Unclear	-0.02	±0.39	-0.02	±0.40
Mognoni's Test	$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	24/58/18	Unclear	-0.10	±0.34	0.11	±0.42
	MOG_{HR} (bpm)	3/33/65	Possibly small	-0.27	±0.37	-2.24	±3.17
HIT	$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	0/9/90	Likely small	-0.53	±0.33	-1.48	±0.98
	$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	0/6/94	Likely small	-0.49	±0.31	-1.42	±1.02
	$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	93/7/0	Likely small	0.43	±0.35	1.19	±1.04
	HIT_{HR} (bpm)	3/32/66	Possibly small	-0.29	±0.41	-0.87	±1.23
Yo-Yo IR1 Test	Distance (m)	9/44/47	Unclear	-0.22	±0.35	-0.76	±1.22
CMJ test	CMJ_h (cm)	57/38/5	Possibly trivial	0.20	±0.38	0.76	±1.54
	PPO ($W \cdot kg^{-1}$)	63/33/3	Possibly small	0.25	±0.41	1.15	±1.91
	PF ($N \cdot kg^{-1}$)	42/47/11	Unclear	0.20	±0.54	0.42	±1.08
	PPO (W)	85/14/1	Likely small	0.42	±0.40	2.72	±2.63
	PF (N)	74/25/2	Possibly small	0.35	±0.43	1.30	±1.59

		DIVISION III VS DIVISION VI					
Anthropometrics	Stature (cm)	98/2/0	Very likely moderate	0.71	±0.41	-	
	Body mass (kg)	100/0/0	Almost certain moderate	1.04	±0.46	19.69	±8.94
	Body fat (%)	22/56/22	Unclear	0.00	±0.40	-0.00	±0.51
Mognoni's Test	$MOG_{[La-]}$ ($mmol·L^{-1}$)	0/0/100	Almost certain moderate	-0.74	±0.38	-4.05	±2.05
	MOG_{HR} (bpm)	0/1/99	Very likely moderate	-0.76	±0.39	-7.04	±3.61
HIT	$HIT_{[La-]}$ ($mmol·L^{-1}$)	0/0/100	Almost certain moderate	-1.08	±0.39	-2.98	±1.06
	$HIT_{[H+]}$ ($mmol·L^{-1}$)	0/2/98	Very likely moderate	-0.74	±0.44	-2.05	±1.24
	$HIT_{[HCO3-]}$ ($mmol·L^{-1}$)	100/0/0	Almost certain large	1.29	±0.46	3.21	±1.17
	HIT_{HR} (bpm)	0/2/98	Very likely moderate	-0.69	±0.40	-2.21	±1.27
Yo-Yo IR1 Test	Distance (m)	100/0/0	Almost certain large	1.56	±0.56	6.92	±2.51
CMJ test	CMJ_h (cm)	0/2/98	Very likely moderate	-0.90	±0.52	-2.04	±1.23
	PPO ($W·kg^{-1}$)	0/0/100	Almost certain large	1.22	±0.46	-3.90	±1.51
	PF ($N·kg^{-1}$)	0/3/97	Very likely moderate	-0.61	±0.37	-1.94	±1.14
	PPO (W)	30/55/15	Unclear	0.12	±0.49	0.36	±1.52
	PF (N)	74/24/2	Possibly small	0.34	±0.41	1.37	±1.64

Abbreviations: CL, confidence limits; CMJ_h, Counter-movement jump height; ES, effect size; MBI (%), percent of chances of positive/trivial/negative effects; MOG, Mognoni's test; HIT, High-intensity Intermittent Test; HR, heart rate; PPO, peak power output; PF, peak force; SNR, Signal to noise ratio; [H+], blood hydrogen ion concentration; [HCO3-], blood bicarbonates concentration; [La-], blood lactate concentration.

Table 3.3. Anthropometric characteristics and physical tests results relative to playing positions.

	GUARDS		FORWARDS		CENTRES	
	Anthropometric Characteristics					
	n=45 (17-13-15)		*n=35 (14-9-12)*		*n=21 (8-6-7)*	
Age (years)	24.6	± 4.7	25.4	± 5.3	25.7	± 5.7
Stature (cm)	189	± 6	200	± 4	206	± 6
Body mass (kg)	83.6	± 8.3	97.5	± 6.0	106.8	± 8.2
Body fat (%)	9.5	± 2.6	12.3	± 3.4	13.7	± 3.4
	Mognoni's Test					
	n=42 (16-13-13)		*n=31 (11-8-12)*		*n=20 (7-6-7)*	
$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	3.5	± 1.3	3.9	± 1.4	4.6	± 1.6
MOG_{HR} (bpm)	160	± 9	164	± 8	163	± 12
	High-intensity Intermittent Test					
	n=42 (14-13-15)		*n=30 (10-8-12)*		*n=20 (7-6-7)*	
$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	4.7	± 2.1	5.6	± 2.3	5.9	± 2.4
$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	45.7	± 4.3	50.2	± 8.3	48.9	± 8.2
$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	21.4	± 2.9	20.1	± 2.8	19.3	± 3.1
HIT_{HR} (bpm)	154	± 11	157	± 8	156	± 12
	Yo-Yo Intermittent Recovery Test – level 1					
	n=27 (0-14-13)		*n=20 (0-10-10)*		*n=12 (0-6-6)*	
Distance (m)	2447	± 427	2078	± 350	1853	± 524
	Counter-Movement Jump test					
	n=42 (16-11-15)		*n=32 (12-8-12)*		*n=21 (8-6-7)*	
CMJ_h (cm)	49.2	± 4.9	48.6	± 6.0	45.8	± 6.0
PPO ($W \cdot kg^{-1}$)	57.2	± 5.5	56.0	± 6.2	52.2	± 6.5
PF ($N \cdot kg^{-1}$)	27.6	± 2.8	26.3	± 2.4	24.8	± 2.6
PPO (W)	4785	± 678	5436	± 738	5560	± 682
PF (N)	2304	± 333	2547	± 262	2645	± 287

Abbreviations: CMJh, Counter-movement jump height; MOG, Mognoni's test; HIT, High-intensity Intermittent Test; HR, heart rate; n, sample size (Division I, Division II, Division III); PPO, peak power output; PF, peak force; [H+], blood hydrogen ion concentration; [HCO3-], blood bicarbonates concentration; [La-], blood lactate concentration.

Table 3.4. Comparison of anthropometrical and physical tests results between playing positions.

		MBI (%)	Rating	ES (90% CL)		SNR (90% CL)	
			GUARDS VS FORWARDS				
Anthropometrics	Stature (cm)	0/0/100	Almost certain very large	-2.60	±0.45	-	
	Body mass (kg)	0/0/100	Almost certain very large	-2.28	±0.43	-20.98	±4.18
	Body fat (%)	0/0/100	Almost certain moderate	-0.81	±0.33	-0.81	±0.32
Mognoni's Test	$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	1/20/79	Likely small	-0.35	±0.38	-1.58	±1.70
	MOG_{HR} (bpm)	0/12/87	Likely small	-0.48	±0.41	-3.30	±2.81
HIT	$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	1/16/83	Likely small	-0.39	±0.38	-1.35	±1.29
	$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	0/4/96	Very likely small	-0.52	±0.33	-1.53	±0.88
	$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	84/15/1	Likely small	0.44	±0.40	0.88	±0.80
	HIT_{HR} (bpm)	2/34/64	Possibly small	-0.31	±0.45	-0.79	±1.19
Yo-Yo IR1 Test	Distance (m)	99/1/0	Very likely moderate	1.01	±0.52	3.61	±1.92
CMJ test	CMJ_h (cm)	41/51/8	Unclear	0.10	±0.36	0.41	±1.36
	PPO ($W \cdot kg^{-1}$)	54/42/4	Possibly trivial	0.19	±0.36	0.80	±1.52
	PF ($N \cdot kg^{-1}$)	88/12/0	Likely small	0.51	±0.41	1.23	±1.02
	PPO (W)	0/0/100	Almost certain moderate	-0.86	±0.37	-4.86	±2.06
	PF (N)	0/0/100	Almost certain moderate	-0.91	±0.43	-2.62	±1.28
			GUARDS VS CENTRES				
Anthropometrics	Stature (cm)	0/0/100	Almost certain very large	-2.88	±0.44	-	
	Body mass (kg)	0/0/100	Almost certain very large	-2.74	±0.43	-31.56	±4.97
	Body fat (%)	0/0/100	Almost certain moderate	-1.20	±0.40	-1.24	±0.38
Mognoni's Test	$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	0/1/99	Very likely moderate	-0.68	±0.42	-3.13	±1.75
	MOG_{HR} (bpm)	6/36/58	Unclear	-0.22	±0.42	-2.04	±3.48
HIT	$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	0/8/91	Likely small	-0.48	±0.43	-1.73	±1.46
	$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	2/18/80	Likely small	-0.37	±0.39	-1.07	±0.92
	$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	95/4/0	Very likely moderate	0.65	±0.44	1.56	±1.01
	HIT_{HR} (bpm)	12/46/42	Unclear	-0.13	±0.43	-0.45	±1.41
Yo-Yo IR1 Test	Distance (m)	99/1/0	Very likely moderate	1.05	±0.53	7.21	±3.26
CMJ test	CMJ_h (cm)	94/5/0	Likely small	0.56	±0.41	2.10	±1.44
	PPO ($W \cdot kg^{-1}$)	98/1/0	Very likely moderate	0.74	±0.41	3.43	±1.80
	PF ($N \cdot kg^{-1}$)	100/0/0	Almost certain moderate	1.01	±0.45	2.89	±1.31
	PPO (W)	0/0/100	Almost certain moderate	-1.09	±0.43	-5.71	±2.24
	PF (N)	0/0/100	Almost certain moderate	-1.14	±0.46	-3.47	±1.45

			FORWARDS VS CENTRES				
Anthropometrics	Stature (cm)	0/0/100	Almost certain moderate	-1.00	±0.41	-	
	Body mass (kg)	0/0/100	Almost certain moderate	-1.10	±0.41	-12.39	±4.23
	Body fat (%)	1/19/79	Likely small	-0.41	±0.45	-0.42	±0.46
Mognoni's Test	$MOG_{[La-]}$ ($mmol·L^{-1}$)	1/18/80	Likely small	-0.39	±0.44	-1.78	±1.91
	MOG_{HR} (bpm)	46/42/12	Unclear	0.12	±0.42	1.29	±4.18
HIT	$HIT_{[La-]}$ ($mmol·L^{-1}$)	13/43/44	Unclear	-0.11	±0.46	-0.46	±1.84
	$HIT_{[H+]}$ ($mmol·L^{-1}$)	44/45/11	Unclear	0.15	±0.47	0.49	±1.55
	$HIT_{[HCO3-]}$ ($mmol·L^{-1}$)	64/30/6	Unclear	0.26	±0.45	0.64	±1.12
	HIT_{HR} (bpm)	40/44/16	Unclear	0.07	±0.41	0.35	±1.76
Yo-Yo IR1 Test	Distance (m)	84/12/4	Likely small	0.40	±0.53	3.06	±3.56
CMJ test	CMJ_h (cm)	83/15/1	Likely small	0.45	±0.45	1.66	±1.65
	PPO ($W·kg^{-1}$)	91/8/0	Likely small	0.56	±0.45	2.57	±2.02
	PF ($N·kg^{-1}$)	91/8/0	Likely small	0.54	±0.44	1.59	±1.27
	PPO (W)	9/43/48	Unclear	-0.17	±0.47	-0.97	±2.63
	PF (N)	3/27/70	Possibly small	-0.33	±0.44	-0.95	±1.24

Abbreviations: CL, confidence limits; CMJh, Counter-movement jump height; ES, effect size; MBI (%), percent of chances of positive/trivial/negative effects; MOG, Mognoni's test; HIT, High-intensity Intermittent Test; HR, heart rate; PPO, peak power output; PF, peak force; SNR, Signal to noise ratio; [H+], blood hydrogen ion concentration; [HCO3-], blood bicarbonates concentration; [La-], blood lactate concentration.

Discussion

The present study provides novel insights into the physical and physiological characteristics of a large cohort of adult male basketball players competing at different levels (from elite to amateur levels) during the competitive phase of the season. The main results showed that physiological responses to a submaximal high-intensity intermittent run (i.e. HIT) discriminated adult players of different competitive levels. In addition, individuals competing at higher levels produced greater PF and PPO during vertical jumps compared to lower levels basketball players. Professional (i.e. Division II) and semi-professional (i.e. Division III) athletes also performed better in Yo-Yo IR1 and Mognoni's test compared to amateur players (Division VI), however these tests did not discriminate between Division II and III players.

The present results confirm that stature and body mass are fundamental prerequisites for higher level (i.e. Division I, II and III) basketball players (Drinkwater et al. 2008). Indeed, the Division VI athletes were the shortest and lightest group assessed in the present study. Division I and II players had similar stature, body mass and body fat percentage, confirming previous findings observed among Division I and II basketball players competing in the French (Sallet et al. 2005), Greek (Metaxas et al. 2009), Spanish (Vaquera et al. 2015) and Turkish (Koklu et al. 2011) leagues.

In the present study, the aerobic fitness of basketball players was evaluated using responses to a submaximal continuous running test (Mognoni's test). Unclear to possibly small differences were observed in the physiological responses ($MOG_{[La-]}$ and MOG_{HR}) to the Mognoni's test between Division I, II and III players, but these all performed better than their Division VI counterparts. These findings partially confirm previous studies (Ferioli et al. 2017, Koklu et al. 2011), which reported aerobic fitness level did not discriminate between adult basketball players of different competitive levels (i.e from elite to semi-professional).

The distances covered during the Yo-Yo IR1 by Division II and Division III players were slightly higher than performances reported in Italian Division I basketball players (1945 ±144 m) (Manzi et al. 2010), but lower compared to Tunisian National players (2619 ±731 m) (Ben Abdelkrim et al. 2010c). Different body mass and competitive level of the various cohorts of players might explain these contrasting findings. Whilst previous research has shown the Yo-Yo IR1 differentiates between playing levels (e.g. elite vs subelite) in young basketball players (Vernillo et al. 2012), the present study showed similar results between the professional (Division II) and semi-professional (Division III) athletes. Notably however, these professional and semi-professional players had greater Yo-Yo IR1 than their amateur counterparts (Division VI). These findings agree with a recent research that showed no differences in Yo-Yo IR1 in a small cohort of professional and semi-professional male adult basketball players assessed befor and after the preparation period (Ferioli et al. 2017). These findings suggest that Division II and III basketball players should have well-developed fitness capacities to cope with maximal high-intensity intermittent running. In contrast however, the ability to perform maximal high-intensity intermittent exercise did not discriminate between playing levels amongst the high-level basketball players (i.e. Division II and III). It is unfortunate that the Division I players in the present study were not able to perform the Yo-Yo IR1 which limits the generalisability of our findings. Future studies should further confirm the use of Yo-Yo IR1 as a valid tool to differentiate the competitive level among elite and professional adult players in basketball.

In the present study, the physiological responses to HIT were influenced by the competitive level of the players. Indeed, Division I athletes had lower $HIT_{[La-]}$, $HIT_{[H+]}$ and HIT_{HR} and higher $HIT_{[HCO3-]}$ compared to Division II individuals, while Division III performed better than Division VI counterparts. These results highlight the ability of top professional players (i.e. Division I) to maintain acid-base balance during submaximal intermittent exercise, confirming recent reports observed after the preparation period among a small cohort of players (Ferioli et al. 2017). The lower $HIT_{[La-]}$ of players competing at higher level suggests that these players have a lower anaerobic contribution to standardized high-intensity intermittent running protocol. Furthermore, the lower $HIT_{[H+]}$ and higher $HIT_{[HCO3-]}$ measured in higher competitive level players suggest a greater buffering capacity compared to lower competitive level counterparts. The results of the present study suggest that the physiological responses to a submaximal high-intensity intermittent exercise could be more sensitive for differentiating between the competitive level of adult basketball players than a maximal intermittent running test (such as Yo-Yo IR1). Indeed, likely small differences in the physiological responses to HIT were found between Division II and Division III players, despite similar Yo-Yo IR1 performance. Unfortunately, this reasoning cannot be inferred to Division I players, because they did not perform the Yo-Yo IR1. Regardless, however, an important practical consequence of the present observations is that the submaximal HIT test offers practical advantage over alternate maximal fitness tests due to the increased compliance with players.

Studies comparing strength characteristics of basketball players of different competitive level have reported conflicting results (Delextrat and Cohen 2008, Koklu et al. 2011, Metaxas et al. 2009). In the present study, the absolute PF and PPO produced during the CMJ were possibly greater in Division I. It has been reported that these parameters are better related to absolute values of dynamic strength than jump height (Nuzzo et al. 2008). Although the difference for absolute PF and PPO were small, their SNRs were large, suggesting that these parameters are appropriate indicators to distinguish between different competitive levels. The likely reason for the higher absolute PF and PPO in the top professional players of the present study is their higher body mass (Jaric 2002). Notably, the CMJ height measured in the present study are slightly lower to those previously reported in professional basketball players (52.0 ±7.5 cm) (Shalfawi et al. 2011) and in elite basketball players competing in Tunisian national team (49.7 ±5.8 cm) (Ben Abdelkrim et al. 2010c). Although relative strength/power parameters might enable players to move more efficiently overcoming their body inertia down the basketball court, we found unclear to possibly small differences in the vertical jumping height, PPO and PF normalized by body mass between Division I, II and III players. Notably, these jump measures were greater in Division VI players compared to their Division III counterparts. For these reasons, we recommend that vertical jumping height, PPO and PF normalized by body mass should not be considered as major factors of success in basketball. Rather, we recommend that greater focus be placed on developing absolute PPO and PF in talented basketball players, as these qualities might be advantageous during physical contact activities between players during the game.

Many studies (Ben Abdelkrim et al. 2010c, Boone and Bourgois 2013, Cormery et al. 2008, Delextrat and Cohen 2008, Ostojic et al. 2006, Sallet et al. 2005) have described the position-specific anthropometric and physiological profile of young and adult male basketball players. However, the present study provides novel insight into the physical profile of a large cohort of adult male basketball players (i.e. 101) assessed in the middle of the regular season. In agreement with previous studies, (Ben Abdelkrim et al. 2010c, Boone and Bourgois 2013, Cormery et al. 2008, Delextrat and Cohen 2008, Ostojic et al. 2006, Sallet et al. 2005) we observed Forwards to be taller and heavier compared to Guards, but shorter and lighter compared to Centres. Small likely differences were observed in aerobic fitness between the playing roles, with Forwards performing better than Centres but worse than Guards in the Mognoni's test. The ability to sustain high-intensity intermittent exercise (i.e. HIT and Yo-Yo IR1) was greater in Guards compared to Forwards. However, unclear to small differences were observed between Forwards and Centres in the physiological responses to HIT and in the distances covered during the Yo-Yo IR1. In line with previous findings (Ben Abdelkrim et al. 2010c, Cormery et al. 2008, Ostojic et al. 2006, Sallet et al. 2005), these results may be ascribed to the higher physiological load at which Guards are subjected during games and training (Ben

Abdelkrim et al. 2007). Moreover, the Guards performed better in vertical jumping performance (i.e. CMJ_h) compared to Centres, who were characterized by higher level of muscle strength and power compared to Guards (Ben Abdelkrim et al. 2010c, Boone and Bourgois 2013, Ziv and Lidor 2009). The present findings show that basketball players of different playing roles are characterized by a different physical and physiological profile. These differences are likely a consequence of the specific physical demands of basketball practice.

The main limitation of this study is that basketball players were selected from just one national tournament. Therefore, normative data might not be extended reliably to overall high-level basketball players. Moreover, only a limited number of anthropometrical and physiological capacities could be assessed, to develop a more holistic understanding of these capacities in basketball, we suggest that future studies utilize a wider range of test parameters. Furthermore, due to the difficulties in assessing elite and professional players, the evaluations have been performed during a 4 months-period. To overcome potential bias effect of time on the outcome variable, we assessed a similar number of athletes from each Division within each month.

Conclusions and practical applications

The physiological test carried out in the present study can be used to assess the fitness status of player; the results should be used to develop individualized and more accurate training programs based on the weaknesses of players according to their competitive level and playing position. Strength and conditioning coaches should focus to enhance the ability to sustain intermittent efforts at higher intensities and to improve strength/power characteristics of the athletes, while technical coaches should use basketball-specific exercises to enhance these characteristics (e.g. small side-games). Furthermore, the findings of the present study highlight the anthropometrical characteristics that are generally required to compete at high level (i.e.

Division I and II). In addition, the present results provide useful insight into the talent identification and into the determination of the athlete's playing role in basketball. In conclusion, we recommend the use of physical tests to assess the ability to sustain high-intensity intermittent efforts (e.g. HIT and YO-YO IR1) and the absolute values of strength/power characteristics of the athletes.

CHAPTER FOUR

Different training loads partially influence physiological responses to preparation period in basketball.

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Abstract

Purpose: 1) to compare perceived TL (sRPE-TL), training volume (TV) and the changes in physical fitness between professional (n=14) and semi-professional (n=18) basketball players during the preparation period. 2) to investigate the relationships between sRPE-TL and TV with changes in physical fitness level.

Methods: The players performed the Yo-Yo Intermittent Recovery Test (Yo-Yo IR1) before and after the preparation period. In addition, physiological responses to a standardized 6-min continuous running test (Mognoni's test) and to a standardized 5-min high-intensity intermittent running test (HIT) were measured.

Results: sRPE-TL and TV were greater for professional (5241±1787 AU; 914±122 min) compared to semi-professional players (2408±487 AU; 583±65 min). Despite these differences, Yo-Yo IR1 performance improvements (~30%) and physiological adaptations to the Mognoni's test were similar between the two groups. Furthermore, physiological adaptations to HIT were slightly greater for professional compared to semi-professional players, however the magnitude of these effects was only small/moderate. No clear relationships were found between sRPE-TL and changes in Yo-Yo IR1 performance and Mognoni's test (r_s ± 90%CI: Yo-Yo IR1, 0.18±0.30; Mognoni's test, -0.14±0.29). Only moderate relationships were found between sRPE-TL and changes in HIT (r_s ± 90%CI: [La^-], -0.48±0.23; [H^+], -0.42±0.25).

Conclusions: These results raise doubts on the effectiveness of using high sRPE-TL and TV during the preparation period to improve the physical fitness level of players. The Yo-Yo IR1 appears to be sensitive to monitor changes induced by the preparation period, however its use is not recommended to discriminate between adult basketball players of different competitive level.

Keywords: session RPE, Competitive level; Intermittent exercise; Yo-Yo test.

Introduction

The quantification of training load (TL) is a key component of a team-sports training process. When TL is properly prescribed, the physiological adaptations to training are more pronounced and the risk of injuries and non-functional overreaching are reduced (Halson 2014). The session rating of perceived exertion (sRPE) is a low cost and valid method to quantify TL in endurance (Foster et al. 2001) and team sports like soccer (Impellizzeri et al. 2004).

Basketball is an intermittent team sport, characterized by alternating low and high intensity phases (McInnes et al. 1995). During basketball matches, aerobic and anaerobic mechanisms are strongly activated and require activation of both the cardiorespiratory and neuromuscular systems (Ziv and Lidor 2009). The preparation period at the beginning of the season represents a crucial phase in which to optimize athletes's performance. In this period, the athletes begin performing physical activity following some weeks of complete or nearly complete rest (Hoffman 2000). For these reasons, TL should be progressively increased throughout the first part of the preparation period (Rowbottom 2000) to reduce the risk of injuries (Drew and Finch 2016). The remaining phase of the preparation period is generally characterized by higher levels of TL compared to those observed during the competitive season (Aoki et al. 2017). The athletes perform a higher number of training sessions and greater training volume (TV) due to the absence of official competitive matches. However, information regarding the correct level of TL and TV to be performed during the preparation period are limited.

In team sports such as soccer and rugby, the associations between TL and TV with changes in physical performance have been investigated (Jaspers et al. 2017). After 9 weeks of in-season soccer training, Gil-Rey et al. (2015) reported that changes in time to exhaustion in a continuous progressive maximal running test were positively associated with TV and perceived TL (i.e. respiratory and muscular) in young soccer players. Los Arcos et al. (2015) monitored a similar age group of professional soccer players during the first 9 weeks of training and found a large negative correlation between muscular perceived TL and changes in blood lactate concentration ([La$^-$]) measured after a submaximal incremental running test. Conversely, no significant correlations were observed between RPE-based TL and changes in physiological responses in youth soccer players following a submaximal incremental step exercise (Akubat et al. 2012) or a submaximal interval shuttle run test (Brink et al. 2010). Furthermore, variations in maximal aerobic power, estimated using the multi-stage fitness test, were not significantly related to RPE-based TL in rugby players (Gabbett and Domrow 2007).

Indeed, the effects of TL on physical performance and fitness are not clear. Possible reasons for the contrasting results of previous studies were due to the use of different types of physical assessments (i.e. maximal and submaximal) to evaluate the athletes' fitness levels. However, it is unclear whether athletes from different sports would be expected to achieve similar results. To the best of our knowledge, no studies verified the possible relationships between TL and changes in basketball players' fitness levels. In addition to this, there is limited information regarding the TL sustained by basketball players of different competitive levels. This information may be of interest in planning an effective training process to improve performance during the preparation period in basketball. Therefore, the aims of this study were: 1) to compare the perceived TL, TV and the changes in physical fitness between professional and semi-professional basketball players during the preparation period; 2) to investigate the relationships between TL and TV with changes in physical fitness level during the same period.

Methods

Experimental Approach to the Problem

This observational study was conducted during the 2015-16 preparation period, from August to October. Participants performed maximal and submaximal running tests on two separate occasions, prior to and following the preparation period. On day 1, the athletes underwent the

Yo-Yo Intermittent Recovery Test – level 1 (Yo-Yo IR1). On day 2, the participants performed a submaximal physical test session, consisting of a continuous running test (Mognoni's), followed by a High-intensity Intermittent Test (HIT). The physical test session was carried out between 2 to 6 days after the Yo-Yo IR1. The players TL was assessed during the preparation period using the sRPE as previously reported (Impellizzeri et al. 2004).

Subjects

Fourteen professional (age: 25.6 ± 6.0 years, height: 198 ± 10 cm, body mass: 95.5 ± 13.0 kg) and eighteen semi-professional (age: 23.3 ± 4.7 years, height: 190 ± 9 cm, body mass: 82.2 ± 11.6 kg) basketball players participated in this study. Professional players were from Italian Serie A and Italian Serie A2 divisions, while semi-professional players belonged to third division basketball clubs (Italian Serie B). Players trained 5 to 12 times a week throughout the preparation period, with training lasting from 60 to 120 min (excluding cool down or stretching exercises). Standard training schedules performed by professional and semi-professional players during the first (week 1-2) and the second part of the preparation period (week 3-7) are presented in Table 4.1. According to Brunelli et al. (2012), players had to perform more than 80% of team training sessions to be included in the study. The participants' dropout rate of this study corresponded to ~25%. Written informed consent was received from all players after verbal and written explanation of the experimental design and potential risks and benefits of the study. The Independent Institutional Review Board of Mapei Sport Research Centre approved the study in accordance with the spirit of the Helsinki Declaration.

Table 4.1. Standard training schedules performed by professional and semi-professional players during the first (weeks 1-2) and the second part of the preparation period (weeks 3-7).

	Professional players		Semi-professional players	
	1st part	2nd part	1st part	2nd part
Monday	**Morning**: Endurance **Afternoon**: Core Stability + Technical/Tactical	**Morning**: Endurance **Afternoon**: Core stability + Technical/Tactical	**Morning**: Endurance **Afternoon**: Technical/Tactical	**Morning**: Rest **Afternoon**: Speed and Agility + Technical/Tactical
Tuesday	**Morning**: Strength or Endurance **Afternoon**: Injury prevention or Endurance + Technical/Tactical	**Morning**: Explosive strength and Power **Afternoon**: Speed and Agility + Technical/Tactical	**Morning**: Rest **Afternoon**: Strength or Endurance + Technical/Tactical or Shooting session	**Morning**: Rest **Afternoon**: Explosive strength and Power + Technical/Tactical
Wednesday	**Morning**: Rest **Afternoon**: Endurance + Shooting session or Technical/tactical	**Morning**: Rest **Afternoon**: Friendly match or Technical/Tactical	**Morning**: Rest **Afternoon**: Endurance or Repeated Sprint Ability	**Morning**: Rest **Afternoon**: Rest or Friendly match
Thursday	**Morning**: Strength or Endurance **Afternoon**: Core stability + Technical/Tactical	**Morning**: Rest or Explosive strength and Power **Afternoon**: Speed and Agility + Technical/Tactical	**Morning**: Rest **Afternoon**: Strength + Technical/Tactical or Shooting session	**Morning**: Rest **Afternoon**: Explosive strength and Power + Technical/Tactical
Friday	**Morning**: Strength or Endurance **Afternoon**: Technical/Tactical	**Morning**: Rest or Explosive strength and Power **Afternoon**: Injury prevention + Technical/Tactical	**Morning**: Rest **Afternoon**: Endurance + Technical/Tactical	**Morning**: Rest **Afternoon**: Technical/Tactical
Saturday	**Morning**: Rest or Pool **Afternoon**: Technical/Tactical	**Morning**: Shooting session or Technical/Tactical **Afternoon**: Friendly match or Technical/Tactical	**Morning**: Endurance/Core stability + Shooting session **Afternoon**: Rest	**Morning**: Rest **Afternoon**: Rest or Friendly match
Sunday	**Morning**: Technical/Tactical or Shooting session or **Day OFF**	**Morning**: Rest **Afternoon**: Rest or Friendly match	**Day OFF**	**Morning**: Rest **Afternoon**: Rest or Friendly match

Procedures

Physical fitness assessment

Testing procedures took place during the first week of training (T1) and during the weeks preceding the first or the second official competitive matches (T2) of the season. To avoid potential confounding effects of prior exercise fatigue on the outcome variables, no heavy training sessions were performed the day preceding the assessments. Both testing sessions were performed in the same conditions (i.e. testing venue, order of the tests and time of the day). The duration of the preparation period ranged between 5 and 7 weeks.

Yo-Yo Intermittent Recovery Test – level 1

Athletes performed the Yo-Yo IR1, according to previously described procedures (Krustrup et al. 2003). Yo-Yo IR1 consisted of 20-m shuttle runs performed at increasing velocities (beginning speed of 10 $Km \cdot h^{-1}$) with 10 s of active recovery (consisting of 2x5-m of jogging) between runs until exhaustion. The test was considered concluded when participants failed to complete the distance in time twice (objective evaluation) or a player felt unable to complete another shuttle run at the dictated speed (subjective evaluation). The total distance covered during Yo-Yo IR1 was considered as the test "score" (Krustrup et al. 2003). Heart rate was continuously monitored using Polar Team[2] Pro System (Kempele, Finland) and all the athletes achieved at least the 90% of the predicted maximal heart rate, estimated as 220 – age (Howley et al. 1995).

Continuous Running Test (Mognoni's)

Mognoni's test (Impellizzeri et al. 2005, Sirtori et al. 1993) consisted of a 6-min continuous run at a constant speed of 13.5 km·h^{-1}. All the tests were carried out on a motorized treadmill (HP Cosmos, Nussdorf – Traunstein,Germany) that was periodically checked for accuracy. Capillary Blood [La$^-$] was measured immediately after the completion of the test using a portable amperometric microvolume lactate analyser (Lactate Plus, Nova Biomedical, Waltham, MA, USA). Athletes were instructed to abstain from any kind of warm-up prior to the test to avoid potential confounding effects on the physiological responses to the Mognoni's test.

High-intensity Intermittent Test

The HIT (Rampinini et al. 2010) protocol comprised 10 x 10 s shuttle runs over a 25+25 m course with a 180° change of direction and 20 s of passive recovery between each bout. The players were required to run at 18 Km·h^{-1}, respecting a sequence of audio signals. Immediately after the HIT protocol, a 100 μL capillary blood sample was drawn into a heparinised capillary tube and analysed for blood hydrogen ion concentration ([H$^+$]) and bicarbonate concentration ([HCO3$^-$]) using a calibrated blood-gas analyser (GEM Premier 3000, Instrumentation Laboratory, Milan, Italy) with an Intelligent Quality Management System cartridge. Capillary blood samples (5 μL) were also analysed for [La$^-$] using a portable amperometric microvolume lactate analyser (Lactate Plus, Nova Biomedical, Waltham, MA, USA).

Training load quantification

The TL was determined multiplying the training duration (minutes) by the sRPE as described by Foster et al. (2001). Subjects' sRPE were assessed using the CR-10 Borg's scale (Borg

1998). Athlete's sRPE was collected 30-min after each training session (Impellizzeri et al. 2004). The duration of each session was recorded individually, including recovery periods but excluding the cool-down or stretching exercises. The matches durations (warm-up included) were recorded from the beginning to the end of the game including all stops (game stops, injury stops, time-outs and in-between quarter-times stops). All the players were familiar with the use of the sRPE because it was previously utilized prior to commencing the study. Indeed, some of the players used this method during the final part of the former basketball season while the others during the training week preceding the study.

Statistical analysis

The participants' descriptive results are reported as means ± standard deviations (SD). Assumption of normality was verified using the Kolmogorov-Smirnov test. The magnitude-based inference (MBI) approach was used to analyse the data according to Hopkins et al. (2009). All data were first log-transformed to reduce bias arising from non-uniformity of effects or errors (Hopkins et al. 2009). Post only's spreadsheets and parallel group's spreadsheets (Hopkins 2006a) were used for the statistical analysis. The former was utilized to calculate the within-group changes for all physical tests from T1 to T2; the latter was utilised to determine the between-group differences at each time point. Practical significance of changes was also assessed by calculating the Cohen's d effect size (ES) (Cohen 1988). ES were considered as follow: ≤0.02, trivial; >0.2-0.6, small; >0.6-1.2, moderate; >1,2-2.0, large; >2.0-4.0, very large (Hopkins et al. 2009). Probabilities were also calculated to compare the true (unknown) differences and the smallest worthwhile changes (SWC). SWC was obtained multiplying the between-subject SD by 0.2. Quantitative chances of harmful, trivial or beneficial differences were evaluated qualitatively according to established criteria: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain. When the probability of having higher or lower values than the SWC was less than 5%, the true difference was assessed as unclear. Due to the non-normal distribution of TV and s-RPE-TL data, spearman's rank correlation coefficients (r_s, 90% confidence intervals) were used to determine the relationships between weekly TV and weekly sRPE-TL with changes (%) in fitness performance. The magnitude of relationships was assessed according to the following thresholds: ≤0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect. Practical inferences of the correlations were also considered (Hopkins 2007). Modified statistical Excel spreadsheets (Hopkins 2006a, b, 2007) and SPSS statistical software (version 23.0, IBM SPSS Statistics, Chicago, IL, USA) were utilised to perform data analysis.

Results

Weekly training load and volume

Mean weekly sRPE-TL and TV in professional and semi-professional players during the preparation period are presented in Figure 4.1.

Professional players accumulated an almost certain (100/0/0) greater sRPE-TL (ES = 5.56, CI 3.86 to 7.26) and an almost certain (100/0/0) greater TV (ES = 4.84, CI 3.93 to 5.75) compared to semi-professional players.

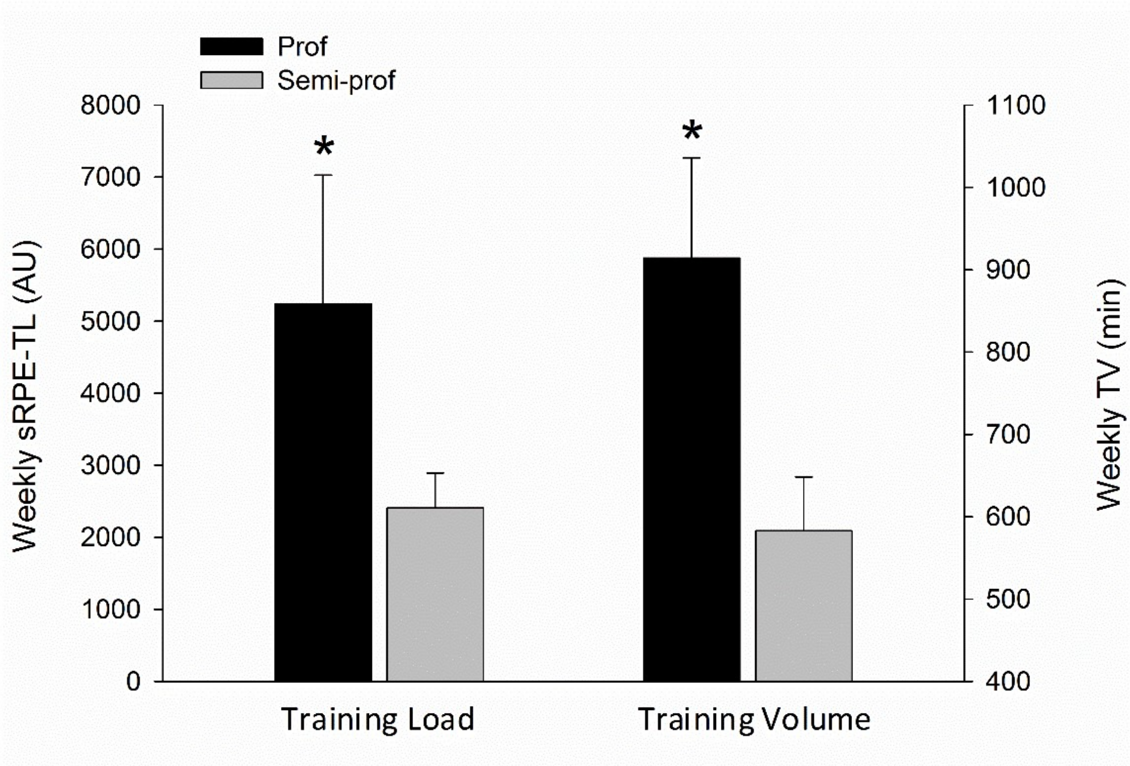

Figure 4.1. Mean weekly sRPE-TL and TV in professional and semi-professional teams during the preparation period. sRPE-TL: session-rating of perceived exertion training load; TV: training volume. * almost certain greater compared to semi-professional team.

Physical fitness variations

Data of physical fitness for professional and semi-professional players before and after the preparation period are presented in Table 4.2.

Between-groups mean differences for all the physical fitness tests are presented in Figure 4.2.

At T1, no clear differences were found between groups. At T2, blood [La^-] and [H^+] measured after HIT were likely lower for professional compared to semi-professional players (ES = -0.60, CI -1.20 to -0.01 and -0.75, CI -1.33 to -0.17, for blood [La^-] and [H^+] respectively). Furthermore, at the same time point, blood [$HCO3_-$] was possibly higher for professional players (ES = 0.44, CI -0.15 to 1.03).

Table 4.2. Physical fitness results of professional and semi-professional players before (T1) and after (T2) the preparation period.

	Team	n	T1	T2	Mean change % (90% CI)	ES (90% CI)	MBI (%)	Rating
Yo-Yo IR1 *(m)*	Prof	14	1669 ± 357	2154 ± 362	30.0 (24.6 to 35.7)	1.28 (1.08 to 1.49)	0/0/100	Almost certain large
	Semi-prof	16	1708 ± 444	2205 ± 397	31.6 (23.1 to 40.7)	1.06 (0.85 to 1.28)	0/0/100	Almost certain moderate
Mognoni's$_{[La-]}$ *(mmol·L^{-1})*	Prof	14	5.0 ± 1.6	4.1 ± 1.3	-18.3 (-28.4 to -6.8)	-0.53 (-0.90 to -0.16)	0/4/96	Very likely small
	Semi-prof	18	4.8 ± 2.3	4.2 ± 2.1	-12.5 (-23.9 to 0.5)	-0.24 (-0.55 to 0.08)	1/30/69	Possibly small
HIT$_{[La-]}$ *(mmol·L^{-1})*	Prof	14	7.0 ± 2.5	4.5 ± 2.5	-41.8 (-51.7 to -29.8)	-0.95 (-1.20 to -0.69)	0/0/100	Almost certain moderate
	Semi-prof	18	7.6 ± 2.1	5.9 ± 2.2	-23.8 (-33.6 to -12.7)	-0.78 (-1.15 to -0.41)	0/1/99	Almost certain moderate
HIT$_{[H+]}$ *(mmol·L^{-1})*	Prof	14	51.9 ± 7.4	44.6 ± 5.2	-13.8 (-17.7 to -9.7)	-0.93 (-1.24 to -0.63)	0/0/100	Almost certain moderate
	Semi-prof	18	53.2 ± 7.1	49.3 ± 7.1	-7.3 (-11.5 to -2.9)	-0.52 (-0.84 to -0.19)	1/4/95	Very likely small
HIT$_{[HCO3-]}$ *(mmol·L^{-1})*	Prof	14	18.1 ± 2.8	20.9 ± 2.9	13.0 (10.3 to 22.0)	0.98 (0.65 to 1.30)	0/0/100	Almost certain moderate
	Semi-prof	18	17.2 ± 3.4	19.6 ± 2.8	14.9 (8.2 to 22.0)	0.68 (0.41 to 0.95)	0/0/100	Almost certain moderate

CI: confidence intervals; ES: effect size; [H+]: blood hydrogen ion concentration; [HCO3-]: blood bicarbonates concentration; HIT: High-intensity intermittent running test; [La-]: blood lactate concentration; MBI: magnitude-based inferences; MBI (%): percent chances of harmful/trivial/beneficial effects; Yo-Yo IR1: distance covered during the Yo-Yo Intermittent Recovery test - level 1.

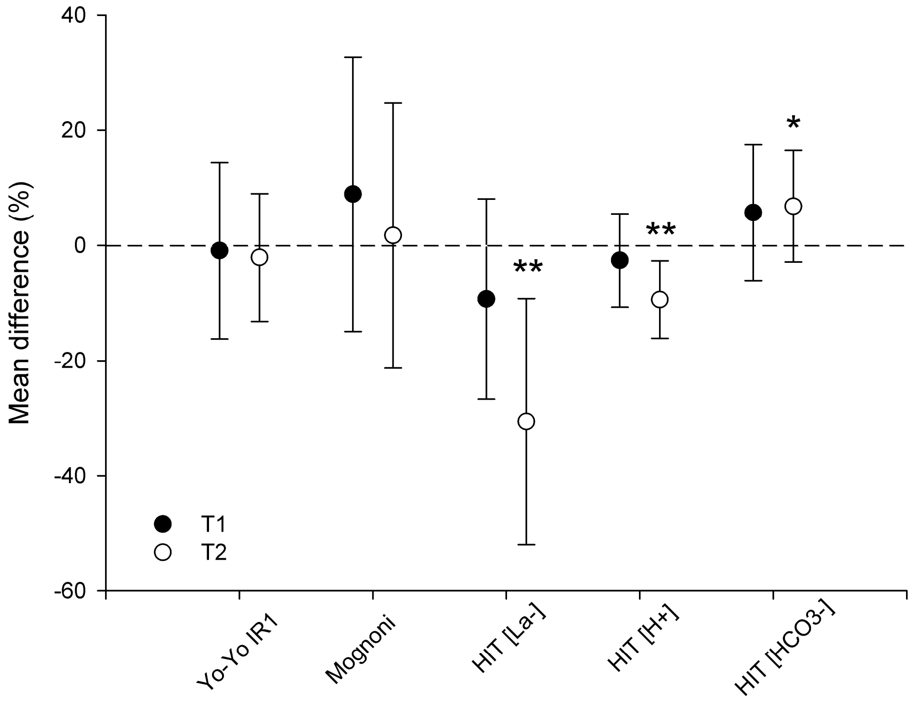

Figure 4.2. Professional – semi-professional between-groups mean differences for the physical fitness tests. * possible, ** likely difference between groups. [H^+]: blood hydrogen ion concentration; [$HCO3^-$]: blood bicarbonates concentration; HIT: High-intensity intermittent running test; [La^-]: blood lactate concentration; Mognoni: blood lactate concentration measured after Mognoni's test; T1: test before the preparation period; T2: test after the preparation period; Yo-Yo IR1: distance covered during the Yo-Yo Intermittent Recovery test - level 1.

Relationships between training load and volume with physical fitness variations

Within-player correlations between mean weekly sRPE-TL or TV, and variations in physical fitness performance tested after the preparation period were obtained pooling the data of professional and semi-professional players (Table 4.3).

Very likely moderate relationships were observed between weekly sRPE-TL and changes in blood [La^-] and [H^+] measured after HIT. Similarly, the relationships between TV and the same parameters measured after HIT were likely moderate. No clear relationships were found between sRPE-TL or TV and changes in Yo-Yo IR1 performance and blood [La^-] measured after Mognoni's test.

Table 4.3. Within-player correlations between mean weekly sRPE-TL and training volume, and changes in fitness parameters from T1 to T2.

		Weekly sRPE-TL			Weekly volume	
	n	r_s	(90% CI)	Rating	r_s	(90% CI)	Rating
Yo-Yo IR1$_{distance}$	30	0.18	(-0.13 to 0.46)	Unclear	0.10	(-0.21 to 0.39)	Unclear
Mognoni's$_{[La-]}$	32	-0.14	(-0.42 to 0.16)	Unclear	-0.04	(-0.33 to 0.26)	Unclear
HIT$_{[La-]}$	32	-0.48	(-0.68 to -0.21)	Very likely moderate	-0.32	(-0.57 to -0.03)	Likely moderate
HIT$_{[H+]}$	32	-0.42	(-0.64 to -0.14)	Very likely moderate	-0.33	(-0.57 to -0.03)	Likely moderate
HIT$_{[HCO3-]}$	32	0.28	(-0.02 to 0.53)	Likely small	0.09	(-0.21 to 0.37)	Unclear

CI: Confidence intervals; [H^+]: blood hydrogen ion concentration; [HCO_3^-]: blood bicarbonates concentration; HIT: High-intensity intermittent running test; [La^-]: blood lactate concentration; r_s = Spearman's rank correlation coefficient; sRPE-TL: session-rating of perceived exertion training load; T1: test before the preparation period; T2: test after the preparation period; Yo-Yo IR1$_{distance}$: distance covered during the Yo-Yo Intermittent Recovery test - level 1.

Discussion

This study aimed to compare the changes in physical fitness levels induced by the preparation period in professional and semi-professional basketball players. The present study also aimed to describe the sRPE-TL and TV sustained during the same period of the season. Although professional players underwent a higher sRPE-TL and TV compared to semi-professional players, similar improvements were observed in the Yo-Yo IR1 and Mognoni's test performance between the two groups. Professional players demonstrated a slightly greater physiological adaptation in HIT than semi-professional No clear relationships were found between sRPE-TL and TV with changes in physical fitness, with the exception of variations in HIT.

During the preparation period, professional players accumulated approximately double the amount of weekly sRPE-TL compared to semi-professional players. This difference was due to higher sRPE (~40%) and higher (~60%) weekly TV sustained by the professionals compared to semi-professional players. The greater number of weekly training sessions performed by professional athletes, 9.2 vs 5.5 sessions/week for professional and semi-professional respectively, contributed to the difference in TV between the two groups. The mean weekly sRPE-TL sustained by the professional players involved in the present study was found to be greater than that reported by Manzi et al. (2010) (5241 ± 1787 vs 3334 ± 256 AU). This difference could be explained by the different training phase during which the TL was collected in the two studies (i.e. preparation vs competitive period). The preparation period tends to be characterized by higher levels of TL compared to the competitive period of the season (Aoki et al. 2017).

Despite the large difference in sRPE-TL and TV, the increase in total distance covered during the Yo-Yo IR1 was similar between professional and semi-professional players. Furthermore, Yo-Yo IR1 performance was not significantly different between the two groups both before and after the preparation period. The improvements observed in distance covered during the Yo-Yo IR1 in the present study (~30%) were comparable to that reported in soccer and basketball literature (Aoki et al. 2017, Bangsbo et al. 2008). The distance covered during the Yo-Yo IR1 was considerably higher for professional players involved in the present study compared to values reported by Aoki et al. (2017) for professional Brazilian players (before preparation period: 1669 ± 357 vs 1120 ± 413 m; after preparation period: 2154 ± 362 vs 1737 ± 515 m, respectively). Furthermore, performance in Yo-Yo IR1 was slightly higher than the distances reported by Manzi et al. (2010) for Italian Serie A players (1945 ± 144 m). This might be due to the different period during which the Yo-Yo IR1 was performed in the two studies. Indeed, values reported by Manzi et al. (2010) were collected at the end of the regular season and not at the end of the preparation period like in the present study.

Traditionally, the Yo-Yo IR1 delivers very different results when carried out by team sports athletes, such as soccer players, of different competitive levels (Bangsbo et al. 2008). Similar findings could be expected in basketball, yet, the results of the present study suggest that professional and semi-professional adult players achieve comparable results. These findings appear to be in contrast with previous results reported in basketball literature on young players, where different categories achieved different results. For example, Yo-Yo IR1 can highlight differences in performance between senior, under 20 and under 18 basketball players (Ben Abdelkrim et al. 2010c). Furthermore, among young basketball players (from under 14 to under 17), Yo-Yo IR1 distance appears to differ between elite and sub-elite athletes (Vernillo et al. 2012). It is difficult to explain the lack of difference in performance between professional and semi-professional adult players involved in the present study as no physiological responses, except for the heart rate, were measured during the test.

Conversely to the similar improvements observed in the Yo-Yo IR1 between the two groups of players, we found a slightly greater physiological adaptation to the HIT in professional players.

Specifically, the professional players accumulated likely lower blood [La^-] and [H^+] and possibly higher blood [$HCO3_-$] after HIT at T2. However, the magnitude of these effects was only small to moderate. These results point out the better ability of professional players to maintain acid-base balance during submaximal intermittent exercise after the preparation period. The lower rate of blood [La^-] accumulation during HIT suggests a lower anaerobic contribution to the test. The lower blood [H^+] and higher blood [$HCO3^-$] may also reflect a greater buffering capacity of professional compared to semi-professional players. Although it is well known that muscle pH is not the sole cause of fatigue during brief high-intensity exercise (Bangsbo et al. 2007), a low muscle pH has been shown to reduce muscle contractibility (Westerblad et al. 2002) and to inhibit glycolytic activity (Hollidge-Horvat et al. 1999). As a consequence, a better physiological response to HIT could facilitate the physical performance during matches. However, further research is needed to verify the relationships between the physiological responses to HIT and actual physical basketball match performance. Furthermore, these results suggest that the physiological responses to a submaximal high-intensity intermittent exercise could be more sensitive to training adaptations than a maximal intermittent running test (such as Yo-Yo IR1). In accordance with our findings, a number of previous studies reported a higher sensitivity to training-induced changes of submaximal parameters compared to maximal indices (Casajus 2001, Impellizzeri et al. 2006, Laplaud et al. 2004, Sassi et al. 2008).

Blood [La^-] measured after the submaximal continuous running test (such as Mognoni's) has been reported to be a valid method to assess aerobic fitness in team sports (Garcia-Tabar et al. 2017, Impellizzeri et al. 2005). Due to the importance of the aerobic mechanisms for basketball performance (Ziv and Lidor 2009), Mognoni's test was performed to evaluate the aerobic fitness level of basketball players. Despite the large differences in sRPE-TL and TV, the preparation period induced only small physiological adaptations to the Mognoni's test in both professional and semi-professional players. No clear differences were found between groups both at T1 and T2 suggesting a low level of sensitivity for this kind of evaluation in basketball. The poor sensitivity may be related to the non-sport specific type of the exercise utilized during the Mognoni's test (i.e. continuous vs intermittent running).

The present study is the first to examine the relationships between sRPE-TL and TV recorded during the preparation period with changes in physical fitness levels in basketball. No clear relationships were found between sRPE-TL and TV with changes in a maximal intermittent running performance (i.e. Yo-Yo IR1). Similar findings, with no clear relationships, were observed in variations of blood [La^-] measured after the continuous running exercise (i.e. Mognoni's test). sRPE-TL and TV sustained during the preparation period resulted moderately associated with variations in the physiological responses (i.e. blood [La^-] and [H^+]) to a submaximal high-intensity intermittent exercise (i.e. HIT). However, it is worth remembering that the magnitude of the effects was only small/moderate and these relationships are not to be considered sensitive in determining basketball players performance levels. These results are in contrast to those recently reported by Gil-Rey et al. (2015) and Los Arcos et al. (2015), who quantified TL differentiating between respiratory and muscular TL. However, a number of previous studies did not find any relationship between overall sRPE-TL and training-induced changes in submaximal aerobic fitness markers (Akubat et al. 2012, Brink et al. 2010) in youth soccer players. The contrasting findings might be due to the different age group of athletes (i.e. young vs senior), the different type of sport investigated (i.e. soccer vs basketball) and the use of different perception scales (i.e. overall sRPE, muscular sRPE and respiratory sRPE). In conclusion, it is not possible to predict the changes in physical fitness induced by the preparation period using the sRPE-TL quantification.

Some limitations should be taken into consideration. TL was quantified only using the sRPE and TV, however other measures of external and internal TL might be considered. It cannot be excluded that quantification of total distance covered, time spent in high intensity phases and the monitoring of heart rate may be more appropriate measurements to predict changes in physical fitness.

Practical applications

The weekly training of basketball players of different levels can be effectively monitored utilizing the sRPE-TL to determine the players internal load. In addition, this study suggests that very high levels of sRPE-TL and TV during the preparation period are not necessary in order to enhance the physical fitness levels of players. According to the results of the present study, the Yo-Yo IR1 can be used to track changes in fitness levels of players induced by the preparation period, while HIT can also be utilized to differentiate the competitive level of adult basketball players.

CHAPTER FIVE

The preparation period in basketball: training load and neuromuscular adaptations.

Ferioli D, Bosio A, Bilsborough JC, La Torre A, Tornaghi M, Rampinini E. (2018). "The preparation period in basketball: training load and neuromuscular adaptations." *International Journal of Sports Physiology and Performance.* [Epub ahead of print]

Abstract

Purpose: To investigate the 1) effect of the preparation period on the neuromuscular characteristics of 12 professional (PRO) and 16 semi-professional (SEMI-PRO) basketball players; 2) relationships between training load indices and changes in neuromuscular physical performance.

Methods: Prior to (T1) and following (T2) the preparation period, players underwent a counter-movement jump (CMJ) test, followed by a repeated change of direction (COD) test consisting of 4 levels with increasing intensities. The peripheral neuromuscular functions of the knee extensors (peak torque, PT) were measured using electrical stimulations after each level (PT1, PT2, PT3 and PT4). Furthermore, PT Max (the highest value of PT) and PT Dec (PT decrement from PT Max to PT4) were calculated.

Results: Trivial-to-small (effect size, ES: -0.17 to 0.46) improvements were found in CMJ variables, regardless of the competitive levels. After the preparation period, peripheral fatigue induced by a COD test was similarly reduced in both PRO (PT Dec: from 27.8±21.3% to 11.4±13.7%, ES±90%CI= -0.71±0.30) and SEMI-PRO (PT Dec: from 26.1±21.9% to 10.2±8.2%, ES±90%CI= -0.69±0.32). Moderate-to-large relationships were found between session rating of perceived exertion training load and changes in PPO measured during the CMJs (r_s ±90%CI: PPO_{abs}, -0.46±0.26; PPO_{rel}, -0.53±0.23) and in some PTs measured during the COD test (PT1, -0.45±0.26; PT2, -0.44±0.26; PT3, -0.40±0.27 and PT Max, -0.38±0.28).

Conclusions: Preparation period induced minimal changes in the CMJ, while the ability to sustain repeated COD efforts was improved. Reaching high session rating of perceived exertion training loads might partially and negatively affect the ability to produce strength and power.

Key Words: Session RPE; Competitive level; Vertical jump; Change of direction; Peripheral fatigue.

Introduction

The quantification of training load (TL) is a common practice in basketball with the aim to ensure that players achieve an adequate training stimulus and to reduce the negative consequences of training (i.e. risk of injury and non-functional overreaching) and the chances of undertraining (Fox et al. 2017, Weiss et al. 2017). The session rating of perceived exertion (sRPE) is a valid method to quantify the individual TL in professional (PRO) and semi-professional (SEMI-PRO) basketball players (Manzi et al. 2010, Scanlan et al. 2014a). This low cost and user-friendly tool (Fox et al. 2017) represents a practical, reliable and valid method to monitor the athlete internal TL (Bourdon et al.).

The general and specific preparation periods at the beginning of the season are considered crucial phases in preparing athletes for competition. In this period, athletes begin training after a period of complete or near-to-complete rest. The initial phase (general preparation) should provide a gradual increase in TL to reduce the risk of injuries, while the remaining part of the preparation period (specific preparation) is generally characterized by higher TL compared to those observed during the competitive season. While monitoring TL in basketball is important during the preparation period (Fox et al. 2017), data pertaining to the TLs achieved in this period are not well established in the research (Aoki et al. 2017, Ferioli et al. 2017, Scanlan et al. 2014a, Scanlan et al. 2014b).

The relationships between TL with changes in physical performance have been widely investigated in team sports such as soccer and rugby (Jaspers et al. 2017). The resulting literature on the topic, however, offers contrasting results, which indicates that the effect of TL on physical performance and fitness are not clear. In a recent study, and for the first time in basketball, a relationship between TL indicators and physical fitness variations has been established (Ferioli et al. 2017). It has been suggested that high sRPE-TL during the preparation period are not essential to enhance the physical fitness levels (quantified using maximal and sub-maximal intermittent running tests) of PRO and SEMI-PRO basketball players. Due to the limited data, further insights are needed to draw definitive conclusions.

Basketball is an intermittent team sport, characterized by changes of actions every 2-3 s (Ziv and Lidor 2009), therefore neuromuscular abilities (i.e. power, strength, speed) are heavily taxed during basketball matches (McInnes et al. 1995). Specifically, the ability to quickly change direction and jumping performance appear to be key components of basketball (McInnes et al. 1995). Despite the importance of neuromuscular factors in basketball performance (McInnes et al. 1995), no previous study has assessed the relationships between TL indicators and changes in neuromuscular physical performance. This information may be of interest to plan an effective training process to improve performance during the preparation period. Additionally, there is limited and contrasting information regarding the effect of the preparation period on neuromuscular characteristics of basketball players. Aoki et al. (2017) and Hoffman et al. (1991) investigated the changes in vertical jumping performance induced by the preparation period in PRO and NCAA basketball players. PRO players demonstrated moderate-to-large improvements in squat jump height and counter-movement jump (CMJ) height, while collegiate players showed a moderate decrease in jumping performance (i.e. CMJ height). Additionally, there is limited information regarding the variations in change of direction (COD) ability across the preparation period in adult basketball players. The few studies on the topic (Hoffman et al. 1991, Montgomery et al. 2008b) assessed COD ability using various COD tests in NCAA Division I or young basketball players, but the contrasting results do not allow definitive conclusions to be made. Therefore, the aims of this study were to investigate the 1) effect of the preparation period on the neuromuscular characteristics of PRO and SEMI-PRO basketball players measured using a vertical jump test and a repeated COD test; 2) relationships between TL with changes in neuromuscular physical performance during the same period.

Methods

Subjects

Twelve PRO and sixteen SEMI-PRO male basketball players (age: 26.2±6.5 and 23.6±4.9 years, respectively) were recruited for this study (Table 5.1). The PRO competed in the Italian first or second division (i.e. Serie A and Serie A2), while SEMI-PRO were from Italian third division (i.e. Serie B). During the preparation period, athletes trained 5 to 12 times a week, with 60-120 min training sessions, excluding cool down and/or stretching exercises. Standard training schedules performed by PRO and SEMI-PRO players during the general (week 1-3) and the specific (week 3-7) preparation periods are presented in Table 5.2. All the basketball players included in this study performed more than 80% of the team training sessions (Brunelli et al. 2012). The participants' dropout rate of this study corresponded to ~30%. Written informed consent was received from all players after verbal and written explanation of the experimental design and potential risk and benefits of the study. An Independent Institutional Review Board approved the study in accordance with the spirit of the Helsinki Declaration.

Table 5.1. Anthropometric characteristics of professional (PRO) and semi-professional (SEMI-PRO) players.

		PRO (n=12)	SEMI-PRO (n=16)
Stature (cm)		197 ± 10	188 ± 8
Body mass (kg)	T1	93.7 ± 13.0	81.8 ± 10.3
	T2	93.6 ± 12.8	81.6 ± 9.6
Body fat (%)	T1	10.9 ± 3.3	10.5 ± 4.0
	T2	10.0 ± 3.2	9.6 ± 3.6

Abbreviations: T1, before preparation period; T2 after preparation period.

Table 5.2. Standard training schedules performed by professional (PRO) and semi-professional (SEMI-PRO) players during the general (weeks 1-3) and the specific (weeks 4-7) preparation periods.

		PRO		SEMI-PRO	
		General preparation	Specific preparation	General preparation	Specific preparation
Monday	a.m.	Endurance	Endurance	Endurance	Rest
	p.m.	Core Stability + Technical/Tactical	Core stability + Technical/Tactical	Technical/Tactical	Speed and Agility + Technical/Tactical
Tuesday	a.m.	Strength or Endurance	Explosive strength and Power	Rest	Rest
	p.m.	Injury prevention or Endurance + Technical/Tactical	Speed and Agility + Technical/Tactical	Strength or Endurance + Technical/Tactical or Shooting session	Explosive strength and Power + Technical/Tactical
Wednesday	a.m.	Rest	Rest	Rest	Rest
	p.m.	Endurance + Shooting session or Technical/tactical	Friendly match or Technical/Tactical	Endurance or Repeated Sprint Ability	Rest or Friendly match
Thursday	a.m.	Strength or Endurance	Rest or Explosive strength and Power	Rest	Rest
	p.m.	Core stability + Technical/Tactical	Speed and Agility + Technical/Tactical	Strength + Technical/Tactical or Shooting session	Explosive strength and Power + Technical/Tactical
Friday	a.m.	Strength or Endurance	Rest or Explosive strength and Power	Rest	Rest
	p.m.	Technical/Tactical	Injury prevention + Technical/Tactical	Endurance + Technical/Tactical	Technical/Tactical
Saturday	a.m.	Rest or Pool	Shooting session or Technical/Tactical	Endurance/Core stability + Shooting session	Rest
	p.m.	Technical/Tactical	Friendly match or Technical/Tactical	Rest	Rest or Friendly match
Sunday	a.m.	Technical/Tactical or Shooting session	Rest	Day OFF	Rest
	p.m.	Day OFF	Rest or Friendly match		Rest or Friendly match

Design

This observational study was conducted from mid-August to mid-October during the preparation period of the season 2015-16. Prior to and following this period, athletes underwent several neuromuscular evaluations, comprising of a CMJ test, followed by a repeated COD test. The individual TL of athletes was quantified during the preparation period using the sRPE method (Foster et al. 2001).

Methodology

Neuromuscular evaluations

Athletes were assessed during the first week of training (T1) and during the weeks preceding the first or the second official competitive matches (T2) of the season. The duration of this period ranged between 5 and 7 weeks. Before each testing session, stature and body mass were measured, while body density was estimated through the skin-fold technique described by Jackson and Pollock (1978) and then transformed to body fat percentage using the Siri's equation (Siri 1961). Neuromuscular evaluations were performed after a standardized warm-up consisting of a 6-min continuous run at a constant speed of 13.5 $km \cdot h^{-1}$, followed by two sub-maximal CMJs. No stretching exercises were allowed prior to the tests. To avoid potential confounding effects of prior exercise fatigue on the outcomes variables, no heavy training sessions were performed the day preceding the neuromuscular evaluations. Both testing sessions were carried out in the same conditions (i.e. testing venue, time of the day and order and procedures of the tests).

Counter-Movement Jump Test

The CMJ test was performed using a portable force platform (Quattro Jump, Kistler, Winterthur, Switzerland) and its Application Software (Version 1.1.1.4). Each athlete performed 5 bilateral single CMJs from a standing position with hands placed on the hips to minimize any influence of the arms. Players were instructed to perform a quick downward movement reaching about 90° knee flexion, promptly followed by a fast-upward movement with the aim to jump as high as possible. During the concentric phase of each CMJ, absolute peak power output (PPO_{abs}), absolute peak force (PF_{abs}) and jump height were measured. Furthermore, PPO_{abs} and PF_{abs} were normalized to each athlete's body mass (PPO_{rel} and PF_{rel} respectively) measured using a portable scale (Seca, mod762, Birmingham UK). The average of the best 3 values was used for analysis (Claudino et al. 2016).

Repeated Change of Direction Test

This test aims to assess peripheral fatigue of the knee extensor (KE) muscles induced by repeated CODs. The COD test consisted of 4 levels of increasing standardized intensity. The players, paced by an audio signal, run back and forth repeatedly with 180° COD over an 8 m course. During the first and second levels, athletes carried out 11 CODs in 31.5 s and 28.5 s respectively, while the third and the fourth levels were composed of 13 CODs performed in 30.0 s and 26.0 s respectively. The instantaneous running speed sustained by each player during the COD levels was recorded using a radar device (Stalker ATS, Radar Sales, Minneapolis, MN). Furthermore, actual instantaneous metabolic power was estimated to quantify the actual exercise intensity during each COD level using the equation proposed by Di Prampero et al. (2005) and then modified by Osgnach et al. (2010) The peripheral neuromuscular function of the KE was assessed at baseline, prior to the standardized running warm-up, and 30 s after completion of each COD level. The neuromuscular assessments were performed in isometric conditions, measuring firstly KE torque of the right thigh and secondly KE torque of the left thigh. The athletes were seated in a purpose-built leg extension machine with the lower leg and thigh fixed at an angle of 90° from full extension. The ankle of the assessed leg was secured to the leg extension machine via Velcro® straps. The mechanical response was recorded using a load cell connected to a data acquisition system (BIOPAC MP100; BIOPAC Systems, Inc., Santa Barbara, CA) at a sampling rate of 250 Hz. The KE contractions were induced by direct stimulation of the femoral nerve using large area electrodes (Compex, Ecublens, Switzerland) placed in the femoral triangle (cathode, 5 x 5 cm) and in the gluteal fold (anode, 10 x 5 cm). The electrodes were positioned by the same technician and their location marked on the skin. The intensity of the electrical current was defined by sending a small electrical stimulus (Digitimer DS7AH; Hertfordshire, United Kingdom; maximal voltage = 400 V), and progressively increasing the intensity by 10-mA until a plateau was reached by twitch torque values of the KE. This intensity was subsequently increased by a further 20%. The mechanical responses of the KE were then measured via the administration of 3 single stimuli, each separated by 3 s. The stimuli were produced using square pulses (200 μs). The highest value of torque production (PT) was calculated from the mean torque response of the 3 evoked contractions. The four PT values obtained at the end of each COD level were plotted against the actual corresponding metabolic power (measured by the radar system). A regression line was calculated by interpolating the four measured PT using a polynomial equation of second order. PT at 4 fixed metabolic powers (i.e. 19, 23, 27 and 31 $W \cdot kg^{-1}$) was then estimated from regression equation (PT1, PT2, PT3 and PT4 respectively, Figure 5.1). Furthermore, the following parameters were calculated: 1) the highest value of PT (PT Max); 2) the decrease in percentage from PT Max to PT4 (PT Dec); 3) and the metabolic power corresponding to PT Max (MP Max) (Figure 5.1). This procedure was carried out separately for the right and left KE muscles and the mean value of the two legs was used for analysis.

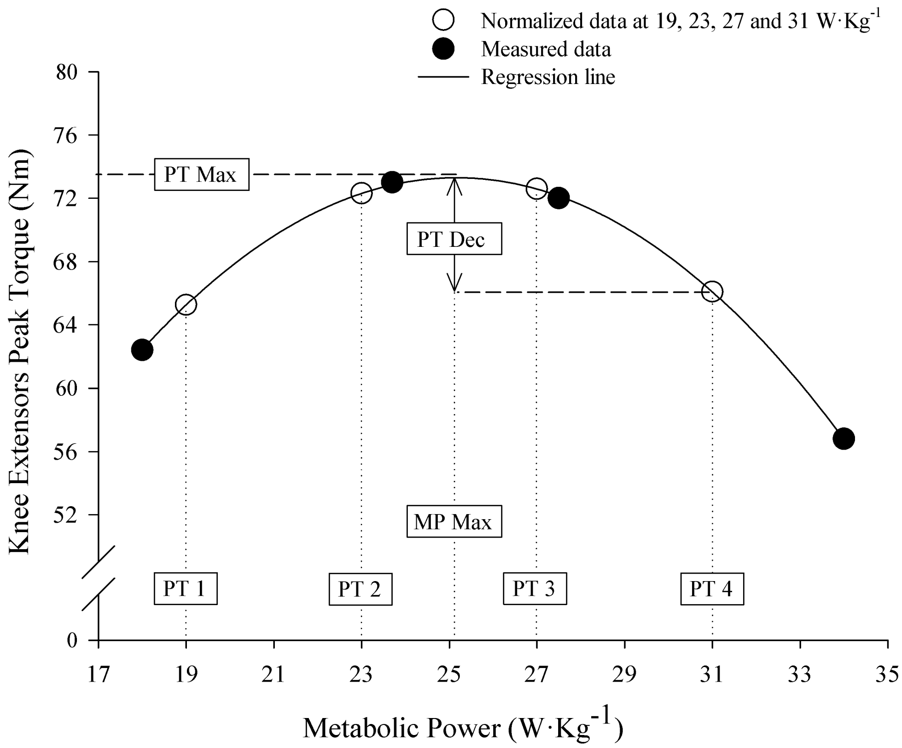

Figure 5.1. Example of the regression line calculated by interpolating the peak torques (measured data) measured after each changes of direction level. MP Max: metabolic power corresponding to PT Max; PT: peak torque corresponding to a metabolic power of 19 (PT1), 23 (PT2), 27 (PT3) and 31 (PT4) $W{\cdot}kg^{-1}$; PT Max: the highest value of PT calculated from the peak torque-metabolic power relationship; PT Dec: decrease in percentage from PT Max to PT4.

Training load quantification

The TL was quantified by multiplying training/game duration in minutes (training volume, TV) by the sRPE as previously described by Foster et al. (2001). sRPE were assessed using the CR-10 Borg's scale (Borg 1998) and collected 30 min after each training session in each player (Impellizzeri et al. 2004). The duration of each session was recorded individually, including within-session recovery periods and warm-up, but excluding the cool-down or stretching exercises. The match durations (warm-up included) were recorded from the beginning to the end of the game including all stops (game stops, injury stops, time-outs and in-between quarter-times stops). All players were familiar with the use of the sRPE as it had previously been utilized prior to commencing the study.

Statistical analysis

Descriptive results are reported as means ± standard deviations (SD). Assumption of normality was verified using the Kolmogorov-Smirnov test. The magnitude-based inference (MBI) approach was used to analyze the data according to Hopkins et al. (2009). All data were first log-transformed to reduce bias arising from non-uniformity of effects or errors (Hopkins et al. 2009). Standardised differences were calculated, and interpreted as follows: ≤0.02, trivial; >0.2-0.6, small; >0.6-1.2, moderate; >1,2-2.0, large; >2.0-4.0, very large; >4.0, extremely large (Hopkins et al. 2009). Probability was also calculated to compare the true (unknown) differences and the smallest worthwhile change (SWC). SWC was obtained multiplying the between-subject SD by 0.2. Quantitative chances of harmful, trivial or beneficial differences were evaluated qualitatively according to established criteria: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain. When the probability of having higher or lower values than the SWC was less than 5%, the true difference was assessed as unclear. Due to the non-normal distribution of TV and sRPE-TL data, spearman's rank correlation coefficients (r_s, 90% confidence intervals) were used to determine the relationships between weekly sRPE-TL and TV with changes (%) in neuromuscular evaluations. The magnitude of relationships was assessed according to the following thresholds: ≤0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect. Practical inferences of the correlations were also considered (Hopkins et al. 2007). Test-retest reliability of CMJ and COD variables was determined in our laboratory on two trials in 15 and 11 amateur basketball players respectively (Table 5.3). Customized spreadsheets and SPSS statistical software (version 23.0, IBM SPSS Statistics, Chicago, IL, USA) were used to perform data analysis.

Table 5.3. Test-retest reliability of the CMJ and COD variables.

	%CV (90% CI)	ICC (90% CI)
	Counter-Movement Jump test	
Height	3.8 (2.8-6.1)	0.82 (0.55-0.94)
PPO_{rel}	2.9 (2.1-4.6)	0.87 (0.65-0.95)
PF_{rel}	3.8 (2.7-6.3)	0.95 (0.85-0.98)
PPO_{abs}	2.5 (1.8-4.0)	0.94 (0.83-0.98)
PF_{abs}	3.8 (2.8-6.4)	0.96 (0.87-0.99)
	Repeated Changes of Direction test	
PT bas	8.9 (6.5-14.5)	0.66 (0.24-0.87)
PT1	8.4 (6.1-13.7)	0.80 (0.51-0.93)
PT2	5.5 (4.0-8.8)	0.87 (0.66-0.96)
PT3	5.1 (3.8-8.3)	0.89 (0.72-0.96)
PT4	8.1 (5.9-13.2)	0.91 (0.75-0.97)
PT Max	5.3 (3.9-8.6)	0.88 (0.68-0.96)
PT Dec	5.3 (3.9-8.5)	0.78 (0.47-0.92)
MP Max	4.6 (3.4-7.4)	0.87 (0.65-0.95)

Abbreviations: abs, absolute; CI: Confidence intervals; %CV: coefficient of variation in percentage; ICC: intraclass correlation coefficient; MP Max: metabolic power corresponding to PT Max; PF, peak force; PPO, peak power output; PT: peak torque corresponding to a metabolic power of 19 (PT1), 23 (PT2), 27 (PT3) and 31 (PT4) $W \cdot kg^{-1}$; PT Bas: PT measured at baseline; PT Max: the highest value of PT calculated from the peak torque-metabolic power relationship; PT Dec: decrease in percentage from PT Max to PT4; rel, relative – normalized to body mass.

Results

The PRO accumulated almost certain greater sRPE-TL (5058±1849 vs 2373±488 AU; ES: 5.22, CL: ±1.90; MBI: 100/0/0) and TV (909±130 vs 587±65 AU; ES: 4.68, CL: ±1.04; MBI: 100/0/0) compared to SEMI-PRO.

Neuromuscular variations

Counter-Movement Jump Test

The CMJ variables of PRO and SEMI-PRO measured before and after the preparation period are presented in Table 5.4.

Between-groups standardized differences for the CMJ variables are presented in Figure 5.2.

At T1, no clear differences were found between groups, except for PPO_{abs} and PF_{abs}, which were very likely higher for PRO compared to SEMI-PRO (ES: 1.15, CL: ±0.63 and ES: 1.18, CL: ±0.64 respectively). At T2, PPO_{abs} and PF_{abs} resulted likely and very likely greater for PRO (ES: 0.75, CL: ±0.63 and ES: 1.20, CL: ±0.65, respectively). For the between-groups changes from T1 to T2, small differences were observed in PPO_{abs} (ES: -0.31, CL: ±0.21) and PPO_{rel} (ES: -0.52, CL: ±0.28).

Table 5.4. CMJ variables of professional (PRO) and semi-professional (SEMI-PRO) players before (T1) and after (T2) the preparation period.

	Team	n	T1	T2	ES (90% CL)	MBI (%)	Likelihood and magnitude
Height (cm)	PRO	12	50.3 ± 5.4	49.3 ± 5.8	-0.17 ± 0.26	2/51/47	Possibly harmful
	SEMI-PRO	16	49.4 ± 5.4	49.8 ± 6.2	0.07 ± 0.21	13/85/3	Likely trivial
PPO_{rel} ($W \cdot kg^{-1}$)	PRO	12	55.4 ± 5.7	54.9 ± 5.6	-0.10 ± 0.19	1/78/21	Likely trivial
	SEMI-PRO	16	53.9 ± 5.1	56.3 ± 6.1	0.45 ± 0.22	96/4/0	Very likely beneficial
PF_{rel} ($N \cdot kg^{-1}$)	PRO	12	25.7 ± 1.9	26.7 ± 2.2	0.46 ± 0.45	84/15/1	Likely beneficial
	SEMI-PRO	16	25.6 ± 2.0	26.3 ± 2.2	0.32 ± 0.37	72/27/1	Possibly beneficial
PPO_{abs} (W)	PRO	12	5153 ± 593	5107 ± 650	-0.07 ± 0.17	1/87/13	Likely trivial
	SEMI-PRO	16	4405 ± 667	4589 ± 696	0.26 ± 0.16	79/21/0	Likely beneficial
PF_{abs} (N)	PRO	12	2397 ± 262	2492 ± 338	0.34 ± 0.34	72/27/1	Possibly beneficial
	SEMI-PRO	16	2087 ± 249	2135 ± 218	0.18 ± 0.27	56/43/1	Possibly beneficial

Abbreviations: abs, absolute; CL, confidence limits; ES, effect size; MBI, magnitude-based inferences; MBI (%), percent chances of beneficial/trivial/harmful effects; PF, peak force; PPO, peak power output; rel, relative – normalized to body mass; T1, before preparation period; T2 after preparation period.

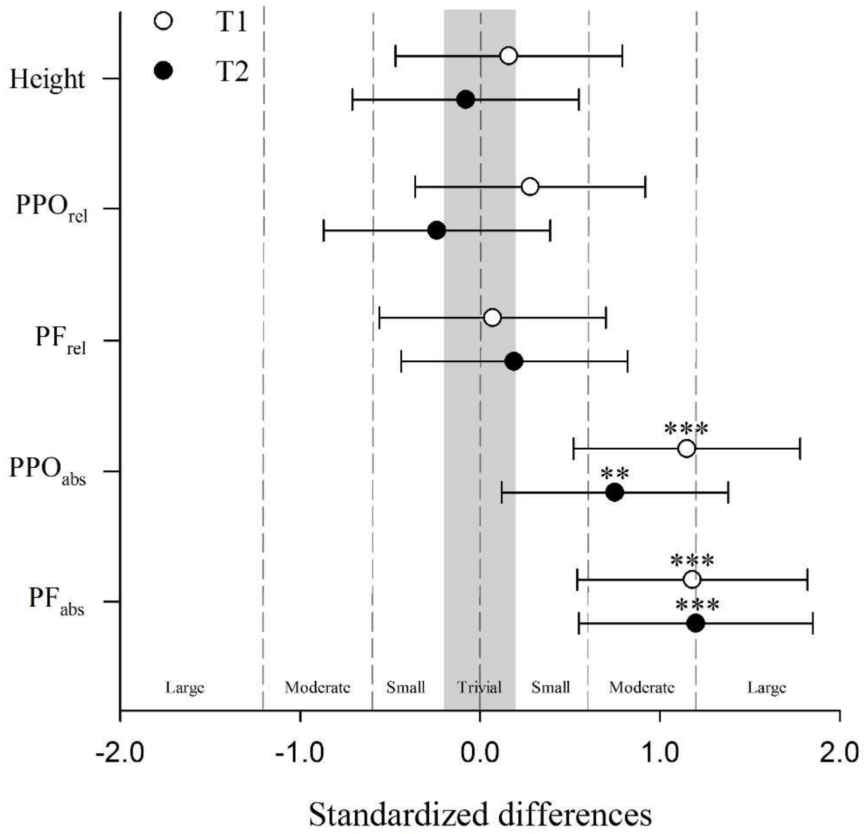

Figure 5.2. Standardized differences (90% confidence intervals) for the CMJ variables between professional and semi-professional players. ** likely, *** very likely difference between professional and semi-professional players. T1: test before the preparation period; T2: test after the preparation period; values above zero: greater for professional players; values below zero: greater for semi-professional players.

Repeated Changes of Direction Test

No clear variations were observed in PT Bas from T1 to T2 for both PRO (60.3±12.4 vs 57.2±9.6 N·m; ES: -0.23, CL: ±0.41; MBI: 7/36/56) and SEMI-PRO (52.0±11.7 vs 51.8±10.7 N·m; ES: -0.01, CL: ±0.31; MBI: 19/59/22).

KE contractile properties (i.e. PT at fixed metabolic power) measured during the COD test are presented in Figure 5.3.

No clear variation was observed in PT Max from T1 to T2 in PRO (76.8±12.0 vs 73.8±11.5 N·m; ES: -0.24, CL: ±0.40; MBI: 5/35/60), while a possible reduction was found in SEMI-PRO (69.1±14.6 vs 65.6±13.9 N·m; ES: -0.23, CL: ±0.28; MBI: 2/36/62).

The PT Dec was reduced from T1 to T2 for both PRO (27.8±21.3% vs 11.4±13.7%; ES: -0.71, CL: ±0.30; MBI: 0/0/100) and SEMI-PRO (26.1±21.9% vs 10.2±8.2%; ES: -0.69, CL: ±0.32; MBI: 0/1/99).

The MP Max increased from T1 to T2 for both PRO (23.5±1.4 vs 25.7±1.8 W·kg-1; ES: 1.46, CL: ±0.65; MBI: 100/0/0) and SEMI-PRO (24.1±1.7 vs 25.2±1.8 W·kg-1; ES: 0.63, CL: ±0.47; MBI: 93/7/0).

Between-groups standardized differences for the MP Max and for the KE contractile properties measured at baseline and during the COD test are presented in Figure 5.4.

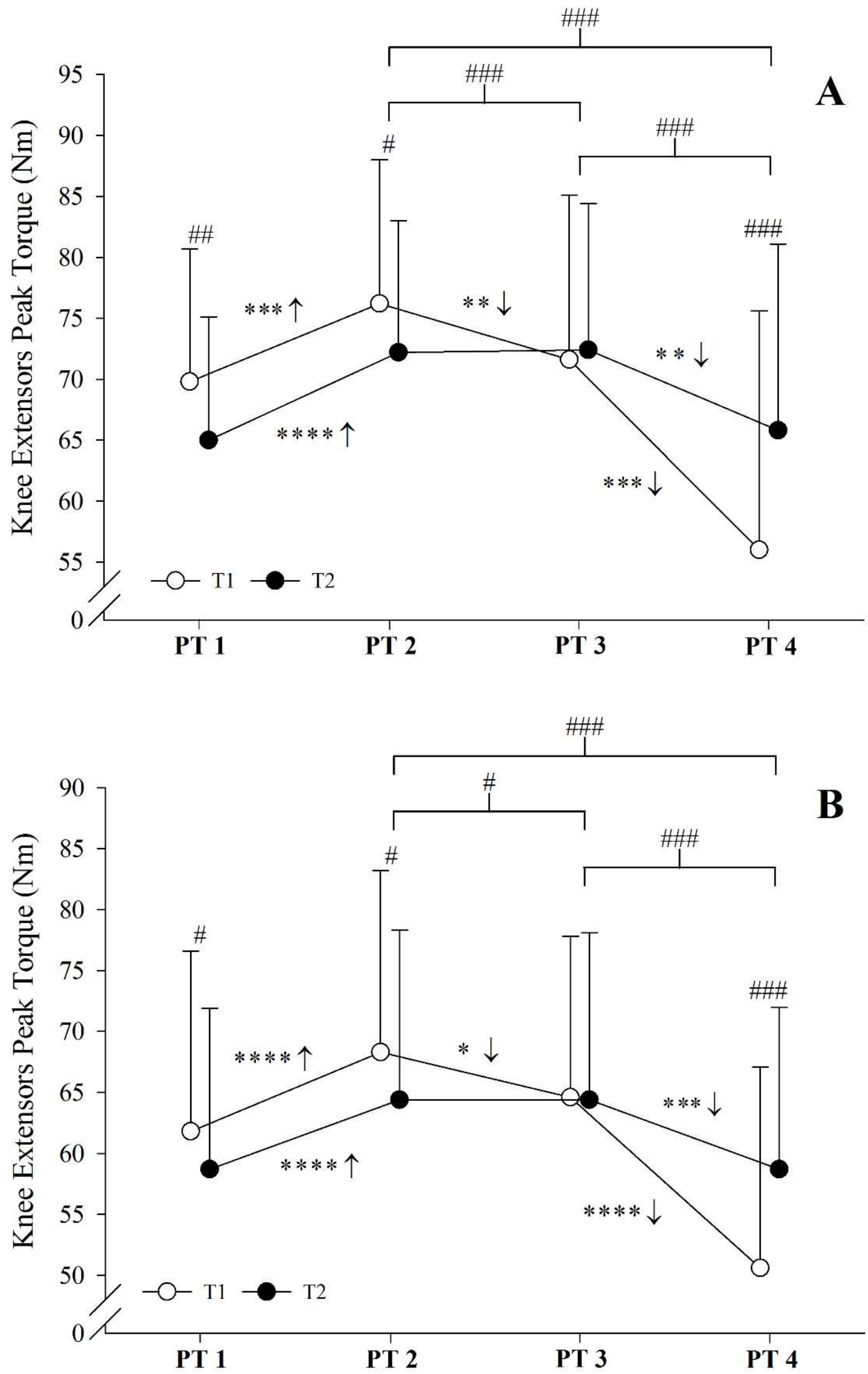

Figure 5.3. Knee extensors contractile properties measured during the COD test in professional (A) and semi-professional (B) players. ↓ decrease; ↑ increase; * possible, ** likely, *** very likely, **** almost certain change; # possible, ## likely, ### very likely difference between T1 and T2. PT: peak torque corresponding to a metabolic power of 19 (PT1), 23 (PT2), 27 (PT3) and 31 (PT4) $W \cdot kg^{-1}$; T1: test before the preparation period; T2: test after the preparation period.

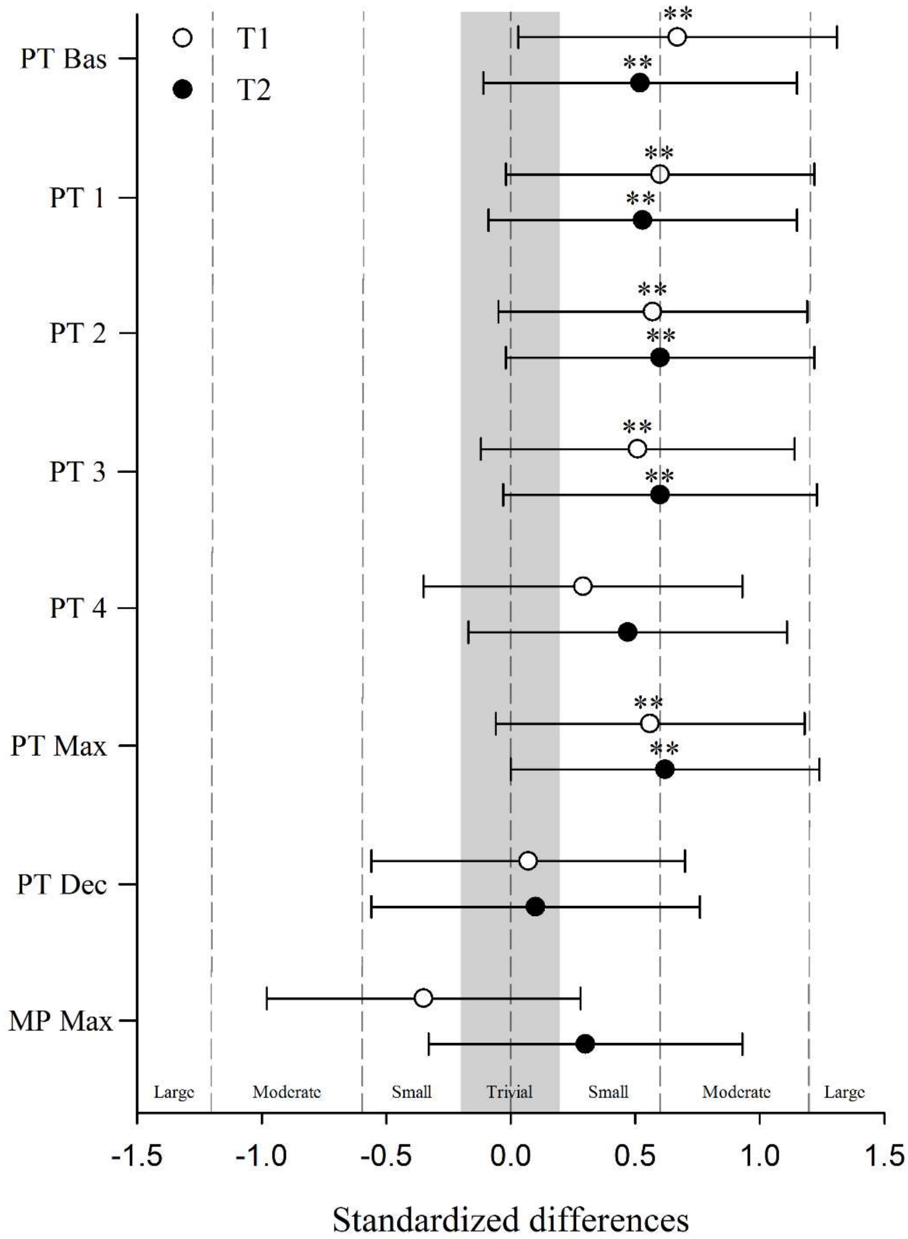

Figure 5.4. Between-groups standardized differences (90% confidence intervals) for the MP Max and for the knee extensor contractile properties measured at baseline and during the COD test. ** likely difference between professional and semi-professional players. MP Max: metabolic power corresponding to PT Max; PT: peak torque corresponding to a metabolic power of 19 (PT1), 23 (PT2), 27 (PT3) and 31 (PT4) W·kg^{-1}; PT Bas: PT measured at baseline; PT Max: the highest value of PT calculated from the peak torque-metabolic power relationship; PT Dec: decrease in percentage from PT Max to PT4; T1: test before the preparation period; T2: test after the preparation period; values above zero: greater for professional players; values below zero: greater for semi-professional players.

Relationships between training load and volume with neuromuscular variations

Within-player correlations between mean weekly sRPE-TL or TV, and variations in neuromuscular performance tested after the preparation period were obtained pooling the data of PRO and SEMI-PRO (Table 5.5).

Table 5.5. Within-player correlations between mean weekly sRPE-TL and training volume, and changes in neuromuscular evaluations from T1 to T2.

		Weekly sRPE-TL			Weekly volume		
	n	r_s (90% CL)		Rating	r_s (90% CL)		Rating
Counter-Movement Jump test							
Height	28	-0.32	±0.29	Likely moderate	-0.31	±0.29	Likely moderate
PPO_{rel}	28	-0.53	±0.23	Very likely large	-0.52	±0.24	Very likely large
PF_{rel}	28	-0.10	±0.31	Unclear	-0.09	±0.32	Unclear
PPO_{abs}	28	-0.46	±0.26	Very likely moderate	-0.50	±0.25	Very likely moderate
PF_{abs}	28	-0.06	±0.32	Unclear	-0.07	±0.32	Unclear
Repeated Changes of Direction Test							
PT Bas	28	-0.17	±0.31	Unclear	0.18	±0.31	Unclear
PT1	28	-0.45	±0.26	Very likely moderate	-0.26	±0.30	Likely small
PT2	28	-0.44	±0.26	Very likely moderate	-0.31	±0.29	Likely moderate
PT3	28	-0.40	±0.27	Likely moderate	-0.38	±0.28	Likely moderate
PT4	28	-0.05	±0.32	Unclear	-0.16	±0.31	Unclear
PT Max	28	-0.38	±0.28	Likely moderate	-0.26	±0.30	Likely small
PT Dec	28	0.07	±0.32	Unclear	-0.07	±0.32	Unclear
MP Max	28	0.08	±0.32	Unclear	0.05	±0.32	Unclear

Abbreviations: r_s = Spearman's rank correlation coefficient; abs, absolute; CL: Confidence limits; MP Max: metabolic power corresponding to PT Max; PF, peak force; PPO, peak power output; PT: peak torque corresponding to a metabolic power of 19 (PT1), 23 (PT2), 27 (PT3) and 31 (PT4) $W \cdot kg^{-1}$; PT Bas: PT measured at baseline; PT Max: the highest value of PT calculated from the peak torque-metabolic power relationship; PT Dec: decrease in percentage from PT Max to PT4;rel, relative – normalized to body mass; sRPE-TL: session-rating of perceived exertion training load; T1: test before the preparation period; T2: test after the preparation period.

Discussion

This study investigated the changes induced by the preparation period on some neuromuscular characteristics (i.e. vertical jump and COD ability) among PRO and SEMI-PRO male basketball players. The likely ineffective training stimuli or overreaching phenomenon occurred during the preparation period, given there were trivial-to-small improvements in CMJ variables, regardless of the competitive levels. Peripheral fatigue induced by a COD test was moderately reduced, suggesting that the ability to sustain repeated CODs was improved. The negative relationships found between sRPE-TL and TV with peripheral neuromuscular functions and CMJ variables, suggest that reaching high sRPE-TL and TV might negatively impact on strength and power properties.

The PRO accumulated approximately twice as much weekly sRPE-TL as SEMI-PRO during the preparation period. The mean weekly sRPE-TL sustained by PRO involved in the present study were greater than the amount previously observed by Manzi et al. (2010) (5058±1849 vs 3334±256 AU). However, sRPE-TL were collected during different training phases in the two studies (i.e. preparation vs competitive period). The preparation period tends to be characterized by higher TLs compared to the competitive period of the season (Aoki et al. 2017). The mean weekly sRPE-TL sustained by SEMI-PRO athletes of the present study (2373±488 AU) was greater than the amount previously reported for Australian SEMI-PRO basketball players (~900-1200 AU) (Scanlan et al. 2014a, Scanlan et al. 2014b). This gap is a result of the different training interventions performed among SEMI-PRO players of these different countries, with Italian players training more times per week (5-6 vs 3 sessions/week) and for longer training session durations than the Australian players.

The average height of the CMJs (Claudino et al. 2016) measured in the present study is similar to those previously reported by Ben Abdelkrim et al. (2010c) for elite basketball players competing in the Tunisian national team (49.7±5.8 cm) and by Shalfawi et al. (2011) for professional basketball players (52.0±7.5 cm). In the present study, no statistical variation in CMJ heights and small improvement in PF were found among the two groups of players, while a small increase in PPO was observed only among SEMI-PRO. The similar or slightly improved jumping performance among the two groups could be a consequence of the ineffective exercise stimuli or, conversely, could be partially influenced by fatigue state occurred during the preparation period (Claudino et al. 2016). Power and force produced during CMJ, when considered in absolute terms (i.e. PPO_{abs} and PF_{abs}), were found to be substantially greater in PRO compared to SEMI-PRO. Therefore, the ability to produce high levels of force and power during vertical jumps might represent variables that discriminate adult players of different competitive level (Delextrat and Cohen 2008). This information suggests the importance of strength and power characteristics for success in basketball.

A novel application for the quantification of peripheral fatigue induced by repeated CODs was used in the present study. The current findings suggest that the ability to sustain repeated CODs efforts may be improved after the preparation period, as peripheral neuromuscular fatigue induced by the COD test was reduced in both groups. Compared to T1, the considerably higher level of PT4 and the reduced PT Dec measured at T2 indicate that PRO and SEMI-PRO enhanced their ability to sustain repeated COD at high intensities. Indeed, the highest values of PT (i.e. PT Max) recorded during the COD test were associated with substantially higher metabolic power (i.e. MP Max) after the preparation period, despite no clear to possibly small reduction observed in PT Max and no clear variations found in PT Bas. These findings suggest that after the preparation period the post-activation potentiation phenomenon is present until a higher absolute exercise intensity and that the occurrence of fatigue is postponed. As the post-activation potentiation has shown to be primarily determined by the relative exercise intensity (Baudry and Duchateau 2007, Place et al. 2010), it is possible to hypothesize that the ability to produce maximal power during repeated CODs was increased. Despite the substantial differences in sRPE-TL and TV, similar neuromuscular adaptations to the COD test were found between PRO and SEMI-PRO. The likely greater levels of PTs (i.e. PT Bas, PT1, PT2, PT3 and PT Max) measured in PRO compared to SEMI-PRO suggest better peripheral contractile properties of the KEs for players of higher competition level. The increased ability to sustain repeated CODs efforts might be an important physical determinant for performance during matches. However, further research is required to confirm these findings.

The present study is the first to investigate the relationships between TL indicators quantified during the preparation period with changes in neuromuscular physical performance in basketball. Negative relationships were found between sRPE-TL and TV with changes in PPO measured during the CMJs (i.e. PPO_{abs} and PPO_{rel}) and PT measured during the COD test (i.e. PT1, PT2, PT3 and PT Max). Similarly, Los Arcos et al. (2015) reported negative correlations between changes in neuromuscular fitness parameters (i.e. jumping and sprinting) with TV and respiratory and muscular sRPE-TL among professional soccer players. These results suggest that reaching high sRPE-TL and TV during the preparation period might negatively affect strength and power properties. This phenomenon might be ascribed to a residual fatigue that exists due to the daily training (often two daily training sessions) typical of the preparation period. However, the magnitude of these effects was small-to-large (range r_s: -0.53 to -0.26) and these relationships are not to be considered strong enough to predict the changes in neuromuscular physical performance induced by the preparation period in basketball.

Limitations of the current study are that sRPE-TL and TV were the only TL indicators quantified. Future research should investigate the relationships between neuromuscular adaptations and other measures of external and internal TL. In the present study, no measures of external TL using microtechnology, were included due to their high costs. Furthermore, due to the difficulties in assessing professional players, the duration from T1 to T2 ranged between 35 and 47 days. However, further adaptations likely did not occur in the players with extra days of training, as this period was part of the “re-activation” and “tapering” phases at the beginning of the preparation and competitive period respectively.

Practical applications

A high force and power production should be considered as a prerequisite for success in basketball practice, thus we suggest that strength and conditioning coaches develop training programs to proper enhance these physical characteristics. We also recommend that physical tests carried out in the present study can be used to evaluate the neuromuscular status of players across the preparation period. Specifically, the COD test used in the present study represents a novel application for the quantification of peripheral fatigue induced by repeated CODs. Basketball practitioners should consider that achieving high sRPE-TL and TV during preparation period might negatively impact strength and power properties. This is evidenced by the negative relationships between sRPE-TL and TV with changes in neuromuscular responses encountered.

Conclusions

In general, regardless of the competition level, the preparation period appears to minimally affect variables measured during vertical jump test, but enhance the ability to sustain repeated COD efforts. The present results suggest that PRO basketball players can produce higher level of force and power compared to lower level basketball players.

CHAPTER SIX

Peripheral neuromuscular function during repeated changes of direction in basketball: effect of competitive level and seasonal variations.

Ferioli D, Rampinini E, Bosio A, La Torre A, Maffiuletti NA. (*In Preparation*). "Peripheral neuromuscular fatigue induced by repeated changes of direction in basketball."

Abstract

Purpose: Two studies were conducted to examine 1) the differences among a large sample size of basketball players of different competitive levels (from elite to amateur levels) and 2) the changes over an entire basketball season of PNF measured following standardized repeated CODs exercises.

Methods: In Study 1, 111 adult male basketball players from 4 different Divisions performed the COD test during the competitive phase of the season. In study 2, 32 adult male basketball players from 3 different Divisions performed the COD test at different time points: before (T1) and after (T2) the preparation period and during the in-season period (T3). The COD test consisted of 4 levels with increasing intensities. The PNF of KE (peak torque, PT) were measured using electrical stimulations after each level (PT1, PT2, PT3 and PT4). Furthermore, PT Max (the highest value of PT) and PT Dec (PT decrement from PT Max to PT4) were calculated.

Results: Study 1: PTs of Division I and II were likely greater compared to PTs of Division III and VI. No clear to possibly small differences were found in PT Dec and MP Max when Division II players were compared with Division I or Division III athletes. Study 2: The main differences in PTs (PT1, PT2, PT3, PT4 and PT Dec) were found between T1 and T2. Different changes in PTs Max were found among players of different Divisions.

Conclusions: Elite and professional basketball players are characterized by better PNF and by less fatigue levels following repeated CODs runs compared to lower level counterparts. The majority of changes in PNF following CODs exercises occurs after the preparation period, when the KEs appear to be less fatigable.

Key Words: Competitive level; Seasonal variation; Peak torque; Metabolic power; Neuromuscular functions.

Introduction

Basketball is a physically demanding team sport characterized by frequent high-intensity phases (Stojanovic et al. 2017), during which neuromuscular factors are heavily taxed (Ziv and Lidor 2009). Players are frequently asked to quickly accelerate, decelerate and change direction during basketball games (McInnes et al. 1995, Ziv and Lidor 2009). Specifically, time-motion analysis of matches revealed that players carry out 50-60 changes in speed and direction per games, confirming the importance of these physical characteristics (Ben Abdelkrim et al. 2007, McInnes et al. 1995).

As several studies reported the change of direction (COD) ability to be a main determinant for successful participation in modern team sports, numerous tests have been developed to assess COD performance (e.g. Illinois agility test, T-test, 505 agility test) (Brughelli et al. 2008). Despite these tests are usually characterized by several different variables (e.g. number of COD, total distance covered, type of force application), most of them quantify the total running time as test score (Brughelli et al. 2008). A lower total running time to complete these tests is usually considered as a better ability in rapidly decelerate, change direction and reaccelerate in a new direction. While many studies have focused on the physiological characteristics of basketball players (Ziv and Lidor 2009), only few studies compared the COD ability of adult players competing at different playing levels (Spiteri et al. 2017). A faster performance in the T-test and in the reactive Y-shaped agility test was found among professional and semi-professional male basketball players compared to lower competitive level counterparts (Delextrat and Cohen 2008, Koklu et al. 2011, Lockie et al. 2014, Sekulic et al. 2017). In addition, the 505 agility test was found to discriminate COD performance across three different female basketball leagues (Spiteri et al. 2017). Furthermore, Ben Abdelkrim et al. (2010c) reported a faster performance in the T-test for Senior and Under 20 compared with under 18 Tunisian national players. On the contrary, Koklu et al. (2011) and Sekulic et al. (2017) found no significant differences among Division I and Division II players in the T-test. These contrasting results may be attributed to the different type/characteristics of tests used to evaluate the COD ability of players. Furthermore, some limitations should be acknowledged, such as a limited number of players involved and only two competitive level groups compared (e.g. Division I vs Division II or Professional vs Semi-professional players). For these reasons, further insight about COD ability among players of different competitive levels are needed. Additionally, there is limited information regarding the changes in COD ability across an entire basketball season. Hoffman et al. (Hoffman et al. 1991, Hoffman and Kaminsky 2000) observed no variations in T-test performance during preparation and competitive periods in NCAA Division I and young basketball players. On the contrary, when assessed with the in line drill test the COD ability of junior male and female players resulted substantially affected by the period of the season (Hoffman and Kaminsky 2000, Montgomery et al. 2008b). These contrasting results might be attributed to the different characteristics of the various COD tests performed by the athletes (Brughelli et al. 2008). A thorough knowledge of the effect of an entire basketball season on COD ability might highlight useful information for physical preparation.

Lower body strength and power characteristics have been reported to affect the COD ability of athletes. Indeed, increased lower body strength capacities were reported to permit athletes to carry out the COD movements in lower body positions, enhancing the ability to produce greater force during the deceleration and reacceleration phase of the COD movement (Spiteri et al. 2013). In addition, lower body strength characteristics have been shown to be reduced after COD runs (Hader et al. 2014). Assessing the neuromuscular functions of lower limbs following COD exercises might be useful to quantify the fatigue level induced by COD movements. Fatigue induced by COD may be caused by a combination of central and peripheral factors (Taylor and Gandevia 2008). However, peripheral mechanisms of fatigue appear to be more involved during high-intensity short-duration exercises, while central mechanisms have been reported to be developed especially following submaximal prolonged exercises (Taylor and Gandevia 2008).

Therefore, in the present study the peripheral neuromuscular functions (PNF) of the knee extensor (KE) muscles following repeated CODs efforts were assessed. The aims of the present study were to examine the 1) differences among a large cohort of adult basketball players of different competitive level (from elite to amateur levels); 2) changes over an entire basketball season of PNF measured following standardized repeated CODs exercises.

It was hypothesized that athletes competing at a higher level would have had better PNF measured following repeated CODs runs compared with lower levels counterparts. Furthermore, we also hypothesized that the PNF measured following standardized repeated CODs exercises would be affected by the preparation and competitive phase of the season. This information could be useful to further verify the construct validity of the measurement of PNF during a repeated CODs test.

Methods

Subjects and Design

The present investigation consisted of two separate observational studies involving a total of 111 male basketball players participating in one or both studies. Data collection started in 2014 and finished in 2017. After verbal and written explanation of the experimental design and potential risk and benefits of the study, written informed consent was signed by all players or their respective parents/guardians if underage. The study was approved by the Independent Institutional Review Board of Mapei Sport Research Centre in accordance with the Helsinki Declaration. To avoid potential confounding effects on the outcomes variables, no heavy training sessions were performed the day preceding the assessments and no stretching exercises were allowed prior to the COD tests. Before the commencement of each COD test, the athletes carried out a standardized warm-up consisting of a continuous run at constant speed, followed by counter-movement jumps and high-intensities intermittent runs.

Study 1

Differences between competitive levels. 111 male basketball players competing in the Italian Serie A (Division I, n=27, age: 25.3 ± 5.2 years, stature: 198 ± 9 cm, body mass: 95.9 ± 12.2 kg), Serie A2 (Division II, n=25, age: 24.5 ± 3.9 years, stature: 197 ± 7 cm, body mass: 93.2 ± 11.4 kg), Serie B (Division III, n=32, age: 24.1 ± 5.7 years, stature: 193 ± 8 cm, body mass: 89.0 ± 11.6 kg) and Serie D (Division VI, n=27, age: 21.6 ± 5.3 years, stature: 187 ± 8 cm, body mass: 78.8 ± 9.8 kg) took part in the present study. Players were selected from a total of 14 basketball teams (i.e. 3 or 4 teams for each division) and performed the COD test during the competitive phase of the seasons 2014-15, 2015-16 or 2016-17. Playing roles were equally represented in all Division groups to avoid potential bias effects of playing position on the outcomes variables.

Study 2

Seasonal changes. In the second study, data were collected from 32 adult basketball players competing in the Italian Serie A (Division I, n=11, age: 27.0 ± 6.1 years, stature: 201 ± 10 cm, body mass: 100.0 ± 11.0 kg), Serie A2 (Division II, n=10, age: 23.8 ± 4.7 years, stature: 196 ± 7 cm, body mass: 89.9 ± 11.9 kg) and Serie B (Division III, n=11, age: 24.2 ± 5.2 years, stature: 190 ± 7 cm, body mass: 84.5 ± 10.7 kg). Players were selected from a total of 6 basketball teams (i.e. 2 teams for each division) during the competitive seasons 2015-16 or 2016-17. Athletes completed the COD test 3 times during the entire basketball season: the first week of the preparation period (T1); within the first 2 weeks from the start of the competitive season (T2); and during the competitive phase of the season (T3), at least 9 weeks after T2. All the testing sessions were performed in the same conditions (i.e. testing venue, time of the day and procedures of the test). On average, Division I and Division II athletes trained 7 to 11 times a week, while Division III players performed 5 to 8 training sessions a week. Training sessions lasted 60-120 min, excluding cool down and/or stretching exercises. All the basketball players included in this study performed more than 80% of the team training sessions and were not injured during the testing period. The participants' dropout rate of this study corresponded to ~35%.

Methodology

Repeated Changes of Direction Test

The COD test consisted of 4 levels of increasing standardized intensity. The players, paced by an audio signal, run back and forth repeatedly with 180° COD over an 8 m course. During the first and second levels, athletes carried out 11 CODs in 31.5 s and 28.5 s respectively, while the third and the fourth levels were composed of 13 CODs performed in 30.0 s and 26.0 s respectively. The instantaneous running speed sustained by each player during the COD levels was recorded using a radar device (Stalker ATS System, Radar Sales, Minneapolis, MN). Furthermore, actual instantaneous metabolic powers were estimated for each COD level using the equation proposed by Di Prampero et al. (2005) and then modified by Osgnach et al. (2010) The PNF of the KE was assessed at baseline (Bas, that is prior to the standardized running warm-up) and 30 s after the completion of each COD level. The neuromuscular assessments were performed in isometric conditions, measuring firstly KE torque of the right thigh and secondly KE torque of the left thigh. The athletes were seated in a purpose-built leg extension machine with the lower leg and thigh fixed at an angle of 90° from full extension. The ankle of the assessed leg was secured to the leg extension machine via Velcro® straps. The mechanical response was recorded using a load cell connected to a data acquisition system (BIOPAC MP100; BIOPAC Systems, Inc., Santa Barbara, CA) at a sampling rate of 250 Hz. The KE contractions were induced by direct stimulation of the femoral nerve using large area electrodes (Compex, Ecublens, Switzerland) placed in the femoral triangle (cathode, 5 x 5 cm) and in the gluteal fold (anode, 10 x 5 cm). The electrodes were positioned by the same technician and their location marked on the skin. The intensity of the electrical current was defined by sending a small electrical stimulus (Digitimer DS7AH; Hertfordshire, United Kingdom; maximal voltage = 400 V), and progressively increasing the intensity by 10 mA until a plateau was reached by twitch torque values of the KE. This intensity was subsequently increased by a further 20%. The mechanical responses of the KE were then measured via the administration of 3 single stimuli, each separated by 3 s. The stimuli were produced using square pulses (200 µs). The highest value of torque production (PT) was calculated from the mean torque response of the 3 evoked contractions. The four PT values obtained at the end of each COD level were plotted against the actual corresponding metabolic power (measured by the radar system). A regression line was calculated by interpolating the four measured PT using a polynomial equation of second order. PT at 4 fixed metabolic powers (i.e. 19, 23, 27 and 31 $W \cdot kg^{-1}$) was then estimated from the regression equation (PT1, PT2, PT3 and PT4 respectively, Figure 6.1). Furthermore, the following parameters were calculated: 1) the highest value of PT (PT Max); 2) the percentage decrease from PT Max to PT4 (PT Dec) that can be considered as an index of muscle fatigability; 3) and the metabolic power corresponding to PT Max (MP Max) (Figure 6.1). This procedure was carried out separately for the right and left KE muscles and the mean value of the two legs was used for the statistical analysis.

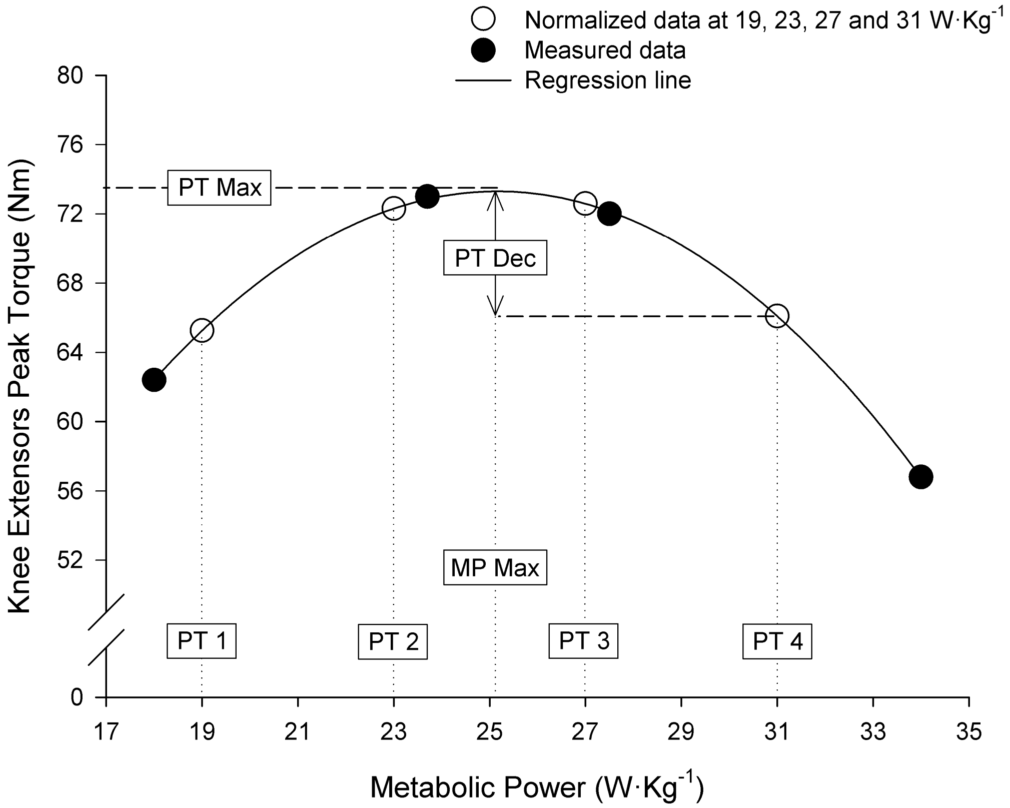

Figure 6.1. Example of the regression line calculated by interpolating the peak torques (measured data) measured after each changes of direction level. MP Max: metabolic power corresponding to PT Max; PT: peak torque corresponding to a metabolic power of 19 (PT1), 23 (PT2), 27 (PT3) and 31 (PT4) W·kg^{-1}; PT Max: the highest value of PT calculated from the peak torque-metabolic power relationship; PT Dec: decrease in percentage from PT Max to PT4.

Statistical analysis

The participants' descriptive results are reported as means ± standard deviations (SD). The magnitude-based inference approach was used to analyse the data according to Hopkins et al. (2009) All data were first log-transformed to reduce bias arising from non-uniformity of effects or errors (Hopkins et al. 2009). Practical significance of changes was assessed by calculating Cohen's d effect size (ES) (Cohen 1988). ES were considered as follow: ≤0.02, trivial; >0.2-0.6, small; >0.6-1.2, moderate; >1,2-2.0, large; >2.0-4.0, very large (Hopkins et al. 2009). Probability was also calculated to compare the true (unknown) differences and the smallest worthwhile changes (SWC). SWC was obtained multiplying the between-subject SD by 0.2. Quantitative chances of harmful, trivial or beneficial effects were evaluated qualitatively according to established criteria: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain. When the probability of having higher or lower values than the SWC was less than 5%, the true difference was assessed as unclear. Test-retest reliability of all the variables was determined using the intraclass correlation coefficient (ICC) and the typical error of measurement expressed as coefficient of variation (CV). Test-retest reliability coefficients were determined in our laboratory in 11 basketball players on 2 trials, resulting as follow: PT Bas, ICC 0.66 (90% confidence intervals, CI, 0.24-0.87) and CV 8.9% (90%CI, 6.5-14.5%); PT1, ICC 0.80 (90%CI, 0.51-0.93) and CV 8.4% (90%CI, 6.1-13.7%); PT2, ICC 0.87 (90%CI, 0.66-0.96) and CV 5.5% (90%CI, 4.0-8.8%); PT3, ICC 0.89 (90%CI, 0.72-0.96) and CV 5.1% (90%CI, 3.8-8.3%); PT4, ICC 0.91 (90%CI, 0.75-0.97) and CV 8.1% (90%CI, 5.9-13.2%); PT Max, ICC 0.88 (90%CI, 0.68-0.96) and CV 5.3% (90%CI, 3.9-8.6%); PT Dec, ICC 0.78 (90%CI, 0.47-0.92) and CV 5.3% (90%CI, 3.9-8.5%); MP Max, ICC 0.87 (90%CI, 0.65-0.95) and CV, 4.6% (90%CI 3.4-7.4%). Customized spreadsheets and SPSS statistical software (version 24.0, IBM SPSS Statistics, Chicago, IL, USA) were used to perform data analysis.

Results

Study 1

The KE contractile properties (i.e. PT at fixed metabolic power) measured during the COD test are presented in Figure 6.2. Similar PTs were observed between Division I and Division II players, whose PTs resulted likely greater compared to Division III athletes. PTs of Division VI players were possibly-to-very likely lower compared to PTs of Division III individuals.

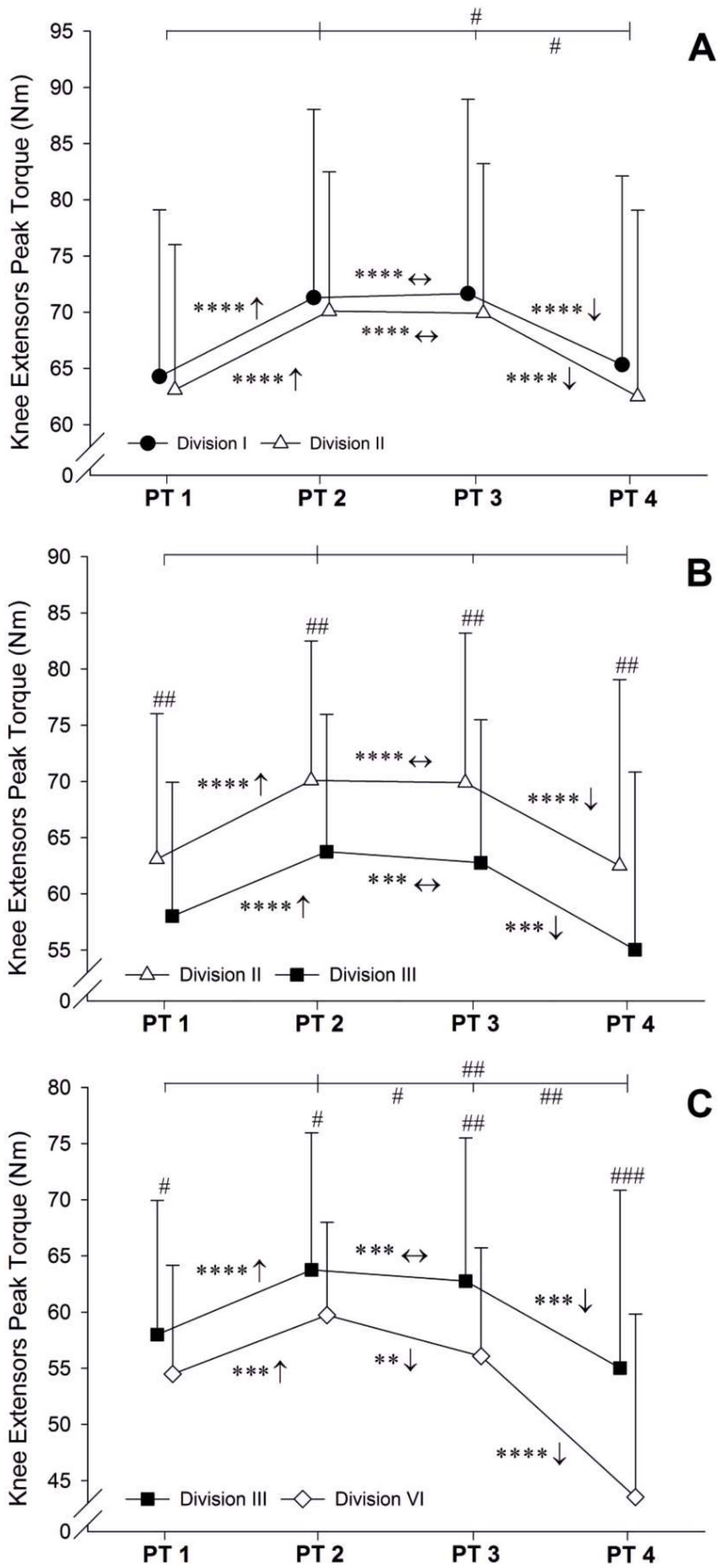

Figure 6.2. Knee extensors contractile properties measured during the COD test. A: Division I vs Division II; B: Division II vs Division III; C: Division III vs Division VI. ↓ decrease; ↑ increase; ↔ stable; ** likely, *** very likely, **** almost certain change; # possible, ## likely, ### very likely difference between the compared Divisions. PT: peak torque corresponding to a metabolic power of 19 (PT1), 23 (PT2), 27 (PT3) and 31 (PT4) W·kg^{-1}.

MP Max and KE contractile properties measured at baseline and during the COD test are reported in Table 6.1.

Table 6.1. MP Max and knee extensors contractile properties measured at baseline and during the COD test.

	DIVISION I *n=27*		DIVISION II *n=25*		DIVISION III *n=32*		DIVISION VI *n=27*	
PT Bas (Nm)	60.1	± 14.3	55.9	± 11.2	52.9	± 10.2	52.7	± 8.8
PT Max (Nm)	73.1	± 17.4	71.5	± 12.65	65.0	± 12.17	61.1	± 8.3
PT Dec (%)	10.1	± 8.3	13.5	± 12.2	15.7	± 16.8	28.7	± 23.9
MP Max ($W \cdot kg^{-1}$)	25.4	± 2.1	25.2	± 1.7	24.7	± 2.1	23.3	± 2.4

Abbreviations: MP Max: metabolic power corresponding to PT Max; PT: peak torque; PT Bas: PT measured at baseline; PT Max: the highest value of PT calculated from the peak torque-metabolic power relationship; PT Dec: decrease in percentage from PT Max to PT corresponding to a metabolic power of 31 $W \cdot kg^{-1}$.

Between-groups standardized differences for the PT Bas, PT Max, PT Dec and MP Max are presented in Figure 6.3.

No clear to possibly small differences were found in PT Dec and MP Max when Division II players were compared with Division I or Division III athletes, whose variables (i.e. PT Dec and MP Max) were observed to be very likely different compared to Division VI ones.

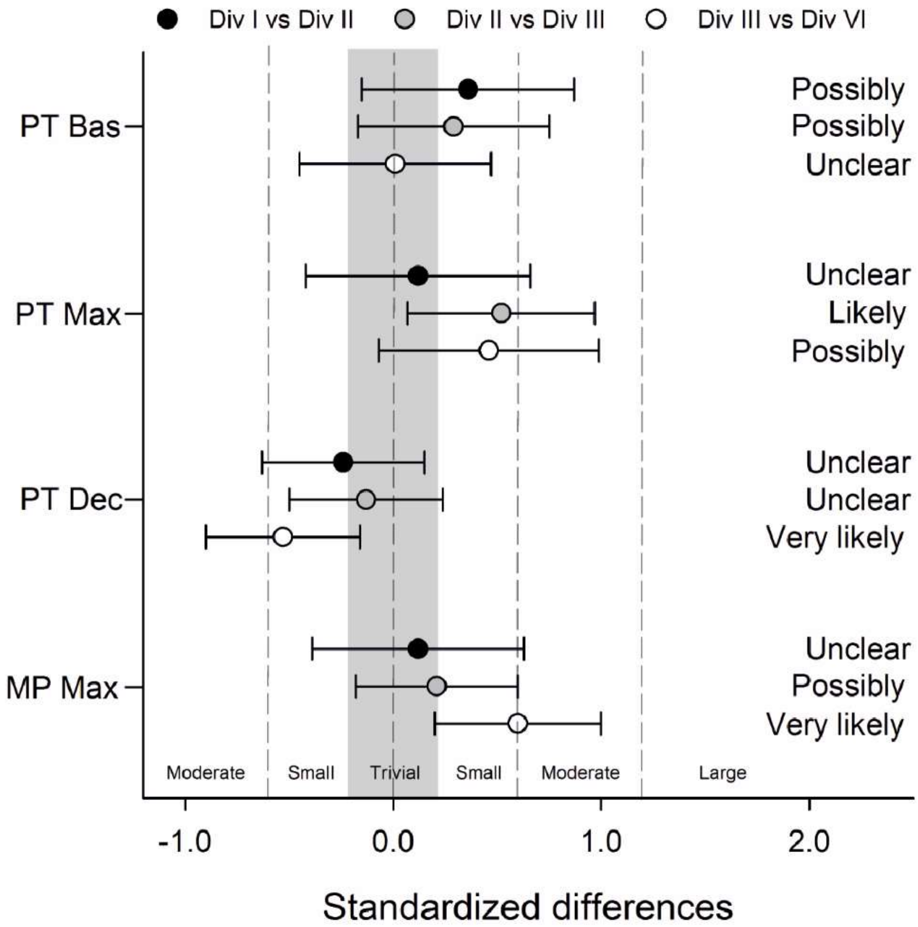

Figure 6.3. Between-groups standardized differences (90% confidence intervals) for the MP Max and for the knee extensor contractile properties measured at baseline and during the COD test. Div: Division; MP Max: metabolic power corresponding to PT Max; PT Bas: peak torque measured at baseline; PT Max: the highest value of peak torque calculated from the peak torque-metabolic power relationship; PT Dec: decrease in percentage from PT Max to peak torque corresponding to a metabolic power of 31 $W \cdot kg^{-1}$.

Study 2

The KE contractile properties (i.e. PT at fixed metabolic power) measured during the COD test at T1, T2 and T3 are presented in Figure 6.4. The main differences in PTs variations among the COD test were found between T1 and T2. Similar PTs variations among the COD were found comparing T2 and T3.

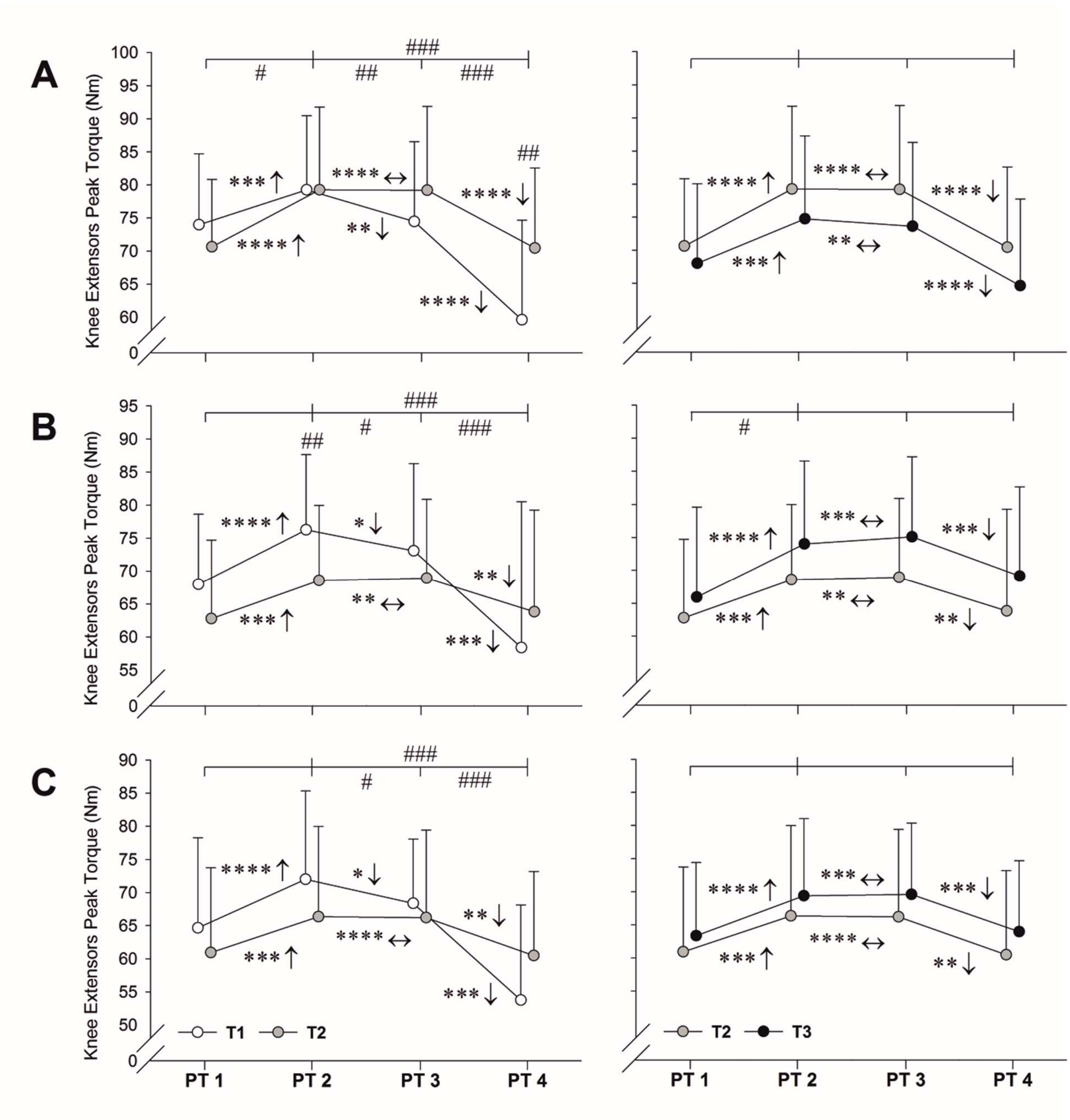

Figure 6.4. Knee extensors contractile properties measured during the COD test in Division I (A), Division II (B) and Division III (C) players. ↓ decrease; ↑ increase; ↔ stable; * possible, ** likely, *** very likely, **** almost certain change; # possible, ## likely, ### very likely difference between T1 and T2 or T2 and T3. PT: peak torque corresponding to a metabolic power of 19 (PT1), 23 (PT2), 27 (PT3) and 31 (PT4) W·kg^{-1}; T1: before the preparation period; T2: after the preparation period; T3: during the competitive phase of the season.

MP Max and KE contractile properties measured at baseline and during the COD test at T1, T2 and T3 are reported in Table 6.2.

Table 6.2. MP Max and knee extensors contractile properties measured at baseline and during the COD test.

	Team	T1		T2		T3	
PT Bas (Nm)	Division I	68.6	± 13.4	62.4	± 10.7	57.1	± 7.8
	Division II	56.2	± 10.5	54.3	± 10.5	57.8	± 11.4
	Division II	52.5	± 12.0	51.8	± 12.0	55.4	± 9.8
PT Max (Nm)	Division I	79.9	± 11.3	80.8	± 13.0	76.4	± 12.6
	Division II	77.1	± 11.4	70.8	± 11.7	76.1	± 12.2
	Division II	72.9	± 12.8	67.5	± 13.6	71.0	± 11.3
PT Dec (%)	Division I	25.6	± 13.3	12.5	± 9.2	15.4	± 11.3
	Division II	24.9	± 26.2	10.2	± 14.9	9.3	± 9.0
	Division II	24.3	± 22.9	9.9	± 9.4	9.4	± 9.9
MP Max ($W·kg^{-1}$)	Division I	23.0	± 1.6	25.0	± 1.8	24.4	± 2.0
	Division II	24.3	± 1.3	25.9	± 3.6	25.9	± 1.8
	Division II	24.6	± 1.7	25.1	± 1.9	25.9	± 2.1

Abbreviations: MP Max: metabolic power corresponding to PT Max; PT: peak torque; PT Bas: PT measured at baseline; PT Max: the highest value of PT calculated from the peak torque-metabolic power relationship; PT Dec: decrease in percentage from PT Max to PT corresponding to a metabolic power of 31 $W·kg^{-1}$; T1, before the preparation period; T2, after the preparation period; T3, during the competitive phase of the season.

Within-groups standardized differences for the PT Bas, PT Max, PT Dec and MP Max measured at T1, T2 and T3 are presented in Figure 6.5. PT Dec was very likely reduced from T1 to T2 but remained stable from T2 to T3 in all Divisions. PTs Max measured in Division II and Division III players were likely to very likely lower in T2 compared with T1 but possibly to very likely greater in T3 compared to T2. PT Max Division I values remained stable from T1 to T2, but were likely reduced from T2 to T3.

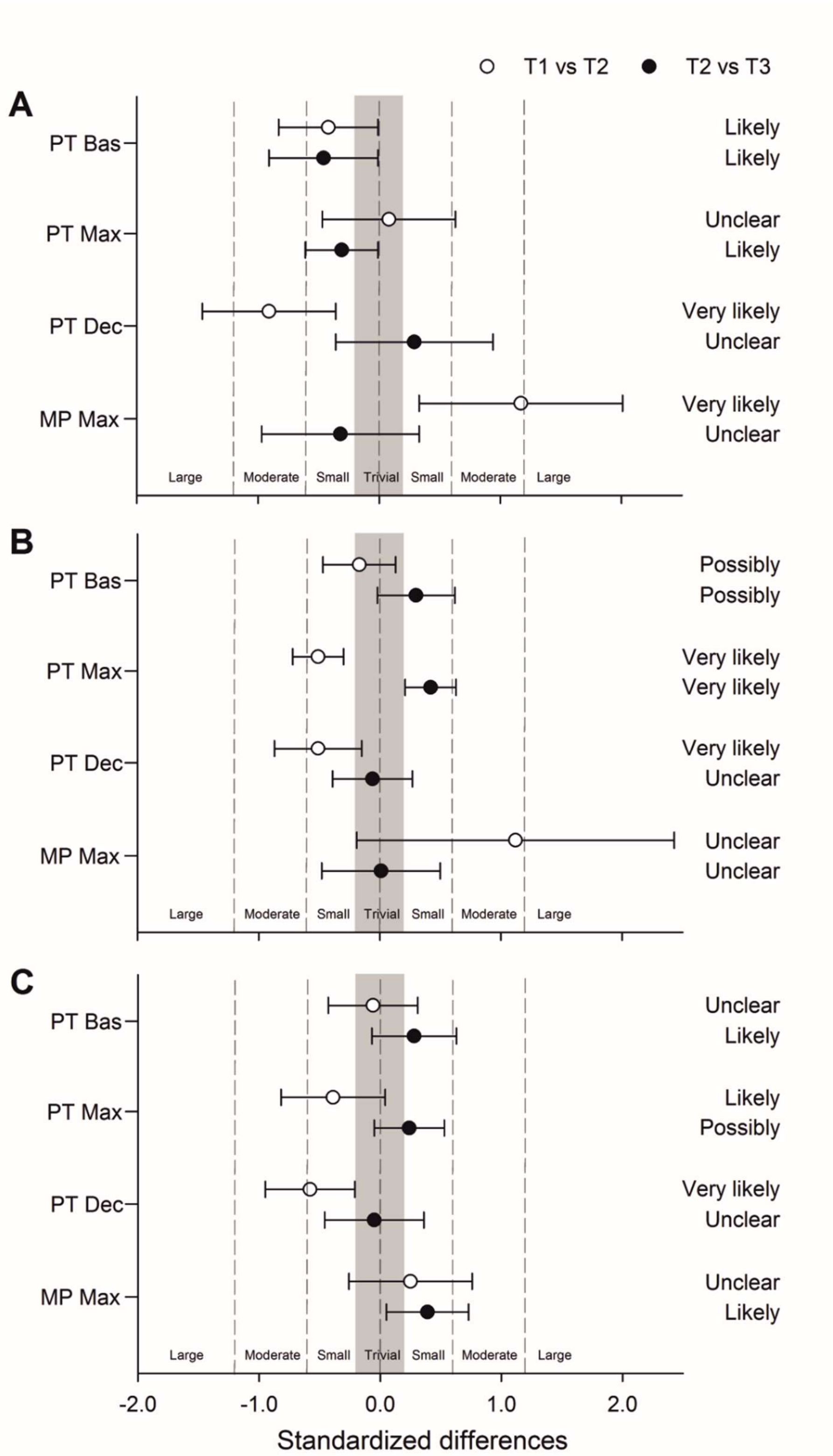

Figure 6.5. Between-groups standardized differences (90% confidence intervals) for the MP Max and for the knee extensor contractile properties measured at baseline and during the COD test. MP Max: metabolic power corresponding to PT Max; PT Bas: peak torque measured at baseline; PT Max: the highest value of peak torque calculated from the peak torque-metabolic power relationship; PT Dec: decrease in percentage from PT Max to peak torque corresponding to a metabolic power of 31 $W \cdot kg^{-1}$; T1: before the preparation period; T2: after the preparation period; T3: during the competitive phase of the season.

Discussion

The present study examined the differences among a large group of basketball players of different competitive level and the changes over an entire basketball season of PNF of KEs measured following standardized repeated CODs exercises. Athletes of higher competitive level are characterized by better peripheral contractile properties of the KEs at baseline and by better PNF following repeated CODs runs. The majority of variations in PNF measured during the COD test occurred during the preparation period. Indeed, the PNF and fatigue levels measured following standardized repeated CODs runs remained stable during the competitive phase of the season compared with the end of the preparation period.

Studies comparing COD ability of basketball players of different competitive levels reported conflicting results (Delextrat and Cohen 2008, Delextrat et al. 2015, Koklu et al. 2011, Sekulic et al. 2017, Spiteri et al. 2017). A novel application for the quantification of peripheral fatigue induced by repeated CODs was used in the present study. The PNF of KEs measured after repeated CODs efforts were affected by the competitive level of play. Despite elite, professional and semi-professional player were characterized by a similar PT Dec, Division II players produced possibly to likely greater levels of PTs (i.e. PT Bas, PT1, PT2, PT3, PT4 and PT Max) compared to Division III counterparts. The highest value of PT (i.e. PT Max) recorded in Division II players during the COD test was associated with a possibly higher metabolic power (i.e. MP Max) compared to Division III individuals. This might suggest a better ability of professional players to sustain repeated CODs efforts at higher intensities than semi-professional ones. Amateur players were characterized by lower PTs and by a substantially greater level of peripheral neuromuscular fatigue induced by the repeated COD test (i.e PT Dec) compared to semi-professional athletes. These findings suggest that KEs PNF might represent variables that discriminate top and moderate professional athletes from lower competitive levels counterparts for what concerns the capacity to exert evoked peripheral muscle force (i.e. PTs).

Furthermore, the ability to sustain repeated CODs exercise at high intensity without the occurrence of severe fatigue might be considered as an important characteristic for successful participation in basketball. However, it is worth noting that Division I and Division II players were characterized by similar PNF and fatigue levels measured during the COD test, which might suggest a comparable ability in sustain repeated CODs efforts. The limited sensitivity of the COD test to distinguish between elite and professional basketball players should be always taken into account. The results of the present study confirm previous findings in literature: no differences in COD performance between male Division I and Division II basketball players (Koklu et al. 2011, Sekulic et al. 2017), while a better COD ability was reported for elite/professional basketball players compared to semi-professional/amateur ones (Delextrat and Cohen 2008, Lockie et al. 2014, Sekulic et al. 2017).

The majority of changes in PNF measured during the COD test occurred during the preparation period. Division I players appeared to improve their ability to sustain repeated CODs effort after the preparation period, as peripheral neuromuscular fatigue induced by the COD test was reduced. Indeed, higher level of PT4 and reduced PT Dec were observed at T2 compared to T1 in elite players. Furthermore, the highest values of PT (i.e. PT Max) recorded during the COD test remained stable during the preparation period, but at T2 it was associated with a very likely greater MP Max. These findings suggest that after the preparation period, Division I players enhanced their ability to sustain repeated CODs at high intensity. Indeed, the post-activation potentiation phenomenon is present until a higher absolute exercise intensity and the occurrence of fatigue is postponed (Figure 6.1). Furthermore, it can be speculated that the ability to produce maximal power during repeated CODs was increased among elite players, as the post-activation potentiation has shown to be primarily determined by the relative exercise intensity (Baudry and Duchateau 2007, Place et al. 2010). PNF of KEs measured following the CODs runs (i.e. PT1, PT2, PT3 and PT4) in Division II and Division III athletes were found to be similar before and after the preparation period. Despite no differences have been found in PT4 among these two groups, the force reductions from PT2 and PT3 to PT4 were substantially greater at T1 than T2. Indeed, the PT Dec was reduced after the preparation period in both groups. Furthermore, it should be considered that after the preparation period PT Max was reduced in Division II and Division III players, but no differences were found in MP Max. These findings appear to suggest that after the preparation period, KEs of professional and semi-professional players are less fatigable during repeated CODs runs but the ability to produce greater level of forces might be partially impaired. However, this quality is restored during the competitive phase of the season, when Division II and Division III athletes produced similar PT Max values compared to T1. The PNF of KEs and fatigue level (i.e. PT Dec) measured following standardized repeated CODs exercises remained stable during the competitive phase of the season compared to the end of the preparation period in all Divisions. These results indicate that the ability to sustain repeated CODs efforts is preserved during the competitive period, regardless of the competitive levels of players.

The main limitation of this study is that basketball players were selected from just one national tournament, thus measured data might not be extended reliably to overall high-level basketball players.

Conclusions and practical applications

The present study clearly show how elite and professional basketball players are characterized by better PNF and by less fatigue levels following repeated CODs runs compared to lower level counterparts. The majority of changes in PNF following CODs exercises occurs after the preparation period, when the KEs appear to be less fatigable. The ability to sustain repeated

CODs efforts at high intensities without the occurrence of severe fatigue should be considered as an important determinant for success in basketball.

The results of this study partially confirm the construct validity of the measurement of PNF of KEs during a repeated CODs test in basketball. However, further confirmations of the validity of this test should be achieved verifying the possible relationships between PNF and fatigue levels measured during the COD test and actual physical basketball match performance.

CHAPTER SEVEN

Seasonal changes in physiological characteristics of basketball players according to competitive level.

Ferioli D, Bosio A, La Torre A, Rampinini E. (*In Preparation*). "Seasonal changes in physiological characteristics of basketball players according to competitive level."

Abstract

Purpose: to quantify the seasonal changes in physical performance of basketball players of different competitive levels.

Methods: Before (T1) and after (T2) the preparation period and during the in-season period (T3), 38 male adult basketball players from 3 different Divisions performed a standardized 6-min continuous running test (Mognoni's test), a Counter-movement jump (CMJ) test and a standardized 5-min High-intensity Intermittent running test (HIT). In addition, on a separate day, athletes underwent Yo-Yo IR1 at all-time points.

Results: The main improvements in performance occurred during the preparation period, when the aerobic fitness and the ability to sustain high-intensity intermittent exercise (HIT and YO-YO IR1) were likely to almost certain improved among all Divisions. At T3, Division II and Division III further increased their aerobic fitness, while likely to very likely better physiological responses to HIT were observed only among Division I. After the preparation period, Division I produced possibly to likely greater peak power (PPO) and peak force (PF) during CMJ, but only PPO was possibly to likely increased from T2 to T3. Unclear to likely trivial changes were found in PPO and PF produced during CMJ by Division II across the season.

Conclusions: The preparation period appears to minimally affect vertical jump ability but enhance the aerobic fitness and the ability to sustain high-intensity intermittent exercise. The changes in physical performance during the competitive phase of the season seem to be affected by the competitive level of play.

Key Words: Competitive level; Seasonal variation; Intermittent exercise; Yo-Yo test; Vertical jump.

Introduction

Basketball is an intermittent team sport, characterized by alternating low- and high-intensity phases (Ben Abdelkrim et al. 2007, McInnes et al. 1995). The ability to sustain intermittent exercise, resist fatigue during high-intensity exercise and produce greater leg strength / power are important physical performance characteristics for basketball players (Ben Abdelkrim et al. 2010c, Ferioli et al. 2017, Ziv and Lidor 2009). In addition, the ability to quickly accelerate, decelerate, change direction and jump appear to be key components of the game's demands (Ben Abdelkrim et al. 2007, McInnes et al. 1995, Ziv and Lidor 2010). Due to these physical demands both aerobic and anaerobic mechanisms are strongly activated to provide energy during basketball (Ziv and Lidor 2009).

The assessment of players' physical fitness across an entire basketball season allows to monitor the effectiveness of conditioning programs and to quantify the changes in the fitness status of players over the different phases of season (Drinkwater et al. 2008). The greatest improvement in athletes' physical fitness usually occurs during the preparation period, when players begin performing physical activity after a prolonged period of complete or nearly complete rest (Drinkwater et al. 2008, Hoffman 2000). During the competitive phase of the season, strength and conditioning programs aim to maintain players' physical fitness, although realistically fitness may slightly increase or decrease (Drinkwater et al. 2008).

Several studies have investigated the seasonal changes in physical fitness of junior and collegiate (NCAA) basketball players, reporting that aerobic fitness is generally slightly increased after the preparation period, while it remains stable or returns to off-season level during the competitive phase of the season (Bolonchuk et al. 1991, Caterisano et al. 1997, Drinkwater et al. 2005, Hoffman et al. 1991, Hunter et al. 1993, Tavino et al. 1995). Anaerobic fitness appears to be improved after the preparation period and to be preserved or slightly increased during the competitive phase of the season (Bolonchuk et al. 1991, Caterisano et al.

1997, Drinkwater et al. 2005, Hoffman et al. 1991, Hunter et al. 1993, Tavino et al. 1995). On the other hand, these studies showed contrasting results on the variations in anthropometric characteristics and in vertical jumping performance across an entire basketball season (Bolonchuk et al. 1991, Caterisano et al. 1997, Drinkwater et al. 2005, Drinkwater et al. 2008, Groves and Gayle 1993, Hoffman et al. 1991, Hunter et al. 1993, Tavino et al. 1995).

Despite the importance of monitoring physical fitness of athletes, only few studies have been focused on adult professional basketball players (Aoki et al. 2017, Ferioli et al. 2017, Gonzalez et al. 2013). The lack of scientific data in literature can be due to the difficulty of involving professional athletes in longitudinal studies. Recently, Gonzalez et al. (2013) investigated performance changes among 7 NBA basketball players from the beginning to the end of the regular season. Authors reported athletes to improve lower limb power produced during squat exercise and during repeated vertical jumps. Furthermore, starters maintained their body mass and percentage of body fat during the regular season. Aoki et al. (2017) reported small-to-large improvements in vertical jumping performance and moderate-to-large greater distances covered during the Yo-Yo Intermittent recovery test (Yo-Yo IR1) among professional Brazilian players after 4 and 9 weeks from the beginning of the season. Similarly, professional Italian basketball players were found to moderately to largely improve their ability to perform maximal and sub-maximal high-intensity intermittent runs, but only to slightly enhance their aerobic fitness during the preparation period (Ferioli et al. 2017).

These studies provided preliminary useful information on the effect of basketball seasonal phases on physical fitness level of professional adult players. However, it should be acknowledged that most of these studies involved a limited number of players from the same team, thus the results might not be extended reliably to overall basketball players. In addition, only one study assessed the physical fitness of professional adult players across different phases of the entire season (i.e. preparation period and in-season period) (Aoki et al. 2017). Further researches need to be conducted to advance the knowledge on the topic. Previous studies reported changes in physical fitness of basketball players to be affected by the competitive level of play (Drinkwater et al. 2007, Drinkwater et al. 2008, Ferioli et al. 2017). Thus, a thorough knowledge of seasonal fitness variations at different playing levels might highlight useful information for physical preparation. Therefore, the aim of this study was to quantify the changes in physical fitness of basketball players selected from different teams of different competitive levels during preparation and in-season periods.

Methods

Subjects

Thirty-eight male basketball players competing in the Italian Serie A (Division I, n=13, age: 27.2 ± 5.7 years, stature: 202 ± 9 cm), Serie A2 (Division II, n=12, age: 23.7 ± 4.4 years, stature: 198 ± 8 cm) and Serie B (Division III, n=13, age: 23.8 ± 4.9 years, stature: 193 ± 8 cm) were recruited for this observational study. Players were selected from a total of 7 basketball teams (i.e. 2 or 3 teams for each division) during the competitive seasons 2015-16 or 2016-17. On average, Division I and Division II athletes trained 7 to 11 times a week, while Division III players performed 5 to 8 training sessions a week. Training sessions lasted 60-120 min, excluding cool down and/or stretching exercises. All the basketball players included in this study performed more than 80% of the team training sessions and were not injured during the testing period (Brunelli et al. 2012). The participants' dropout rate of this study corresponded to ~32%. After verbal and written explanation of the experimental design and potential risks and benefits of the study, written informed consent was signed by all players. The study was approved by the Independent Institutional Review Board of Mapei Sport Research Centre in accordance with the Helsinki Declaration.

Design and Methodology

Players were assessed 3 times during the entire basketball season: the first week of the preparation period (T1); within the first 2 weeks from the start of the competitive season (T2); and during the competitive phase of the season (T3), at least 9 weeks after T2. Each time athletes underwent physical assessments on two separate test days. On day 1 the players underwent Yo-Yo IR1, while on day 2 they performed a physical test session, consisting in a continuous running test (Mognoni's test), followed firstly by a counter-movement jump (CMJ) test and by a High-intensity Intermittent running test (HIT). The second test day was carried out between 2 to 7 days after the Yo-Yo IR1. Due to restrictions made by technical coaches, the Division I athletes did not carry out the Yo-Yo IR1. To avoid potential confounding effects of prior exercise fatigue on the outcomes variables, no training sessions were performed the day preceding the assessments. In addition, no stretching exercises were allowed prior to the tests.

Yo-Yo Intermittent Recovery Test – level 1

Athletes performed the Yo-Yo IR1, according to previously described procedures (Krustrup et al. 2003). Yo-Yo IR1 consisted of 20-m shuttle runs performed at increasing velocities (beginning speed of 10 $km \cdot h^{-1}$) with 10 s of active recovery (consisting of 2x5-m of jogging) between runs until exhaustion. The test concluded when participants failed to complete the distance in time twice (objective evaluation) or due to volitional fatigue. The total distance covered during Yo-Yo IR1 was considered as the test "score" (Krustrup et al. 2003). Heart rate was continuously monitored using Team² Pro System (Polar, Kempele, Finland) and all the athletes achieved at least the 90% of the predicted maximal heart rate, estimated as 220 – age (Howley et al. 1995).

Antropometrics

Stature, body mass and body fat percentage of athletes were determined before the commencement of physical test session. The estimation of the body fat percentage with the skin-fold technique was based on the Jackson and Pollock formula (Jackson and Pollock 1978).

Continuous Running Test (Mognoni's)

Mognoni's test (Sirtori et al. 1993) consisted of a 6-min continuous run at a constant speed of 13.5 $km \cdot h^{-1}$ on a motorized treadmill (HP Cosmos, Nussdorf – Traunstein,Germany). Capillary blood lactate concentration ($MOG_{[La-]}$) was measured immediately after the completion of the test using a portable amperometric microvolume lactate analyser (Lactate Plus, Nova Biomedical, Waltham, MA, USA). Heart rate was continuously monitored using Team^2 Pro System (Polar, Kempele, Finland) and the mean heart rate (MOG_{HR}) of the last minute of running was considered for analysis. Athletes were instructed to abstain from any kind of warm-up prior to the test to avoid potential confounding effects on the physiological responses to the Mognoni's test.

Counter-Movement Jump Test

Before the CMJ test, athletes carried out 2 submaximal CMJs. The CMJ test was performed using a portable force platform (Quattro Jump, Kistler, Winterthur, Switzerland) and its Application Software (Version 1.1.1.4). Each athlete performed 5 bilateral single CMJs from a standing position with hands placed on the hips to minimize any influence of the arms. Players were instructed to perform a quick downward movement reaching about 90° knee flexion, promptly followed by a fast-upward movement with the aim to jump as high as possible. During the concentric phase of each CMJ, peak power output (PPO), peak force (PF) and jump height (CMJ_h) were measured. The average of the best 3 values was used for analysis.

High-intensity Intermittent Test

The HIT protocol has been described previously (Rampinini et al. 2010) and comprised 10 x 10 s shuttle runs over a 25+25 m course with a 180° change of direction and 20 s of passive recovery between each bout. The players were required to run at 18 $km{\cdot}h^{-1}$, following a sequence of audio signals. Immediately after the HIT protocol, a 100 µL capillary blood sample was drawn into a heparinised capillary tube and analysed for blood hydrogen ion concentration ($HIT_{[H+]}$) and bicarbonate concentration ($HIT_{[HCO3-]}$) using a calibrated blood-gas analyser (GEM Premier 3000, Instrumentation Laboratory, Milan, Italy) with an Intelligent Quality Management System cartridge. Capillary blood samples (5 µL) were also analysed for blood lactate concentration ($HIT_{[La-]}$) using a portable amperometric microvolume lactate analyser (Lactate Plus, Nova Biomedical, Waltham, MA, USA). Heart rate was continuously monitored using Team^2 Pro System (Polar, Kempele, Finland) and the mean heart rate of the test (HIT_{HR}) was considered for the analysis.

Statistical analysis

The participants' descriptive results are reported as means ± standard deviations (SD). The magnitude-based inference approach was used to analyse the data according to Hopkins et al. (2009) All data were first log-transformed to reduce bias arising from non-uniformity of effects or errors (Hopkins et al. 2009). Standardised differences were calculated, and interpreted as follow: ≤0.02, trivial; >0.2-0.6, small; >0.6-1.2, moderate; >1,2-2.0, large; >2.0-4.0, very large; >4.0, extremely large (Hopkins et al. 2009). Practical significance of differences was also assessed using the signal to noise ratio (SNR), which was calculated as the mean difference between the test scores at two time points (i.e. T1, T2, T3) divided by typical error of measurement (Amann et al. 2008). The mean percentage differences between the test scores at two time points were considered as the signal and the absolute reliability (expressed as a percentage value) as the noise (Amann et al. 2008). For this purpose, test-retest reliability coefficients were established using a typical error of measurement expressed as coefficient of variation (CV). CVs were determined in our laboratory in 15 basketball players on 2 trials, resulting as follow: Body mass, 0.7%; Body fat percentage, 3.4%; $MOG_{[La-]}$, 8.0%; MOG_{HR}, 0.8%; $HIT_{[La-]}$, 12.4%; $HIT_{[H+]}$, 5.3%; $HIT_{[HCO3-]}$, 7.2%; HIT_{HR}, 2.3%; CMJ_h, 3.8%; absolute PPO, 2.5%; relative PPO, 2.9%; absolute and relative PF, 3.8%. The CV of the Yo-Yo IR1 has been described previously (Krustrup et al. 2003). Probabilities were also calculated to compare the true (unknown) differences and the smallest worthwhile changes (SWC). SWC was obtained multiplying the between-subject SD by 0.2. Quantitative chances of harmful, trivial or beneficial differences were evaluated qualitatively according to established criteria: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain. When the probability of having higher or lower values than the SWC was less than 5%, the true difference was assessed as unclear. Customized spreadsheets and SPSS statistical software (version 24.0, IBM SPSS Statistics, Chicago, IL, USA) were utilised to perform data analysis.

Results

Anthropometric characteristics and physical test results at T1, T2 and T3 are presented in Table 7.1, while standardized differences within Division I, Division II and Division III are reported in Table 7.2, 7.3 and 7.4, respectively. As four Division II and five Division III players did not perform the Yo-Yo IR1 at all-time points during the season, their data were not included in the statistical analysis of the test.

After the preparation period, likely to almost certain improvements have been found in Mognoni's test and HIT physiological responses among all Divisions. In addition, Yo-Yo IR1 performance was almost certain increased from T1 to T2 in Division II and III, but only likely improved further in Division III during the in-season phase. From T2 to T3, $MOG_{[La-]}$ was very likely reduced among Divisions II and Divisions III, while likely to very likely better physiological responses to HIT (i.e. $HIT_{[La-]}$, $HIT_{[H+]}$ and $HIT_{[HCO3-]}$) were observed in Division I. After the preparation period, Division I produced possibly to likely greater PPO and PF during CMJ, but only PPO were possibly to likely increased from T2 to T3. Unclear to likely trivial changes were found in PPO and PF produced during CMJ by Division II across the season. The CMJ variables were possibly to very likely improved from T1 to T3 in Division III.

Table 7.1. Anthropometric characteristics and physical tests data measured across the basketball season.

		T1	T2	T3
		Anthropometric Characteristics		
Body mass (kg)	Division I	99.3 ± 11.4	99.0 ± 11.1	98.5 ± 11.3
	Division II	92.7 ± 12.7	92.4 ± 12.1	92.1 ± 11.9
	Division III	86.6 ± 11.7	86.4 ± 11.3	87.1 ± 11.8
Body fat (%)	Division I	13.3 ± 4.1	12.3 ± 4.1	12.1 ± 3.7
	Division II	10.5 ± 3.2	10.4 ± 3.1	10.7 ± 3.3
	Division III	10.8 ± 4.2	9.5 ± 3.7	9.5 ± 3.5
		Mognoni's Test		
$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	Division I	4.3 ± 1.6	3.4 ± 1.3	3.4 ± 1.2
	Division II	4.8 ± 1.5	4.3 ± 1.4	3.4 ± 0.8
	Division III	4.2 ± 1.5	3.5 ± 1.1	3.0 ± 1.0
MOG_{HR} (bpm)	Division I	165 ± 7	156 ± 6	159 ± 9
	Division II	168 ± 11	157 ± 6	160 ± 7
	Division III	166 ± 11	162 ± 12	160 ± 10
		High-intensity Intermittent Test		
$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	Division I	5.3 ± 2.6	3.9 ± 1.4	3.3 ± 1.5
	Division II	8.2 ± 2.5	4.8 ± 2.4	5.1 ± 1.5
	Division III	7.5 ± 1.7	4.9 ± 1.1	4.6 ± 1.5
$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	Division I	46.7 ± 6.7	43.2 ± 2.9	40.9 ± 2.4
	Division II	53.1 ± 6.5	45.5 ± 4.5	47.7 ± 4.0
	Division III	52.8 ± 6.3	47.8 ± 3.7	47.2 ± 4.7
$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	Division I	20.3 ± 3.5	21.9 ± 1.7	23.1 ± 2.4
	Division II	16.6 ± 2.4	20.4 ± 2.5	20.1 ± 2.1
	Division III	17.0 ± 3.3	20.8 ± 1.7	20.7 ± 2.7
HIT_{HR} (bpm)	Division I	160 ± 8	150 ± 5	149 ± 9
	Division II	164 ± 7	150 ± 8	155 ± 9
	Division III	169 ± 12	156 ± 12	154 ± 11

		Yo-Yo Intermittent Recovery Test – level 1					
Distance (m)	Division I	-		-		-	
	Division II	1765	± 324	2250	± 247	2225	± 217
	Division III	1610	± 330	2140	± 373	2390	± 419
		Counter-Movement Jump test					
CMJ_h (cm)	Division I	46.9	± 4.4	46.1	± 5.6	47.2	± 5.6
	Division II	50.9	± 5.6	49.7	± 4.6	50.4	± 4.4
	Division III	50.1	± 4.8	51.1	± 5.3	51.6	± 5.1
PPO ($W·kg^{-1}$)	Division I	53.5	± 4.8	55.3	± 5.8	57.2	± 5.1
	Division II	56.1	± 5.2	56.1	± 4.9	56.1	± 4.8
	Division III	54.4	± 5.1	56.2	± 5.8	57.2	± 5.7
PF ($N·kg^{-1}$)	Division I	25.7	± 1.9	26.9	± 2.3	27.1	± 2.3
	Division II	25.9	± 2.0	26.2	± 3.0	26.1	± 2.9
	Division III	25.1	± 1.9	25.5	± 2.4	25.6	± 1.8
PPO (W)	Division I	5282	± 582	5445	± 562	5611	± 681
	Division II	5182	± 745	5172	± 722	5162	± 732
	Division III	4691	± 624	4836	± 680	4972	± 783
PF (N)	Division I	2539	± 271	2658	± 345	2663	± 348
	Division II	2388	± 294	2408	± 318	2392	± 332
	Division III	2166	± 249	2191	± 285	2219	± 282

Abbreviations: CMJ_h, Counter-movement jump height; MOG, Mognoni's test; HIT, High-intensity Intermittent Test; HR, heart rate; PPO, peak power output; PF, peak force; [H+], blood hydrogen ions concentration; [HCO3-], blood bicarbonates concentration; [La-], blood lactate concentration; T1, before the preparation period; T2, after the preparation period; T3, during the competitive phase of the season.

Table 7.2. Comparison of anthropometric characteristics and physical test results between seasonal phases in Division I.

		MBI (%)	Rating	ES (90% CL)	SNR (90% CL)
		T2 VS T1			
Anthropometrics	Body mass (kg)	0/100/0	Almost certain trivial	-0.02 ±0.08	-0.28 ±1.22
	Body fat (%)	77/23/0	Likely beneficial	-0.23 ±0.12	-0.29 ±0.15
Mognoni's Test	$MOG_{[La-]}$ (mmol·L^{-1})	98/2/0	Very likely beneficial	-0.51 ±0.30	-2.62 ±1.52
	MOG_{HR} (bpm)	100/0/0	Almost certain beneficial	-1.16 ±0.52	-7.08 ±3.18
HIT Test	$HIT_{[La-]}$ (mmol·L^{-1})	84/15/1	Likely beneficial	-0.52 ±0.32	-1.56 ±0.98
	$HIT_{[H+]}$ (mmol·L^{-1})	92/7/1	Likely beneficial	-0.49 ±0.38	-1.29 ±1.00
	$HIT_{[HCO3-]}$ (mmol·L^{-1})	93/6/1	Likely beneficial	0.41 ±0.36	1.23 ±1.07
	HIT_{HR} (bpm)	100/0/0	Almost certain beneficial	-1.20 ±0.56	-2.74 ±1.28
Yo-Yo IR1 Test	Distance (m)	-	-	-	-
CMJ test	CMJ_h (cm)	1/53/46	Possibly harmful	-0.17 ±0.26	-0.53 ±0.79
	PPO (W·kg^{-1})	83/17/0	Likely beneficial	0.36 ±0.27	1.16 ±0.86
	PF (N·kg^{-1})	94/5/0	Likely beneficial	0.60 ±0.40	1.23 ±0.82
	PPO (W)	73/27/0	Possibly beneficial	0.26 ±0.22	1.27 ±1.06
	PF (N)	86/13/0	Likely beneficial	0.41 ±0.28	1.16 ±0.78
		T3 VS T2			
Anthropometrics	Body mass (kg)	0/100/0	Almost certain trivial	-0.05 ±0.07	-0.88 ±1.28
	Body fat (%)	3/97/0	Very likely trivial	-0.04 ±0.12	-0.05 ±0.15
Mognoni's Test	$MOG_{[La-]}$ (mmol·L^{-1})	12/68/20	Unclear	-0.02 ±0.28	0.14 ±2.07
	MOG_{HR} (bpm)	3/31/66	Possibly harmful	0.38 ±0.52	1.98 ±2.67
HIT Test	$HIT_{[La-]}$ (mmol·L^{-1})	91/9/0	Likely beneficial	-0.42 ±0.37	-1.78 ±1.57
	$HIT_{[H+]}$ (mmol·L^{-1})	96/4/0	Very likely beneficial	-0.76 ±0.42	-1.01 ±0.56
	$HIT_{[HCO3-]}$ (mmol·L^{-1})	95/5/0	Likely beneficial	0.67 ±0.36	0.74 ±0.39
	HIT_{HR} (bpm)	42/37/21	Unclear	-0.15 ±1.03	-0.30 ±2.11
Yo-Yo IR1 Test	Distance (m)	-	-	-	-
CMJ test	CMJ_h (cm)	54/46/0	Possibly beneficial	0.18 ±0.18	0.62 ±0.61
	PPO (W·kg^{-1})	79/20/1	Likely beneficial	0.30 ±0.29	1.22 ±1.16
	PF (N·kg^{-1})	20/79/1	Likely trivial	0.09 ±0.19	0.21 ±0.46
	PPO (W)	62/37/1	Possibly beneficial	0.28 ±0.34	1.16 ±1.42
	PF (N)	4/93/3	Likely trivial	0.01 ±0.17	0.05 ±0.63

			T3 VS T1				
Anthropometrics	Body mass (kg)	4/96/0	Very likely trivial	-0.07	±0.11	-1.16	±1.89
	Body fat (%)	82/18/0	Likely beneficial	-0.27	±0.18	-0.35	±0.22
Mognoni's Test	$MOG_{[La-]}$ (mmol·L^{-1})	99/1/0	Very likely beneficial	-0.53	±0.26	-2.51	±1.22
	MOG_{HR} (bpm)	98/2/0	Very likely beneficial	-0.84	±0.50	-5.20	±3.06
HIT Test	$HIT_{[La-]}$ (mmol·L^{-1})	99/1/0	Very likely beneficial	-0.74	±0.40	-3.00	±1.61
	$HIT_{[H+]}$ (mmol·L^{-1})	99/1/0	Very likely beneficial	-0.82	±0.46	-2.23	±1.25
	$HIT_{[HCO3-]}$ (mmol·L^{-1})	99/1/0	Very likely beneficial	0.74	±0.42	2.03	±1.16
	HIT_{HR} (bpm)	100/0/0	Almost certain beneficial	-1.30	±0.59	-3.02	±1.37
Yo-Yo IR1 Test	Distance (m)	-	-	-		-	
CMJ test	CMJ_h (cm)	13/79/8	Unclear	0.05	±0.25	0.07	±0.33
	PPO (W·kg^{-1})	100/0/0	Almost certain beneficial	0.73	±0.29	2.42	±0.97
	PF (N·kg^{-1})	96/4/0	Very likely beneficial	0.70	±0.46	1.45	±0.95
	PPO (W)	97/3/0	Very likely beneficial	0.53	±0.31	2.46	±1.44
	PF (N)	86/14/0	Likely beneficial	0.43	±0.34	1.21	±0.95

Abbreviations: CL, confidence limits; CMJ_h, Counter-movement jump height; ES, effect size; MBI (%), percent chances of beneficial/trivial/harmful effects; MOG, Mognoni's test; HIT, High-intensity Intermittent Test; HR, heart rate; PPO, peak power output; PF, peak force; SNR, Signal to noise ratio; [H+], blood hydrogen ions concentration; [HCO3-], blood bicarbonates concentration; [La-], blood lactate concentration; T1, before the preparation period; T2, after the preparation period; T3, during the competitive phase of the season.

Table 7.3. Comparison of anthropometric characteristics and physical test results between seasonal phases in Division II.

		MBI (%)	Rating	ES (90% CL)		SNR (90% CL)	
			T2 VS T1				
Anthropometrics	Body mass (kg)	0/100/0	Almost certain trivial	-0.02	±0.07	-0.28	±0.94
	Body fat (%)	13/83/4	Likely trivial	-0.04	±0.21	-0.04	±0.21
Mognoni's Test	$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	71/25/3	Possibly beneficial	-0.31	±0.45	-1.34	±1.91
	MOG_{HR} (bpm)	100/0/0	Almost certain beneficial	-0.91	±0.35	-8.03	±3.17
HIT Test	$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	100/0/0	Almost certain beneficial	-1.23	±0.28	-3.66	±0.88
	$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	100/0/0	Almost certain beneficial	-1.07	±0.37	-2.62	±0.94
	$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	100/0/0	Almost certain beneficial	1.49	±0.46	3.26	±1.03
	HIT_{HR} (bpm)	100/0/0	Almost certain beneficial	-1.98	±0.66	-3.92	±1.35
Yo-Yo IR1 Test	Distance (m)	100/0/0	Almost certain beneficial	1.33	±0.31	5.84	±1.79
CMJ test	CMJ_h (cm)	4/39/57	Possibly harmful	-0.21	±0.33	-0.59	±0.95
	PPO ($W \cdot kg^{-1}$)	11/78/10	Unclear	0.00	±0.24	0.01	±1.52
	PF ($N \cdot kg^{-1}$)	33/59/8	Unclear	0.16	±0.45	0.27	±0.75
	PPO (W)	2/94/4	Likely trivial	-0.01	±0.16	-0.06	±0.81
	PF (N)	23/70/8	Unclear	0.06	±0.30	0.22	±1.03
			T3 VS T2				
Anthropometrics	Body mass (kg)	1/99/0	Very likely trivial	-0.02	±0.10	-0.44	±1.72
	Body fat (%)	1/81/18	Likely trivial	0.09	±0.19	0.08	±0.17
Mognoni's Test	$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	97/3/0	Very likely beneficial	-0.63	±0.33	-2.46	±1.28
	MOG_{HR} (bpm)	0/21/78	Likely harmful	0.46	±0.36	2.32	±1.81
HIT Test	$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	2/27/72	Possibly harmful	0.11	±0.30	1.19	±3.27
	$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	0/15/84	Likely harmful	0.46	±0.40	0.93	±0.80
	$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	13/57/30	Unclear	-0.11	±0.45	-0.15	±0.64
	HIT_{HR} (bpm)	0/8/92	Likely harmful	0.54	±0.40	1.42	±1.04
Yo-Yo IR1 Test	Distance (m)	4/81/15	Likely trivial	-0.09	±0.32	-0.20	±0.69
CMJ test	CMJ_h (cm)	42/57/1	Possibly beneficial	0.16	±0.26	0.43	±0.71
	PPO ($W \cdot kg^{-1}$)	7/87/5	Unclear	0.01	±0.19	0.03	±0.65
	PF ($N \cdot kg^{-1}$)	17/54/28	Unclear	-0.04	±0.37	-0.13	±1.09
	PPO (W)	2/94/4	Likely trivial	-0.01	±0.16	-0.09	±1.05
	PF (N)	10/66/25	Unclear	-0.05	±0.32	-0.21	±1.41

			T3 VS T1				
Anthropometrics	Body mass (kg)	1/99/0	Very likely trivial	-0.04	±0.08	-0.71	±1.33
	Body fat (%)	5/80/15	Likely trivial	0.04	±0.22	0.04	±0.20
Mognoni's Test	$MOG_{[La-]}$ ($mmol \cdot L^{-1}$)	100/0/0	Almost certain beneficial	-0.92	±0.41	-3.53	±1.62
	MOG_{HR} (bpm)	98/2/0	Very likely beneficial	-0.66	±0.37	-5.86	±3.27
HIT Test	$HIT_{[La-]}$ ($mmol \cdot L^{-1}$)	100/0/0	Almost certain beneficial	-1.13	±0.29	-3.01	±0.80
	$HIT_{[H+]}$ ($mmol \cdot L^{-1}$)	100/0/0	Almost certain beneficial	-0.76	±0.32	-1.82	±0.79
	$HIT_{[HCO3-]}$ ($mmol \cdot L^{-1}$)	100/0/0	Almost certain beneficial	1.38	±0.43	3.07	±0.97
	HIT_{HR} (bpm)	98/2/0	Very likely beneficial	-1.32	±0.85	-2.63	±1.71
Yo-Yo IR1 Test	Distance (m)	100/0/0	Almost certain beneficial	1.26	±0.28	5.59	±1.67
CMJ test	CMJ_h (cm)	12/59/29	Unclear	-0.08	±0.32	-0.18	±0.76
	PPO ($W \cdot kg^{-1}$)	21/61/18	Unclear	0.01	±0.34	0.05	±2.53
	PF ($N \cdot kg^{-1}$)	26/62/13	Unclear	0.10	±0.45	0.14	±0.65
	PPO (W)	5/86/9	Likely trivial	-0.03	±0.20	-0.15	±1.16
	PF (N)	14/73/13	Unclear	0.01	±0.30	0.01	±0.24

Abbreviations: CL, confidence limits; CMJ_h, Counter-movement jump height; ES, effect size; MBI (%), percent chances of beneficial/trivial/harmful effects; MOG, Mognoni's test; HIT, High-intensity Intermittent Test; HR, heart rate; PPO, peak power output; PF, peak force; SNR, Signal to noise ratio; [H+], blood hydrogen ions concentration; [HCO3-], blood bicarbonates concentration; [La-], blood lactate concentration; T1, before the preparation period; T2, after the preparation period; T3, during the competitive phase of the season.

Table 7.4. Comparison of anthropometric characteristics and physical test results between seasonal phases in Division III.

		MBI (%)	Rating	ES (90% CL)		SNR (90% CL)	
			T2 VS T1				
Anthropometrics	Body mass (kg)	0/100/0	Almost certain trivial	-0.02	±0.06	-0.30	±1.08
	Body fat (%)	92/8/0	Likely beneficial	-0.27	±0.13	-0.36	±0.17
Mognoni's Test	$MOG_{[La-]}$ (mmol·L^{-1})	82/16/1	Likely beneficial	-0.41	±0.36	-1.81	±1.59
	MOG_{HR} (bpm)	76/21/3	Likely beneficial	-0.39	±0.47	-3.48	±4.23
HIT Test	$HIT_{[La-]}$ (mmol·L^{-1})	100/0/0	Almost certain beneficial	-1.42	±0.52	-2.78	±1.02
	$HIT_{[H+]}$ (mmol·L^{-1})	99/1/0	Very likely beneficial	-0.76	±0.38	-1.75	±0.89
	$HIT_{[HCO3-]}$ (mmol·L^{-1})	100/0/0	Almost certain beneficial	1.06	±0.40	3.31	±1.24
	HIT_{HR} (bpm)	100/0/0	Almost certain beneficial	-1.05	±0.46	-3.41	±1.49
Yo-Yo IR1 Test	Distance (m)	100/0/0	Almost certain beneficial	1.43	±0.36	6.83	±2.20
CMJ test	CMJ_h (cm)	47/53/0	Possibly beneficial	0.19	±0.21	0.49	±0.54
	PPO (W·kg^{-1})	80/20/0	Likely beneficial	0.33	±0.27	1.12	±0.91
	PF (N·kg^{-1})	42/51/6	Unclear	0.18	±0.41	0.33	±0.76
	PPO (W)	54/46/0	Possibly beneficial	0.22	±0.21	1.21	±1.17
	PF (N)	25/69/6	Unclear	0.10	±0.29	0.27	±0.80
			T3 VS T2				
Anthropometrics	Body mass (kg)	0/100/0	Almost certain trivial	0.06	±0.07	1.03	±1.38
	Body fat (%)	2/96/1	Very likely trivial	-0.01	±0.14	-0.02	±0.20
Mognoni's Test	$MOG_{[La-]}$ (mmol·L^{-1})	98/2/0	Very likely beneficial	-0.47	±0.18	-2.06	±0.78
	MOG_{HR} (bpm)	46/49/6	Unclear	-0.16	±0.33	-1.50	±3.12
HIT Test	$HIT_{[La-]}$ (mmol·L^{-1})	71/28/2	Possibly beneficial	-0.30	±0.43	-0.82	±1.18
	$HIT_{[H+]}$ (mmol·L^{-1})	36/54/10	Unclear	-0.13	±0.55	-0.23	±0.96
	$HIT_{[HCO3-]}$ (mmol·L^{-1})	6/75/19	Unclear	-0.05	±0.50	-0.13	±1.41
	HIT_{HR} (bpm)	31/59/10	Unclear	-0.09	±0.34	-0.32	±1.16
Yo-Yo IR1 Test	Distance (m)	84/14/2	Likely beneficial	0.60	±0.62	2.36	±2.45
CMJ test	CMJ_h (cm)	27/71/2	Possibly beneficial	0.09	±0.21	0.29	±0.65
	PPO (W·kg^{-1})	46/54/1	Possibly beneficial	0.16	±0.21	0.64	±0.82
	PF (N·kg^{-1})	21/74/5	Unclear	0.04	±0.22	0.15	±0.88
	PPO (W)	43/57/0	Possibly beneficial	0.19	±0.18	1.04	±1.01
	PF (N)	21/78/1	Likely trivial	0.09	±0.18	0.33	±0.65

			T3 VS T1				
Anthropometrics	Body mass (kg)	0/99/1	Very likely trivial	0.04	±0.09	0.73	±1.70
	Body fat (%)	85/15/0	Likely beneficial	-0.29	±0.20	-0.37	±0.25
Mognoni's Test	$MOG_{[La-]}$ (mmol·L^{-1})	100/0/0	Almost certain beneficial	-0.76	±0.32	-3.57	±1.51
	MOG_{HR} (bpm)	97/3/0	Very likely beneficial	-0.57	±0.32	-4.93	±2.77
HIT Test	$HIT_{[La-]}$ (mmol·L^{-1})	100/0/0	Almost certain beneficial	-1.62	±0.38	-3.32	±0.77
	$HIT_{[H+]}$ (mmol·L^{-1})	100/0/0	Almost certain beneficial	-0.84	±0.27	-1.96	±0.63
	$HIT_{[HCO3-]}$ (mmol·L^{-1})	100/0/0	Almost certain beneficial	1.04	±0.26	3.15	±0.79
	HIT_{HR} (bpm)	100/0/0	Almost certain beneficial	-1.15	±0.29	-3.71	±0.94
Yo-Yo IR1 Test	Distance (m)	100/0/0	Almost certain beneficial	2.10	±0.62	9.97	±3.64
CMJ test	CMJ_h (cm)	80/20/0	Likely beneficial	0.29	±0.21	0.79	±0.57
	PPO (W·kg^{-1})	98/2/0	Very likely beneficial	0.52	±0.25	1.78	±0.84
	PF (N·kg^{-1})	55/42/2	Possibly beneficial	0.22	±0.35	0.48	±0.75
	PPO (W)	93/7/0	Likely beneficial	0.42	±0.22	2.28	±1.21
	PF (N)	48/51/1	Possibly beneficial	0.20	±0.27	0.61	±0.81

Abbreviations: CL, confidence limits; CMJ_h, Counter-movement jump height; ES, effect size; MBI (%), percent chances of beneficial/trivial/harmful effects; MOG, Mognoni's test; HIT, High-intensity Intermittent Test; HR, heart rate; PPO, peak power output; PF, peak force; SNR, Signal to noise ratio; [H+], blood hydrogen ions concentration; [HCO3-], blood bicarbonates concentration; [La-], blood lactate concentration; T1, before the preparation period; T2, after the preparation period; T3, during the competitive phase of the season.

Discussion

This study aimed to quantify the changes in physical fitness of basketball players selected from different teams of different playing levels (from elite to semi-professional) during the preparation and competitive phases of the season. The main improvements in performance occurred during the preparation period, when the aerobic fitness and the ability to sustain high-intensity intermittent exercise were likely to almost certain improved among all Divisions. The likely ineffective training stimuli or overreaching phenomenon occurred during the preparation period, determined trivial-to-small improvements in CMJ variables, regardless of the competitive levels. During the competitive phase of the season, we found different changes in physical fitness level among the Divisions involved in the present study. Division II and Division III further increased their aerobic fitness, while likely to very likely better physiological responses to a submaximal high-intensity intermittent run were observed only among Division I. The different variations in fitness performance among the Divisions may be due to the different training stimuli (e.g. training load) and game activity demands in which athletes of different playing levels usually undergo during the entire season.

The present results show that anthropometric characteristics of basketball players are minimally affected by the different phases of the season. Athletes' body mass was maintained at all-time points among the Divisions, while trivial to small reduction in body fat percentage were found after the preparation period. Similar results were previously reported among NCAA and NBA basketball players (Caterisano et al. 1997, Gonzalez et al. 2013, Groves and Gayle 1993, Hoffman et al. 1991).

The physiological responses to a submaximal continuous running test (Mognoni's test) were used to evaluate the aerobic fitness of basketball players (Ferioli et al. 2017, Sirtori et al. 1993). The preparation period induced possibly to almost certain adaptations to the Mognoni's test among all Divisions. Very likely reductions in $MOG_{[La-]}$ were observed form T2 to T3 in

Division II and Division III, but no further adaptations were found in Division I. These findings confirm previous studies, which reported aerobic fitness level to improve after the preparation period and to be preserved or slightly further increased during the competitive phase of the season (Aoki et al. 2017, Bolonchuk et al. 1991, Caterisano et al. 1997, Drinkwater et al. 2005, Ferioli et al. 2017, Hoffman et al. 1991, Hunter et al. 1993, Tavino et al. 1995). $MOG_{[La-]}$ can be efficiently used to monitor the aerobic fitness of basketball athletes. However, the magnitude of these physiological adaptations were only small to moderate, which may be related to the nonsport-specific type of exercise performed during this test (i.e. continuous vs intermittent running).

Several studies had analyses seasonal changes in Yo-Yo IR1 performance among adult player of different team sports like soccer (Bangsbo et al. 2008), but only few studies have focused on basketball (Aoki et al. 2017, Ferioli et al. 2017). The improvements of Yo-Yo IR1 performance observed in the present study after the preparation period were similar to those previously reported in professional adult basketball players (Aoki et al. 2017, Ferioli et al. 2017). From T2 to T3, Yo-Yo IR1 performance was likely maintained and likely further increased in Division II and Division III respectively. These results are partially in contrast with recent research that showed Brazilian professional players cover greater distances during the Yo-Yo IR1 during the in-season phase compared to the 4th week of the preparation period (Aoki et al. 2017). However, this difference can be due to the greater fitness level of the Division II athletes assessed in the present study, who covered considerably greater distances during the Yo-Yo IR1 compared to the Brazilian players (before preparation period: 1765±324 vs. 1120±413 m; mid-after preparation period: 2250±247 vs. 1355±466 m; in-season: 2225±217 vs. 1737±515, respectively). During the competitive phase of the season, the Yo-Yo IR1 performance of Division II and Division III was lower compared to Tunisian National players (2619 ±731 m) (Ben Abdelkrim et al. 2010c), but slightly higher than performance measured in Italian Division

I basketball players (1945 ±144 m) at the end of the regular season (Manzi et al. 2010). The large SNR values observed for Yo-Yo IR1 suggest that this test can be effectively used to monitor changes in performance during the preparation period, as the variations observed from T1 to T2 are higher than test-retest error (reliability) of the test (Amann et al. 2008). However, practitioners should consider the difficulties associated with the use of a maximal test with professional athletes during the competitive phase of the season. Indeed, Division I players of the present study did not performed the Yo-Yo IR1 due to restrictions made by technical coaches, while four Division II and five Division III players were not able to carry out the test at all-time points during the season.

In the present study, the physiological responses to HIT were influenced by the different phases of the season. Specifically, after the preparation period, $HIT_{[La-]}$, $HIT_{[H+]}$ and HIT_{HR} were likely to almost certain reduced, while $HIT_{[HCO3-]}$ was likely to almost certain increased among all Divisions. The magnitude of these effects (i.e. $HIT_{[La-]}$, $HIT_{[H+]}$ and $HIT_{[HCO3-]}$) was small for Division I, but moderate to large for Division II and III. Similar results have been previously reported among professional and semi-professional Italian basketball players (Ferioli et al. 2017). During the competitive phase of the season, physiological responses to HIT (i.e. $HIT_{[La-]}$, $HIT_{[H+]}$ and $HIT_{[HCO3-]}$) were further improved in Division I players. However, unclear to only small changes were observed in HIT performance from T2 to T3 among Division II and III. These results suggest that Division I further enhanced their ability to maintain acid-base balance during submaximal intermittent exercise within the competitive phase of the season. Indeed, the reduction in $HIT_{[La-]}$ reflects a lower anaerobic contribution to the test, while the lower $HIT_{[H+]}$ and the higher $HIT_{[HCO3-]}$ suggest an improvement in the buffer capacity. The additional adaptations observed among Division I during the competitive phase of the season may be a consequence of the greater intermittent workload and high-intensity phases which occur during elite competitions compared to lower level ones (Ben Abdelkrim et al. 2007, Stojanovic et al.

2017). In addition, higher-level competitive players usually undergo a greater training load than lower level counterparts (Ferioli et al. 2017). Training load has been previously reported to be moderately associated with beneficial variation in physiological responses (i.e. $HIT_{[La-]}$, $HIT_{[H+]}$) to HIT (Ferioli et al. 2017). These results suggest that the measurement of physiological responses to a submaximal high-intensity intermittent exercise could represent a valid alternative to investigate the training adaptations across an entire basketball season than using a maximal intermittent running test (e.g. Yo-Yo IR1). Indeed, the high SNR values observed for HIT from T1 to T3 demonstrate the practical significance of this test because the performance changes observed from the beginning of the preparation period and the competitive phase of the season are higher than the test-retest error (reliability) of the tests (Amann et al. 2008).

Studies comparing changes in strength characteristics of basketball players across different seasonal phases reported contrasting results (Bolonchuk et al. 1991, Caterisano et al. 1997, Drinkwater et al. 2005, Drinkwater et al. 2008, Groves and Gayle 1993, Hoffman et al. 1991, Hunter et al. 1993, Tavino et al. 1995). In the present study, trivial to small variations were observed in CMJ variables among Division II and Division III during the different seasonal phases. On the other hand, after the preparation period, Division I produced possibly to likely greater PPO and PF during CMJ, but only PPO were possibly to likely increased from T2 to T3. It has been reported that these parameters are better related to absolute values of dynamic strength than jump height (Nuzzo et al. 2008). Although the magnitude of the variations of PF and PPO was small to moderate, their SNRs were large, suggesting that these parameters are appropriate indicators to monitor the neuromuscular status of players across the different periods of the season. The similar or slightly improved jumping performance among the Divisions could be a consequence of the ineffective exercises stimuli or, conversely, could be partially influenced by fatigue state occurring during the preparation and competitive phases of the season (Claudino et al. 2016). Considering that strength and power have been previously reported to be indicators of playing time and to be important characteristics for success in basketball (Hoffman et al. 1996, Ziv and Lidor 2009), strength and conditioning coaches should monitor these characteristics within the seasonal phases.

Although these studies provide, for the first time, insight into changes in physical fitness of adult basketball players of different playing level competing in Europe, athletes were selected from just one national tournament, thus measured data might not be representative of overall basketball players. In addition, only a limited number of anthropometrical and physiological capacities could be assessed in the present study. Thus, to develop a more holistic understanding of these capacities among European basketball players, we suggest that future studies utilize a wider range of test parameters.

Conclusions and practical applications

The present study provides information regarding changes in physical performance during the different seasonal phases in adult basketball players. In general, the preparation period appears to minimally affect variables measured during vertical jump test but enhance the aerobic fitness and the ability to sustain high-intensity intermittent exercise. The changes in physical performance during the competitive phase of the season seem to be affected by the competitive level of play. We recommend that physical and physiological tests be used to evaluate the fitness status of players during the different seasonal phases.

CHAPTER EIGHT

Activity demands of basketball games: comparison between different competitive levels.

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"Activity demands of basketball games: comparison between different competitive levels."

Abstract

Purpose: to examine the differences in the activity demands of basketball games between different competitive levels.

Methods: Video-based time-motion analysis was performed to assess the players' physical activity across 33 Division I, 37 Division II, 36 Division III and 30 Division VI individual official games. The frequency of occurrence (n/min) and the duration in percentage of playing time (i.e. total and live time) were calculated for high-, moderate-, low- intensity activities (HIA, MIA and LIA, respectively) and recovery (REC).

Results: Division I performed an almost certain greater number of HIA, MIA and total actions per minutes of playing time compared to Division II, that performed similarly to Division III. Division VI carried out a likely-to-very likely lower number of LIA, MIA and total actions per minutes of playing time compared to Division III. Division I spent almost certain greater playing time competing in HIA and MIA compared to lower divisions. Time spent at REC was very likely greater in Division VI compared to all other Divisions.

Conclusions: The present study clearly shows that basketball games of different competitive levels are characterized by different physical activities. The ability to sustain a greater intermittent workload and HIA during competitions should be considered as an important characteristic for success in basketball.

Key Words: Competitive level; Time-motion analysis; Activity demands; High-intensity.

Introduction

The quantification of team sports competition demands provides useful information for developing specific team-based trainings, for analysing players' physical performance and for designing rehabilitation and return-to-play programs (Taylor et al. 2017). The specific competition demands have been assessed in terms of internal (e.g. heart rate and metabolic measurements) and external (e.g. frequency and durations of activities) responses to the games within several team sports (Fox et al. 2017, Taylor et al. 2017). Whilst physiological responses to basketball competitions have been widely reported in literature (Beam and Merrill 1994, Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2009, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, Klusemann et al. 2013, Matthew and Delextrat 2009, McInnes et al. 1995, Montgomery et al. 2010, Moreira et al. 2012, Narazaki et al. 2009, Torres-Ronda et al. 2016, Vaquera et al. 2008), an increasing number of studies have recently focused on the activity demands across games (Stojanovic et al. 2017). Due to the high-cost and/or the limited effectiveness of the available micro-technologies (e.g. global positioning systems and micro-sensors), time-motion analysis (TMA) has been widely used for measuring the activity demands within male basketball competitions (Fox et al. 2017). The resulting data on the topic demonstrated the intermittent nature of basketball games, during which players perform on average 758 to 2749 movements lasting up to 2-3s (Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, McInnes et al. 1995, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Stojanovic et al. 2017, Torres-Ronda et al. 2016). In addition, male players were reported to spend ~28-63% recovering (REC) and ~14-40%, ~11-28% and ~11-20% performing Low-intensity activities (LIA), Moderate-intensity activities (MIA) and High-intensity activities (HIA) respectively during playing time (Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, McInnes et al. 1995, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Stojanovic et al. 2017, Torres-Ronda et al.

2016). The wide variations observed in these results are likely due to the different game rules applied (e.g. match duration) and methodologies used to classify movement patterns. Although these studies have provided important insights on the topic, some limitation should be acknowledged. Most of these studies analysed collegiate or junior teams (Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, Conte et al. 2016, Montgomery et al. 2010, Narazaki et al. 2009), players from the same club (Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2007, Bishop and Wright 2006, Conte et al. 2016, McInnes et al. 1995, Montgomery et al. 2010, Narazaki et al. 2009, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Torres-Ronda et al. 2016), a limited number of athletes (i.e. 6 to 14) (Bishop and Wright 2006, McInnes et al. 1995, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Torres-Ronda et al. 2016), and/or non-official competitive games (Torres-Ronda et al. 2016. Therefore, to overcome these limitations, studies that assess the activity demands of a large sample of senior basketball players during official competitions are required.

The comparison of match activity demands at different playing levels would provide important insight for the identification of the key physical elements of the game and for the development of more specific training programs (Scanlan et al. 2011). However, only few studies have compared the game activity demands between different competitive levels in basketball (Ben Abdelkrim et al. 2010a, Scanlan et al. 2011, Scanlan et al. 2015b). Ben Abdelkrim et al. (2010a) described the game activity requirements of international and national junior Tunisian male basketball players. The former performed a greater number of HIA (280±54 vs 198±25) and total movements (1105±74 vs 1004±27) and spent significantly more live time in HIA (20.3±2.1% vs 16.2±1.2%) and REC (28.1±2.9% vs 24.9±3.2%), while the latter completed a significantly greater proportion of MIA (31.0±3.9% vs 24.4±3.6%) during matches. On the contrary, Scanlan et al. (2011) reported open-age Australian male elite players performing more activities at moderate to high intensities compared to sub-elite counterparts, who complete more maximal efforts interspersed by longer periods at low-intensities during games. These partially contrasting results might be attributed to the different age group of players (i.e. junior vs senior) and TMA methodologies used. Whilst these studies provide preliminary insights into the game activity demands of junior and open-age male basketball players at different competitive level, only two groups of players were compared (i.e. international vs national and elite vs sub-elite). Furthermore, these data are only indicative of the teams and competitions investigated, thus the results might not be extended reliably to overall high-level basketball players. For these reasons, more studies on the topic are needed. A thorough knowledge of match activity demands at different playing levels might highlight useful information for physical preparation and identification of talents in basketball.

Therefore, the aim of the present study was to examine the differences in the activity demands of official basketball games between different competitive levels (from elite to amateur levels) among a large sample of senior basketball players.

Methods

Subjects

Data were collected from 91 male basketball players competing in the Italian Serie A (Division I, n=25; age: 27±5 years; body mass: 94.8±10.8 kg; stature: 198±9 cm), Serie A2 (Division II, n=20; age: 25±4 years; body mass: 93.3±11.3 kg; stature: 197±8 cm), Serie B (Division III, n=22; age: 26±6 years; body mass: 87.9±14.8 kg; stature: 191±8 cm) and Serie D (Division VI, n=24; age: 22±5 years; body mass: 79.3±10.8 kg; stature: 187±8 cm). Players were selected from a total of 12 basketball teams (i.e. 3 teams for each division). Throughout the data collection period, Division I and Division II athletes were training 7 to 11 times a week, while Division III and Division VI teams were performing on average 5 to 8 and 3 to 4 training sessions a week, respectively. Training sessions lasted 60-120 min, excluding cool down and/or stretching exercises. All the basketball players included in this study were members of the teams from the entire preparation period and had to have played ≥10 minutes per game to be considered for the individual player analysis. All the reserves (those players who play less than 10 minutes per game) were excluded from the study (Hoffman 2000). After verbal and written explanation of the experimental design and potential risks and benefits of the study, written informed consent was signed by all players or their respective parents/guardians if underage. The study was approved by the Independent Institutional Review Board of Mapei Sport Research Centre in accordance with the Helsinki Declaration.

Design and Methodology

A between-subject observational study design was used to assess the game activity demands of basketball players of different competitive levels. A total of 136 individual player activities (Division I, n=33; Division II, n=37; Division III, n=36; Division VI, n=30) were collected across 20 official games throughout the regular competitive seasons 2014-15, 2015-16 and 2016-17. One or two individual game activities were analysed for each player involved in the present study. Playing positions were equally represented in all Division groups to avoid potential bias effects of playing position on the outcomes variables. According to the FIBA rules, games consisted of four 10-min quarters, with 2-min inter-quarter breaks and a 15-min half-time break.

Time-motion analysis

All matches were recorded using a fixed camera (GoPro hero 4 silver edition, San Mateo, CA, USA), located in such a position that allowed a full coverage of the court. All games were captured at a sample rate of 30 Hz and at a resolution of 1080p. Basketball games were recorded for their entire duration, including all stoppages in play. A manual frame by frame software (SICS VideoMatch Basket, version 5.0.5) was used to determine the player activities. According to Mc Innes et al. (1995), individual movement patterns were classified into 8 movement categories as follows: (a) standing/walking; (b) jogging; (c) running; (d) sprinting; (e) low-; (f) moderate-; (g) high- specific movements and (h) jumping. The movements differing from ordinary walking or running were classified as "specific movements", which mainly included shuffling, rolling, reversing and cross-over running activities. All the movements were then grouped according to their relative intensity into REC, LIA, MIA and HIA (Ben Abdelkrim et al. 2007). The activity demands, in terms of frequency of occurrence and duration, were analysed during both live time (LT) and total time (TT). The former includes all the movements of the players on court when the game clock was running, while the latter refers to all the time that the subject was on the court, including all stoppages in play (e.g. free throw phases, fouls), but excluding breaks between quarters and time outs. Frequency of occurrence was calculated as the total number of events (n) performed during the game and normalized by playing time (n/min). Duration of movements was analysed as (a) total time spent performing the movements across the playing time, (b) mean duration of each movement category and (c) in percentage (%) to the playing time. Frequency of occurrence normalized by playing time and duration in percentage to the playing time were considered for statistical analysis. All game demands analyses were performed by two members of the research team. The intra- and inter-tester reliability of TMA were assessed by having the two investigators analysing the first quarter of 10 individual games on two separate occasions. The intra- and inter-tester reliability were determined using the intraclass correlation coefficient and the typical error of measurement expressed as coefficient of variation. All measures possessed acceptable intra- and inter-tester reliability (Table 8.1).

Table 8.1. Intra- and inter-tester reliability of time-motion analysis variables.

		ICC (CI90%)		CV% (CI90%)	
		Inter-operator	Intra-operator	Inter-operator	Intra-operator
Occurrance	REC	0.96 (0.87-0.99)	0.98 (0.96-0.99)	11.4 (8.2-19.4)	5.0 (3.8-7.3)
	LIA	0.95 (0.85-0.98)	0.99 (0.97-1.00)	8.9 (6.4-15.0)	4.1 (3.1-6.1)
	MIA	0.85 (0.59-0.95)	0.88 (0.72-0.96)	15.1 (10.8-26.1)	13.8 (10.5-20.9)
	HIA	0.80 (0.47-0.93)	0.96 (0.89-0.98)	17.5 (12.5-30.4)	12.1 (9.2-18.1)
Duration	REC	0.99 (0.98-1.00)	1.00 (0.99-1.00)	4.1 (2.9-6.8)	1.9 (1.4-2.7)
	LIA	0.98 (0.94-0.99)	0.99 (0.98-1.00)	8.9 (6.4-15.1)	3.7 (2.8-5.4)
	MIA	0.88 (0.66-0.96)	0.88 (0.71-0.96)	15.3 (10.9-26.4)	14.0 (10.6-21.1)
	HIA	0.76 (0.40-0.92)	0.98 (0.95-0.99)	13.6 (9.7-23.3)	10.6 (8.1-15.9)

Abbreviations: CI, confidence intervals; CV%, coefficient of variation in percentage; ICC, intraclass correlation coefficient; REC, Recovery; LIA, low-intensity activities; MIA, medium-intensity activities; HIA, High-intensity activities.

Statistical analysis

The TMA descriptive results are reported as means ± standard deviations (SD). The magnitude-based inference (MBI) approach was used to analyse the data according to Hopkins et al. (2009). All data were first log-transformed to reduce bias arising from non-uniformity of effects or errors (Hopkins et al. 2009). Standardised differences were calculated, and interpreted as follow: ≤0.02, trivial; >0.2-0.6, small; >0.6-1.2, moderate; >1,2-2.0, large; >2.0-4.0, very large; >4.0, extremely large (Hopkins et al. 2009). Probability was also calculated to compare the true (unknown) differences and the smallest worthwhile change (SWC). SWC was obtained by multiplying the between-subject SD by 0.2. Quantitative chances of harmful, trivial or beneficial differences were evaluated qualitatively according to established criteria: <1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain. When the probability of having higher or lower values than the SWC was less than 5%, the true difference was assessed as unclear. Customized spreadsheets were used to perform data analysis.

Results

Data of TMA movement patterns for each competitive level relative to TT and LT are presented in Table 8.2 and 8.3 respectively.

TMA movements pooled into their relative intensities for each competitive level are reported in Table 8.4 and 8.5 for TT and LT respectively, while standardized differences between groups are reported in Table 8.6.

Division I performed an almost certain greater number of HIA, MIA and total actions per minutes of LT and TT compared to Division II, who performed similarly to Division III. Division VI carried out a likely-to-very likely lower number of LIA, MIA and total actions per minutes of playing time (i.e. both LT and TT) compared to Division III. Division I spent almost certain greater LT and TT competing in HIA and MIA compared to lower divisions. Time spent at REC was very likely greater in Division VI compared to all other Divisions.

Table 8.2. Frequency and duration of time-motion analysis movement patterns relative to competitive levels of play during the total time.

TOTAL TIME								
	Stand/walk	Jog	Run	Sprint	Low-SM	Medium-SM	High-SP	Jump
Frequency of occurrence (n)								
DIV I	184 ± 57	98 ± 39	42 ± 15	26 ± 11	208 ± 58	64 ± 21	53 ± 16	29 ± 12
DIV II	184 ± 52	106 ± 36	32 ± 14	15 ± 11	190 ± 50	50 ± 24	37 ± 21	26 ± 10
DIV III	182 ± 63	99 ± 32	31 ± 13	14 ± 16	164 ± 56	43 ± 23	33 ± 25	23 ± 12
DIV VI	179 ± 64	84 ± 36	25 ± 17	18 ± 18	137 ± 50	34 ± 24	30 ± 25	27 ± 14
Frequency of occurrence (n/min)								
DIV I	4.15 ± 0.60	2.19 ± 0.54	0.95 ± 0.26	0.61 ± 0.28	4.77 ± 0.79	1.47 ± 0.34	1.25 ± 0.39	0.66 ± 0.23
DIV II	3.98 ± 0.63	2.29 ± 0.46	0.71 ± 0.29	0.34 ± 0.27	4.16 ± 0.73	1.13 ± 0.53	0.85 ± 0.48	0.57 ± 0.20
DIV III	4.30 ± 0.43	2.37 ± 0.44	0.76 ± 0.28	0.34 ± 0.33	3.96 ± 0.74	1.05 ± 0.49	0.79 ± 0.48	0.53 ± 0.17
DIV VI	4.40 ± 0.49	2.10 ± 0.62	0.61 ± 0.31	0.41 ± 0.36	3.44 ± 0.74	0.79 ± 0.42	0.66 ± 0.43	0.65 ± 0.22
Total duration (s)								
DIV I	1599 ± 468	251 ± 89	81 ± 26	42 ± 18	447 ± 165	103 ± 41	93 ± 36	28 ± 12
DIV II	1757 ± 502	293 ± 102	58 ± 24	24 ± 17	455 ± 149	85 ± 49	68 ± 50	24 ± 10
DIV III	1645 ± 612	281 ± 107	66 ± 31	25 ± 23	366 ± 119	70 ± 38	61 ± 50	20 ± 10
DIV VI	1685 ± 682	248 ± 101	53 ± 39	28 ± 28	310 ± 80	57 ± 41	51 ± 48	24 ± 14
Mean duration (s)								
DIV I	8.84 ± 1.46	2.62 ± 0.35	2.00 ± 0.31	1.67 ± 0.31	2.16 ± 0.52	1.58 ± 0.21	1.73 ± 0.30	0.97 ± 0.08
DIV II	9.68 ± 1.72	2.77 ± 0.37	1.88 ± 0.32	1.71 ± 0.54	2.43 ± 0.58	1.70 ± 0.37	1.67 ± 0.39	0.92 ± 0.11
DIV III	9.06 ± 1.47	2.80 ± 0.36	2.11 ± 0.37	1.94 ± 0.55	2.28 ± 0.42	1.62 ± 0.18	1.72 ± 0.36	0.90 ± 0.09
DIV VI	9.32 ± 1.24	3.00 ± 0.39	2.12 ± 0.47	1.70 ± 0.40	2.37 ± 0.42	1.65 ± 0.30	1.58 ± 0.35	0.87 ± 0.12
Total time (%)								
DIV I	60.0 ± 5.9	9.4 ± 2.1	3.1 ± 0.8	1.7 ± 0.7	17.1 ± 4.9	3.9 ± 1.2	3.7 ± 1.5	1.1 ± 0.4
DIV II	63.0 ± 7.5	10.5 ± 2.1	2.2 ± 0.8	1.0 ± 0.7	16.7 ± 4.6	3.2 ± 1.8	2.6 ± 1.9	0.9 ± 0.3
DIV III	64.1 ± 5.8	11.1 ± 2.5	2.7 ± 1.0	1.0 ± 0.9	15.2 ± 4.4	2.9 ± 1.5	2.4 ± 1.6	0.8 ± 0.2
DIV VI	67.6 ± 4.9	10.5 ± 3.3	2.2 ± 1.2	1.1 ± 1.0	13.6 ± 3.6	2.2 ± 1.3	1.9 ± 1.4	1.0 ± 0.4

Abbreviations: SM, specific movements.

Table 8.3. Frequency and duration of time-motion analysis movement patterns relative to competitive levels of play during the live time.

LIVE TIME								
	Stand/walk	Jog	Run	Sprint	Low-SM	Medium-SM	High-SP	Jump
Frequency of occurrence (n)								
DIV I	157 ± 51	91 ± 37	40 ± 14	24 ± 11	192 ± 54	61 ± 20	50 ± 15	27 ± 11
DIV II	158 ± 50	98 ± 34	31 ± 14	14 ± 10	175 ± 46	47 ± 23	35 ± 20	25 ± 9
DIV III	158 ± 57	93 ± 31	30 ± 13	14 ± 15	153 ± 50	41 ± 22	31 ± 24	22 ± 11
DIV VI	158 ± 60	80 ± 36	24 ± 16	16 ± 16	128 ± 48	33 ± 23	27 ± 24	25 ± 14
Frequency of occurrence (n/min)								
DIV I	6.34 ± 1.09	3.61 ± 0.88	1.65 ± 0.44	1.06 ± 0.52	7.91 ± 1.08	2.52 ± 0.55	2.16 ± 0.76	1.13 ± 0.42
DIV II	6.15 ± 1.10	3.82 ± 0.83	1.22 ± 0.48	0.58 ± 0.45	6.89 ± 0.98	1.90 ± 0.87	1.43 ± 0.78	0.97 ± 0.31
DIV III	6.66 ± 0.59	3.97 ± 0.74	1.30 ± 0.47	0.58 ± 0.55	6.66 ± 1.25	1.79 ± 0.81	1.30 ± 0.79	0.91 ± 0.29
DIV VI	7.10 ± 0.61	3.61 ± 0.98	1.09 ± 0.58	0.70 ± 0.60	5.87 ± 1.22	1.40 ± 0.77	1.12 ± 0.77	1.13 ± 0.37
Total duration (s)								
DIV I	506 ± 192	227 ± 88	77 ± 25	40 ± 18	410 ± 154	96 ± 38	85 ± 33	26 ± 11
DIV II	592 ± 215	273 ± 102	56 ± 23	23 ± 16	423 ± 139	80 ± 45	63 ± 46	22 ± 9
DIV III	583 ± 264	264 ± 102	63 ± 29	24 ± 23	339 ± 105	66 ± 35	56 ± 47	19 ± 9
DIV VI	614 ± 269	233 ± 97	51 ± 36	26 ± 24	286 ± 74	53 ± 38	45 ± 42	22 ± 13
Mean duration (s)								
DIV I	3.21 ± 0.53	2.54 ± 0.33	1.98 ± 0.31	1.66 ± 0.32	2.14 ± 0.52	1.56 ± 0.21	1.67 ± 0.28	0.95 ± 0.09
DIV II	3.73 ± 0.70	2.77 ± 0.37	1.88 ± 0.32	1.70 ± 0.53	2.45 ± 0.57	1.69 ± 0.36	1.65 ± 0.36	0.91 ± 0.11
DIV III	3.61 ± 0.82	2.78 ± 0.38	2.10 ± 0.36	1.95 ± 0.57	2.27 ± 0.42	1.61 ± 0.18	1.69 ± 0.35	0.89 ± 0.10
DIV VI	3.81 ± 0.52	2.98 ± 0.40	2.13 ± 0.47	1.70 ± 0.42	2.35 ± 0.43	1.62 ± 0.28	1.54 ± 0.32	0.86 ± 0.11
Live time (%)								
DIV I	33.9 ± 7.8	15.1 ± 3.5	5.4 ± 1.4	2.9 ± 1.3	28.2 ± 7.3	6.6 ± 2.0	6.2 ± 2.9	1.8 ± 0.7
DIV II	38.2 ± 9.9	17.6 ± 4.3	3.7 ± 1.3	1.6 ± 1.2	27.8 ± 6.7	5.3 ± 2.9	4.2 ± 2.9	1.5 ± 0.5
DIV III	39.9 ± 8.6	18.5 ± 4.1	4.5 ± 1.7	1.7 ± 1.5	25.3 ± 7.5	4.8 ± 2.5	3.8 ± 2.6	1.3 ± 0.4
DIV VI	45.0 ± 7.1	17.8 ± 5.1	3.9 ± 2.1	1.9 ± 1.6	22.9 ± 5.6	3.8 ± 2.3	3.1 ± 2.4	1.6 ± 0.6

Abbreviations: SM, specific movements.

Table 8.4. Frequency and duration of intensity activity classes relative to competitive levels of play during the total time.

TOTALTIME					
	REC	LIA	MIA	HIA	All movements
Frequency of occurrence (n)					
DIV I	184 ± 57	306 ± 92	106 ± 31	107 ± 26	703 ± 182
DIV II	184 ± 52	296 ± 77	82 ± 34	78 ± 35	640 ± 165
DIV III	182 ± 63	263 ± 81	74 ± 33	71 ± 47	589 ± 202
DIV VI	179 ± 64	221 ± 79	59 ± 40	74 ± 51	533 ± 210
Frequency of occurrence (n/min)					
DIV I	4.15 ± 0.60	6.96 ± 1.10	2.42 ± 0.47	2.52 ± 0.59	16.05 ± 1.62
DIV II	3.98 ± 0.63	6.45 ± 0.90	1.84 ± 0.73	1.76 ± 0.80	14.04 ± 2.29
DIV III	4.30 ± 0.43	6.33 ± 0.85	1.81 ± 0.66	1.66 ± 0.85	14.10 ± 2.13
DIV VI	4.40 ± 0.49	5.54 ± 1.05	1.40 ± 0.68	1.72 ± 0.86	13.07 ± 1.84
Total duration (s)					
DIV I	1599 ± 468	698 ± 213	184 ± 53	164 ± 48	2644 ± 681
DIV II	1757 ± 502	748 ± 200	143 ± 62	116 ± 69	2764 ± 660
DIV III	1645 ± 612	647 ± 187	135 ± 63	106 ± 76	2533 ± 832
DIV VI	1685 ± 682	559 ± 160	110 ± 76	104 ± 81	2458 ± 906
Mean duration (s)					
DIV I	8.84 ± 1.46	2.31 ± 0.37	1.75 ± 0.18	1.52 ± 0.19	3.77 ± 0.36
DIV II	9.68 ± 1.72	2.56 ± 0.45	1.76 ± 0.29	1.42 ± 0.28	4.40 ± 0.82
DIV III	9.06 ± 1.47	2.49 ± 0.25	1.82 ± 0.20	1.46 ± 0.23	4.36 ± 0.70
DIV VI	9.32 ± 1.24	2.61 ± 0.36	1.88 ± 0.31	1.29 ± 0.27	4.68 ± 0.64
Total time (%)					
DIV I	60.0 ± 5.9	26.6 ± 4.7	7.0 ± 1.4	6.4 ± 1.9	-
DIV II	63.0 ± 7.5	27.2 ± 4.1	5.4 ± 2.3	4.4 ± 2.7	-
DIV III	64.1 ± 5.8	26.2 ± 4.0	5.6 ± 2.2	4.2 ± 2.5	-
DIV VI	67.6 ± 4.9	24.1 ± 5.2	4.4 ± 2.3	4.0 ± 2.4	-

Abbreviations: REC, Recovery; LIA, low-intensity activities; MIA, medium-intensity activities; HIA, High-intensity activities.

Table 8.5. Frequency and duration of intensity activity classes relative to competitive levels of play during the live time.

LIVE TIME					
	REC	LIA	MIA	HIA	All movements
Frequency of occurrence (n)					
DIV I	157 ± 51	283 ± 87	101 ± 30	102 ± 26	642 ± 168
DIV II	158 ± 50	273 ± 72	78 ± 32	74 ± 33	584 ± 154
DIV III	158 ± 57	246 ± 74	71 ± 32	67 ± 44	543 ± 186
DIV VI	158 ± 60	207 ± 76	57 ± 38	69 ± 48	491 ± 198
Frequency of occurrence (n/min)					
DIV I	6.34 ± 1.09	11.52 ± 1.49	4.17 ± 0.78	4.34 ± 1.22	26.37 ± 2.36
DIV II	6.15 ± 1.10	10.72 ± 1.24	3.11 ± 1.19	2.98 ± 1.29	22.96 ± 2.98
DIV III	6.66 ± 0.59	10.63 ± 1.40	3.10 ± 1.10	2.80 ± 1.40	23.18 ± 3.20
DIV VI	7.10 ± 0.61	9.48 ± 1.51	2.49 ± 1.27	2.95 ± 1.50	22.01 ± 3.05
Total duration (s)					
DIV I	506 ± 192	637 ± 202	174 ± 49	151 ± 46	1468 ± 388
DIV II	592 ± 215	696 ± 190	135 ± 58	109 ± 64	1532 ± 367
DIV III	584 ± 264	603 ± 169	129 ± 60	99 ± 71	1414 ± 459
DIV VI	614 ± 269	518 ± 153	104 ± 71	93 ± 72	1329 ± 470
Mean duration (s)					
DIV I	3.21 ± 0.53	2.28 ± 0.36	1.73 ± 0.18	1.48 ± 0.18	2.29 ± 0.20
DIV II	3.73 ± 0.70	2.58 ± 0.45	1.76 ± 0.28	1.40 ± 0.27	2.66 ± 0.38
DIV III	3.61 ± 0.82	2.48 ± 0.27	1.81 ± 0.21	1.44 ± 0.22	2.64 ± 0.38
DIV VI	3.81 ± 0.52	2.59 ± 0.38	1.87 ± 0.31	1.26 ± 0.25	2.77 ± 0.36
Live time (%)					
DIV I	33.9 ± 7.8	43.3 ± 5.8	12.0 ± 2.4	10.8 ± 3.7	-
DIV II	38.2 ± 9.9	45.4 ± 5.6	9.0 ± 3.6	7.3 ± 4.1	-
DIV III	39.9 ± 8.6	43.8 ± 6.8	9.4 ± 3.6	6.9 ± 3.9	-
DIV VI	45.0 ± 7.1	40.7 ± 7.7	7.7 ± 4.0	6.6 ± 4.1	-

Abbreviations: REC, Recovery; LIA, low-intensity activities; MIA, medium-intensity activities; HIA, High-intensity activities.

Table 8.6. Comparison of time-motion analysis data between competitive levels of play.

		TOTAL PLAYING TIME			LIVE TIME		
		MBI (%)	Likelihood and magnitude	ES (90% CL)	MBI (%)	Likelihood and magnitude	ES (90% CL)
DIV I vs DIV II							
Frequency of occurrence (n/min)	REC	61/35/3	Possibly small	0.25 ±0.38	49/44/7	Unclear	0.17 ±0.39
	LIA	88/12/0	Likely small	0.55 ±0.44	94/6/0	Likely moderate	0.63 ±0.43
	MIA	100/0/0	Almost certain moderate	0.78 ±0.33	100/0/0	Almost certain moderate	0.87 ±0.33
	HIA	100/0/0	Almost certain moderate	0.93 ±0.34	100/0/0	Almost certain moderate	1.03 ±0.38
	All movements	100/0/0	Almost certain moderate	0.86 ±0.34	100/0/0	Almost certain moderate	1.12 ±0.35
Duration (%)	REC	0/15/85	Likely small	-0.40 ±0.35	0/12/88	Likely small	-0.43 ±0.35
	LIA	8/50/42	Unclear	-0.16 ±0.42	1/22/77	Likely small	-0.38 ±0.40
	MIA	100/0/0	Almost certain moderate	0.71 ±0.32	100/0/0	Almost certain moderate	0.80 ±0.33
	HIA	100/0/0	Almost certain moderate	0.75 ±0.34	100/0/0	Almost certain moderate	0.83 ±0.37
DIV II vs DIV III							
Frequency of occurrence (n/min)	REC	0/4/96	Very likely moderate	-0.70 ±0.47	0/4/96	Very likely moderate	-0.85 ±0.57
	LIA	40/51/9	Unclear	0.14 ±0.39	32/56/12	Unclear	0.06 ±0.36
	MIA	20/52/28	Unclear	0.04 ±0.41	19/52/29	Unclear	0.01 ±0.40
	HIA	42/50/8	Unclear	0.12 ±0.37	46/48/6	Unclear	0.13 ±0.37
	All movements	17/57/27	Unclear	-0.03 ±0.40	14/56/30	Unclear	-0.07 ±0.37
Duration (%)	REC	7/51/43	Unclear	-0.18 ±0.44	5/48/47	Unclear	-0.19 ±0.41
	LIA	57/40/3	Possibly small	0.24 ±0.38	61/37/3	Possibly small	0.24 ±0.35
	MIA	12/57/31	Unclear	-0.08 ±0.40	10/56/34	Unclear	-0.10 ±0.38
	HIA	33/57/11	Unclear	0.10 ±0.40	34/56/10	Unclear	0.10 ±0.39
DIV III vs DIV VI							
Frequency of occurrence (n/min)	REC	5/41/55	Possibly small	-0.22 ±0.38	0/2/98	Very likely moderate	-0.70 ±0.40
	LIA	99/1/0	Very likely moderate	0.74 ±0.37	99/1/0	Very likely moderate	0.74 ±0.39
	MIA	98/2/0	Very likely small	0.59 ±0.39	96/4/0	Very likely small	0.47 ±0.38
	HIA	20/54/26	Unclear	-0.07 ±0.40	19/53/28	Unclear	-0.10 ±0.39
	All movements	89/11/0	Likely small	0.55 ±0.43	76/23/1	Likely small	0.37 ±0.41

Duration (%)	REC	0/3/97	Very likely moderate	-0.71	±0.44	0/4/96	Very likely moderate	-0.70	±0.44
	LIA	85/14/1	Likely small	0.40	±0.36	81/18/1	Likely small	0.39	±0.38
	MIA	90/10/0	Likely small	0.50	±0.39	85/15/0	Likely small	0.43	±0.39
	HIA	33/55/12	Unclear	0.09	±0.40	31/55/13	Unclear	0.07	±0.40

Abbreviations: CL, confidence limits; DIV, Division; ES, effect size; MBI (%), percent of chances of positive/trivial/negative effects; REC, Recovery; LIA, low-intensity activities; MIA, medium-intensity activities; HIA, High-intensity activities.

Discussion

The present study examined the differences in the activity demands of official basketball games between different competitive levels (from elite to amateur levels) among a large sample of male players. The main results demonstrated different intermittent profiles among competitive levels, with elite players performing at greater high and moderate intensities and amateur players completing greater recovery periods during competition. The game activity demands of professional and semi-professional players were similar. Thus, this study provided normative match activity data for Italian basketball tournaments

The present results confirm that the intermittent profile of basketball games is affected by the competitive level of play (Ben Abdelkrim et al. 2010a, Scanlan et al. 2011). Indeed, Division I underwent to an almost certain greater intermittent workload compared to lower level Divisions, while Division VI completed a likely lower number of activities per minute than Division III. These results highlight the greater workload exerted by elite players during games as a consequence of the greater energy expended accelerating, decelerating and changing directions to complete more match activities (Ben Abdelkrim et al. 2010a, McInnes et al. 1995, Scanlan et al. 2011). Similarly, previous findings reported Australian elite players and International level junior Tunisian players to perform more total match movements than sub-elite and National level counterparts respectively (Ben Abdelkrim et al. 2010a, Scanlan et al. 2011). Based on these observations, strength and conditioning coaches should develop training programs to properly enhance power and agility, with the aim to elicit the ability to quickly accelerate, decelerate and change directions during basketball games.

The total number of movements completed during LT by elite players of the present study (642±168) is considerably lower compared with previous reported data (from 863 to 2744 movements) (Ben Abdelkrim et al. 2010a, Ben Abdelkrim et al. 2010b, Ben Abdelkrim et al. 2007, McInnes et al. 1995, Scanlan et al. 2011, Scanlan et al. 2015a, Scanlan et al. 2015b, Torres-Ronda et al. 2016). However, these comparisons can be misleading, given that existing game activity data were derived using different movement patterns classification and analytical procedures. Furthermore, the total number of events performed during the game should be normalized by individual athletes' playing time to allow for comparison across players who spent different LT or TT during matches. In the present study, elite players performed ~26 movements per minute of LT. This result is slightly lower than those previously reported for elite male basketball players competing in the Spanish Division I (~34 movements per minute), however this gap may be attributed to the different movement patterns classification used for TMA (Torres-Ronda et al. 2016). In this study, athletes spent ~34-45%, ~41-45%, ~8-12% and ~7-11% completing REC, LIA, MIA and HIA during LT respectively. Similar data have been previously reported in literature across junior and adult male basketball players from different countries (Stojanovic et al. 2017). Spanish Division I players have been recently reported to spend ~35%, ~40%, ~20% and ~10% of LT recovering or performing LIA, MIA and HIA (Torres-Ronda et al. 2016). These results agree with data collected on the Italian Division I players involved in the present study (REC: ~34%, LIA:~43%, ~12% and ~11%).

Division I performed an almost certain greater number of HIA and MIA per minute of LT and TT compared to Division II, that performed similarly to Division III. In addition, time spent at HIA and MIA in percentage of both LT and TT was almost certain higher among elite athletes than lower levels counterparts. These results suggest that the ability to perform at higher intensities for a longer time should be considered as an important characteristic for success in basketball. In addition, Division VI spent a very likely higher percentage of LT and TT at REC compared to Division III, who performed a very likely greater number of REC per minute than Division II. These results suggest that players of lower competitive level require longer and more frequent periods to recover across the game. Thus, the ability to recover quickly from high-intensity phases appear to be a required determinant to compete at elite and professional level. These findings are likely due to the better ability of elite players to sustain high-intensity intermittent exercises, contrasting the occurrence of fatigue (Ben Abdelkrim et al. 2010c, Ferioli et al. 2017, Vernillo et al. 2012). In addition, technical and tactical aspects may have affected the game activity demands across the different competitive levels. The possibly to likely greater time spent at LIA during LT by Division II and Division III compare to lower level counterparts may be attributed to more structured competition at higher competitive level, during which athletes are required to be constantly active during offensive and defensive phases (Scanlan et al. 2011). On the contrary, games of lower competitive level may be based on more individual actions (Scanlan et al. 2011), with players less involved watching the evolution of offensive or defensive phases at REC. These results, to some extent, are similar to previous findings which reported that international level Tunisian junior athletes spent more live time at HIA and elite Australian adult players performing more activities at moderate to high intensities compared to lower level counterparts (Ben Abdelkrim et al. 2010a, Scanlan et al. 2011). In contrast however, Scanlan et al. (2011) observed Australian adult sub-elite athletes spent more time performing maximal high-intensity efforts (i.e. sprint) and longer low-intensity phases than elite players. Furthermore, Ben Abdelkrim et al. (2010a) reported that international level Tunisian junior players completed a significantly greater proportion of REC than national level counterparts. These differences may be attributed to the different game rules applied (e.g. game duration), methodologies used to classify movement patterns and to the different characteristics of players involved (e.g. age, competitive level, fitness level).

Whilst this study provides a direct comparison of game activity demands of a large sample of basketball players belonging to multiple teams and competing at various playing level, there are some limitations that must be acknowledged. The main limitation of this study is that the basketball players were selected from just one national tournament, thus measured data might not be extended reliably to basketball players of other leagues. Moreover, no physiological responses (e.g. heart rate and blood lactate concentration) across basketball games have been measured during this study due to official competition constraints. Future studies should include the measurement of physiological responses to basketball games when directly comparing the game activity demands at different competitive levels.

Conclusions and practical applications

The present study clearly shows that basketball games of different competitive levels are characterized by different physical activities. The ability to sustain a greater intermittent workload and HIA during competitions should be considered as an important characteristic for success in basketball. Thus, strength and conditioning coaches should develop training programs to properly enhance power and agility of players, with the aim to elicit the ability to quickly accelerate, decelerate and change directions during basketball performance. Furthermore, a greater emphasis should be placed on the ability to sustain high-intensity intermittent efforts and the ability to quickly recover from high-intensity phases of the competitions during trainings. This study provides normative match activity data for Italian basketball tournaments, which should be considered to develop specific team-based trainings to prepare athletes for competitions.

CHAPTER NINE

Final considerations

Main findings

The present thesis aimed to describe and to compare the anthropometrical and physiological characteristics of Italian adult male basketball players of different competitive levels during an entire basketball season. Study 1 (chapter 3) examined the anthropometrical and physiological differences in basketball players, from elite to amateur level, during the competitive phase of the season. Results revealed that stature and body mass are fundamental prerequisites to compete at professional level. In addition, higher level competitive players are characterized by a better ability to sustain high-intensity intermittent exercise and to produce greater absolute PF and PPO. Study 2 (chapter 4) and 3 (chapter 5) compared the training load indices and the changes in several physical characteristics between professional and semi-professional basketball players during the preparation period. Results revealed that professional players undergo substantially greater sRPE-TL and TV. The preparation period substantially improved the ability to perform high-intensity intermittent exercises (i.e. Yo-Yo IR1 and HIT), with the greater adaptations observed among professional players when assessed with a submaximal high-intensity intermittent test (i.e. HIT). The preparation period appears to induce only small improvement in the aerobic fitness and to minimally affect variables measured during a vertical jump test. However, the ability to sustain repeated COD efforts is enhanced during the preparation period. In addition, Study 2 and 3 raise doubts on the effectiveness of using high TL and TV during the preparation period to improve the physical fitness level of players. Indeed, reaching high sRPE-TL and TV might negatively impact strength and power properties without further enhanced aerobic fitness. Study 4 (chapter 6) examined the differences among basketball players and the changes over an entire basketball season of PNF following a repeated COD exercises. In this study, elite and professional basketball players were characterized by better PNF and by less fatigue levels following repeated CODs runs compared to lower level counterparts. In addition, results revealed that the majority of changes in PNF following CODs exercises occurs after the preparation period, when the KEs appear to be less fatigable. Study 5 (chapter 7) described the changes in several physical fitness parameters of basketball players, from elite to semi-professional levels, over an entire basketball season. In general, the preparation period appears to minimally affect variables measured during vertical jump test but to enhance the aerobic fitness and the ability to sustain high-intensity intermittent exercise. The changes in physical performance during the competitive phase of the season seem to be affected by the competitive level of play. It was hypothesized that the differences found between elite, professional and semi-professional were due to the different training stimuli (e.g. TL and TV) and game activity demands in which athletes of different playing levels usually undergo during the entire season.

A secondary object of this thesis was to examine the differences in the activity demands of official basketball games between different competitive levels (from elite to amateur levels). Study 6 (chapter 8) provided normative data for Italian basketball tournaments. Higher level competitive players were found to undergo greater intermittent workloads compared to lower level counterparts. In addition, elite players performed at greater high and moderate intensities, while amateur players completed greater recovery periods during competition.

Practical implications

The present thesis provides some practical implications, which are listed below.

- The results of the present thesis revealed that basketball players of different competitive levels and roles are characterized by different anthropometrical and physiological profiles. As a consequence, strength and conditioning coaches should develop individualized and role specific training program to proper enhance physical performance of players.

- A high force and power production and the ability to sustain high-intensity intermittent exercises should be considered as important characteristics for success in basketball. In addition, the ability to sustain repeated CODs efforts at high intensities without the occurrence of severe fatigue should be considered as an important determinant for competing at a higher level. Thus, specific training programs should be developed to enhance these abilities in talented basketball players.
- The physical and physiological tests carried out in the present thesis should be used to evaluate the fitness status of players during the different phases of the competitive season. The results of this thesis revealed that HIT represents a valid alternative to monitor the ability to sustain high-intensity intermittent exercise across the different phases of the season (i.e. preparation and competitive periods) than using a maximal intermittent running test (e.g. Yo-Yo IR1). CMJ can be effectively used to monitor lower limb force and power characteristics among basketball players. However, vertical jumping height, PPO and PF normalized by body mass should not be considered as major factors of success in basketball. Rather, the quantification of PPO and PF in absolute terms during CMJ is recommended, as these variables are more sensitive to discriminate players of different competitive levels. In addition, the results of the present thesis partially confirm the construct validity of the repeated COD test in basketball.
- The sRPE-TL method should be used to quantify the individual TL within basketball players of different competitive levels. Despite it not being possible to predict the changes in physical fitness induced by the preparation period using the sRPE-TL quantification, practitioners should consider that achieving high sRPE-TL and TV during preparation period might negatively impact strength and power properties, without further enhancing the aerobic fitness.

- Game activity demands investigated in the present thesis revealed that the ability to sustain greater intermittent workloads and HIA during competitions represent important determinants for success in basketball. For this reason, strength and conditioning coaches should develop training programs to properly enhance power and agility of players, with the aim to elicit the ability to quickly accelerate, decelerate and change directions during basketball performance.

Future research directions

Further research is needed to expand upon the findings of this thesis, to develop a definitive understanding of the physiological characteristics of basketball players and to provide a greater understanding of game activity demands in basketball. As such, future research should:

- Verify the relationships between the results of the physiological tests carried out in the present thesis and actual physical basketball match performance. This information should be useful to further confirm the "construct validity" of these tests.
- Utilize a wider range of anthropometrical and physiological test parameters to develop a more holistic understanding of the physical profile of adult male basketball players.
- Verify the use of Yo-Yo IR1 as a valid tool to differentiate the competitive level among top and moderate professional adult players in basketball.
- Investigate the relationships between physical fitness changes and other measures of external and internal TL.
- Describe the changes in several physical fitness parameters over the different phases of a competitive season among adult male basketball players of different competitive levels in relation to playing time during competitions (starting vs reserve players).

- Quantify the game activity demands in basketball using new technologies (i.e. radio frequency tracking systems or accelerometers) that may permit for accurate identification of the external load imposed on players in a faster and less resource-intensive way compared to TMA.

Main limitations

The main limitations of the present thesis that should be acknowledged are listed below.

- The data collected within the present thesis are representative of elite, professional, semi-professional and amateur players competing in the Italian basketball tournaments. Therefore, normative data might not be extended reliably to overall basketball players.
- Due to the difficulties in assessing high level basketball players, it was not possible to allow the same exact amount of days to elapse between each teams' physical test sessions performed at different time-points (i.e. T1, T2 and T3).

Conclusions

This thesis provides insight into the anthropometrical and physiological characteristics of basketball players competing in the Italian basketball tournaments across an entire basketball season, highlighting the differences among the various competitive levels of play. This thesis delivers novel insight into the relationships between TL indices and changes in physical fitness in basketball. In addition, this thesis provides normative match activity data for Italian basketball tournaments.

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