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Impact of contextual factors on match demands experienced by elite male referees during international basketball tournaments

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ABSTRACT

We aimed to assess the cardiovascular responses and locomotory demands of male referees during diverse elite, international, basketball matches, and to investigate the influence of moderating factors (competition sex, level and stage) on these demands. Cardiovascular and locomotory responses were monitored in 123 elite, male referees while officiating 283 basketball sessions (preparation until match end), during group and playoff stages, of women's and men's FIBA Continental and World Cups at senior and youth level. The total and average session distance and velocity were ~4740 m, 19.0 m·min $^{-1}$ and 2 km·h $^{-1}$. Referees experienced an average relative HR of 60–65% maximum HR with ~85% of each session spent within the very light to moderate HR categories. The average session relative HR was significantly greater for men compared to women competition, during senior compared to youth sessions, and for the group compared to the playoff stage sessions. Mean distance covered was significantly greater during senior and men compared with youth and women sessions. Elite, international male basketball referees experienced moderate cardiovascular load accompanied with intermittent locomotor activities during international sessions when accounting for all occupational activities. International competitions are more demanding for referees based upon competition sex, level and stage.

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KEYWORDS
Officials; competition; internal load; motion; match demands

Introduction

Basketball is a worldwide sport played by over 450 million people (FIBA, 2020). The International Basketball Federation (FIBA) and its Regional Offices organise and oversee annual international tournaments that provide opportunities for countries and players to showcase their talent during elite matches (FIBA, 2020). Subsequently, interest in the physiological and physical factors related to preparation for basketball competition and actual performance of elite players has grown (Petway et al., 2020). Similar interest has also developed towards elite basketball referee's performance with high-level perceptual-cognitive functioning needed in referees despite significant physical challenges (García-Santos et al., 2020; Nabli et al., 2019) and the cumulation of neuromuscular and mental fatigue (García-Santos et al., 2019; Vaquera et al., 2016a). To assist officiating success, referees' physical preparation and readiness to officiate at the highest level of competition have been focussed upon by the FIBA Referee Department and Regional Referee Managers (FIBA, 2020). This concentration has involved the implementation of a standard strength and conditioning program for international referees to cope with the competitions held annually (FIBA, 2020). This program enables all referees, nominated for international matches (e.g. men's and women's), to optimise their physical fitness for successful completion of FIBA, pre-competition fitness tests and undertake official FIBA competition matches (FIBA, 2020). However, only one aspect of fitness has been historically prioritised for referees (e.g. aerobic capacity) despite a limited knowledge of the physiological and locomotory stresses placed on elite referees (García-Santos et al., 2020; Nabli et al., 2019). A greater understanding of the stresses or demands is necessary to develop appropriate, specific and quality training programs (Nabli et al., 2019).

Previous studies have examined aspects of these demands, however have only included a small number of referees and matches within unique match and/or competition settings across FIBA's regions (Allegretti Mercadante et al., 2015; Borin et al., 2013; Leicht, 2004; Matković et al., 2014; Nabli et al., 2016; Rupčić et al., 2012). For example, Vaquera et al. (2014) examined 26 male referees who officiated 48 matches during all stages at the 2011 EuroBasket Championship. They found that referees experienced an average exercise intensity of ~82% of their maximum heart rate (%HR_{max}) with no significant differences in cardiovascular responses during the different tournament stages. Recently, García-Santos et al. (2019) reported that nine (six male) referees experienced an average exercise intensity of only 62% HR_{max} during the Under-16 Women's EuroBasket championship. Similar variety in referee demands has been noted for locomotion. For example, Borin et al. (2013) used a pedometer to monitor movements and reported that referees covered ~4.0–6.2 km per match with the distance increasing throughout competition phases (e.g. regular season to playoff). Allegretti Mercadante et al. (2015) reported that 4 international- and 2 national-

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ranked Brazilian male referees covered 4520 (493) m per match during two official national matches with most movements being small lateral displacements and walking. García-Santos et al. (2019) reported that referees, on average, covered a distance of 4330 m per match with >80% of the match at velocities of 0.1–12 km·h^{-1} (walking and jogging). These movement patterns are guided by FIBA instructions (e.g. mechanics) to officiate the match with a greater understanding of these demands important to assist in the development of unique fitness capacities and training for elite referees (Vaquera et al., 2016a).

To date, several small studies have examined either the cardiovascular (Leicht, 2004, 2008; Matković et al., 2014; Rupčić et al., 2012; Vaquera et al., 2016a, 2014) or locomotory (Allegretti Mercadante et al., 2015; Rojas-Valverde et al., 2020) demands of elite referees with very few examining both (Borin et al., 2013; García-Santos et al., 2019; Nabli et al., 2016), especially within elite competitions. An examination of a greater number of referees, across multiple elite, international tournaments at the senior and youth levels, and different stages of competition would contribute to a better understanding of the physiological and locomotor demands experienced by international referees during real-world officiating environments (e.g. FIBA Continental and World Cups). Subsequently, the primary aim of this study was to assess the cardiovascular responses (e.g. HR) and locomotory demands (e.g. distances covered, velocity) of a large sample of male referees during diverse elite, international, basketball matches held throughout the world. A secondary aim was to investigate the influence of moderating factors (e.g. competition sex, level and stage) (Nabli et al., 2019) on the physiological responses and locomotory demands during matches. Greater knowledge of the core demands experienced by referees across a range of match types at the elite level would ensure that detection and development of elite referees, would be specific for any FIBA competition in the world.

Methods

Design

This study was a cross-sectional analysis of referee cardiovascular and locomotor responses during the following FIBA Men's and Women's Continental and World Cups: EuroBasket and AmeriCup for Men, Men's and Women's AfroBasket, and U19 Men's and Women's Basketball World Cup. Each tournament consisted of two stages: group stage where each team played the other teams once; and the playoff stage where the top two teams of each group played against each other until a final tournament winner was determined. The tournaments varied in length and included rests days for both players and referees (e.g. EuroBasket, 15 days; AmeriCup, 13 days; Men's AfroBasket, 12 days; Women's AfroBasket, 10 days; U19 Men's and Women's World Cup, 9 days) (Table 1).

Participants

To be eligible to participate, male referees completed the mandatory FIBA aerobic fitness test within the 24–48 h prior to the beginning of the tournaments. All referees were undertaking the same FIBA prescribed training regime in the 12 weeks immediately before each tournament (Vaquera et al., 2016a). One hundred and twenty-three internationally licenced, male referees, from 84 countries across five continents, volunteered and took part in this study. Their average age, height, mass, body mass index, body fat percentage and fat-free mass (FFM) were as follows: 39.8 (5.1) years, 182.5 (6.8) cm, 83.4 (8.4) kg, 25.0 (1.7) kg·m^{-2}, 21.6 (4.1) % and 65.4 (7.2) kg, respectively. The average international officiating experience of referees was 9.7 (4.4) years that ranged 1–20 years. All referees completed a general health pre-screening questionnaire and were classified as healthy (e.g. no known disease). None of these referees were taking medications that could influence HR. Each referee was informed about the research design and the requirements, benefits and risks of the study and provided written informed consent before study commencement. All research procedures were conducted in accordance with the WMA International Code of Medical Ethics and approved by an institutional ethics committee.

Procedures

All matches were scheduled in advance by FIBA with all referees appointed by the FIBA Referee Department to matches based upon referee experience and prior performances, teams playing, and rest time. All referees officiated each day of the tournament with at least 16 hours of rest between matches. Each match consisted of three referees (e.g. crew) who officiated in accordance with the FIBA official rules. Every referee crew followed the standardized off-court and on-court warm-up, and post-match recovery procedures, prescribed by the FIBA Referee Department. The off-court warm-up was performed in the locker room and consisted of self-myofascial release (e.g. foam rolling as an applied modality), static and dynamic stretching, and muscle activation exercises (e.g. double or single leg bridge). Regarding the on-court warm-up (20 min), referees warmed up in a rotational order so as to ensure that one referee observed the court while the other two warmed up on the sidelines. The referees performed low-intensity running and dynamic stretching exercises during the first 10 min followed by 10 min of more intense and specific warm-up including short sprints and change of direction activities. At half time of each match (e.g. 15-min period) referees undertook another warm-up including low-intensity running and dynamic stretching activities during the last 5-min. Following each match (~5 min), the referees met with the scorer's table before leaving the court for their locker room where they performed stretching activities for 5 min.

Variables

Anthropometry and body composition. Every referee's anthropometric measurements were obtained by the same person (FIBA Referees Fitness Coordinator who holds a PhD in Physical Activity and Sport Sciences and Level 3 ISAK certification) with the same instruments and under similar environmental conditions. All assessments were performed the day before the start of the tournament, during a single testing session at the same time of the day (08:00–08:30) after an overnight fast (Vaquera et al., 2016b). Body mass and height were measured

Table 1. Schematic outline of the matches of the major official competitions of FIBA included in the study.

Competition (total number of matches)	Week	Day 1	2	3	4	5	6	7
Men's EuroBasket (79)	1	Gs (12)	Gs (12)	Gs (6)	Gs (6)	Gs (12)	Gs (12)	Gs (4)
	2	R	Pl (4)	Pl (2)	R	Pl (2)	Pl (3)	Pl (2)
	3	R	Pl (2)					
Men's AmeriCup (40)	1	Gs (4)	Gs (4)	Gs (4)	Gs (4)	Gs (4)	R	Gs (4)
	2	Gs (4)	Gs (4)	Gs (4)	R	Pl (2)	Pl (2)	
Men's AfroBasket (44)	1	Gs (4)	Gs (4)	Gs (4)	Gs (4)	Gs (4)	Gs (4)	Pl (4)
	2	Pl (4)	Pl (4)	Pl (2)	Pl (4)	Pl (2)		
Women's AfroBasket (46)	1	Gs (5)	Gs (6)	Gs (6)	Gs (1)	Gs (6)	Gs (6)	R
	2	Pl (6)	Pl (6)	Pl (4)				
U19 Men's Basketball World Cup (56)	1	Gs (8)	Gs (8)	R	Gs (8)	Pl (8)	R	Pl (8)
	2	Pl (8)	Pl (8)					
U19 Women's Basketball World Cup (56)	1	Gs (8)	Gs (8)	R	Gs (8)	Pl (8)	R	Pl (8)
	2	Pl (8)	Pl (8)					

Abbreviations: Gs, Group stage; Pl, Playoff stage; R, Rest day.

with a digital scale (Seca Alpha, GmbH & Company, Igni, France; range 0.1–150 kg, precision 0.01 kg) and a Harpenden digital stadiometer (Pfifter, Carlstadt, NJ, USA; range 70–205 cm, precision 1 mm), respectively, with referee's wearing only underwear. Body fat percentage was determined through electrical bioimpedance (Tanita OMRON BF306, Arlington Heights, USA). Fat-free mass was calculated from the following equation (FFM = Body mass – (Body mass x bioimpedance body fat percentage)) (Loenneke et al., 2012).

Cardiovascular and locomotory responses during matches. The Polar Team Pro System (Polar Electro OY, Kempele, Finland), which integrates multiple sensors (i.e. 10 Hz GPS, accelerometer, gyroscope, digital compass, sampling at 200 Hz) coupled with in-built HR monitoring and proprietary software, was used to determine velocity and distance indoors and record HR continuously at 1-s intervals. These devices relied on non-GPS sensors and manufacturer's proprietary algorithms to calculate velocity and distance covered, which make the sensors attractive and suited to indoor settings as they permit efficient processing and analysis of external workload data (Fox et al., 2019). This microsensor monitoring system has been utilized in various indoor sports such as futsal, basketball or handball (Clemente et al., 2020; Stojanović et al., 2019; Stojiljković et al., 2020). The Polar Team Pro system was reported to be reliable for the measurement of HR responses (Chen et al., 2020; Haddad et al., 2020), as well as locomotory activities (e.g., velocity and distance) in outdoor environments (Huggins et al., 2020).

In accordance with the manufacturer's instructions, each referee wore a sensor attached to an elastic strap positioned on the lower sternum. The same sensor was used by each referee to minimise inter-device variability (Clemente et al., 2020). The sensor was activated in the locker room, 20 min before the beginning of match, and was worn up to 5 min after the match with recordings including both passive and active periods of the pre- and post-match time, as well as actual playing time with applicable match stoppages (e.g. free throws, time-outs, foul and violation calls) (Leicht, 2004). The entire recording or session (Figure 1) was uploaded to a local computer using the manufacturer-supplied interface and online solution (PolarTeam Pro System) for later analyses. We considered a session as the full recording from the start of warm-up, the entire match and ended with the post-match recovery procedures.

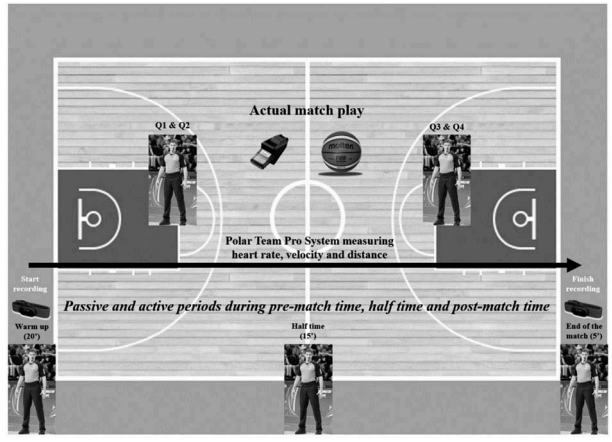

Figure 1. Procedure for collection of cardiovascular and locomotory responses during sessions in elite, international male basketball referees.

Concerning HR, all responses were examined in absolute terms (beats·min^{-1}) and subsequently normalized and expressed as a percentage of each referee's theoretical HR_{max} (220 – age) to reflect relative exercise intensity during each session (Vaquera et al., 2016a, 2014). All HR data were exported and further analysed in Microsoft Excel (v19.0; Microsoft Corporation; Redmond, WA, USA) to calculate the proportion (%) of time spent within different HR intensity categories (Vaquera et al., 2016a). The HR categories employed for this study were: very hard, >89% HR_{max}; hard, 80–89% HR_{max}; moderate, 70–79% HR_{max}; light 60–69% HR_{max}; and very light, 50–59% HR_{max} (Edwards, 1992).

Regarding locomotory demands, mean velocity and total and mean distance covered by referees during each session was calculated, along with absolute distances covered within each of the following locomotor velocity categories: very hard, ≥19 km·h^{-1}; hard, 15–18.99 km·h^{-1}; moderate, 11–14.99 km·h^{-1}; light, 7–10.99 km·h^{-1}; and very light, 3–6.99 km·h^{-1} (Cunniffe et al., 2009).

Statistical analysis

All data were assessed for normality using the Kolmogorov–Smirnov test with Lilliefors significance correction. Comparison of variables based upon competition sex, level and stage (e.g.

men vs. women, youth vs. senior, group vs. playoff, respectively) was conducted via independent t-tests or Mann–Whitney tests, where appropriate. The level of statistical significance was set as $P < 0.05$. Magnitude of difference or effect size (ES) was detected via Cohen's *d* (Cohen, 1988) and interpreted as trivial (<0.2), small (0.20–0.60), moderate (0.61–1.20), large (1.21–2.00) and very large (>2.00) (Hopkins et al., 2009). All values are expressed as mean (SD) with all analyses conducted using the Statistical Package for the Social Sciences (SPSS v24, Armonk, NY: IBM Corp.).

Results

Two-hundred and 83 matches, including group and playoff stages, were examined and resulted in 714 individual data sets as follows: EuroBasket, 205; AmeriCup, 114; Men's AfroBasket, 103; Women's AfroBasket, 43; U19 Men's Basketball World Cup, 158; and U19 Women's Basketball World Cup, 91 (Table 1). The mean session time was approximately 2 hours with significantly shorter sessions for women (moderate ES), youth (small ES) and playoff (small ES) compared to men, senior and group stage, respectively (Table 2).

Cardiovascular responses based upon competition sex, level and stage

The average session HR was ~116 beats·min^{-1} which equated to a light relative exercise intensity (~64% HR_{max}, Table 2). The average session HR was significantly lower for women (small ES) and playoff (small ES) compared to men and group stage sessions, respectively (Table 2). Referees experienced most (~85%) of each session within the very light to moderate HR categories (Table 2). Based upon competition sex, referees experienced a significantly greater proportion of the session within the moderate to very hard categories, and subsequent reduction in the very light and light HR categories, for men compared to women sessions (small ES, Table 2). With regard to competition level, referees experienced a significantly greater proportion of senior sessions within the hard to very hard HR categories, and subsequent reduction in the very light and light HR categories, compared to youth (trivial-small ES, Table 2). For competition stage, referees experienced a significantly greater proportion of group stage sessions within the moderate to very hard HR categories, and subsequent reduction in the very light and light HR categories, compared to playoff (trivial-small ES, Table 2).

Locomotory demands based upon competition sex, level and stage

The total and average session distance and match velocity were ~4740 m, 19.0 m·min^{-1} and 2 km·h^{-1}, respectively (Table 3). The average total and mean session distance were significantly greater for men (trivial ES) and senior (small ES) sessions compared to women and youth, respectively (Table 3). No differences in total and mean session distance were evident between group and playoff stages (trivial ES, Table 3). Based upon competition sex, referees covered more distance within all velocity categories, except light and very hard (trivial-small ES) during men

Table 2. Mean (SD) total session time and cardiovascular responses of elite male basketball referees during international matches based upon competition sex, level and stage.

	Competition sex				Competition level				Competition stage				
Outcome measure	Men (n = 580)	Women (n = 134)	*P* value	ES (*d*)	Youth (n = 249)	Senior (n = 465)	*P* value	ES (*d*)	Group (n = 403)	Playoff (n = 311)	*P* value	ES (*d*)	All (n = 714)
Total session time (min)	122 (25)	104 (28)	**<.001**	−0.68	109 (25)	124 (26)	**<.001**	−0.57	122 (26)	115 (26)	**<.001**	0.27	119 (26)
Mean session HR (beats·min^{-1})	117.1 (13.9)	110.8 (12.9)	**<.001**	−0.46	115.4 (13.5)	116.2 (14.1)	.682	−0.06	117.4 (13.8)	113.9 (13.8)	**.001**	0.25	115.9 (13.9)
(%HR_{max})	64.5 (7.5)	60.0 (6.9)	**<.001**	−0.61	61.9 (7.0)	64.6 (7.7)	**<.001**	−0.36	64.9 (7.4)	62.1 (7.5)	**<.001**	0.38	63.7 (7.6)
Time of session within HR intensity category (% match)													
Very light	28.4 (16.3)	36.9 (18.9)	**<.001**	0.51	31.3 (15.9)	29.4 (17.7)	**.020**	0.11	27.9 (16.0)	32.8 (18.2)	**<.001**	−0.29	30.0 (17.1)
Light	31.8 (9.9)	35.2 (9.9)	**<.001**	0.35	35.2 (9.1)	30.9 (10.1)	**<.001**	0.44	31.6 (9.8)	33.5 (10.1)	**.007**	−0.20	32.4 (10.0)
Moderate	25.5 (11.3)	21.4 (12.2)	**<.001**	−0.36	24.5 (11.7)	24.9 (11.5)	.733	−0.03	25.7 (10.7)	23.5 (12.5)	**.032**	0.20	24.7 (11.6)
Hard	11.8 (11.0)	5.7 (7.6)	**<.001**	−0.58	8.0 (9.0)	12.0 (11.3)	**<.001**	−0.39	12.2 (11.1)	8.6 (9.9)	**<.001**	0.34	10.6 (10.7)
Very hard	2.5 (6.0)	0.8 (2.5)	**<.001**	−0.32	1.0 (2.8)	2.8 (6.5)	**<.001**	−0.34	2.6 (6.2)	1.6 (4.6)	**<.001**	0.18	2.2 (5.6)

Abbreviations: min, minutes; beats·min^{-1}, beats per minute; HR, heart rate; HR_{max}, maximum heart rate; ES, effect size. Note: Very light, 50–59%HR_{max}; Light, 60–69%HR_{max}; Moderate, 70–79%HR_{max}; Hard, 80–89%HR_{max}; Very hard, >89%HR_{max}; Bold values denote statistical significance ($P < 0.05$) vs. Men or Youth or Group within the comparison.

Table 3. Mean (SD) locomotory responses of elite male basketball referees during international matches based upon competition sex, level and stage.

Outcome measure	Competition sex				Competition level				Competition stage				All (n = 714)
	Men (n = 580)	Women (n = 134)	*P* value	ES (*d*)	Youth (n = 249)	Senior (n = 465)	*P* value	ES (*d*)	Group (n = 403)	Playoff (n = 311)	*P* value	ES (*d*)	
Total session distance (m)	4818 (671)	4424 (840)	**<.001**	−0.56	4626 (758)	4807 (694)	**.011**	−0.25	4741 (789)	4747 (624)	.189	−0.01	4744 (722)
Mean session distance (m·min^{-1})	19.0 (10.4)	18.9 (14.4)	**.004**	−0.00	16.8 (12.3)	20.2 (10.4)	**<.001**	−0.31	19.1 (10.8)	18.9 (11.7)	.191	0.01	19.0 (11.2)
Mean session velocity (km·h^{-1})	2.0 (0.3)	2.0 (0.4)	.177	−0.09	2.1 (0.3)	2.0 (0.3)	**<.001**	0.22	2.0 (0.3)	2.0 (0.3)	.630	0.03	2.0 (0.3)
Distance covered during session within velocity category (m)													
Very light	2267 (388)	2029 (448)	**<.001**	−0.60	2094 (404)	2292 (398)	**<.001**	−0.50	2212 (429)	2237 (386)	.828	−0.06	2223 (411)
Light	1031 (202)	1049 (308)	.969	0.08	1030 (235)	1036 (221)	.796	−0.03	1034 (237)	1034 (210)	.600	0.00	1034 (226)
Moderate	701 (200)	609 (257)	**<.001**	−0.43	691 (205)	680 (220)	.243	0.05	677 (222)	693 (204)	.187	−0.08	684 (215)
Hard	280 (162)	248 (170)	**.034**	−0.20	283 (160)	270 (166)	.172	0.08	282 (167)	264 (160)	.181	0.11	274 (164)
Very hard	78 (88)	66 (95)	.066	−0.13	78 (101)	74 (83)	.912	0.04	81 (93)	69 (84)	.066	0.13	76 (90)

Abbreviations: m, metre; m·min^{-1}, metres per minute; km·h^{-1}, kilometres per hour; ES, effect size. Note: Very light, 3–6.99 km·h^{-1}; Light, 7–10.99 km·h^{-1}; Moderate, 11–14.99 km·h^{-1}; Hard, 15–18.99 km·h^{-1}; Very hard, >19 km·h^{-1}; Bold values denote statistical significance ($P < 0.05$) vs. Men or Youth or Group within the comparison.

compared to women sessions (Table 3). With respect to competition level, referees covered a significantly greater distance within the very light velocity category (small ES) during senior compared to youth sessions (Table 3). Referees covered similar distances within all other velocity categories during senior and youth sessions (Table 3). For competition stage, referees covered similar distances within each velocity category during group and playoff stage sessions (trivial ES, Table 3).

Discussion

This is the first study to evaluate cardiovascular responses and locomotory demands of a very large sample of elite, international basketball referees across different competition sexes, levels and stages. The current study identified that elite, international male referees experienced moderate cardiovascular stress and locomotory demands during international basketball matches with these responses primarily dependent upon competition sex and level, with less differences noted for competition stage.

During these elite basketball competitions, referees experienced an average relative HR of 60–65% HR_{max} with ~85% of each session spent within the very light to moderate HR categories. These findings were lower than expected and likely reflected the inclusion of on- and off-court activities. Unlike prior studies (García-Santos et al., 2019; Rojas-Valverde et al., 2020; Vaquera et al., 2016a, 2014), the current study included all activities experienced by referees (e.g. warm-up, quarter and half time breaks) to represent the real-world occupational demands of officiating elite competition (e.g. preparation until match end). Consequently, HR results were lower than those reported for different international and national competitions that only recorded responses during actual match time (Borin et al., 2013; Leicht, 2004, 2008; Matković et al., 2014; Nabli et al., 2016; Rupčić et al., 2012; Vaquera et al., 2016a, 2014). For example, 18 international- and national-ranked, male referees experienced an average cardiovascular demand of ~72-78% HR_{max} during 12 matches of the Brazilian Basketball League (Borin et al., 2013). Similarly, an average match HR intensity of ~75 (5)% HR_{max} was experienced by 31 national-ranked, male referees during the 1st Croatian Basketball League (Matković et al., 2014). A greater average match HR intensity of ~82 (13)% HR_{max} was experienced by 26 male referees officiating 48 matches at the 2011 EuroBasket Championship (Vaquera et al., 2014). Even greater cardiovascular stress (~90 [5]% HR_{max}) was observed in 18 male referees officiating 18 matches during the final round (e.g. playoff stage) of the 2013 Women's EuroBasket Championship (Vaquera et al., 2016a). Collectively, the current and prior studies highlight that referees experience a range of cardiovascular stresses when officiating with the degree of average cardiovascular response possibly dependent upon modulating factors such as competition sex, level and stage (Nabli et al., 2019).

In the present study, the average session HR was significantly greater for men compared to women competition with referees spending a significantly greater proportion of the session within the moderate to very hard categories, and subsequent reduction in the very light and light HR categories. The higher cardiovascular responses for referees were a possible

result of the greater locomotor actions for referees with greater total (m) and average (m·min^{-1}) distance covered, and distance covered within higher velocity categories, experienced during the men sessions. The difference in referee movements between sessions likely represents differences in player movements with locomotory actions (e.g. low intensity running) reported to be lower for female basketball players (Delextrat et al., 2015; Narazaki et al., 2009). While competition sex impacts referee demands, it is important to highlight that international referees officiate both match types and therefore, must be adequately prepared to cope with either competition match type. This unique requirement emphasizes the need for referees to undertake a training regime that develops fitness to a level greater than the greatest match experience (e.g. men) in order to handle the physical demands of the match as well as the high cognitive loading needed for officiating (Morris & O'Connor, 2017). Future research is encouraged to examine the optimal training needed to prepare elite referees both physically and cognitively for greater match performance.

While referee responses were influenced by competition sex, international competition level also had an impact. Specifically, referees experienced greater mean cardiovascular responses during senior (~65 [7]% HR_{max}) compared to youth (~62 [7]% HR_{max}) sessions. Additionally, referees experienced a significantly greater proportion of senior sessions within the hard to very hard HR categories, and subsequent reduction in the very light and light HR categories, compared to youth sessions. In this sense, only one investigation at the international level (six male and three female referees during 15 matches in an FIBA women's youth championship) reported heart rate levels (average match intensity 62% HR_{max}, 83% of match time between 50% and 80% HR_{max}) similar to our findings (García-Santos et al., 2019). This study reinforces the results in this work showing that women and youth competition elicited lower responses than men and senior competition, respectively. Furthermore, our results were in line with previous reports of greater mean HR for international senior (~82 [13]% HR_{max}) (Vaquera et al., 2014) compared with international youth matches (~75 [7]% HR_{max}) (Nabli et al., 2016). The greater cardiovascular and locomotor responses of referees during senior matches were potentially a result of the greater intermittent workloads (e.g. higher velocity movements) experienced by the advanced or better quality players (e.g. seniors) (Ben Abdelkrim et al., 2010; Leicht, 2008; Petway et al., 2020; Scanlan et al., 2011). Subsequently, referees must complement the locomotory activities of players to enable proficient officiating. Furthermore, the selection process of referees to junior and senior tournaments may contribute to differences noted (Matković et al., 2014). Usually, younger referees with less international officiating experience are assigned to youth tournaments to help progressive development whereas the senior tournaments are commonly officiated by more experienced referees for the potentially more demanding and decisive senior tournaments. Therefore, competition level, in addition to sex, needs to be considered when developing and training elite referees with the highest quality of match play recommended as the threshold for future enhancement.

Finally, the current study identified that competition stage impacted upon referee responses with the mean session HR significantly greater for the group stage (~65 [7]% HR_{max}) compared to the playoff stage (~62 [8]% HR_{max}). Moreover, referees experienced a significantly greater proportion of group stage sessions within the moderate to very hard HR categories, and subsequent reduction in the very light and light HR categories, compared to playoff stage sessions. These cardiovascular responses occurred with no differences in any locomotory measure that may indicate a greater level of cognitive (e.g. decision-making and reaction time) (Nabli et al., 2016; Rupčić et al., 2012) rather than physical loading for referees during the group stage. Our results contrast with those of Borin et al. (2013) who reported that the relative match intensity increased non-significantly as competition phases progressed (e.g. qualifying = ~72 [10]% HR_{max}; semifinal = ~75 [7]% HR_{max}; final = ~78 [7]% HR_{max}). However, recently Leicht et al. (2020) noted that sub-elite referees experienced similar exercise volume and intensity during the regular season and playoff matches over a competitive season. Future studies are encouraged to clarify the impact on competition stage on referee responses.

This study has provided new insights into the cardiovascular and locomotory demands highlighting the intermittent nature of locomotory activities (Borin et al., 2013; Leicht, 2004, 2008; Matković et al., 2014; Nabli et al., 2016; Vaquera et al., 2016b, 2014) of elite male basketball referees during international matches held throughout the world. However, bearing in mind that the analysed sessions used three-person officiating, caution must be applied to other referee configurations since the physiological demands and workloads of two-person officiating crews appear to be higher than those of three-person crews (Leicht et al., 2020; Nabli et al., 2019). The strengths of the study were inclusion of a large homogenous sample of elite, international male basketball referees across the world. However, several limitations must be acknowledged. Firstly, recordings included both on- and off-court activities which may have reduced the overall values. Given that standardized preparation protocols prior to and half time were followed by all referees, we expect this inclusion to have had a minimal impact on the competition comparisons (e.g. men vs. women, etc.). However, future studies are encouraged to investigate cardiovascular and locomotor demands separately during the preparation and active play periods. The main limitation of this study was the cross-sectional design of referee comparisons, which may have affected the effects of moderating factors (e.g. competition sex, level and stage). Longitudinal examination of cardiovascular responses and locomotory demands imposed on the same referees across different competition conditions would potentially provide greater clarification of the referee experiences, including a more detailed examination of responses per match quarter, half, etc. Furthermore, the locomotory responses reported were based on default velocity zone settings from the Polar Team Pro System and did not account for locomotor velocity categories below 3 km·h^{-1}. Finally, the locomotor activities were measured by an accelerometer which makes comparisons with prior studies using video time–motion analysis (Allegretti Mercadante et al., 2015; Nabli et al., 2016), pedometers (Borin et al., 2013) and positioning systems (Leicht et al., 2020, 2019) difficult. Standardization of methodology to assess referees' locomotion during matches would enable greater comparability and identification of elite

referees' match locomotor demands for the future development of training regimes.

Conclusions

Elite, international male basketball referees experienced moderate cardiovascular load accompanied with intermittent locomotor activities during international sessions when taking into account on- and off-court activities (e.g. pre-match preparation, half time warm up and between-quarters time). These cardiovascular responses and locomotory demands were influenced by competition sex, level and stage with training of elite male referees encouraged to consider these contextual factors for optimal referee match performance in the future.

Disclosure statement

No potential conflict of interest was reported by the authors.

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