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Identification of games and sex-related activity profile in junior international badminton

Daniel Rojas-Valverde[a,b], Carlos D. Gómez-Carmona[c], Jaime Fernández-Fernández[d], Juan García-López[d], Vicente García-Tormo[d], David Cabello-Manrique[e] and José Pino-Ortega[f]

[a]Centro De Investigación Y Diagnóstico En Salud Y Deporte (CIDISAD), Escuela Ciencias Del Movimiento Humano Y Calidad De Vida (CIEMHCAVI), Universidad Nacional, Heredia, Costa Rica; [b]Research Group on Advances in Sport Training and Physical Conditioning, Sport Science Faculty, University of Extremadura, Caceres, Spain; [c]Optimization of Training and Sport Performance Research Group (GOERD). Sport Science Faculty. University of Extremadura, Caceres, Spain; [d]Human Movement and Sport Performance Research Group (AMRED). Department of Physical Activity and Sport Sciences, Universidad De León, Spain; [e]Department of Physical Education and Sport. Sport Science Faculty. University of Granada, Granada, Spain; [f]Department of Physical Activity and Sport Sciences. International Excellence Campus "Mare Nostrum". Sport Science Faculty, University of Murcia, San Javier, Spain

ABSTRACT
The aims of the present study were (a) to analyse the activity profile in U'18 Badminton players during an international tournament and (b) to compare the games and sex-related differences. Twenty-four players (women = 14; men = 10) were assessed using inertial measurement units with ultra-wideband indoor tracking system. Eleven variables were extracted after principal component analysis (PCA). Differences between games and gender were performed by mixed analysis of variance. In men, PCA of the whole game explained 89.2% and in women 75.7%. The most representative variables in men's and women's were relative distance and maximum accelerations (PC1). The players' activity profile was (men vs women) 44.6 ± 3.8 vs 43.5 ± 5.2 m/min in relative distance, 25.9 ± 1.9 vs 24.7 ± 1.9 n/min in relative acceleration, 3.87 ± 0.3 vs 3.47 ± 0.4 m/s^2 in maximum acceleration, 175.5 ± 9.4 vs 173.2 ± 15.6 bpm in average heart rate. Sex-related differences were found in maximum accelerations ($p < 0.01$) and relative accelerations ($p < 0.01$) and in relative distance by games. The workload dynamics during games and between sexes should be addressed by team staff in order to develop effective tactical and recovery strategies during badminton tournaments.

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Racket sports; time-motion analysis; indoor tracking; inertial devices; load demands

1. Introduction

Badminton is a racket sport characterised by intermittent actions composed of repetitive short periods of exercise with rapid changes of direction combined with explosive bursts lasting between 1-to-9 seconds and short recovery periods of low-intensity activity

CONTACT Carlos D. Gómez-Carmona cdgomezcarmona@unex.es Training Optimization and Sport Performance Research Group (GOERD). Department of Didactics of Music, Plastic and Body Expression. Sport Science Faculty, University of Extremadura. Avenida De La Universidad S/n, Caceres 10071, Spain

(standing or walking for 6-to-15 seconds), that result in an effective playing time of 40–50% (Fernandez-Fernandez et al., 2019; Fuchs et al., 2014; Phomsoupha & Laffaye, 2015). These activity locomotion patterns produce physiological responses associated with the exercise intensity showing relatively high heart rate (HR) responses (80-to-90% of maximum heart rate (HR_{max})) (Cabello-Manrique & González-Badillo, 2003; Deka et al., 2017), moderate oxygen uptake (O_2) with values around 70% of maximum oxygen uptake (VO_{2max}), and low-to-moderate blood lactate (up to 5 $mmol.L^{-1}$). These high-intensity levels can be maintained due to the ratio between playing and resting phases, which is about 1:2 (Phomsoupha et al., 2017), and also because of the longer breaks in play (i.e. 2-min breaks between games or a 60-s break when one side reaches 11-points) (Fernandez-Fernandez et al., 2013).

Competitive badminton matches are typically comprised of a best of 3-set format to 21-points, with total match durations at the top level ranging in men between 2994 ± 1160 and 2745 ± 928 s and in women 2848 ± 995 during the 2010 and 2012 world-series tournaments and 2016 Olympic Games (Chiminazzo et al., 2018; Gawin et al., 2015). Knowledge of the workload profile during competition is fundamental for designing effective physical conditioning programmes. In this regard, the load demands could be influenced by (a) gender, where men engaged in longer rallies, executing more strokes per rally, and with a longer match duration than women, although no differences in physiological and biochemical markers was found (Fernandez-Fernandez et al., 2013; Rampichini et al., 2018), and (b) consecutive matches during a tournament with greater neuromuscular (loss of counter-movement jump height), physiological ($\%HR_{MAX}$), psychological (RPE) and biochemical stress (blood lactate, proteins, glucose, ketone bodies, erythrocytes) (Abian-Vicen et al., 2014; Fernandez-Fernandez et al., 2013).

In this regard, since badminton is an indoor sport, only video recordings have been used to monitor players' activity profiles (Barris & Button, 2008). In recent years, new devices have been developed called electronic performance and tracking systems (EPTS). These devices integrate multiple sensors (e.g. accelerometer, gyroscope, magnetometer) (Wu et al., 2007), and tracking technology that allowing accurate and reliable assessment in sports played indoor and in reduced spaces (Bastida-Castillo et al., 2019, 2018; Luteberget et al., 2018). Several studies have been recently published using this technology in order to quantify badminton loads, through accelerometer variables such as peak acceleration and accumulated accelerometer load (PlayerLoad^{TM}) per axis and per intensity ranges (Abdullahi et al., 2019; Sasaki et al., 2018; Wylde et al., 2018). Quantifying this information during real or simulated badminton matches may help coaches to provide objective knowledge about the demands of badminton play, ultimately improving the development of effective training and recovery programmes.

The EPTS provide a great amount of variables related to the workload profile, such as the magnitude and frequency of actions/skills (impacts, jumps, steps, landings, changes of direction) and travel (distance, speed, accelerations) that are defined as big data (Rojas-Valverde, Gómez-Carmona et al., 2019). In this regard, in order to reduce the amount of data obtained and make the subsequent analysis a little bit easier, a statistical technique conducted in other research areas (e.g. mathematics) has been proposed and implemented in sport science (Federolf et al., 2014; Rojas-Valverde, Sánchez-Ureña et al., 2019; Svilar et al., 2018). The aim of PCA is to select a small number of variables that are not self-correlated and explains a high percentage of the total variance of the analysed data (Rojas-Valverde, Sánchez-Ureña et al., 2019). However, to the best of our knowledge, no previous study has been conducted in racket sports using PCA methodology.

Therefore, due to the need to understand the most important variables that influence performance in badminton, the aims of this study were (a) To analyse the activity profile during an U'18 International badminton tournament and (b) To compare the games and sex-related differences in load demands.

2. Methods

2.1. Design

A cross-sectional design with natural groups was employed in the current study to analyse the activity profile of badminton players during a U'18 youth international tournament and to compare the match games and sex-related differences in the workload dynamics.

2.2. Participants

Twenty-four elite junior Spanish badminton players (10 men and 14 women; age 16.2 ± 0.8 years, body mass 63.5 ± 6.6 kg, height 173.2 ± 6.3 cm) participated in this study. The players were ranked between 1 and 20 in their respective national singles ranking (U'18), they trained 18.2 ± 1.6 h per week and had a training background of 7.2 ± 1.4 years. The participants were not taking medications for the duration of the study and had been free of musculoskeletal injuries during the previous 3 months. Before taking part in the study, participants and their parents/guardians were fully informed about the protocol and provided their written informed consent. The Institutional Ethics Board approved the procedures in accordance with the latest version of the Declaration of Helsinki.

2.3. Procedures

The assessment of the singles matches was conducted using inertial measurement units (IMU, WIMU PRO™, RealTrack Systems, Almería, Spain), which include different sensors to record data on time-motion (outdoor: Global Navigation Satellite System, GNSS; indoor: Ultra-Wideband, UWB), and specific actions/skills (accelerometer, gyroscope, magnetometer) and link with other sensors (Ant+, Bluetooth, Wi-Fi). All players wore a special neoprene vest and the IMU was attached at the interscapular level prior to the warm-up for each match. Besides, players wore an HR band (GARMIN™, Olathe, KA, USA) that sent data to the IMU through Ant+ technology (Molina-Carmona et al., 2018). The sampling frequency of the sensors was 18 Hz for UWB, 100 Hz for accelerometer, magnetometer and gyroscope and 2 Hz for HR telemetry.

UWB indoor tracking technology was used for time-motion analysis. In order to monitor the whole arena (including five courts), six antennae were placed on the perimeter of the arena in order to monitor five matches at the same time (see Figure 1). The UWB equipment calibration was performed following previous study protocols (Bastida-Castillo

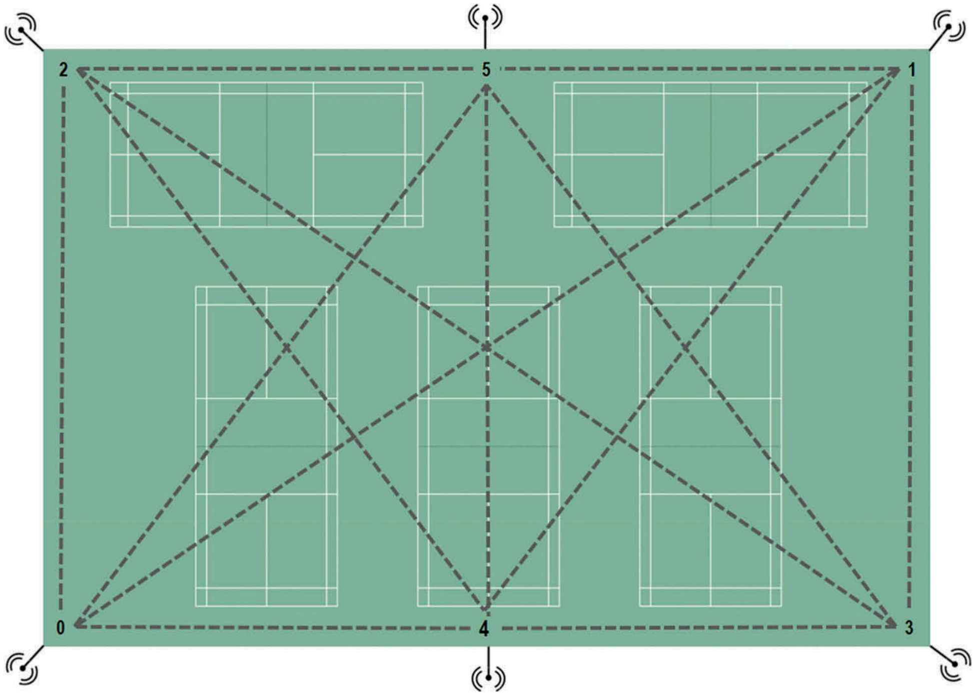

Figure 1. Distribution of inertial measurement unit antennae for the assessment of five simultaneous match courts during a badminton tournament using ultra-wideband technology.

et al., 2019), and the intra-unit and inter-unit reliability have previously been reported for WIMU PRO™ in indoor conditions (Bastida-Castillo et al., 2018). The accelerometer calibration was carried out following previous research (Gómez-Carmona et al., 2019), where intra- and inter-unit reliability was assessed. All data obtained from the devices were linked and extracted after matches for analyses using the manufacturer's software (S PRO™, RealTrack Systems, Almería).

Variables extracted for analysis were (a) relative distance, RD (m/min): total distance covered related to total playing time; (b) relative acceleration, RAcc (n/min): total number of accelerations related to total playing time; (c) maximum acceleration, Acc_{MAX} (m/s^2): maximum acceleration reached during the match; (d) maximum speed, $Speed_{MAX}$ (km/h): maximum speed performed throughout the match (km/h); (e) average HR, HR_{AVG} (bpm); (f) relative jumps, RJumps (n/min): number of jumps performed related to playing time; (g) average takeoff force; $TakeOff_{AVG}$ (g): force average measured at all takeoffs during the match; (h) average landing force, $Landing_{AVG}$ (g): force average measured at all landings during the match; (i) relative takeoff 3–5 g, TakeOff[3–5 g] (n/min): number of takeoffs per minute that are between 3 and 5 g; and (j) relative takeoff 5–8 g, TakeOff[5–8 g] (n/min): number of takeoffs per minute that are between 5 and 8 g.

All measurements were realised during the BWF IBERDROLA Spanish 2018 celebrated in Polideportivo Corredoira Arena (Oviedo, Spain) between 16 and 18 February 2018. This tournament was played in single and doubles modality. Only the Spanish badminton players that participated in the single tournament were registered both in men and women. In this tournament participated youth players of different countries (in alphabetic order, Belgium, Brazil, Chile, Denmark, England, Finland, France, Guatemala, India, Ireland, Italy, Japan, Mauritius, Netherlands, Peru, Portugal, Romania, Spain, Sweden, Switzerland, United States and Uruguay). A total of 35 matches were measured, 21 for the women (best women defeated in quarter-final) and 14 for the men (two players defeated in semi-finals).

First and second games were played to the best of 21 points following International Badminton Federation Rules. Timeouts of 2 min between games and 1-min rest periods when one side reached 11 points were taken. The third set was played to the best of 11 points. In order to have consistent measures, due to the differences between regular games and third games, in the present investigation, only the first two games were considered for analyses. The two games selected for analysis were distributed in the following four games: (a) from the start of the game until the leading score reached 11 points; (b) from when the leading score reached 11 points until the end of 1st set; (c) from the beginning of the 2nd set until the leading score reached 11 points; and (d) from when the leading score reached 11 points until the end of the 2nd set)

In addition, the duration of the different units of analysis was (men vs women, in seconds): (a) total match, 1410 ± 451.06 vs 1127.43 ± 283.05; (b) first game, 315.21 ± 104.75 vs 256.60 ± 49.39; (c) second game, 315.57 ± 102.48 vs 274.59 ± 113.23; (d) third game, 379.86 ± 149.02 vs 303.57 ± 89.50; and (e) fourth game, 401.71 ± 240 vs 264.43 ± 68.78. For this reason, considering the differences between games and total match duration, only relative and maximum variables were considered for analysis (McLaren et al., 2018).

2.4. Statistical analysis

A total of 51 variables were examined for each part of the game and sex in the respective correlation matrix prior to a Principal Component Analysis (PCA) in order to select uncorrelated representative variables; firstly, $r < 0.7$ correlation between variables was considered for extraction (Tabachnick & Fidell, 2007). PCA was performed following previously published guidelines (Federolf et al., 2014; Rojas-Valverde, Sánchez-Ureña et al., 2019). Then, variables with *variance* = 0 were excluded. The 11 selected variables through the previous processes were scaled and centred (*Z-score*). PCA was suitable considering Kaiser-Meyer-Olkin values (KMO = 0.63–0.066) and Barleth Sphericity test significance ($p < 0.05$) (Bartlett, 1954; Kaiser, 1960). Eigenvalues >1 were considered for the extraction of principal components (Kaiser, 1960). A VariMax-orthogonal rotation method was performed in order to identify high correlations of components and guarantee that each principal component offered different information. A threshold of 0.6 in each PC loading was retained for interpretation, extracting the highest factor loading when a cross-loading was found between components.

Mixed analysis of variance was performed in order to explore differences by match games and sex. The magnitude of the differences was qualitatively interpreted using partial omega squared (ω_p2) as follows: <0.01 *trivial*; >0.01 *small*; >0.06 *moderate* and >0.14 *large* (Cohen, 1988). Instead, sex-related differences were analysed by *t*-test of independent sample for whole match variables. The magnitude of differences was interpreted using Cohen's d (*d*) as follows: 0–0.2 *insignificant*; 0.2–0.5 *low*; 0.5–0.8 *moderate* and >0.8 *high* (Cohen, 1988). Statistical differences were considered if $p < 0.05$. Data analysis was performed using the Statistical Package for the Social Sciences (SPSS, IBM, SPSS Statistics, v.22.0 Chicago, IL, USA), and graphs were made using Prism software (GraphPad Software, San Diego, CA).

3. Results

After PCA analysis in men, the activity profile of the whole match was explained in 89.2% of total variance by four principal components (PC1: RD, Acc_{MAX}, HR_{AVG}, RJumps; PC2: RAcc, $TakeOff_{AVG}$; PC3: $Landing_{AVG}$; PC4: $Speed_{MAX}$, TakeOff[3–5 g], TakeOff[5–8 g]). Three to four PCs were extracted for each selected game, explaining 80.7–88.3% of total variance. The PC1 explained 33.1% (RD, $Speed_{MAX}$, HR_{AVG}), 35.9% (RAcc, $TakeOff_{AVG}$, TakeOff[5–8 g]), 35.8% (RD, RJumps, TakeOff[3–5 g]) and 47.3% (Acc_{MAX}, $Speed_{MAX}$) of the total variance in each part of the games. The variables that explained most of the variance were RD (1st, 3rd games and whole match), $Speed_{MAX}$ (1st, 4th games), HR_{AVG} (1st game and whole match), Acc_{MAX} (4th game and whole match), RAcc, $TakeOff_{AVG}$ and TakeOff[5–8 g] (2nd game), RJumps (3rd game and whole match) and $TakeOff_{AVG}$ (3rd game) (see Table 1).

In women, the activity profile of the whole match was explained in 75.7% of total variance by four principal components (PC1: RD, Acc_{MAX}, RJumps; PC2: HR_{AVG}, $TakeOff_{AVG}$, TakeOff[5–8 g]; PC3: RJumps, TakeOff[3–5 g]; PC4: RAcc). Four to five PCs were extracted for each part of the game, explaining 74.2–88% of the total variance. The PC1 explained 39.4% (RD, $Speed_{MAX}$, HR_{AVG}, $Landing_{AVG}$), 30.5% (RD, Acc_{MAX}), 28.9% (RD, Acc_{MAX}) and 32.2% (RD, Acc_{MAX}, $Speed_{MAX}$) of total variance in each part of the matches. The main variables extracted were RD (1st–4th games and whole match), Acc_{MAX} (4th game and whole match), $Speed_{MAX}$ (1st game and whole match), HR_{AVG} (1st, 4th game and whole match), RJumps (whole match) and TakeOff[3–5 g] (3rd game) (see Table 2).

Table 3 shows the comparative analysis of badminton players' activity profiles between games and sex. No significant interaction (sex vs games) was found in external workload variables (RD, RAcc, Acc_{MAX}, $Speed_{MAX}$, RJumps, $TakeOff_{AVG}$, TakeOff[3–5 g], TakeOff [5–8 g]) or internal load variables (HR_{AVG}). Main effect analysis showed significant interaction ($p < 0.01$) by sex in RAcc and Acc_{MAX}, and significant interaction ($p = 0.03$) by games in RD.

Figure 2 shows sex-related differences in the variables analysed. Results showed significant differences in RAcc ($p < 0.01$, $d = 0.64$, *moderate effect*) and Acc_{MAX} ($p < 0.01$, $d = 1.08$, *high effect*), with higher values in men. No significant differences were found in the rest of the variables.

4. Discussion

No previous research has analysed the locomotion and specific actions through UWB technology and identified the principal variables that explained the total variance of load demands in young men and women badminton players in different parts of the match. The aims of the present study were to analyse the activity profile in badminton using principal component analysis as a data reduction technique and to explore sex-related

Table 1. Men principal component analysis by game with respective eigenvalue, variances and %variance explained.

Game	1st				2nd				3rd				4th			Whole Match			
PC	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	1	2	3	4
Eigenvalue	3.65	2.14	1.83	1.3	3.94	2.99	1.71	1.06	3.94	2.91	1.48	1.05	5.2	2.12	1.56	4.09	2.66	1.67	1.39
Variance	33.14	19.43	16.66	11.72	35.86	27.19	15.58	9.67	35.79	26.47	13.49	9.55	47.25	19.29	14.21	37.19	24.18	15.17	12.65
%Variance	33.14	52.58	69.24	80.96	35.86	63.04	78.63	88.3	35.79	62.26	75.7	85.3	47.25	66.53	80.75	37.19	61.37	76.54	89.19
RD (m/min)	.88					.74			.73						.68	.76			
RAcc (n/min)		−.71			.92						.67			.6			.94		
Acc_{MAX} (m/s^2)		.86				.91			-	-	-	-	.86			.87			
$Speed_{MAX}$ (km/h)	.79							−.81		.86			.92						.7
HR_{AVG} (bpm)	.7					.8				.77				.71		.78			
RJumps (n/min)		.7						.91	.87					.76		.85			
$TakeOff_{AVG}$ (g)			.86		.95						.76		-	-	-		.63		
$Landing_{AVG}$ (g)	-	-	-	-			.68					.92			.81			.95	
TakeOff[3–5 g] (n/min)			.94				.88		.92						.86				−.78
TakeOff[5–8 g] (n/min)				.94	.89						.82			.85					.72

PC: Principal component; RD: Relative distance; RAcc: Relative accelerations; Acc_{MAX}: Maximum acceleration; $Speed_{MAX}$: Maximum speed; HR_{AVG}: Heart rate average; RJumps: Relative jumps; $TakeOff_{AVG}$: Takeoff g force average; $Landing_{AVG}$: landing g force average; TakeOff[3–5 g]: number of takeoffs per minute that are between 3 and 5 g; TakeOff[5–8 g]: number of takeoffs per minute that are between 5 and 8 g.

Table 2. Women principal component analysis by game with respective eigenvalue, variances and % variance explained.

Game	1st			2nd					3rd					4th				Whole Match			
PC	1	2	3	1	2	3	4	5	1	2	3	4	5	1	2	3	4	1	2	3	4
Eigenvalue	4.34	2.53	1.3	3.36	2.05	1.46	1.34	1.02	3.18	2.03	1.69	1.57	1.22	3.54	2.45	1.43	1.19	3.21	2.11	1.89	1.12
Variance	39.44	22.96	11.78	30.53	18.6	13.24	12.22	9.24	28.94	18.44	15.32	14.24	11.05	32.21	22.25	12.97	10.79	29.18	19.19	17.11	10.2
%Variance	39.44	62.4	74.19	30.53	49.13	62.37	74.59	83.83	28.94	47.39	62.71	76.95	87.99	32.31	54.47	67.43	78.22	29.18	48.36	65.47	75.68
RD (m/min)	.9			.88					.93					.9				.84			
RAcc (n/min)		.63				.71						.91				.74					.94
Acc_{MAX} (m/s^2)	-	-	-	.63					.63					.82				.9			
$Speed_{MAX}$ (km/h)	.67			-	-	-	-	-					−.8	.69				-	-	-	-
HR_{AVG} (bpm)	.72					.68					−.75			-	-	-	-		−.74		
RJumps (n/min)		.85				.84				.91					.82					.85	
$TakeOff_{AVG}$ (g)			.81		.91						.87						.81		.8		
$Landing_{AVG}$ (n/min)	.76							.93					.8		−75			-	-	-	-
TakeOff[3–5 g] (n/min)			.94				.95			.83				-	-	-	-			.82	
TakeOff[5–8 g] (n/min)		.88			.83						.85					.92			.93		

PC: Principal component; RD: Relative distance; RAcc: Relative accelerations; Acc_{MAX}: Maximum acceleration; $Speed_{MAX}$: Maximum speed; HR_{AVG}: Heart rate average; RJumps: Relative jumps; $TakeOff_{AVG}$: Takeoff g force average; $Landing_{AVG}$: landing g force average; TakeOff[3–5 g]: number of takeoffs per minute that are between 3 and 5 g; TakeOff[5–8 g]: number of takeoffs per minute that are between 5 and 8 g.

Table 3. Differences in junior badminton external and internal load variables between games and genres.

Variables		1st Game	2nd Game	3rd Game	4th Game	*F game* (*p* value)	$\omega_p 2$ *(rating)*
RD (m/min)	Men	46.23 ± 3.73	45.36 ± 2.90	42.55 ± 3.82	44.13 ± 3.99	3.03 (0.03)	0.05 (low)
	Women	44.54 ± 4.46	44.01 ± 5.69	42.75 ± 5.31	42.85 ± 5.39		
	F genre (p value)		2.01 (0.16)			*F Interaction (p value)*	
	$\omega_p 2$ *(rating)*		0.03 (low)			0.27 (0.84)	
RAcc (n/min)	Men	26.33 ± 2.01	26.38 ± 1.75	25.53 ± 1.93	25.26 ± 1.98	1.08 (0.36)	0
	Women	24.77 ± 2.36	24.41 ± 1.76	24.57 ± 1.81	24.96 ± 1.86		
	F genre (p value)		8.8 (<0.01)			*F Interaction (p value)*	
	$\omega_p 2$ *(rating)*		0.06 (moderate)			1.55 (0.21)	
Acc_{MAX} (m/s^2)	Men	3.84 ± 0.36	3.88 ± 0.32	3.89 ± 0.33	3.85 ± 0.32	0.11 (0.95)	0
	Women	3.41 ± 0.37	3.48 ± 0.42	3.43 ± 0.38	3.54 ± 0.39		
	F genre (p value)		27.6 (<0.01)			*F Interaction (p value)*	
	$\omega_p 2$ *(rating)*		0.19 (large)			*0.15 (0.93)*	
$Speed_{MAX}$ (km/h)	Men	10.84 ± 1.46	10.81 ± 1.44	10.74 ± 0.99	11.03 ± 1.74	0.19 (0.9)	0
	Women	10.60 ± 1.65	10.36 ± 1.37	10.68 ± 0.97	11 ± 2.15		
	F genre (p value)		0.99 (0.32)			*F Interaction (p value)*	
	$\omega_p 2$ *(rating)*		0			0.07 (0.55)	
HR_{AVG} (bpm)	Men	172 ± 8.92	177.92 ± 10.09	174.46 ± 9.77	178.55 ± 8	0.29 (0.83)	0
	Women	172.68 ± 11.86	175 ± 11.59	172.85 ± 15.71	172.15 ± 22		
	F genre (p value)		0.75 (0.36)			*F Interaction (p value)*	
	$\omega_p 2$ *(rating)*		0			0.71 (0.86)	
RJumps (n/min)	Men	0.90 ± 0.36	0.88 ± 0.31	0.86 ± 0.54	0.89 ± 0.60	0.24 (0.87)	0
	Women	0.69 ± 0.39	0.81 ± 0.54	0.94 ± 0.59	0.75 ± 0.46		
	F genre (p value)		2.25 (0.14)			*F Interaction (p value)*	
	$\omega_p 2$ *(rating)*		0.01 (trivial)			0.25 (0.53)	
$TakeOff_{AVG}$ (g)	Men	2.29 ± 0.66	2.61 ± 0.93	2.18 ± 0.71	2.31 ± 0.59	0.77 (0.52)	0
	Women	2.29 ± 0.80	2.64 ± 1.03	2.47 ± 1.14	2.97 ± 1.23		
	F genre (p value)		2.47 (0.12)			*F Interaction (p value)*	
	$\omega_p 2$ *(rating)*		0.01 (trivial)			0.75 (0.2)	

(*Continued*)

Table 3. (Continued).

Variables		1st Game	2nd Game	3rd Game	4th Game	*F game* (*p* value)	ω_p2 *(rating)*
$Landing_{AVG}$ (g)	Men	4.57 ± 0.88	4.46 ± 0.76	5.17 ± 1.49	4.82 ± 1.39	0.96 (0.41)	0
	Women	4.23 ± 0.60	4.78 ± 1.71	4.44 ± 0.68	5.22 ± 2.14		
	F genre (*p* value)		0.08 (0.77)			*F Interaction (p value)*	
	ω_p2 *(rating)*		0			1.59 (0.61)	
TakeOff[3–5 g] (n/min)	Men	0.15 ± 0.21	0.17 ± 0.18	0.18 ± 0.18	0.20 ± 0.30	0.11 (0.96)	0
	Women	0.15 ± 0.22	0.12 ± 0.18	0.11 ± 0.16	0.19 ± 0.21		
	F genre (*p* value)		0.27 (0.6)			*F Interaction (p value)*	
	ω_p2 *(rating)*		0			0.61 (0.61)	
TakeOff[5–8 g] (n/min)	Men	0.02 ± 0.05	0.07 ± 0.16	0.02 ± 0.06	0.03 ± 0.07	1.83 (0.15)	0.02 (low)
	Women	0.02 ± 0.07	0.07 ± 0.13	0.08 ± 0.12	0.05 ± 0.09		
	F genre (*p* value)		0.6 (0.44)			*F Interaction (p value)*	
	ω_p2 *(rating)*		0			0.8 (0.5)	

RD: Relative distance; RAcc: Relative accelerations; Acc_{MAX}: Maximum acceleration; $Speed_{MAX}$: Maximum speed; HR_{AVG}: Heart rate average; RJumps: Relative jumps; $TakeOff_{AVG:}$ Takeoff g force average; $Landing_{AVG}$: landing g force average; TakeOff[3–5 g]: number of takeoffs per minute that are between 3 and 5 g; TakeOff[5–8 g]: number of takeoffs per minute that are between 5 and 8 g; F: value F of MANOVA test; p: p value (significance); ω_p2: partial omega squared.

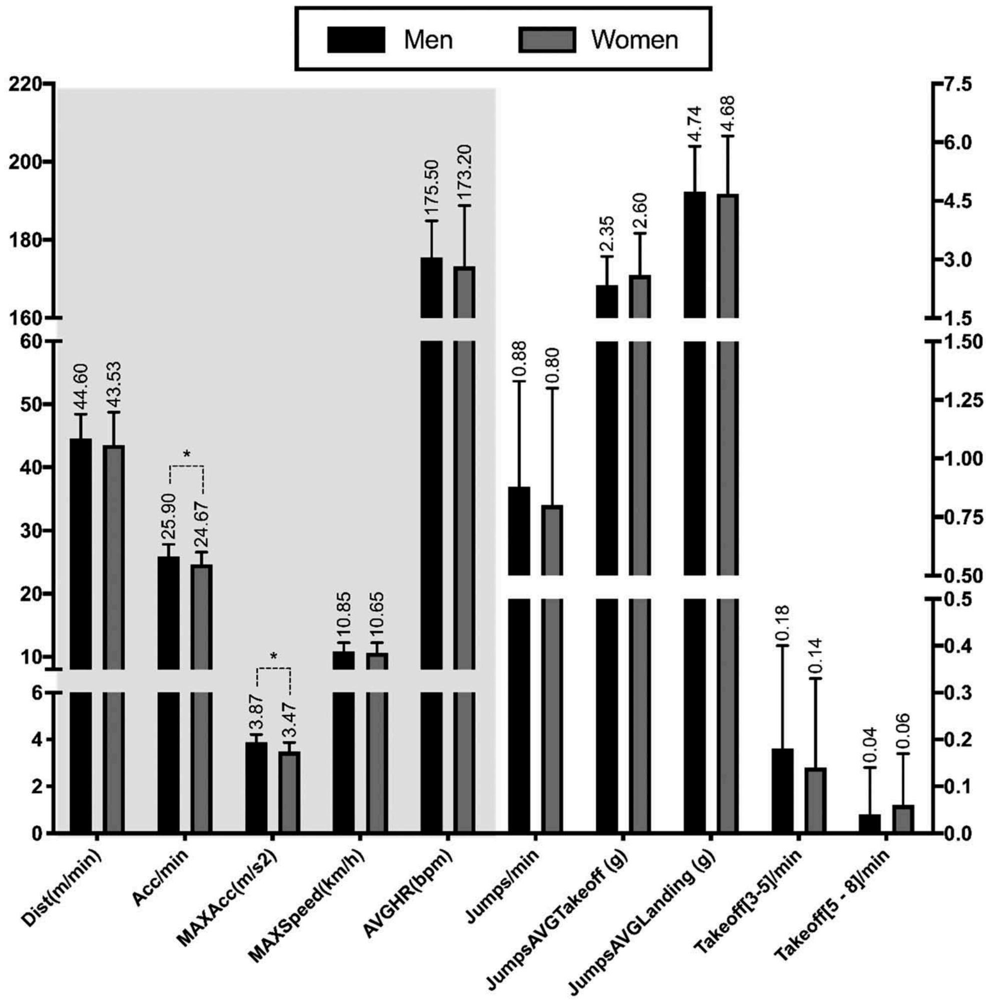

Figure 2. Whole-match sex differences in internal and external load variables in junior international badminton.

differences and fatigue throughout match games. The main results showed that in men PC1 explained 37% of total variance by RD, Acc_{MAX}, RJumps and $TakeOff_{AVG}$. While in women, PC1 explained 29.18% of total variance by RD and Acc_{MAX}. Differences were found in RD throughout the games and differences by sex in RAcc and Acc_{MAX} with higher values in men.

Related to the PCA analysis, in the PC1 RD and Acc_{MAX} were found in both sexes, but in men, $TakeOff_{AVG}$ and RJumps also were part of this first component. This indicates that the number of jumps and the average force in the takeoff phase were important in the men's performance where jumps and lower limb power is crucial with significant differences in smashes, and net points with respect to women in official competitions (Abian-Vicen et al., 2013). Besides, the variables that were part of the PC1 were modified throughout the game. In the first part of the match, RD, $Speed_{MAX}$ and RJumps in men and RD, $Speed_{MAX}$, HR_{AVG} and $Landing_{AVG}$ in women were the workload variables that explain the highest part of total variance. However, in the last part of the second game, Acc_{MAX} and $Speed_{MAX}$ in men and RD, Acc_{MAX} and $Speed_{MAX}$ in women were the variables that explain the greater percentage of total variance. This indicates that the volume of demands (RD, RJumps, $Landing_{AVG}$) is the most important requirement at the start of the match. In contrast, at the end of the match, the high-intensity demands ($Speed_{MAX}$ and Acc_{MAX}) explain the physical performance in the competition. Therefore, if the physical performance was different related to sex and throughout the game, there should be specialisation in training plans. Both sexes need to emphasise high-intensity locomotion due to their importance for physical performance at the end of the matches. Additionally, men should also maximise technical actions that require jumps such as smashes or net points due to their importance for men's physical performance during badminton matches.

In the present research, men performed significantly more RAcc ($p < 0.01$, $d = 0.64$) and Acc_{MAX} ($p < 0.01$, $d = 1.08$) than women. To the best of our knowledge, the present study has been the first to analyse locomotion and skills in badminton. No previous study has analysed these variables in other racket sports, which makes comparisons difficult. In other team sport modalities such as basketball (Scanlan et al., 2015) or handball (Michalsik & Aagaard, 2015) it has been found that women develop higher volume loads (RD) and men higher intensity demands (RD>18 km/h; RAcc and Acc_{MAX}) during official competition. Specifically, in badminton, men's playing rhythm is faster and more intense than women's, according to previous research that found higher rally duration, more strokes per rally, smashes and net points that require more high-intensity locomotion and accelerations in men (Abian-Vicen et al., 2013; Fernandez-Fernandez et al., 2013).

However, no sex differences were found in the other variables analysed ($Speed_{MAX}$, HR_{AVG}, RJumps, $Landing_{AVG}$,TakeOff[3–5 g], $TakeOff_{AVG}$ and TakeOff[5–8 g]) despite RD ($p = 0.03$). Previous studies showed no sex differences in several physiological/ perceptual markers, such as HR_{AVG}, percentage of maximum HR (%HR_{MAX}), blood lactate and rate of perceived exertion (Faude et al., 2007; Fernandez-Fernandez et al., 2013). Therefore, only the difference in the physical dynamics for badminton play between men and women is related to accelerations and high-intensity locomotion, that do not affect the volume of movements, internal load demands or jump capacity.

Finally, with respect to the demands in the different parts of the match, there were found differences in RD. No previous research has analysed fatigue throughout the match sets, but other research has analysed physiological and fatigue biomarkers between matches in tournaments, with a tendency to an increase in values of HR, RPE and La and a reduction of ROM and shoulder strength during the tournament (Faude et al., 2007; Fernandez-Fernandez et al., 2013, 2019). Maintaining maximum effort throughout the match without performance decreasing, presenting more intensity in the last part of the sets in both sexes is possible thanks to (a) a low effective playing time of 40-50% (Cabello-Manrique & González-Badillo, 2003; Fernandez-Fernandez et al., 2019; Fuchs et al., 2014; Phomsoupha & Laffaye, 2015), (b) 1:2 ratio between playing and resting phases (Phomsoupha et al., 2017), and (c) longer breaks in play (i.e. "timeouts" of 2 min between games or 1-min rest periods when one side reaches 11 points) (Fernandez-Fernandez et al., 2019). Therefore, to maintain the best performance throughout the match sets, and specifically at the end of the sets, training sessions should combine high-intensity efforts of very short duration (1-to-9 seconds) with short recovery periods of low-intensity activity (standing or walking for 6-to-15 seconds). This training effort design simulates the competition demands (Cabello-Manrique & González-Badillo, 2003; Fernandez-Fernandez et al., 2019; Fuchs et al., 2014; Phomsoupha & Laffaye, 2015), and helps the player to develop a quick recovery between points with the aim of being at the best physical level for the next point and maintaining their best physical performance throughout the match sets.

While the results of this study have provided information about the physical load demands of young badminton players during an international championship with consecutive games per day recorded by an advanced tracking system, using principal component analysis to determine the locomotion characteristics of the game based on fatigue throughout the sets of the game and sex-related differences, some limitations to the study must be acknowledged. Although the sample used for this study is from young international badminton players, these results should be taken with caution when applying them to senior players. Due to the nature of the tournament, there were contextual conditions that were not controlled such as rest and recovery between efforts that could affect locomotor performance during the competition.

5. Conclusions

Relative distance, maximum acceleration, relative jumps and average TakeOff in men, and relative distance and maximum acceleration in women represented most of the total variance in the locomotion parameter selection by principal component analysis, being considered determinants for U'18 badminton players sports performance. With respect to the demands in the different parts of the match, no differences were found between both genders in any type of locomotion index, although the load dynamics presented more intensity in the last part of the sets (decisive phase to win the set), both in men and women. Regarding sex-related differences, relative acceleration and maximum acceleration presented higher values in men, so the volume of demands is similar in both sexes, the only difference being in the intensity of the locomotion.

New technology such as local positioning tracking systems and microsensor devices allows the collection of data quickly and reliably in indoor conditions. These devices provide a large amount of data which is difficult to process to give a quick and simple report to both athletes and coaching staff. To choose the most important variables of badminton that explain all variance of data, principal component analysis is a mathematical process that can reduce a large number of data to a small number of variables that explain the total behaviour in specific sport modalities.

Both genders obtained equal locomotion demands, but men performed more technical actions that implied jumps. If the high-intensity demands are maintained throughout the game sets it is due to the continuous breaks between rallies and the intra-set and inter-set breaks during the games. Finally, in addition to jumps, men's games are faster than women's due to major demands in Relative Accelerations and Maximum Accelerations. Therefore, all these considerations should be taken into account when designing specific badminton simulated tasks, recovery programmes and strength and conditioning plans in order to achieve the best physical level and maintain the health status of the athlete to avoid injuries.

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ORCID

Daniel Rojas-Valverde http://orcid.org/0000-0002-0717-8827
Carlos D. Gómez-Carmona http://orcid.org/0000-0002-4084-8124
Jaime Fernández-Fernández http://orcid.org/0000-0002-5284-303X
Juan García-López http://orcid.org/0000-0003-2834-3366
Vicente García-Tormo http://orcid.org/0000-0002-8127-5393
José Pino-Ortega http://orcid.org/0000-0002-9091-0897

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