Impact of several consecutive matches in a day on physical performance in elite junior badminton players

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Introduction

Badminton is an indoor racket sport that has gained popularity since its inclusion in the Olympic Games of Barcelona, in 1992. At that time, official matches were played over the best of 3 games of 15 points each. However, a new game scoring system of 21 points with a rally point system over the best of 3 games was introduced in 2006, with the intention of shortening the length of the game (Javier Abian-Vicen, Castanedo, Abian, & Sampedro, 2013; Ming, Keong, & Ghosh, 2008). Thus, for badminton singles matches, the rules state that a match consists of the best of 3 games, with the first player scoring 21 points winning the game. When one side reaches 11 points, both players get a 60-second break and 2-

minute break between games (Fernandez-Fernandez, de la Aleja Tellez, Moya-Ramon, Cabello-Manrique, & Mendez-Villanueva, 2013; Ming, et al., 2008).

The activity pattern in a badminton match is intermittent with repetitive short periods of exercise (i.e., 1–9 seconds) and recovery (i.e., low-intensity activities as standing or walking for 6–15 seconds) interspersed with longer breaks in play (i.e., “time outs” of 120 seconds between games) (Javier Abian-Vicen, et al., 2013; Fernandez-Fernandez, et al., 2013; Lees, 2003; Manrique and Gonzalez-Badillo, 2003). Moreover, badminton is claimed to be the world’s fastest racket sport with the shuttlecock reaching a maximum velocity of 100 $m \cdot s^{-1}$ (360 $km \cdot h^{-1}$) (Ooi et al., 2009). From a physiological point of view, exercise intensity associated with these activity patterns have shown relatively high heart rate (HR) responses (i.e., average intensities around 80–90% of maximum HR (HR_{max}), oxygen uptake (O_2) values around 70% of maximum oxygen uptake (VO_{2max}), and low to moderate blood lactate (La) values (up to 5 $mmol \cdot L^{-1}$) (Faude et al., 2007; Fernandez-Fernandez, et al., 2013; Ooi, et al., 2009). However, previous studies only analyzed simulated match-play conditions, which could differ from real demands.

Moreover, match scheduling, participation in multiple draws (singles, doubles and mixed doubles) and training demands require young elite badminton players to often complete numerous training sessions and/or competitive matches on consecutive days (J. Abian-Vicen et al., 2014; Abian et al., 2016). Thus, players usually take part in two or three consecutive badminton matches in a day (i.e., morning and afternoon sessions) as part of their competition schedule. To the best of our knowledge, only a previous study (J. Abian-Vicen, et al., 2014), analyzed the influence of the competitive round on muscle strength (i.e., counter-movement jump (CMJ) performance and grip strength), and hydration patters in elite badminton players (23.0 ± 4.8 years) during a real competition. The changes in jump height, mean power during the push off phase in a CMJ and the grip strength of both dominant and non-dominant hands were assessed before and after a match. Authors reported that the completion of one singles badminton match led to an increase in CMJ height (4.5 ± 7.3%, $p<0.05$), although they observed no change in handgrip strength in either hand. Given these data, it could be concluded that little fatigue is induced in well-trained players during a single competitive match.

In other racket sports, such as tennis, authors analyzed the physiological, physical, and perceptual responses to repeated days of tennis match play (i.e., 1 to 4 h matches conducted under a tournament scenario simulation) (Gallo-Salazar et al., 2017a; Gescheit, Cormack, Reid, & Duffield, 2015; Ojala and Häkkinen, 2013). Although results are contradictory, from a neuromuscular point of view, some studies have shown force impairments (i.e. rate of force development and maximal strength) in the lower extremities (knee extension)) during simulated tennis tournaments (2-3 h matches on 3 consecutive days) (Ojala and Häkkinen, 2013), while other studies (i.e. 3 consecutive 2 h tennis matches) reported no significant reductions in lower-limb performance (i.e., CMJ and isometric knee torque) (Brink-Elfegoun et al., 2014). Significant reductions in the maximal voluntary contraction have also been found in the upper extremities (i.e., triceps brachii) as well as in both internal (IR) and external (ER) dominant shoulder rotation (Brink-Elfegoun, et al., 2014; Gescheit, et al., 2015). Furthermore, during these tournament scenario simulations, players have reported high values of perceived muscle soreness (Brink-Elfegoun, et al., 2014; Gescheit, et al., 2015; Ojala and Häkkinen, 2013), while the concentration of blood markers of muscle damage (i.e. creatine kinase [CK]) increased over the competition days

(Gescheit, et al., 2015; Ojala and Häkkinen, 2013). More recently, also in young (15 years old) tennis players (Gallo-Salazar et al., 2017b), reported physical impairments in several neuromuscular performance variables involving lower (e.g. jumping, sprinting and change of direction) and upper (e.g. isometric strength and range of motion) limbs the day after playing a competition with two consecutive matches on the same day.

To date, there is a lack of data describing the effects of neuromuscular fatigue imposed during consecutive badminton matches performed under real tournament conditions, despite its growing popularity and significance within the sporting community. Therefore, the aim of this study was to analyze the effects of playing several badminton matches (one singles and one doubles) on the same day on physical performance in elite junior players, during an international junior championship. We hypothesized that physical performance would be significantly reduced after the completion of competitive matches.

Methods

Participants

Thirty-one elite junior badminton players (age 16.6 ± 1.0 years, body mass 63.9 ± 6.1 kg, height 174.8 ± 6.1 cm) participated in this study. From them, nineteen were boys (age 16.4 ± 1.1 years, body mass 65.6 ± 5.3 kg, height 179.6 ± 7.3 cm), and twelve were girls (age 16.9 ± 0.7 years, body mass 61.3 ± 6.7 kg, height 167.3 ± 5.6 cm). The players were ranked between 1 and 40 in their respective national singles ranking (U18), trained 18.4 ± 2.8 hours per week and had a training background of 6.3 ± 1.2 years. The participants were not taking medications for the duration of the study and they had been free of musculoskeletal injuries during the previous three 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 (Spanish Badminton Federation (FESBA)) Ethics Board approved the procedures in accordance with the latest version of the Declaration of Helsinki.

Experimental protocol

Three weeks before the XI Spanish Junior International 2017, held in Oviedo (Spain), all the players who were going to participate in the men's and women's singles/doubles/mixed doubles modalities, were informed by mail about the purpose of the investigation. A cross-sectional repeated measures experimental design was carried out on two consecutive days to observe the effects of playing real badminton matches in the same day on elite junior players, with the rationale to provide useful practical information for coaches and players when planning tournament schedules, as well as preparing match and recovery strategies. Each participant took part in two experimental trials (Pre and post-competition) separated by approximately 24h and both conducted in morning sessions under similar experimental conditions (21.0 ± 2.4 ºC; 50.6 ± 6.3 % of relative humidity). Between the trials, players participated in a real junior championship, including the completion of one singles match and one doubles/mixed doubles match on the same day.

One day before the beginning of the tournament, on arrival at the badminton facility (9 a.m.), participants were randomly distributed in groups of 4 players each. The testing took place in two different locations, a physiotherapy room and an indoor synthetic court. Every group followed the same testing protocol separated by lapses of 10 min between each stage. To reduce the interference of uncontrolled variables, all the participants were lodged in a players' residence within the training facility to control meals and resting times and were instructed to maintain their habitual lifestyle during the study. The participants were familiarized with the measuring protocols corresponding to the maximal effort tests.

Measurements

Vertical Jumping (Counter-movement Jump (CMJ)).

A bilateral CMJ without arm swing was performed on a contact-time platform (Ergojump®, Finland) according to the protocol previously published (Bosco, Mognoni, & Luhtanen, 1983). Each player performed 2 maximal attempts interspersed with 45 s of passive recovery, and the highest jump was recorded and used for statistical analysis. The Intraclass correlation coefficient (ICC) for this test ranged from 0.94 to 0.96.

Grip Strength.

Handgrip strength was measured using a hydraulic hand dynamometer (Saehan Corporation, Masan, Korea). In an upright position, the participant was asked to perform a maximal voluntary contraction standing with the dynamometer at one side (i.e. dominant hand) and gripping the dynamometer as hard as they could for 3 s. This was repeated for each hand (i.e. dominant and non-dominant hand). The average of the 2 attempts (with a 30-second rest period between trials) for each hand was considered to be the maximum voluntary handgrip strength (Brink-Elfegoun, et al., 2014). The ICC for this test ranged from 0.94 to 0.98.

Shoulder range of motion (ROM).

To measure passive glenohumeral rotation we followed the methods previously described (Cools et al., 2014), using an inclinometer (ISOMED, Portland, Oregon) with a telescopic arm (Figure 1). Each participant lay supine on a bench, with the shoulder in 90º of abduction and the elbow flexed to 90º (forearm perpendicular to the bench). From this starting position, an examiner held the participant's proximal shoulder region (i.e. clavicle and scapula) against the bench to stabilize the scapula while another examiner rotated the humerus in the glenohumeral joint to produce maximum passive external rotation (ER) and internal rotation (IR) (Moreno-Pérez, Moreside, Barbado, & Vera-Garcia, 2015). Two attempts at both IR and ER, as well as for both, dominant and non-dominant sides, were performed, with the best result (º) being used for statistical analysis. The ICC for this test ranged from 0.88 to 0.93.

Figure 1. Evaluation of the shoulder ROMs (internal and external rotation on the left and right pictures, respectively)

Isometric maximal voluntary contraction (MVC) of the dominant/non-dominant shoulder.

MVC during internal (IR) and external rotation (ER) of the shoulder were measured using a handheld dynamometer (Lafayette Instrument Company, IN, USA), which was calibrated prior to each test. Testing was undertaken following the methods previously described (Cools, et al., 2014; Couppe et al., 2014). Overall, strength tests were performed in a supine position with the arm in 90° abduction and 0° rotation, in the scapular plane (Figure 2). The elbow was flexed to 90° and the examiner stabilized the humerus by pressing it down toward the examination table. Participants were allowed to grasp the table with the other arm to provide more stabilization. The isometric test consisted of a 5–6 s maximal effort by the player. One examiner performed all the tests and gave standardized verbal encouragement during the effort. Two attempts at both IR and ER as well as for both, dominant and non-dominant sides, were performed, with the best result (Newtons (N)) for each situation being retained. There was a 30-second rest period between trials. The ICC ranged from 0.83 to 0.94.

Figure 2. Evaluation of the MVC of the shoulder (internal and external rotation on the left and right pictures, respectively)

Isometric MVC of the dominant/non-dominant hip.

Hip adduction (ADD) and abduction (ABD) were measured using a handheld dynamometer (Lafayette Instrument Company, IN, USA), which was calibrated prior to each test. Testing was undertaken following the methods previously described (Thorborg et al., 2011). The participants were placed in the supine position and were told to stabilize themselves by holding onto the sides of the table with their hands (figure 3). The examiner applied resistance in a fixed position 5 cm proximal to the proximal edge of the lateral malleolus, and the participants exerted a 5-s MVC against the dynamometer. They performed two attempts at both dominant and non-dominant sides and the highest value was used in the analysis. One examiner performed all the tests and gave standardized verbal encouragement during the effort. There was a 30-second rest period between trials. The ICC ranged from 0.91 to 0.97.

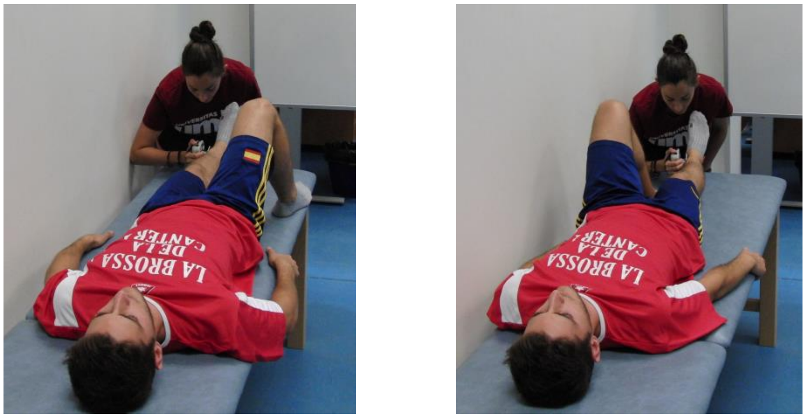

Figure 3. Evaluation of the hip MVC during abduction (left picture) and adduction (right picture).

Hip range of motion (ROM)

The passive hip rotation (internal and external) and passive hip abduction test at 90º of hip flexion ROMs of the dominant and non-dominant limbs were assessed following the methodology previously described (Cejudo, Ayala, De Baranda, & Santonja, 2015; Cejudo, de Baranda, Ayala, & Santonja, 2015; Murray, Birley, Twycross-Lewis, & Morrissey, 2009). Tests were carried out under stable environmental conditions by the same two physical therapists with more than 10 years of experience (one conducted the tests and the other ensured proper testing position of the participants throughout the assessment manoeuvre). The dominant limb was determined according defining the dominant leg as the lower extremity of the ipsilateral side of the smash stroke and the same side as the upper extremity with which the player served (Ellenbecker et al., 2007). An ISOMED inclinometer (Portland, Oregon) with a telescopic arm was used as the key measure for all hip ROMs. The inclinometer was consistently placed level before each measurement to ensure that no change occurred in the sensitivity. A low-back protection support (Lumbosant, Murcia, Spain) was used to standardize the lordotic curve (15º) during the hip extension ROM assessment.

The inclinometer was placed over the greater trochanter of the femur for the hip abduction at 90º of hip flexion ROM (figure 4.3), and over the mid-point of the distal end of the fibula for the hip internal and external rotation ROM (figure 4.1 and 4.2, respectively). Moreover, the distal arm of the inclinometer was aligned parallel to an imaginary bisector line of the limb throughout each trial. Variations in pelvic position and stability may affect the final score of several hip ROM measurements (Bohannon, Gajdosik, & LeVeau, 1985). Thus, to accurately evaluate hip ROMs, the assistant physical therapist stabilized the pelvis during all the tests in this study.

Figure 4. Evaluation of the hip ROM during internal (1), external rotation (2), and abduction (3).

Participants were instructed to perform, in a randomized order, 2 maximal trials of each ROM test for each limb, and the mean score for each test was used in the subsequent analyses. Participants were examined without shoes. A 30-45 s rest was given between trials, limbs and tests. One or both of the following criteria determined the endpoint for each test: (a) palpable onset of pelvic rotation, and/or (b) the participant feeling a strong but tolerable stretch, slightly before the occurrence of pain. An extra endpoint criterion was established for the passive tests, i.e., the examiner's perception of firm resistance (Cejudo, de Baranda, et al., 2015; Moreno-Perez, Ayala, Fernandez-Fernandez, & Vera-Garcia, 2016).

Badminton matches

Each player participated in an international junior competition according to the current rules of the Badminton World Federation (BWF). After an individual warm-up of about 10 minutes (e.g., running, mobility exercises, and playing several points), subjects played their respective matches (i.e., to the best of 3 games), according to their draws (i.e., individual or doubles/mixed doubles). The duration of each match was therefore variable (i.e., ranging from 20 min to 44 min), and recovery times between matches were standardized, following the rules of BWF, allowing the players to have a minimum rest time of 30 minutes between matches.

During matches, HR was monitored and recorded at 5-second intervals during the matches using a chest monitor and wrist receiver (Polar Team Pro, Kempele, Finland), placed on each player before the warm-up. The data obtained from the HR monitors were downloaded on a portable personal computer using the manufacture's software. A predicted maximum HR (HR_{max}) based on the equation of Tanaka, Monahan and Seals (Tanaka-HR_{max} = 208 - 0.7 × age), was used for later analyses (Tanaka, Monahan, & Seals, 2001). HR data were classified based on percentage time spent in 5 zones: (a) <60% HR_{max}, (b) 61–70% HR_{max}, (c) 71–80% HR_{max}, (d) 81–90% HR_{max}, (e) > 91% HR_{max}. Moreover, the training load for each match was calculated using the Session-RPE method for each subject during the study period. This method involved multiplying the match duration in minutes by the mean training intensity. The training intensity was measured using the 0 to10 RPE scale (G. Borg, Hassmen, & Lagerstrom, 1987; G. A. Borg, 1982). Ten min following the completion of each match subjects were asked 'How intense was your match?', and were requested to make certain that their RPE referred to the intensity of the whole activity rather than the most recent match intensity (Foster et al., 2001). Subjects were also asked after the match to score on a visual analogue scale (VAS) the general amount of delayed onset muscle soreness (DOMS). The VAS consisted of a 100 mm line whose endpoints were labeled by “no pain” and the right end by “unbearable pain”. Subjects had to draw a vertical line at a point on the line that best represented their pain at the time of measurement. The Score was the distance in centimeters from the left border of the scale to the point marked (Cleather and Guthrie, 2007; Price, McGrath, Rafii, & Buckingham, 1983).

Participants drank standardized water (~2–3 L dependent on player) and carbohydrate (2.5 $g \cdot kg^{-1}$ body mass) during the matches, while no instructions about drinking were given to the players to avoid any influence of this investigation on their habitual competition routines. All recovery procedures, exercise, food and fluid intake were regulated across consecutive days of play, and standardized across all participants to minimize influence on subsequent match play outcomes. Participants stayed in the same accommodation and completed food diaries each day, with the supervision of the research team, to help ensure further consistency (Gescheit, et al., 2015).

Exercise-induced muscle damage

One blood sample was taken from each participant at three different moments (pre-competition, post-competition and 24 h after the end of the last match) to assess blood markers of muscle damage. Each sample consisted of 0.20 mL of capillary blood obtained by finger prick from the non-dominant hand and subsequently introduced into an EDTA Microtainer tube. Within 15 min of the blood collection, 30μL were applied to a test strip and introduced in the CK analyzer (Reflotron ® Plus system, Roche, Madrid, Spain). The remaining 170μL were introduced in a portable analyzer (Cobas h 232 POC system. Roche, Madrid, Spain) to obtain myoglobin values.

Sweat electrolyte losses

Ten minutes prior to the beginning of the first match warm-up, two patches (Tegaderm + Pad, 3M, St Paul, MN, USA) were placed on participants' forearm to collect sweat samples, as it has been previously described in sport (Del Coso et al., 2016) (Figure 5). For this purpose, non-dominant's forearm skin was cleaned with distilled water and alcohol and dried with clean gauze to eliminate any remains of previous sweat from the skin. The sweat patch was then firmly adhered to the skin and fastened by an elastic tubular net bandage (Elastofix, Insfarma, Zaragoza, Spain). Within the 10 min of the end of the second match the sweat patches were removed using clean tweezers and placed in a sterile 10-mL tube. Sweat patches that were detached from the skin or presented a leak were discarded. The sweat was separated from the patches by centrifugation (10 min at 3000 g), transferred to 5-mL sealed tubes and refrigerated at 4 °C. Within 2 days of the collection, sweat electrolyte concentration (Na^+, K^+ and Cl^-) was measured using an ion selective electrode analyzer (Cobas 6000, Roche, Madrid, Spain).

Figure 5. Participant with the sweat patch.

Body fluid balance

Ten minutes prior to the first match warm up and 2 min after the end of the second match, pre-and post-competition body mass were measured (50 g scale; Radwag, Poland) to obtain body mass changes. During the competition participants drank *ad libitum* only from their own individually labeled bottles and were instructed to avoid drinking from the end of the second match until the post-competition weighting. Fluid intake rate was measured from the change in bottle weight using a 1-g-sensitive scale (Delicia, Tefal, France). Sweat rate was estimated from body mass change, total fluid intake and competition duration.

Statistics

Data are presented as mean ± standard deviation (SD). The distribution of raw data sets was checked using the Kolmogorov–Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$). Dependent t-tests were performed to assess pre-to-post differences for each dependent variable in both groups. Independent sample t-tests were run to evaluate baseline and post-test differences between groups (boys vs. girls) for each dependent variable using software PASW statistics (version 22.0; SPSS Inc., Chicago, IL, USA).

In some of the variables (Exercise-induced muscle damage, sweat electrolyte losses and body fluid balance), differences between variables were calculated using a magnitude-based inference approach (Hopkins, 2009). Pre-to-post changes and differences between male and female badminton players were determined using a spreadsheet for analysis of a post only crossover trial, and a spreadsheet to compare means of two groups respectively (Hopkins, Marshall, Batterham, & Hanin, 2009). The effect-size statistic ± 90% CI was used on log transformed data to reduce bias due to non-uniformity of error. The smallest significant standardized effect threshold was set as 0.2, and a qualitative descriptor was included to represent the likelihood of exceeding this threshold. Ranges of likelihood <1% indicated almost certainly not chances of change; 1% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possible; 75% to 95%, likely; 95% to 99%, very likely; >99%, most likely. Differences were rated as unclear when likelihood exceeded >5% in both positive/negative directions. Effect sizes were interpreted according to the following ranges: <0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; 2.0–4.0, very large and; >4.0, extremely large (Hopkins, et al., 2009).

Results

The pre and post intervention results of each group are reported for descriptive purposes in tables 1 and 2. T-tests showed significant differences ($p < 0.05$) in dominant and non-dominant hip adduction strength, shoulder external rotation ROM of both arms, and all measures of hip ROM, except abduction in non-dominant leg, between pre-test and post-tests in boys. Especially relevant were the losses in dominant internal rotation shoulder strength, hip and shoulder ranges of motion. Contrarily hip strength tests increased considerably. In girls, t-test demonstrated significant differences ($p < 0.05$) in dominant and non-dominant hip adduction strength, dominant hip abduction strength, non-dominant shoulder external rotation ROM, and external and internal hip ROM of both legs, between pre-test and post-tests. The most significant losses in neuromuscular variables after matches were hip and shoulder ranges of motion. On the other hand, most of the strength variables increased highly (see tables).

In addition, there were paired inter-group differences in most of the variables at baseline, except for shoulder ROMs, hip external rotation ROM and Y-balance anterior distance. There were significant post-test differences between genders in absolute and normalised internal and external rotation shoulder strength tests, except dominant external rotation; hip adduction strength both absolute and normalised data and non-dominant abduction range of motion. The inter-groups differences and the pre (baseline) and post intervention results of each group are reported for descriptive purposes also in tables 1 and 2.

Table 1. Pre and post-competition differences in shoulder ROMs and isometric strength.

Protocols and variables	Boys				Girls				*p*
	Baseline (pre-test)	Post-test	Difference	% Dif	Baseline (pre-test)	Post-test	Difference	% Dif	
	Mean ± (SD)				Mean ± (SD)				
Shoulder Strength test (N)									
Internal Rotation D	132.4 ± 16.0	127.3 ± 17.8	-5.1 ± 15.3	-4.02	92.6 ± 6.1	95.5 ± 13.2	2.9 ± 14.7	3.00	0.01
Internal Rotation ND	111.8 ± 17.2	118.5 ± 15.1	6.7 ± 14.8	5.66	79.5 ± 5.9	80.8 ± 10.3	1.3 ± 10.7	1.60	0.00
External Rotation D	100.9 ± 21.6	98.5 ± 18.7	-2.4 ± 10.8	-2.38	75.4 ± 10.0	79.1 ± 7.3	3.7 ± 10.8	4.75	0.14
External Rotation ND	87.0 ± 13.5	93.0 ± 11.3	6.0 ± 12.6	6.42	69.3 ± 4.1	74.5 ± 12.8	5.2 ±12.7	7.01	0.08
Internal Rotation D norm	2.0± 0.2	1.9 ± 0.2	-0.1 ± 0.2	-3.90	1.5 ± 0.2	1.6 ± 0.2	0.1 ± 0.3	1.11	0.006
Internal Rotation ND norm	1.7 ± 0.2	1.8 ± 0.2	0.1 ± 0.2	5.98	1.3 ± 0.2	1.3 ± 0.2	0.0 ± 0.2	6.26	0.005
External Rotation D norm	1.5 ± 0.3	1.5 ± 0.2	0.0± 0.2	-2.22	1.2 ± 0.2	1.3 ± 0.1	0.1 ± 0.2	4.89	0.14
External Rotation ND norm	1.3 ± 0.2	1.4 ± 0.4	0.1 ± 0.3	6.81	1.1 ± 0.1	1.2 ± 0.2	0.1 ± 0.2	6.96	0.06
Shoulder Range of motion (º)									
Internal Rotation D	63.8 ± 13.6	62.3 ± 11.7	-1.5 ± 8.8	-2.41	64.8 ± 16.9	66.5 ±13.3	1.7 ± 10.0	2.46	0.51
Internal Rotation ND	76.2 ± 14.2	73 ± 14.6	-3.2 ±12.6	-4.35	83.9 ± 12.1	82.3 ± 7.3	-1.6 ± 8.6	-1.92	0.24
External Rotation D	150.4 ± 15.2	142.9 ± 12.9	-7.5 ±12.6*	-5.29	152.5 ± 10.2	144.6 ± 14.4	-7.9 ± 14.5	-5.41	0.74
External Rotation ND	142.6 ± 13.1	136.1 ± 8.5	-6.5 ± 9.7*	-4.84	142.6 ± 12.3	129.2 ± 11.8	-13.4 ± 11.6*	-10.39	0.25

a: Normalized to limb length expressed as a percentage; D: dominant; ND: non-dominant; N: newton; kg: kilograms; cm: centimeters; º: degrees;
*: $p < 0.05$ between pre and post-test intra-gender.

Table 2. Pre and post-competition differences in hip ROM, isometric hip strength and the anterior distance in the Y-balance test

Protocols and variables	Boys				Girls				*p*
	Baseline (pre-test)	Post-test	Difference	% Dif	Baseline (pre-test)	Post-test	Difference	% Dif	
	Mean ± (SD)				Mean ± (SD)				
Y Balance test (cm) [a]									
Anterior distance DL	59.3± 5.9	58.6± 5.6	-0.7± 2.4	-1,24	61.6± 5.7	59.7±4.5	-1.9± 4.6	-3.23	0.20
Anterior distance NDL	59.8± 5.1	58.8± 5.5	-1.0± 3.1	-1.74	60.8± 3.8	60.9±4.2	0.1± 2.9	0.16	0.10
Hip Strength test (N) (N/kg)									
Abduction DL	146.6±17.0	156.9±23.2	10.3±23.2	6.55	116.3±12.9	144.5±28.7	28.2±27.3*	19.49	0.50
Abduction NDL	148.3±23.8	155.3±18.3	7.0±23.5	4.48	125.4±24.7	143.9±27.4	18.5±16.6*	12.88	0.82
Adduction DL	160.3±28.7	178.2±31.1	17.9±19.6*	10.04	119.1±16.4	139.1±29.5	20.0±17.7*	14.40	0.01
Adduction NDL	163.8±34.3	177.1±25.4	13.3±19.2*	7.50	121.4±12.1	117.4±29.5	-4.0± 28.5	-3.36	0.002
Abduction DL norm	2.3± 0.2	2.5± 0.2	0.2± 0.3	6.21	1.9± 0.2	2.4± 0.5	0.5± 0.5*	12.88	0.46
Abduction NDL norm	2.3± 0.3	2.4± 0.2	0.1± 0.4	4.47	2.0± 0.2	2.4± 0.4	0.4± 0.3*	12.98	0.77
Adduction DL norm	2.5± 0.4	2.8± 0.4	0.3± 0.3*	10.30	1.9± 0.3	2.3± 0.4	0.4± 0.3*	14.12	0.004
Adduction NDL norm	2.6± 0.4	2.8± 0.3	0.2± 0.3*	7.87	2.0± 0.3	1.9± 0.5	-0.1± 0.5	-4.13	0.002
Hip Range of motion (º)									
Internal Rotation DL	49.7± 8.0	45.3± 6.9	-4.4± 4.8*	-9.61	59.1± 6.5	52.5± 7.6	-6.6± 9.0*	-12.54	0.09
Internal Rotation NDL	50.5± 8.9	45.3± 7.5	-5.2± 7.5*	-11.41	59.8± 7.8	52.3± 12.2	-7.5± 6.2*	-14.17	0.29
External Rotation DL	64.0± 7.4	54.1±12.1	-9.9±13.9*	-18.24	64.5±10.3	49.7± 8.9	-14.8± 8.8*	-29.87	0.08
External Rotation NDL	60.4±10.3	51.1±12.0	-9.3±12.8*	-18.32	66.7± 5.5	53.3± 9.8	-13.4±10.2*	-25.00	0.41
Abduction DL	62.1±10.2	57.8±10.8	-4.3± 6.7*	-7.32	69.8± 7.1	68.4± 7.7	-1.4± 9.4	-2.07	0.07
Abduction NDL	59.5±10.2	59.9± 9.1	0.4± 5.4	0.69	68.3±10.8	69.6± 6.0	1.3± 7.7	1.92	0.01

a: Normalized to limb length expressed as a percentage; D: dominant; ND: non-dominant; N: newton; kg: kilograms; cm: centimetres; º: degrees; *: $p < 0.05$ between pre and post-test intra-gender.

Badminton matches

Overall, duration of matches was 26.9 ± 5.9 min, ranging between 20 and 44 min, with no significant differences between boys and girls (27.7 ± 6.2 min vs. 28.1 ± 5.7 min). Regarding the physiological responses during the game, average percentage of the maximum HR (%HR_{max}) for girls and boys was 80.5 ± 7.1 and 83.2 ± 4.2, respectively. Figure 6 shows the percentage of time spent by girls and boys in the different HR categories during official matches. Comparing the time spent at these HR categories, girls showed less time at 50-60% (5.1 vs 7.6%; ES = -0.51) and 61-70% (7.3 vs. 12.1%; ES = -0.82) of HR_{max} compared to boys, while they spent more time at intensities from 81-91% (43.2 vs. 31.3%; ES = 1.03).

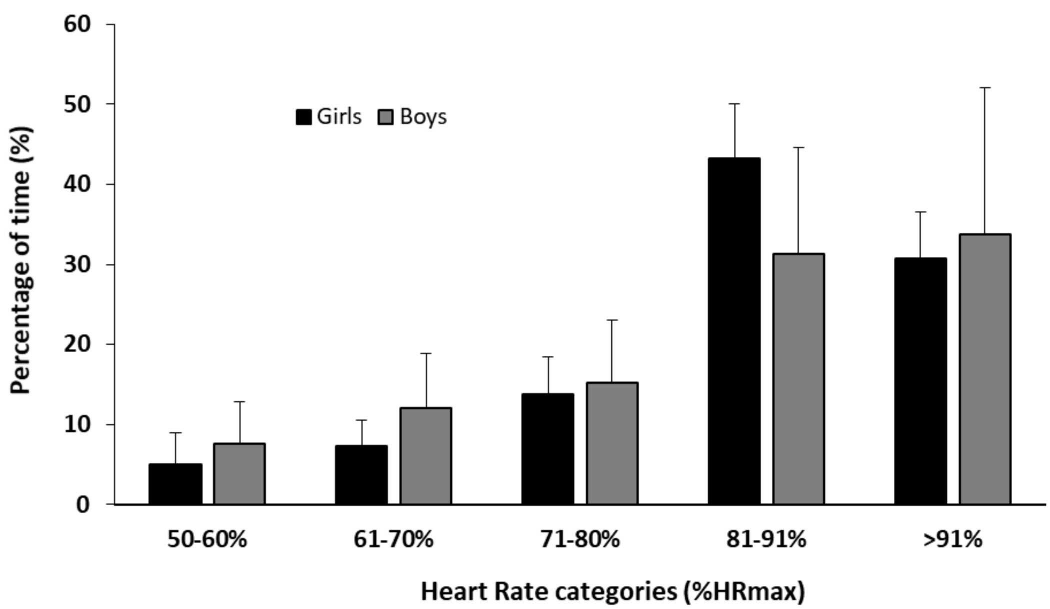

Figure 6. Percentage of time spent by boys and girls in the different HR categories during all matches.

RPE values increased (~ 5%) from the first to the second match, for both boys (5.4 ± 2.1 vs. 5.8 ± 2.2) and girls (5.1 ± 1.9 vs. 5.8 ± 2.5), although ES were trivial to small (0.18 and

0.30 for boys and girls, respectively). On the other hand, VAS results increased considerably (~20%) after matches, for both, boys (2.2 ± 2.1 vs. 3.4 ± 2.2; ES = 0.54) and girls (2.9 ± 2.4 vs. 3.5 ± 2.3; ES = 0.25).

CMJ performance

As previously mentioned, pre CMJ values were significantly different between boys and girls, with data favouring boys. Regarding changes after badminton matches, for boys, there was a trivial increase in bilateral CMJ of 2.5%, as well as a trivial decrease in the unilateral performance (-3.7% and -2.7% for the dominant and non-dominant leg, respectively, with trivial ES). In girls, bilateral CMJ showed a trivial decrease (-0.2%; trivial ES), while unilateral performance was reported as trivial, with slightly increases after matches (2.3% and 2.9% for dominant and non-dominant leg, respectively; trivial ES).

Body fluid balance

On average, pre-competition body mass was not different (mean ± SD; ES ± 90% CI, qualitative descriptor) from post-competition body mass (63.9 ± 6.1 vs 63.9 ± 6.2 kg; ES = 0.00 ± 0.01, most likely trivial) which in turn produced a negligible body mass reduction in the sample of badminton players (-0.03 ± 0.45%; NS). However, the pre-to-post-competition change in body mass presented a high inter-individual variability with ~55% of participants losing body mass after the competition, ~10% of participants without measurable changes in body mass and ~35% of participants with an increased in body mass after the match (range from -0.80 to +1.24%; Figure 7). Specifically, the pre-to-post-competition change in body mass was of similar magnitude in male and female badminton players (-0.01 ± 0.50 vs -0.06 ± 0.31%; ES = 0.50 ± 0.77, unclear). On average, sweat rate during the matches was 1.1 ± 0.5 L/h while the rate of rehydration was very similar (1.1 ± 0.5 L/h), producing the negligible changes in body mass mentioned above. However, both sweat rate (1.2 ± 0.5 vs 0.9 ± 0.5 L/h; ES = 0.71 ± 0.57, likely) and rehydration rate (1.2 ± 0.5 vs 0.8 ± 0.6 L/h; ES = 0.73 ± 0.54, likely) were higher in male vs female badminton players.

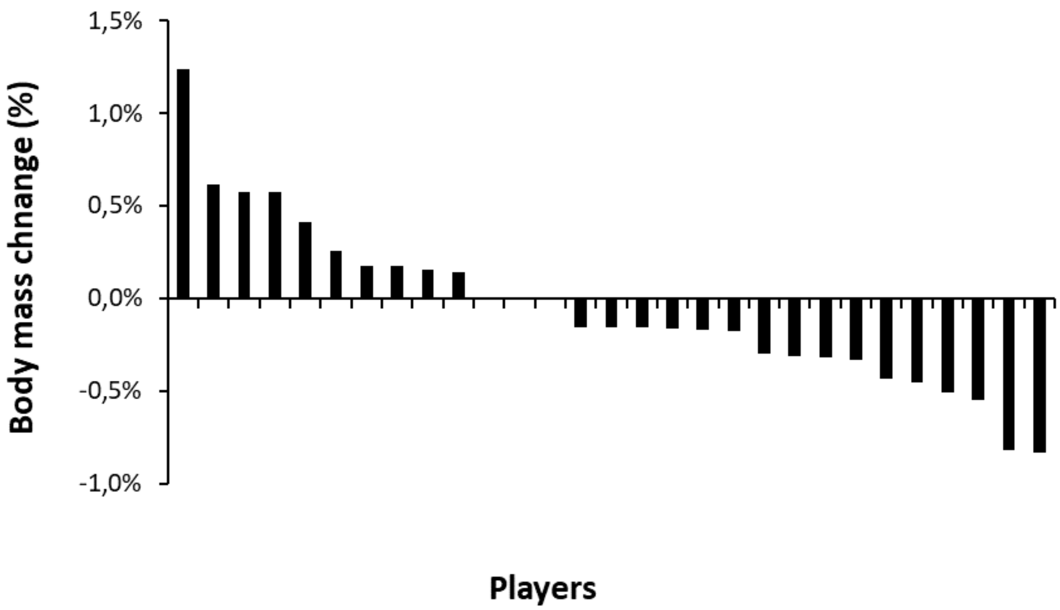

Figure 7. Individual data for the pre-to-post-competition change in body mass. Positive values indicate individuals that increased their body mass after the competition and negative values indicate individuals that lost body mass after the competition.

Sweat electrolyte losses

On average, sweat Na^+ concentration was 54.5 ± 24.9 mmol/L (24.0-111.0 mmol/L), sweat Cl^- (9.9-74.1 mmol/L) concentration was 32.1 ± 16.8 mmol/L (5.4–9.7 mmol/L) and sweat K^+ concentration was 7.0 ± 1.3 mmol/L. The concentrations for these electrolytes were not different between male and female participants (ES = 0.37 ± 0.69, unclear; ES = 0.40 ±

0.72, unclear; ES = 0.45 ± 0.70, unclear; for sweat Na+, Cl- and K+, respectively; Figure 8). The total sweat Na^+ (27.7 ± 16.3 vs 28.7 ± 22.9 mmol; ES = 0.03 ± 0.67, unclear), Cl^- (16.3 ± 12.1 vs 16.7 ± 13.1 mmol; ES = 0.05 ± 0.70, unclear) and K^+ (3.5 ± 1.0 vs 3.6 ± 2.6 mmol; ES = 0.17 ± 0.62, unclear) lost during the badminton competition was also similar between male and female badminton players.

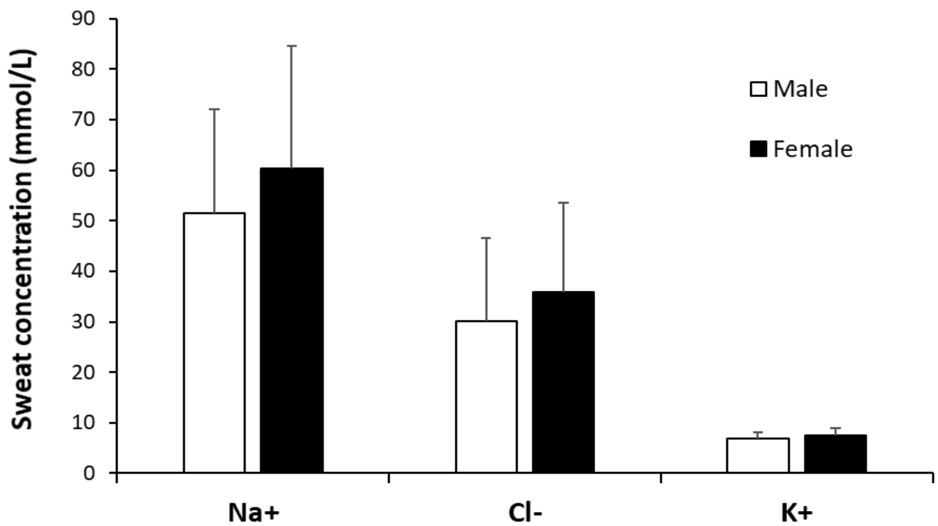

Figure 8. Sweat sodium (Na^+), chloride (Cl^-) and potassium (K^+) concentration in male and female badminton players during a badminton competition.

Exercise-induced muscle damage

Before the competition, the serum concentration of CK was 130 ± 115 U/L (12-322 U/L) and the serum concentration of myoglobin was 30.2 ± 12.9 ng/mL (15.0-46.0 ng/mL). Just after the competition, the serum concentration of CK increased to 468 ± 290 U/L (60-1180 U/L; ES = 1.58 ± 0.24, most likely) and the concentration of myoglobin reached 94.7 ± 71.3 ng/mL (15.0-257.0 ng/mL; ES = 1.71 ± 0.44, most likely). Twenty-four hours after the competition, the concentration of CK was reduced but it was still high respect to the pre-competition values (357 ± 295 U/L (56-1360 U/L; ES = 1.07 ± 0.49, most likely) while the concentration of myoglobin returned to basal levels 37.8 ± 31.9 ng/mL (15.0-147.0 ng/mL). This pattern was similar between male and female participants although the serum concentrations of CK and myoglobin were higher in the male sample of badminton players after the competition (Figure 9; ES = 0.78 ± 0.61, likely and ES = 1.21 ± 0.65, very likely, respectively). Nevertheless, the self-reported values for muscle pain after the competition were similar for male (3 ± 2 point) and female (4 ± 2 point; ES= 0.01 ± 0.63, unclear).

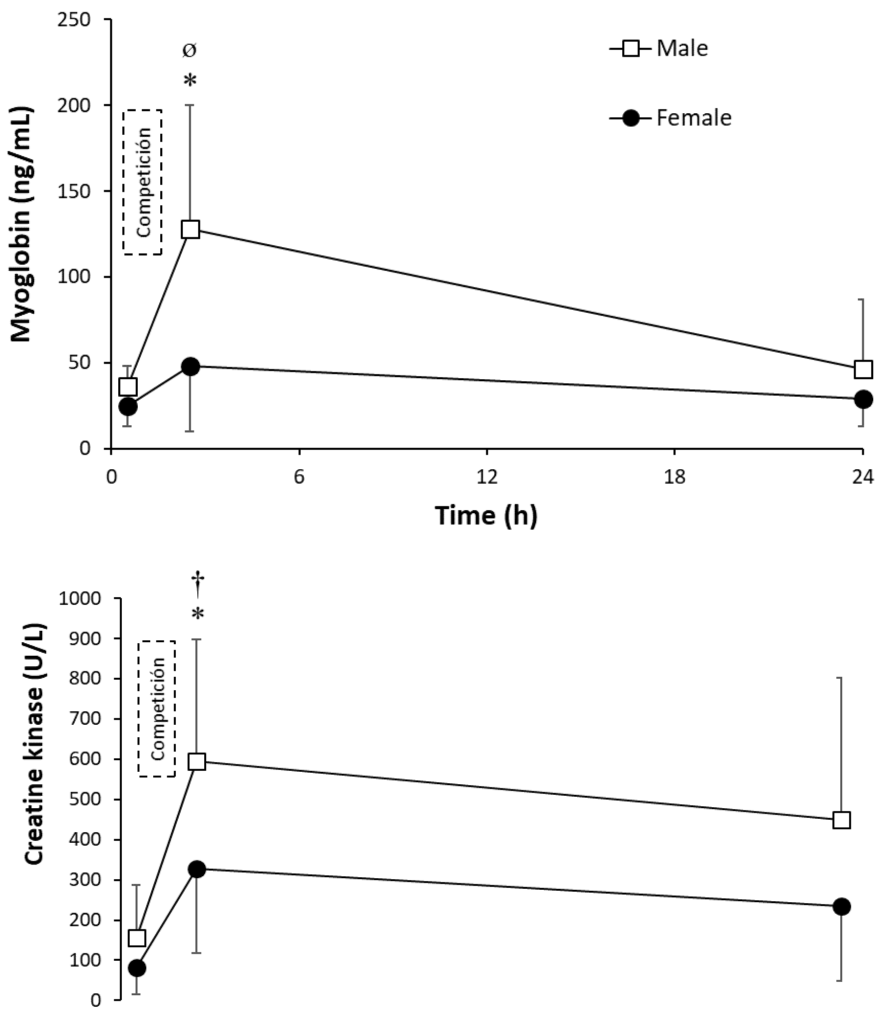

Figure 9. Serum creatine kinase (upper panel) and myoglobin (lower panel) concentrations before and after a badminton competition. (*) Post-competition different from pre-competition. ES = large. (†) Male different from female badminton players. ES = moderate. (ø) Male different from female badminton players. ES = large

Discussion

To the best of our knowledge, this is the first study analysing neuromuscular performance as well as muscle damage during a real badminton tournament. This study provides a novel insight into the physiological and perceptual responses to badminton match play in youth elite male and female players. Our hypothesis was that physical performance would be significantly reduced after the completion of competitive matches. In this regard, results partially supported our initial hypothesis, as significant decreases were found in several measurements (i.e., hip adduction strength, shoulder external rotation ROM, hip ROM) for both, boys and girls (see tables 1 and 2). However, there were significant increases in most of the strength values analysed (i.e., Shoulder IR/ER, Hip ABD/ADD), for both, boys and girls, after the completion of two matches. Regarding sweat rate measures, data showed similar rates between boys and girls, with no signs of dehydration. Moreover, a moderate-to-high levels of exercise-induced muscle damage was found in the present sample of players, as measured by several folds increases in the pre-to-post-competition values of serum CK and myoglobin, highlighting the high-intensity nature of badminton competition.

Results showed similar HR values during matches, for boys and girls (80 to 85%), with intensities ranging from 77 to 85% of HR_{max}. Results are in line with previous research conducted under simulated tournament conditions (Faude, et al., 2007; Fernandez-Fernandez, et al., 2013), with no influence of gender on the different physiological parameters, including blood lactate and HR. Overall, based on previous research (Javier Abian-Vicen, et al., 2013; Fernandez-Fernandez, et al., 2013; Manrique and Gonzalez-Badillo, 2003), although the shuttlecock is in play less than half of the time (average effective playing time for players ~ 35%), the average HR_{max} of players was above 80%, which demonstrates the considerable physiological stress induced by badminton match play in both male and female players. Values were in range of previous research, including young, but also adult badminton players (Faude, et al., 2007; Fernandez-Fernandez, et al., 2013; Manrique and Gonzalez-Badillo, 2003). A more detailed analysis of the HR responses during match play, with the description of intensity periods expressed as $\%HR_{max}$ (Fernandez-Fernandez, et al., 2013), may provide a better representation of the intermittent and high-intensity nature of badminton. Thus, 73.9% of the match time, girls played above 80% of HR_{max}, while in boys, this time accounted for 65.1% of the whole match time. In this regard, results showed slight differences between boys and girls, with girls spending more time at intensities 81-91% of HR_{max}. Although speculative, this could be related to a higher psychological stress or emotion and/or lower fitness levels, as reported in other sports (Filaire, Alix, Ferrand, & Verger, 2009; Helsen and Bultynck, 2004). Based on these results, and from a practical perspective, high percentage of training programs should include specific (i.e., game-related) training exercises characterized by short high intensity (>90% of HR_{max}) efforts interspersed by short recovery periods.

While RPE has been reported to be a valid index of exercise intensity in other intermittent sports (Bourdon et al., 2017), to our knowledge, only a previous study reported changes in perceived exertion during the course of a badminton match (Fernandez-Fernandez, et al., 2013). Present results were in line of this previous study, with RPE values averaging ~ 5 arbitrary units, classifying the matches as “hard”, for both, boys and girls. In this regard, although RPE can be used as an estimate of exercise intensity during badminton play, more work is needed to fully understand its use during this type of exercise and the correspondence between perceptual and other physiological variables (Fernandez-Fernandez, et al., 2013; Manzi et al., 2010). Moreover, it would be interesting to analyse the evolution of the training load during typical parts of the preparation/competitive season, to analyse the relationship between values.

Based on the characteristics of badminton competitions (i.e., the need of play several consecutive matches), it can be expected that acute fatigue will be an important issue in the sport. A simple definition of fatigue could be the reduction in the maximum capacity of the muscle to generate force (Gandevia, 2001). Several studies have shown that vertical jump height is one of the most sensitive markers of fatigue to monitor elite athletes (Loturco et al., 2017; Nakamura, Pereira, Rabelo, Ramirez-Campillo, & Loturco, 2016), with CMJ as one of the most used measures in sports performance (Claudino et al., 2017). Results of the present study showed no differences in the bilateral/unilateral CMJ after two badminton matches, with possibly trivial changes for both, boys and girls. The fact that badminton players are used to perform technical actions (i.e., smashes), which are biomechanically similar to the CMJ, could be related to the lack of important decreases in the CMJ performance. Also, in the present study we used the highest CMJ performance for analysis, similar to the vast majority of previous studies (Claudino, et al., 2017). In this regard, it has been suggested that the averaged jump results were more sensitive than the highest jump in detecting fatigue. This could be a limiting factor which should be taken into account for future studies. Finally, regarding the CMJ, although it is a valid test for general assessments of neuromuscular function, its relationship with badminton-specific performance (i.e., smash velocity) is unknown, and will be also an interesting topic for future research.

Regarding hip strength values (i.e., absolute and normalized values), surprisingly, results showed important improvements for both, boys and girls, with percentages of improvement ranging from 5 to 19% in the dominant/non-dominant abduction and adduction, except in the non-dominant abduction for girls, with significant decreases (-4.1%). It is difficult to make comparisons as no previous study has reported hip strength values in badminton players. Only a previous study showed hip strength values in young tennis players (Gallo-Salazar, et al., 2017a), also after playing two consecutive matches in a day, with increases in the ADD strength in both legs, while there was a small decrease in the non-dominant ABD strength. In the specific case of this decrease for the girls, it can be attributed to a higher level of fatigue in these muscles than in boys. First, girls showed less power in the lower body and also less body height than boys, which could be related to differences in a badminton-specific action, which is the lunge. In the case of girls, because of the shorter leg-length, they must follow the lunge movement, always performed with the dominant leg, with the non-dominant leg, which would lead to a higher activation of the adductor muscles compared to the boys. Because we did not use EMG analyses, it´s only speculation, based on external observations and coaches' opinions.

Although speculative, improvements in the other hip strength measures could be related to the post-activation potentiation (PAP) phenomenon. PAP is acknowledged as a short-term enhancement in muscle strength and power after performing a high-intensity conditioning activity (Hodgson, Docherty, & Robbins, 2005). It has been demonstrated that such high-intensity exercises during warm-up routines may improve performance in speed and power events (Seitz and Haff, 2016). In addition, some recent studies have reported jump potentiation after different endurance running exercises in endurance athletes (Boullosa, del

Rosso, Behm, & Foster, 2018). However, there are several issues we should take into account when referring to PAP. Although the time-window in which players performed the post-tests are in agreement with literature recommendations (i.e., 10 min post-exercise) (Boullosa, et al., 2018), muscle temperature could be a confounding factor. In this regard, although players performed a supervised warm-up protocol before pre-tests, it was obvious that body temperature before performing the post-tests was significantly higher. Again, this is also a limitation of the present study, because we did not measure player´s internal temperate, and it´s based on simple observations. The possible increased muscle temperature has been documented to increase instantaneous power output and maximal sprint cycling power output, and is likely attributed to increased muscle temperature-related increases in ATP turnover rate (Gray, De Vito, Nimmo, Farina, & Ferguson, 2006), positive shifts in the force velocity curve, increased enzymatic cell reactions and nerve conduction velocity (McGowan, Pyne, Thompson, & Rattray, 2015). Thus, positive acute adaptations the activity such as elevation of muscle temperature and increased metabolic responses should be differentiated from potentiation of contractile capacity per se (Boullosa, et al., 2018). Also, the aim of the present study was not to analyse the PAP phenomenon, but it seems that results showed a balance between fatigue and potentiation. The hip muscles analysed, abductors and adductors, are consider stabilizing muscles for the pelvis, showing a muscle fiber composition being predominantly type 1 (slow twitch) fibers (Tyler, Fukunaga, & Gellert, 2014). Previous research suggested that prolonged activities at submaximal intensities would induce a greater force production capacity as a consequence of a better PAP/fatigue relationship (Mettler and Griffin, 2012). Given the greater fatigue resistance of slow-twitch fibres, a better PAP/fatigue balance would be expected with endurance trained muscles during and after appropriate conditioning activities (Boullosa, et al., 2018). Finally, It has been reported in animal models that the presence of adrenaline and estradiol concentrations has been proposed to influence the PAP, expecting a greater potentiation (Decostre, Gillis, & Gailly, 2000; Lai, Collins, Colson, Kararigas, & Lowe, 2016). In the present study, post-tests were carried out right after finishing the second match, and, again, although we didn't measure blood catecholamine concentrations, the activation level of the players was very high, and this could affect the post-test results, especially the strength tests.

The amount of lower body activity during a badminton match is important, and previous studies about competitive badminton reported that the lunge represented over 15% of all the movements in a single match (Kuntze, Mansfield, & Sellers, 2010). As previously mentioned, the ability to move quickly with power and an appropriate range of motion (ROM) is a requisite for a good lunge performance (Fu, Ren, & Baker, 2017). Moreover, the repetitive ballistic trunk movement required, together with the 'hyperextension' during the smash motion may be associated with lower back problems, as it happens in tennis (Moreno-Pérez, Ayala, Fernandez-Fernandez, & Vera-Garcia, 2016). In this regard, it has been theorized that the mechanical stress imposed to the lumbar spine during these motions may be higher when a deficit in hip rotation ROM is present (Moreno-Pérez, et al., 2016).

When analysing ROM values, it is important to highlight if there are significant bilateral differences between the dominant and non-dominant sides, taking into account the cut-off values reported in the literature (>10%) (Ellenbecker, et al., 2007) . Unfortunately, we are not aware of any previous research conducted with badminton players, and no comparison can be made. Overall, average IR/ER and ABD hip values are higher than in other racket sports, such as tennis (Ellenbecker, et al., 2007; Moreno-Pérez, et al., 2016), with an average of more than 10º in each test.

Present results showed no bilateral differences in both sexes, in any of the measures performed (2.4% in the IR/ER and 3.6% in the ABD). Also, interestingly, based on the values reported in previous research, the mean ROM values obtained for the hip internal/external rotation and abduction might be considered as normal, based on the reference values reported in previous research (>25º for internal rotation; >35º for external rotation; >40º for abduction) (Gerhardt, Cocchiarella, & Lea, 2002; Roach, San Juan, Suprak, & Lyda, 2013). In addition, the greater passive hip external rotation found (>10º on average), compared with internal rotation, is consistent with values reported in different athletes, including elite tennis players (Ellenbecker, et al., 2007; Moreno-Pérez, et al., 2016), as well as in general population (Kouyoumdjian, Coulomb, Sanchez, & Asencio, 2012). However, from a clinical standpoint application, the magnitude of some of the differences found should be taken into account, as they exceed the threshold of 10º proposed in previous studies for other athletes (i.e., male and female elite tennis players) (Ellenbecker, et al., 2007; Moreno-Pérez, et al., 2016; Young et al., 2014). Calculating the number of players with bilateral differences greater than 10º in any hip ROM measure, we found that 7 players (22.6%) were identified for IR and ER, and 4 players (12.9%) for ABD. After playing two matches, the profiles are not changing considerably, but in some cases, bilateral differences were greater than 30º. Thus, the inclusion of in-between matches stretching exercises, or an increase in their dose should be included in badminton-conditioning and preventative programs, with the aim of achieving or maintaining normal or low injury risk values for hip internal/external rotation, as well as abduction ROMs.

In case of the shoulder strength (shoulder IR/ER), upper body performance seems to be an important factor in badminton players, as they must perform a great number of powerful strokes over concentrated periods of time (~40% of the whole match time) (Fernandez-Fernandez, et al., 2013). Descriptive values of the players analysed here showed that boys were stronger than girls in both, IR and ER, not only analysing absolute values, but also relative after adjustment for body weight. To the best of our knowledge, only a previous study analysed the shoulder (i.e., ROM and IR/ER strength) of a similar age-range of national badminton players (Couppe, et al., 2014), showing absolute and relative values lower than in the present study. It would be necessary to conduct more badminton-specific research in order to compare not only boys and girls, but also different performance levels.

In terms of overall bilateral differences in the shoulder strength, data showed most likely differences of 13.9% (Moderate ES=0.8) and 9.7% (Moderate ES=0.6) in the IR and ER, respectively, favouring the dominant side. When analysing boys and girls separately, differences were also found. In boys, IR and ER were most likely higher in the dominant compared to the non-dominant side, with 13.9% and 9.7% differences for the IR and ER, respectively (moderate ES (1.5 to 1.9)). In girls, similar values were obtained, with 12.8% and 7.5% differences in the IR and ER, respectively (moderate to large ES (1.1 to 2.0)).

In general, with respect to cut-off values distinguishing a healthy shoulder from a shoulder at risk, an isometric ER/IR ratio of 75% is advised, with a general rotator cuff strength increase of 10% of the dominant throwing side compared to the non-dominant side (Cools, et al., 2014). Our results showed an ER/IR ratio of 78% and 81% for the dominant and non-dominant sides, respectively, suggesting that in terms of injury risk, these sample of junior badminton players, show “safe” values of shoulder IR/ER strength. However, as players are still young and they will be submitted to great training loads, caution should be taken in this regard, as analysing individual data, results showed ratios exceeding 90% or even more (i.e., two cases over 100%). Therefore, based on the individual reports, the inclusion of training programs aimed to the rotator cuff strengthening should be recommended. Regarding the effects of playing two matches in the same day on the shoulder strength values, results showed different results for boys and girls. In boys, IR and ER strength of the dominant side decreased 4% and 2.4%, respectively, while values for the non-dominant side surprisingly increased (i.e., +5-6%). In case of girls, data are more surprising, with increases in all measures ranging from 1.1 to 7%. It is difficult to compare data with previous studies, as there is no information available regarding badminton players. Several previous studies, conducted with tennis players and analysing IR/ER maximal strength production of the shoulder after consecutive matches or days of prolonged match play, reporting reductions in the dominant shoulder rotation levels ranging from 6 to 8% (Gallo-Salazar, et al., 2017a; Gescheit, et al., 2015). In accordance with common definitions of fatigue (Gandevia, 2001), we could state that, in boys, upper-body strength was affected by fatigue, and although these reductions are trivial (ES<0.2), values are in agreement with previous tennis-specific research showing decreases in serve velocity either as training and matches progress or subsequent to their completion (Mendez-Villanueva, Fernandez-Fernandez, & Bishop, 2007). In badminton, this could lead to a less effective use of the stretch shortening cycle in the shoulder rotators during the cocking and acceleration phases and consequently to a decrease in smash performance.

In girls, results are the opposite to boys, excluding the non-dominant values, which also increased in boys, with increases in all the measures (small ES: 0.3 to 0.5). In general, differences can be related to the strength levels in girls, which are significantly lower than in boys. This could lead to a less powerful game style and therefore, the previously suggested balance between potentiation and fatigue could benefit the first factor. Thus, although speculative, improvements in shoulder strength measures in girls could be related to the PAP phenomenon, as previously described. More information would be needed in order to establish more conclusions. In case of the increases obtained for the non-dominant side, for both, boys and girls, results could be also related to the potentiation factor, which could be more evident in this side, as high fatigue levels are not expected. However, the high muscular activity of this side while playing is evident, as players are continuously required to balance the body and generate powerful strokes and movements, in which the non-dominant side is fundamental.

Excessive or limited shoulder ROM may contribute to shoulder pathologies such as instability and impingement (Martin, Kulpa, Ezanno, Delamarche, & Bideau, 2016). However, the information on shoulder ROM in badminton is very scarce. Only a previous study analysed the rotational profile of healthy young players, with lower ROM values than in the present study, which together with the strength measures, highlight the higher level of the present sample of players. Results showed that, after two matches, ROM values decreased for both, boys and girls, in the dominant and non-dominant IR and ER, except in the IR ROM of the girls ‘dominant side. deficits in the IR values of the dominant side averaged 2% in boys, while in girls values increased 2.4%. Deficits in the boys were lower than previous values reported in tennis or baseball specific research after a ‘‘normal’’ baseball throwing game (50 to 72 throws) or after a prolonged tennis match (3h), with deficits ranging from 4 to 20% (Gallo-Salazar, et al., 2017a; Martin, et al., 2016; Reinold et al., 2008). Differences between boys and girls could be related to the strength differences previously mentioned. Interestingly, ER values, for both dominant and non-dominant side, and for both, boys and girls, decreased significantly, with values ranging from 5.4 to 10.4%. This can be related to the high number of powerful strokes which are performed overhead, but with a shoulder ER (i.e., defensive clear under pressure).

From a pathological point of view, although present results showed important decreases in the dominant side IR, values are already in the limit (bilateral differences of 19º for girls and 13º for boys), as shoulder IR problems are identified when there is a loss of rotation greater than 18º to 20º, with a corresponding loss of total ROM greater than 5º when compared bilaterally (Cools, Ellenbecker, & Michener, 2017). Moreover, caution should be taken, as present individual values can be already considered as dangerous, with bilateral differences exceeding in some cases more than 30º. Regarding TROM values, again, in the present study were less than 10º for both, boys and girls. However, as in the case of IR ROMs, individual cases should be analysed, as we reported individual TROM values higher than 40º.

The sweat rate reported in this investigation with young badminton players was similar to the mean values measured in elite badminton players during a national championship (1.1 L/h; (J. Abian-Vicen, Del Coso, Gonzalez-Millan, Salinero, & Abian, 2012)). The current investigation has also determined a likely sex-difference in the sweat rate measured during the competition which is in part explained by the difference in exercise intensity between boys and girls, as average HR is a little bit higher in boys. Both, boys and girls, rehydrated at a rate similar to the sweat lost during the competition which in turn produced that the body mass lost during the badminton matches, a sign of dehydration, was negligible on average. However, the individual responses for the body mass changes in the competition reflect that some individuals lost body mass while other increased their body mass from pre-to-post-competition (Figures 7 and 8). None of the individuals that lost body mass during the competition surpassed a loss of > 2% and thus, their fluid replacement strategies were in agreement with previous recommendations for exercise (Sawka et al., 2007). However, ten individuals (7 male and 3 female badminton players) increased their body mass during the matches which should be avoided to prevent electrolyte disturbances (Hew-Butler et al., 2015), especially in those players that compete several times during a day. Although the competition conditions of modern badminton ease rehydration within and between matches due to pauses in the game (J. Abian-Vicen, et al., 2014), it is still necessary the adoption of individualized fluid guidelines to prevent excessive body mass loss/gain during badminton competitions.

A previous investigation has determined the presence of moderate levels of exercise-induced muscle damage after a badminton match, although the magnitude of the damage attained during the game was not related to decreased sprint or power performance in lower leg muscle (Abian, et al., 2016). In the current investigation, it has also been found a moderate-to-high levels of exercise-induced muscle damage in this sample of elite and young badminton players, as measured by several folds increases in the pre-to-post-competition values of serum creatine kinase and myoglobin (Figure 9). With a very high probability, boys presented a higher post-competition concentration of creatine kinase and myoglobin than girls, suggesting again the higher physical demands and intensity of the single men category of badminton that translates into a higher magnitude of exercise-induced muscle damage. As the muscle pain reported after the competition was not different between boys and girls, it can be assumed that this difference was not translated into a worsened muscle performance (Abian, et al., 2016). Interestingly, the values of these blood markers of muscle damage returned to pre-competition values 24 hours after the end of the competition, which suggests that skeletal muscle was recovered after this period of time. As badminton training simulates the routines and movements of competition (Lees, 2003), it is possible that elite badminton players are accustomed to the development of exercise-induced muscle damage during high-intensity training sessions and to the recovery of the signs and symptoms of this phenomenon for the next session.

In summary, results partially supported our initial hypothesis, as significant decreases were found in several measurements (i.e., hip adduction strength, shoulder external rotation ROM, hip ROM) for both, boys and girls, with strength values being potentiated after the completion of two matches. Regarding sweat rate measures, data showed similar rates between boys and girls, with no signs of dehydration. Moreover, a moderate-to-high levels of exercise-induced muscle damage was found in the present sample of players, as measured by several folds increases in the pre-to-post-competition values of serum CK and myoglobin, highlighting the high-intensity nature of badminton competition. Moreover, based on the ROM impairments reported, it appears necessary, especially at young ages, to restore the "normal" shoulder ROM before having to play the next match as well as to improve general flexibility. This can be done educating the players to use specific stretching routines, joint mobilization, and other short-term recovery strategies, such as self-myofascial release using a foam roller (Gallo-Salazar, et al., 2017a), in order to avoid overuse injuries and to maintain performance levels. Light joint mobilizations (i.e., for both, the upper and lower body) together with stretching routines involving those overloaded joints (i.e., shoulder and hips) should be performed a minimum of twice a week for a total of 15-20 min per session (Moreno-Pérez, et al., 2016). Moreover, the use of the foam roller (2-3 sets of 30 s to 1 min) may offer short-term benefits for increasing joint ROMs at the hip, knee, and/or ankle without affecting muscle performance (Cheatham, Kolber, Cain, & Lee, 2015). Although these are general recommendations, it seems that monitoring changes in the strength as well as ROM profile of the badminton players are recommended in order to avoid overuse injuries, as players are usually submitted to very demanding training and competitive schedules. The measures conducted in the present study (i.e., ROM and manual strength testing), show excellent relative reliability for several for the evaluation of the shoulder/hip, and also show clinically acceptable absolute reliability values (Cools, et al., 2014). Thus, they should be included in the regular testing programs of badminton players.

It seems also important to highlight several limitations of the present study. First, because of the real tournament demands, individual differences were important, as for example, match duration was not balanced, as well as the level of the opponents, which depended on the tournament draw. Moreover, adding more measurements could have provided further information about the real impact of every match on performance, enhancing the value of the research. However, due to the real tournament conditions, the present study offers a unique insight into the competitive demands of elite junior badminton players, and data can be used to design sport-specific routines in terms of performance, injury prevention and nutrition.

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