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**Research article**

# Analysis of Time-Motion and Heart Rate in Elite Male and Female Beach Handball

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## Abstract

Beach handball is a spectacular new team sport; however, scientific knowledge about the demands in beach handball is very low. Consequently, the aim of this study was to analyze the physical demands of elite beach handball players by means of time-motion analysis with GPS technology and physiological response with Heart Rate (HR). Both male (n = 12) and female (n = 12) players from the Spanish Beach Handball National Team were recruited for this study. The sample consisted in four matches of two 10-min periods each. Time-motion analysis was performed through GPS devices (SPI Pro X, 15 Hz, GPSports) with synchronized HR monitoring (Polar Electro, Finland). All parameters were recorded for matches and halves to express overall and time-dependent physical and physiological responses. Total match distance covered by male and female players were 1234.7 ± 192 m and 1118.2 ± 221.8 m, respectively. Female players covered more total distance ($p = 0.049$, ES = 0.79) and distance walking ($p < 0.001$, ES = 2.04) in the first half, whereas they covered more distance standing ($p = 0.008$, ES = 1.05) in the second half at a higher average speed ($p < 0.001$, ES = 2.28). The number of accelerations distributed over low-, moderate- and high-intensity categories were 43.2 ± 11.6, 9.4 ± 4.9; 0.8 ± 0.9 m/s$^2$ for male players, and 40.3 ± 12.7, 4.3 ± 3.0; 0.1 ± 0.3 m/s$^2$ for female players; equivalent to one body acceleration every 23 s and 27 s, respectively. Finally, male and female players obtained a maximum/mean HR of 173 ± 13 / 137 ± 12 bpm, and 177 ± 13 / 138 ± 18 bpm, with 20.3% and 29.2% of the total time in the anaerobic zone (81 – 90% HRmax), respectively. These results demonstrated that beach handball is a demanding sport, with numerous moderate-to-high intensity displacements, distributed intermittently throughout the game: long periods of low intensity activity interspersed by short bursts of high intensity.

**Key words:** Performance analysis, time-motion analysis, Global Positioning System (GPS), load intensity, elite, technology.

## Introduction

Team-handball is a physically demanding sport that is characterized by fast-paced end-to-end actions in which two teams pass a ball with the aim of scoring goals. As with other team sports, such as football (Castellano and Casamichana, 2010), volleyball (Jimenez-Olmedo et al., 2016), tennis (Sánchez and Gómez-Mármol, 2013) or rugby (Martins and Gas, 2014), handball has also been adapted to the sandy surface of the beach. Beach handball has emerged as a new worldwide, popular discipline with the support of the International, European and National Handball Federations.

Beach handball was created with specific rules to be more spectacular than indoor handball. Among them, we can find a double score for goals scored in flight, 360 degrees throwing or the use of the goalkeeper to attack. Beach handball is played by four players, one of them being the goalkeeper, on a sandy rectangular field of 27-meter length and 12-meter width. The match consists of two 10-minute sets with a shoot out to get a winner team in case of a tied match. Therefore, beach handball is characterized by the combination of high-intensity efforts, such as sudden accelerations with short recoveries, heterogeneously distributed across a match. As a result, players are exposed to both high- and low-level work rates which demand appropriate speed, sprint ability, strength and power (Lara-Cobos, 2011).

In order to improve performance, the demands of the sport must be known to design specific training. Therefore, physical and physiological analysis provides scientists and coaches with accurate information to set up routines and goals. Similar to analysis in other disciplines, such as beach soccer (Castellano and Casamichana, 2010), the assessment of running demands as an indicator of physiological load, together with Heart Rate (HR) measurements, are crucial to determine if there are differences between competition levels or genders. Kinematic variables such as distance, velocity, time sprinting and accelerations required by professional beach handball players during competitions at specific HR intensities would help coaches in optimizing the training process, since tailored training programs can be designed to match these demands (Campos-Vazquez et al., 2015).

A number of studies have been carried out on analyzing the physical profile of classic handball (Chaouachi et al., 2009; Gorostiaga et al., 2006; Manchado et al., 2013; Póvoas et al., 2012) and other sport variations, such as small-sided handball (Corvino et al., 2014; 2016; Dello-Iacono et al., 2016). Beach handball has been studied through notational analysis (Gruić et al., 2011; Morillo-Baro and Hernández-Mendo, 2015; Morillo-Baro et al., 2015) and psychology (Morillo-Baro et al., 2016). However, to the knowledge of the authors, there are currently no studies that analyze physical demands during a competition match in male and female players at national and international levels. Consequently, the aims of the present study were to investigate the physical demands by means of time-motion analysis of beach handball players with GPS technology, and the subsequent physiological

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response by means of HR responses.

## Methods

### Subjects

Twelve male (mean age: 26.3 ± 4.8 yrs, range 20–33 yrs; body weight: 84.5 ± 12.1 kg; body height: 1.87 ± 0.09 m; training experience: 9.5 yrs, training: 24.5 h/week) and female (mean age: 23.7 ± 4.8 yrs, range 17–33 yrs; body weight: 62.4 ± 4.6 kg; body height: 1.68 ± 0.05 m; training experience: 7.1 yrs, training: 23.5 h/week) beach handball players of the Spanish National Team were recruited for this study. The female Spanish National Team became Champion of the 2016 Beach Handball World Championship held in Budapest, Hungary. Similarly, the male Spanish National Team ranked fifth in the same competition.

All the players were previously informed about the research aims, experimental protocol and procedures of the study and voluntary gave their informed written consent to participate. The Ethics Committee at the University of Alicante gave institutional approval to this study, in accordance with the Declaration of Helsinki.

### Procedures

The study was conducted during the pre-game meeting prior to the 2nd Annual Spanish Beach Handball Cup held in June 2016. Male and female teams played two matches of two 10-min periods within each team. Since recordings were captured each half, a total of 48 records were attained for each group. To ensure that time-motion analysis was considered only when each player was involved in the game, goalkeepers and resting or bench periods were excluded.

The player's running profile during the competitive matches was assessed using a portable GPS device (SPI Pro X; GPSports Systems, Canberra, Australia) worn in a special harness on each player's back (mass: 76 g, dimensions 48 x 20 x 87 mm). Speed and distance were recorded at a sampling frequency of 15 Hz, whereas acceleration was recorded at 100 Hz by means of a built-in triaxial accelerometer. In order to capture HR data, an HR transmitter belt was also worn by each player (Polar Electro, Kempele, Finland). Once raw data had been gathered, the software provided by the manufacturer was used to download and analyze data in detail (Team AMS R1 2015, GPSports, Australia). Studies on validity and reliability of GPS devices reported that GPS analysis is a valid and reliable method for time-motion tracking in athletes during field sports (Coutts and Duffield, 2010; Jennings et al., 2010; Köklü et al., 2015).

The running profile was evaluated according to their frequency and duration using the distance attained in six speed zones: zone 1: *standing* (0–0.4 km/h), zone 2: *walking* (0.5–4 km/h), zone 3: *jogging* (4.1–7 km/h), zone 4: *cruising* (7.1–13 km/h), zone 5: *high-intensity running* (13.1–18 km/h) and zone 6: *sprinting* (>18 km/h). Speed zone labels were considered as similar to those used in other studies conducted in intermittent team sports (Cummins et al., 2013). However, speed zone intervals were corrected accordingly since beach handball is played on sandy surfaces which prevent players from performing quick movements. Therefore, the speed zones proposed by Castellano and Casamichana (2010) for beach soccer were used, together with the *standing* zone to account for lack of movement. The maximum speed achieved by males and females were 21.2 km/h and 18.5 km/h, respectively, which are in accordance with *sprinting* zones.

By means of the integrated triaxial accelerometer in each GPS device, accelerations and decelerations on three reference planes are measured as changes in gravitational forces, knowing that gravity of 9.8 $m/s^2$ equals 1 g. Player exposure to collisions was graded according to six impact zones provided by system manufacturer and used in previous studies (Cunniffe et al., 2009; McLellan and Lovell, 2012): zone 1: light impact, hard acceleration/deceleration/change of direction (5–6 g), zone 2: light-moderate impact, minor player collision, contact with the ground (6–6.5 g), zone 3: moderate-heavy impact, tackle (6.5–7 g), zone 4: heavy impact, tackle (7–8 g), zone 5: very heavy impact, high collision, tackle (8–10 g) and zone 6: severe impact/tackle/collision (>10 g). Body load during exercise is a measure of high impact activities, computed by the system software as a weighted sum of intense accelerations, decelerations, changes in direction, rapid changes in posture and collisions. Acceleration was also analyzed in zones: zone 1: low (1–2 $m/s^2$), zone 2: moderate (2–3 $m/s^2$) and zone 3: high (>3 $m/s^2$), according to previous studies ( Akenhead et al., 2013; Osgnach et al., 2010).

Finally, physiological demands were analyzed by means of HR data. In order to estimate the maximum HR (HRmax) of each player, the formula proposed by Tanaka et al. (2001) was used. However, for players with higher HRmax value during matches than the estimated one, the reference for calculating heart rate zones was the actual maximum value. Heart rate zones were determined as a function of each player's HRmax as follows: zone 1: <60% HRmax, zone 2: 61–70% HRmax, zone 3: 71–80% HRmax, zone 4: 81–90% HRmax, zone 5: 91–95% HRmax, and zone 6: >95%.

### Statistical analysis

All results were analyzed using Statistical Package for Social Sciences (SPSS v.22 for Windows, SPSS Inc, Chicago, USA). Data is presented as mean and standard deviation and the alpha level of significance was set at $p < 0.05$. The Kolmogorov-Smirnoff test was first applied to establish the goodness of fit to normality, confirming that the variables studied are normally distributed. Therefore, the t-test was applied for the analysis of differences for all variables over each half of every match. Additionally, Cohen's d effect sizes (ES) between groups were calculated to provide meaningful analysis for significant comparisons by applying the t-test. The following scale was applied for effect sizes: <0.2 (trivial), 0.2–0.6 (small), 0.6–1.2 (moderate), >1.2 (large) (Batterham and Hopkins, 2006). Due to the small sample in this study (n = 24), the bias-corrected effect size was used (Hedges and Olkin, 1985). Also, a two-way ANOVA (factor sex and factor half time) was performed to compare differences in half times, between male and female players and interaction between these factors, with significance at $p < 0.05$.

## Results

Table 1 presents the results of the time-motion analysis for male and female teams. For the match analysis, the zones where male players have traveled the most are *walking* (0.5–4 km/h) and *jogging* (4.1–7 km/h). However, the comparison between halves showed significant differences in mean distance in the walking category only (20.5% higher in the first half).

For female players, the *walking* (0.5–4 km/h) and *jogging* (4.1–7 km/h) zones were the most travelled, following the same trend as male team. The following variables showed significant differences between halves (corrected Cohen's ES between brackets): total distance (moderate), average speed (large), distances covered in the *standing* (moderate) and *walking* (large) speed categories and average time spent in sprint (small). Female players covered 21.7% more distance in the first half than in the second half but with lower average speed (78.6%).

Table 2 shows accelerometer data provided in speed changes and collisions through g force zones. Players' exposure to impacts is similar for male and female players. Both groups received a large number of very light impacts, consisting of accelerations or decelerations and changes of direction while running (zone 1). The number of impacts in this zone equals the sum of the rest of the zones, which means that collisions, tackles and moderate-to heavy-impacts are not common in beach handball. Furthermore, a slight decrease of such low-impacts (zone 1) is observed in male players, whereas female players showed the opposite trend. Table 2 also depicts the number of times male and female players change speed in defined categories over 1 s time intervals, in terms of matches and comparing halves. The starting speed threshold was set to 1.5 km/h due to the relatively low values of average speed. For both male and female players, the number of accelerations ranging 1–2 $m/s^2$ is similar, around 40 for the whole match, whereas for the rest of ranges covering more explosive accelerations, results show different values. No significant differences were observed in number of impacts and accelerations between first and second halves for both groups.

The maximum and mean HR values for the male and female teams are depicted in Table 3, together with percentage of time spent in each HR zone. Regarding HR zones, results showed that percentage of time spent in zone 3 (71–80% HRmax) and zone 2 (61–70% HRmax) were the largest ones for male players, accounting for more than half of the total time, whereas female players spent most of the time in zone 4 (81–90% HRmax), with nearly a third of the total. Comparison between halves for female players revealed that mean HR value was significantly higher in the second half (149 ± 15 bpm) than in the first (126 ± 14 bpm) with corrected Cohen's ES as large (1.63). Regarding percentage of time spent in each zone, there were significant differences in all zones, except for zone 3.

**Table 1.** Distance and speed per sex during matches and comparing first and second halves. Data are means (±SD).

| | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| | Match (*n*=24) | 1st half (*n*=12) | 2nd half (*n*=12) | ES | Match (*n*=24) | 1st half (*n*=12) | 2nd half (*n*=12) | ES |
| **Total distance (m)** | 1235 (192) | 669 (155) | 566 (138) | .69 | 1118 (222) | 614 (145) | 504 (130)* | .79 |
| **Average speed (km/h)** | 4.2 (.6) | 1.9 (.45) | 2.2 (.5) | –.62 | 3.9 (.8) | 1.4 (.3) | 2.5 (.6) † | –2.28 |
| | | | | **Distance (m)** | | | | |
| ***Standing* (0–0.4 km/h)** | 2.7 (1.6) | 1.5 (1.1) | 1.1 (.7) | .42 | 2.2 (1.0) | .8 (.6) | 1.4 (.5)* | –1.05 |
| ***Walking* (0.5–4 km/h)** | 395 (62) | 216 (34) | 179 (44) * | .92 | 407 (64) | 244 (44) | 163 (34) † | 2.04 |
| ***Jogging* (4.1–7 km/h)** | 433 (103) | 232 (61) | 200 (58) | .53 | 371 (94) | 202 (63) | 169 (41) | .61 |
| ***Cruising* (7.1–13 km/h)** | 356 (101) | 196 (87) | 160 (57) | .49 | 318 (109) | 157 (66) | 161 (70) | –.05 |
| ***HI running* (13.1–18 km/h)** | 45.8 (31.7) | 22.4 (25.2) | 23.3 (21.7) | –.04 | 20.2 (16.2) | 9.9 (9.2) | 10.4 (12.9) | –.04 |
| ***Sprinting* (>18.1 km/h)** | 2.31 (4.0) | .87 (2.0) | 1.4 (3.8) | –.17 | – | – | – | – |
| **Average time spent in sprint (s)** | 4.3 (.5) | 2.1 (.4) | 2.2 (.2) | –.31 | 4.4 (.5) | 2.3 (.3) | 2.0 (.3)* | .32 |

* $p<0.05$, † $p<0.01$ compare with first half. ES: Effect size 1st vs 2nd half

**Table 2.** Summary of game collisions, body load and accelerations per sex during matches and comparing first and second halves. Data are means (±SD).

| | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| | Match (*n*=24) | 1st half (*n*=12) | 2nd half (*n*=12) | ES | Match (*n*=24) | 1st half (*n*=12) | 2nd half (*n*=12) | ES |
| **Z1: Impacts 5–6 g** | 39.6 (13.8) | 20.5 (8.0) | 19.3 (8.9) | .14 | 51.1 (15.0) | 24.7 (11.9) | 24.9 (11.0) | –.02 |
| **Z2: Impacts 6–6.5 g** | 12.9 (5.8) | 7.0 (4.6) | 5.9 (2.9) | .28 | 12.7 (5.9) | 6.2 (3.9) | 5.9 (3.1) | .08 |
| **Z3: Impacts 6.5–7 g** | 8.0 (3.9) | 4.1 (2.7) | 4.0 (2.6) | .04 | 8.1 (4.0) | 4.6 (2.9) | 4.1 (1.9) | .20 |
| **Z4: Impacts 7–8 g** | 6.1 (2.7) | 3.8 (1.8) | 2.2 (2.1) | .80 | 9.8 (3.9) | 4.6 (3.7) | 4.9 (1.3) | –.11 |
| **Z5: Impacts 8–10 g** | 4.2 (3.5) | 1.8 (1.9) | 2.4 (2.2) | –.29 | 6.0 (4.3) | 3.2 (2.4) | 2.7 (2.5) | .20 |
| **Z6: Impacts >10 g** | 7.6 (4.3) | 4.1 (2.3) | 3.5 (3.2) | .21 | 6.25 (4.5) | 3.7 (3.7) | 2.5 (2.1) | .39 |
| **Total no. of impacts** | 78.4 (25.7) | 41.0 (15.7) | 37.4 (15.6) | .23 | 94.6 (29.2) | 47.1 (24.4) | 45.0 (15.0) | .10 |
| **Total body load** | 22.7 (9.2) | 13.0 (4.2) | 9.7 (6.2) | .61 | 24.4 (9.5) | 13.8 (7.8) | 10.6 (2.6) | .54 |
| **Z1: Accel. 1–2 $m/s^2$** | 43.2 (11.6) | 22.7 (8.5) | 20.4 (7.4) | .28 | 40.3 (12.7) | 18.8 (8.2) | 21.5 (8.3) | –.32 |
| **Z2: Accel. 2–3 $m/s^2$** | 9.4 (4.9) | 4.6 (3.2) | 4.8 (4.1) | –.05 | 4.3 (3.0) | 1.4 (1.7) | 2.9 (2.3) | –.73 |
| **Z3: Accel. > 3 $m/s^2$** | .8 (.9) | .6 (.7) | .25 (.4) | .60 | .1 (.3) | – | .1 (.3) | –.46 |

Z1–Z6: Collision Zones 1 to 6, Z1–Z3: Acceleration Zones 1 to 3.

**Table 3.** Heart rate and percent time spent in each HR zone per sex during the match and comparing first and second halves. Data are means (±SD).

| | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| | Match (*n*=24) | 1st half (*n*=12) | 2nd half (*n*=12) | ES | Match (*n*=24) | 1st half (*n*=12) | 2nd half (*n*=12) | ES |
| **HRmax (bpm)** | 173 (13) | 174 (15) | 172 (12) | .19 | 177 (13) | 178 (15) | 177 (12) | .05 |
| **Mean HR (bpm)** | 137 (12) | 134 (11) | 140 (13) | –.46 | 138 (18) | 126 (14) | 149 (14.9)† | –1.63 |
| **Z1: <60% HRmax** | 19.1 (16.5) | 23.1 (15.0) | 15.1 (17.6) | .48 | 26.7 (21.8) | 41.0 (20.5)† | 12.4 (11.4) | 1.70 |
| **Z2: 61–70% HRmax** | 25.5 (12.0) | 27.0 (12.6) | 24.0 (11.8) | .24 | 15.8 (10.8) | 22.3 (10.1)† | 9.3 (6.9) | 1.48 |
| **Z3: 71–80% HRmax** | 26.0 (11.5) | 23.8 (10.2) | 28.3 (12.8) | –.38 | 17.6 (13.2) | 15.4 (6.0) | 19.8 (17.8) | –.33 |
| **Z4: 81–90% HRmax** | 20.3 (14.4) | 17.9 (13.2) | 22.8 (15.8) | –.33 | 29.2 (20.4) | 17.4 (12.8) | 41.0 (20.1)† | –1.38 |
| **Z5: 91–95% HRmax** | 7.0 (10.4) | 6.1 (8.5) | 8.0 812.4) | –.18 | 8.3 (12.1) | 3.1 (3.6) | 13.5 (15.4)* | –.91 |
| **Z6: >95% HRmax** | 1.9 (4.2) | 2.0 (4.8) | 1.7 (3.6) | .07 | 2.3 (6.4) | .7 (1.1) | 3.9 (8.9)* | –.50 |

* p<0.05, †p<0.01, HR: Heart Rate, HRmax: Maximum Heart Rate, Z1–Z6: HR Zones 1 to 6.

**Table 4.** Results of the Two-Way ANOVA investigating the effects of sex and half time on all parameters.

| | Sex | | Half time | | Interaction | |
|---|---|---|---|---|---|---|
| | F | p | F | p | F | p |
| **Total distance (m)** | 2.01 | .16 | 6.77 | <.05 | .01 | .94 |
| **Average speed (km/h)** | .89 | .35 | 19.55 | <.01 | 7.34 | <.05 |
| **Distance (m) *standing* (0–0.4 km/h)** | 1.32 | .26 | .47 | .49 | 5.46 | <.05 |
| **Distance (m) *walking* (0.5–4 km/h)** | .28 | .60 | 26.84 | <.01 | 3.83 | .06 |
| **Distance (m) *jogging* (4.1–7 km/h)** | 3.64 | .06 | 3.98 | .05 | .01 | .97 |
| **Distance (m) *cruising* (7.1–13 km/h)** | .87 | .36 | .64 | .43 | .94 | .34 |
| **Distance (m) *HI running* (13.1–18 km/h)** | 5.76 | <.05 | .02 | .89 | .01 | .97 |
| **Distance (m) *sprinting* (>18.1 km/h)** | 3.35 | .07 | .21 | .65 | .21 | .65 |
| **Average time spent in sprint (s)** | .07 | .79 | 1.54 | .22 | 3.80 | .06 |
| **Z1: Impacts 5–6 g** | 2.94 | .09 | .01 | .91 | .04 | .84 |
| **Z2: Impacts 6–6.5 g** | .12 | .73 | .44 | .51 | .12 | .73 |
| **Z3: Impacts 6.5–7 g** | .16 | .69 | .16 | .69 | .08 | .78 |
| **Z4: Impacts 7–8 g** | 6.02 | <.05 | .81 | .37 | 1.89 | .17 |
| **Z5: Impacts 8–10 g** | 1.59 | .21 | n.s. | n.s. | .78 | .38 |
| **Z6: Impacts >10 g** | .61 | .44 | 1.16 | .29 | .15 | .69 |
| **Total no. of impacts** | 1.71 | .19 | .29 | .59 | .02 | .89 |
| **Total body load** | .27 | .60 | 4.04 | .05 | .01 | .99 |
| **Z1: Accel. 1–2 m/s$^2$** | .37 | .55 | .01 | .94 | 1.14 | .29 |
| **Z2: Accel. 2–3 m/s$^2$** | 8.83 | <.05 | 1.05 | .31 | .53 | .47 |
| **Z3: Accel. > 3 m/s$^2$** | 9.2 | <.05 | 1.02 | .32 | 2.83 | .10 |
| **HRmax (b/min)** | 1.37 | .25 | .17 | .68 | .06 | .81 |
| **Mean HR (b/min)** | .01 | .91 | 14.84 | <.01 | 5.65 | <.05 |
| **Z1: <60% HRmax** | 2.57 | .12 | 14.84 | <.01 | 4.66 | <.05 |
| **Z2: 61–70% HRmax** | 10.05 | <.05 | 6.79 | <.05 | 2.69 | .11 |
| **Z3: 71–80% HRmax** | 5.48 | <.05 | 1.53 | .22 | .01 | .99 |
| **Z4: 81–90% HRmax** | 3.79 | .06 | 9.84 | <.05 | 4.23 | <.05 |
| **Z5: 91–95% HRmax** | .16 | .69 | 3.82 | .06 | 1.79 | .19 |
| **Z6: >95% HRmax** | .07 | .79 | .83 | .37 | 1.23 | .27 |

n.s.: not significant due to equal means, *df*=1 in all values

The comparison between male and female players, together with the effect of halves and possible interactions between them is shown in Table 4. The two-way ANOVA found significant half time and interaction effects in several parameters, indicating that differences with respect to halves can be attributed to the female players' contribution. Average speed in the second half is higher (2.4 km/h) than in the first half (1.7 km/h) due to an increase in the female team (1.4 to 2.5 km/h) and mean HR and HR percentage in zone 4 are higher in second half (144.7 b/min and 31.2%) than in first half (130.2 b/min and 17.6%) due to female team performance (125.8 to 149.4 b/min and 17.4% to 41.0%). Finally, the decrease in HR percentage in zone 1 in second half (13.8%) with respect to first half (32.1%) can also be attributed to a large decrease in the HR of the female team (41.0% to 12.4%). On the other hand, comparison with regards to sex shows that male players covered more distance while *HI running*, perform more accelerations in zones 2 and 3 and spent more time in HR zones 2 and 3. The mean values for these parameters can be found in Tables 1, 2 and 3 under the column Match.

## Discussion

To the best of the authors' knowledge, this study is the first to investigate the physical and physiological demands of male and female beach handball players competing at national top level. A few months after completing this study, the same female and male players finished 1st and 5th during the 2016 Beach Handball World Championship, respectively. Although beach handball differs from team handball in some aspects, the present results will be compared with team handball, but considering its distinctive characteristics and other forms of sand arena sports, such as beach soccer or beach volleyball, to account for the effect of the sandy surface.

Beach handball is a heterogeneous high-intensity sport with a variety of physiological demands involving short sprints and short efforts of maximal power and strength. Time-motion analysis showed average match time of 17.7 min and 18.7 min for male and female, respectively. This active time is relatively low compared with team handball 73.6 ± 4.5 min (Póvoas et al., 2012), both for male players, 53.85 ± 5.87 min and female players, 50.70 ± 5.83 min (Michalsik and Aagaard, 2015), where the field surface poses less constraints for locomotion. As a result, there will be differences in the total distance travelled by players, as one of the first GPS variables to be reported, between beach handball and other team sports. Our study reported 1234.7 ± 192.0 m for male players and 1118.2 ± 221.8 m for female players. Studies reported higher total distance covered by team handball players in the range of 3900 to 4700 m (Wagner et al. 2014): male 3945 ± 538 m (Michalsik and Aagaard ,2015), female 3627 ± 568 m (Michalsik et al., 2015), 4002 ± 551 m (Michalsik et al., 2013), 3399.2 ± 362.3 m (Belka et al. 2014), 4693 ± 333 m (Michalsik and Aagaard, 2015), and unspecified sex 4964 ± 642 m (Póvoas, 2009), 4370 ± 702 m (Póvoas et al., 2012). The sandy surface of beach handball also affects players' running demands and therefore, the total match distance. Castellano and Casamichana (2010) analyzed beach soccer players, resulting in a total mean distance of 1135 ± 26.8 m, like the data obtained in our study. Such running demands can also be found in average speed: our study reported 4.2 ± 0.6 km/h and 3.9 ± 0.8 for male and female players, respectively; whereas team handball showed fairly higher values, 6.10 ± 1.01 km/h and 5.31 ± 0.33 for male and female players, respectively (Michalsik and Aagaard 2015). We found that both male and female players covered less distance in the second half, but at the expense of higher average speed, with the female players as main factor in this study ($p < 0.01$). The latter could be explained in the context of neuromuscular factors in the sandy surface. In addition to muscle fatigue for both groups resulting in lower covered distance, the degree of muscular coordination and stability, which is more important than muscle fiber size, can be an advantage for female players in acquiring faster speeds in second halves.

In a sport with an unlimited number of substitutions, such as beach handball, the distance travelled per minute of competition game may be regarded as a scale of match intensity rather than the total distance (Cummins et al., 2013), since total distance may be influenced by the time each player is actively playing. Our results showed that male and female players covered a relative distance similar to team handball: 69.7 m/min and 59.8 m/min, in comparison to 68 ± 9, 60 ± 10, 68 ± 11, 78.9 m/min (Michalsik et al., 2015; 2013; Póvoas, 2009; Póvoas et al., 2012). In spite of similar relative distances, match intensity may be greater due to the sandy surface (Smith, 2006), as reported by Castellano and Casamichana (2010) in beach soccer with 97.7 ± 15.1 m/min. Other studies in indoor small-sided team handball reported higher relative distances, in spite of a reduced court: 110.7, 118.5, 113.3 ± 9.7 m/min (Belka et al. 2014; Corvino et al., 2014; 2016). Contrastingly, Corvino et al. (2014; 2016) reported very high values for 8-min matches in team handball with small-sided courts: 110.7 and 118.5 m/min. Although such courts have almost identical dimensions as in beach volleyball, the reduced play time and the sandy surface, which prevents players from applying fast propulsion in their displacements (Barrett et al., 1997), would explain the huge differences in distance travelled per minute.

In this study, work rate patterns were categorized into six speed zones considering beach handball's specific movements, as an adaptation of similar team sports (Cummins et al., 2013). Similarly to these studies, each zone was linked with a description of the work intensity. Due to the nature of the game, we included the standing speed zone (0–0.4 km/h) as a measure of distance covered in minimal activity and sprinting (>18 km/h) bearing in mind maximal speeds attained during matches. Male players covered most distance while jogging: 432.7 ± 103.3 m and partially cruising: 356.0 ± 100.8 m (zones 4.1–13 km/h) during a match. These findings are in agreement with other studies on small-sided team handball, where the most distance covered was in zone 5–12 km/h: 526.7 ± 30.8 m (Corvino et al., 2014), and 613.4 ± 66.6 m (Corvino et al., 2016). Female players showed lower speed zones of maximal displacement: *walking*: 407.3 ± 64.3 m and partially *jogging*: 370.6 ± 94.1 m (zones 0.5–7 km/h) during a match. Again, studies on female team handball reported similar trends: zones 0.5–4 km/h and 0–5 km/h were the zones with most distance travelled (1424 ± 265 m and 2103 ± 334 m, respectively) (Michalsik et al. 2013; Michalsik et al. 2015).We found that male players covered more distance while *HI running* than female players ($p < 0.05$), which can be explained by a lower maximum speed in the female team (18.5 km/h). However, since energy expenditure on sand is greater than firm surfaces (Smith, 2006), the physiological and physical profile for activities played on sand must be interpreted with caution (Castellano and Casamichana, 2010).

Another measure of high-intensity exertions in team sports is acceleration. Studies on acceleration profiles are limited, with the exception of rugby, using micro sensors (Jones et al., 2015) and GPS motion-analysis (Suárez-Arrones et al., 2012). To calculate the magnitude of effort, changes in velocity are categorized into low-, medium- and high-intensity efforts with different thresholds. Our results reported lower acceleration occurrences than team handball: Barbero et al. (2014) reported total mean values of 113 accelerations and decelerations for the first two 10-min periods in a simulated 30-min match between elite team handball male players (5.6 acc/min), whereas our results showed 53.4 accelerations (2.6 acc/min). Likewise, Luteberget and Spencer (2016) obtained higher acceleration values (over 2.5 $m/s^2$) in official international matches for female team handball (0.7 acc/min) than our results for the combined zones 2 and 3 (0.2 acc/min) in female team suggest. Therefore, the number of accelerations during the game is lower than in team handball since the sandy surface in which exertions are performed would place higher physiological demands on players. Our results indicated that the most common body acceleration was in the low-intensity zone (1–2 $m/s^2$), with 80.9 % and 90.1% of the total for male and female players, respectively. These findings are in agreement with team handball players, spending 84.8% of the total accelerations between 1–2 $m/s^2$ (Barbero et al., 2014). These results suggest that beach handball players spend most of their time in low-intensity activity, as in team handball, but the frequency of occurrence is lower in beach handball (Póvoas et al., 2012). On the other hand, male players performed more moderate- and high-intensity accelerations (zones 2 and 3) than female players ($p < 0.05$), which can be explained by the high energetic expenditure to perform quick changes in speed on the sand. On average, every 23 s and 27 s, a body acceleration was produced by male and female players, respectively. In addition, 3.9 and 4.7 impacts/min during the game were observed for male and female players, respectively, indicating that impact intensity is lower than team handball, 13.6 impacts/min, (Barbero et al., 2014) and other team sports, such as basketball, 8.2 impacts/min (Puente et al., 2017) or rugby, 21 impacts/min (Cummins et al., 2013). This decrease could be related to the physiological demands of high-intensity activities played on sand, which, despite of their short duration, require high levels of strength and speed. Sand surface acts as a shock absorber, dissipating most of the applied energy, which reduces reaction forces needed to apply fast impulses (Bishop, 2003).

Comparing intensities over play time, a number of studies indicated that acceleration values decreased between halves on a range of team sports: soccer (Akenhead et al., 2013), rugby (Higham et al., 2012), Australian football (Varley et al., 2014) and team handball (Wik, 2015). In our study, the number of accelerations in second half periods is 8.8% lower than in first half periods for male players, in accordance with the decrease between 10-min periods of 9.2% (1st to 2nd) and 5.9% (2nd to 3rd) (Barbero et al., 2014). Surprisingly, the female team showed opposite behavior: the number of accelerations increased 21.5% between periods globally (20.2 to 24.5 times) and also in the three intensity categories: 18.8 to 21.5, 1.4 to 2.9 and none to 0.1 (low-, moderate- and high-intensity). According to this study, the intermittent nature of the game may allow sufficient recovery between high-intensity actions to preserve the performance level throughout the match. However, the decrease occurrence of high-intensity activities observed during the second half in team handball cannot be associated to fatigue effect or from changes in game dynamics (Karcher and Buchheit, 2014), so the difference in beach handball players' sex is actually unclear.

HR is a common method to estimate exercise intensity, despite the known variation due to a number of factors (Achten and Jeukendrup, 2003). Our results indicate that beach handball players perform high physiological demands, as depicted by HR. The results of maximal HR (173 ± 13 bpm for male players and 177 ± 13 bpm for female players) are similar to other beach handball studies: 165 ± 13 bpm for recreational male players (Bělka et al., 2015) and female players 174 bpm (Lara-Cobos ,2011). Other beach sports showed similar figures, such as beach soccer 188 ± 6 bpm (Castellano and Casamichana, 2010) and 188 ± 11 bpm (Scarfone et al., 2015), and beach volleyball 180 bpm for blocker and 188 bpm for defender (Jimenez-Olmedo et al., 2017). For team handball, maximum values are also comparable: 185 ± 10 bpm (Póvoas et al., 2012) and 182 ± 9 bpm (Cunniffe et al., 2015), being the last two studies performed with female players.

The percentage of time spent in each HR zone revealed that zone 3 (71–80% HRmax) and zone 4 (81–90% HRmax) were the most common intensity zones for male and female players, with 26.0% and 29.2% of the total time, respectively. However, in the only study describing such percentages for beach handball, made with male recreational players, the most common intensity zone was higher: >90% HRmax with 39% of total time (Bělka et al., 2015), where HRmax was calculated with a modified version of Tanaka's formula. In the latter study, a beach volley tournament was played for three hours, followed by a rest period of 60 minutes, before starting three beach handball matches, so the previous load was significant. In our study, percentage values were lower than those reported for other beach sports, such as beach soccer: 59.3 % for >90% HRmax (Castellano and Casamichana, 2010), and 35.0 % for 85–95% HRmax (Scarfone et al., 2015), for small-sided team handball (size 24x12 m): 53.7 % and 56.1% for >90% HRmax (Corvino et al., 2014; 2016), and for team handball: 83% for >85% HRmax (Belka et al. 2014). In these studies, HRmax was calculated with the Yo-Yo Intermittent Recovery Test Level 1, except for small-sided team handball, which used the Karvonen formula.

Regarding the comparison between first and second halves, HR mean was higher in the second half, both for male (4.2%) and female players (18.7%). This trend can also be found in female beach handball: 172.16 ± 9.97 b/min vs 176 ± 9 bpm (Lara-Cobos, 2011), and in team handball: 153 ± 19 b/min vs 160 ± 17 bpm (Póvoas et al., 2012). With the exception of zone 6 for male players, low-intensity activities (zones 1 and 2) showed decreased HR over halves, whereas in moderate- and high-intensity activities (zones 3 to 6), an increase in HR was found, both for male and female players. These results are in agreement with the study of Lara Cobos (2011) with female players. The rise in the high-intensity zones could be due to the physiological demands derived from an increased distance covered while *HI running* and *sprinting* (males), and *cruising* and *HI running* (females), which demands high energy due to the sandy surface, whereas the decrease could be related to the reduction of intensity of the match actions due to fatigue. There are no studies in sand sports relating first and second halves by HR zones, but in team handball, mixed results can be found, showing either a similar trend, where low-intensity zones decreased and high-intensity increased (Lara-Cobos, 2011), or the opposite behavior (Belka et al., 2014; Cunniffe et al., 2015). However, since beach handball is typically performed outdoors under hot environmental conditions, high sweat losses would produce dehydration trough match time. Therefore, the increase in HR through halves may also be explained by the effect of cardiovascular strain on players, since every 1% of body weight loss due to dehydration increases HR by 5–8 b/min (Magalhães et al., 2011).

The main findings of our study were that beach handball players covered substantially more distance in the first half but at the expense of lower speed, mostly due to female players. In addition, the same group showed lower percentage of time in low HR zones (<60% and 61–70% HRmax) in the first half and opposite trend for high HR zones: the percentage of time in high HR zones (81–90%, 91–95% and >95% HRmax) was higher for the second half. As a consequence, the mean HR value was substantially higher in the second half (18.7%). The effect size of these results was mostly large.

## Conclusions

The present findings of this study show that beach handball is a demanding sport, with numerous moderate-to-high intensity displacements and actions, distributed intermittently throughout the game: long periods of low intensity activity interspersed by short bursts of high intensity. The number and frequency of intense actions and associated HR zones suggest that high amounts of energy requirements via the anaerobic system are needed. Therefore, the training protocols of elite beach handball players should prioritize exercises to enhance the ability to perform high-intensity short activities followed by less intense periods to facilitate recovery. From a neuromuscular perspective, a beach handball specific program should include instability routine and explosive exercises to compensate for modified ground reaction forces in sand in comparison to firm surfaces. These data can also be useful in the design of game-based performance tests to specifically assess the performance under conditions similar to competition (Wagner et al., 2016) or a training program according to physical performance level of cluster groups of beach handball players (Bautista et al., 2016).

Due to the relatively small number of subjects and matches, specific tactical or playing positions and the effect of fatigue over successive matches were not addressed. In the future, we recommend addressing this aspect, as demonstrated in other team sports, since physical demands of each playing position can have large variations (Di Salvo et al., 2007) and fatigue could prevent physiological and functional variables from recovering back to baseline at the start of a new match (Magalhães et al., 2011). A more specific study focusing on these aspects would certainly increase our knowledge of beach handball and help coaches and athletic trainers to improve the training and testing processes.

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## Key points

- Beach handball is a demanding sport, with numerous moderate-to-high intensity displacements, distributed intermittently throughout the match.
- Despite the sandy surface, the distance covered per minute in beach handball is similar to team handball.
- On average, every 23 s and 27 s, a body acceleration was produced by male and female players, respectively.
- Female players covered substantially more distance in the first half but at the expense of lower speed.

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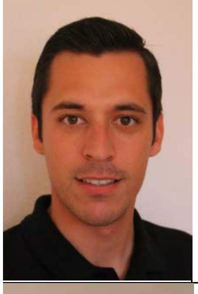

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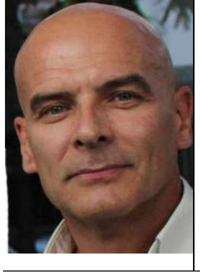

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