Metabolic Power in the Men's European Handball Championship 2020

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Abstract

Purpose: We aim to ascertain the typical metabolic power characteristics of elite handball players of different positions, and whether changes occur within matches.

Methods: 414 elite male handball players were included. During all 65 matches of the EURO 2020, local positioning system data were collected, yielding 1853 datasets. Field players were categorized into six positional groups: center backs (CB), left and right wings (LW/RW), left and right backs (LB/RB) and pivots (P). Metabolic power, total energy expenditure, high-power energy, and the equivalent distance index were calculated. We used linear mixed models with players as random and positions as fixed effects models. Intensity models included time played to account for the time-dependency of the intensity.

Results: LW/RW spent most time on the pitch, expended most total energy, and most relative energy per kg body weight in the high intensity categories. CB played at the highest mean intensity (highest mean metabolic power) (7.85 W/kg; CI$_{95\%}$ [7.67, 8.03]). Playing intensity decreased by 2.5% (0.2 kJ/kg/s; CI$_{95\%}$ [0.17, 0.23]) per 10 minutes played.

Conclusion: Metabolic power intensity profiles are modulated by playing positions and players’ time on the pitch. Analysis of metabolic intensity in handball should take these parameters into account.

Keywords: energy expenditure, external load, activity profile, local positioning system, mixed models.

Introduction

Handball is a highly intermittent team sport with fast transitions between offensive and defensive phases [1]. To improve training prescriptions, it is important to understand the physical position-specific on-court demands, e.g. volume and intensity, besides technical-tactical actions[1]. Previously used analyses of physical demands during handball matches mainly used distance and speed, and revealed position-dependent differences between players. For example, wings covered more total distance [2,3], spent more time and covered more distance in high speed and sprinting zones compared to backs and pivots [4]. Total distance is important because it determines energy expenditure regardless of movement speed [5], and is thus often used as an indicator for exercise volume. Movement speed has been assumed to represent exercise intensity [6].

However, to capture volume and intensity of an intermittent sports game like handball, it is not sufficient to only assess distance and speed. Accelerations and decelerations are also physiologically relevant in handball even at submaximal speed [7], and are thought to be the most demanding elements in team sports directly contributing to energy cost [8]. Further, accelerating is even more energy demanding than maintaining velocity [9]. Therefore, distance alone is not sufficient to represent volume, and speed alone cannot signify exercise intensity in handball. The focus on accelerations alone is insufficient, as the energetic demand for a given acceleration varies when starting speed is taken into account [10]. Therefore, one should instead account for the interplay between velocity and acceleration when analyzing metabolic demands in handball. The respective parameter concerning both is metabolic power. Metabolic power is the product of the energy cost of running and the running speed itself (instantaneous values or time courses) [11]. The metabolic power approach derived parameters for volume in team sport are the total energy expenditure and the equivalent distance. The equivalent distance represents the distance that the player would have run at a steady pace on the field using the total energy spent over the match. Mean metabolic power reflects the intensity of match-play. The equivalent distance index is the ratio between equivalent distance and total distance, and reflects the erraticness of running [10,8]. To the best of our knowledge, metabolic power has not been analyzed so far during top-level handball matches to determine the energetic costs of horizontal movement patterns.

The specific rules in handball enable the teams to interchange their players any number of times, resulting in different playing times for single players and between positions. Therefore, playing time has to be taken into account for any detailed analyzis of physical demands in handball. Previous studies reported that there is a decrease in total distance covered during the second half of the match, and that the distance covered at high speed is lower as the game continues [12,2]. Knowledge of the dependency of individual playing time on metabolic power-derived parameters in handball is missing.

Thus, the first aim of this study was to assess the volume and intensity of top-level handball match-play at different positions using the energy-based metabolic power approach by Osgnach et al. [10]. The second aim was to analyze the time course of intensity as a function of playing time. We hypothesized that (1) positional differences in the volume and intensity parameters exist, and that (2) intensity decreases with increasing playing time.

Materials and Methods

Study design and ethical aspects

A prospective cohort observational study was performed. Data were obtained from players participating in European Handball Federation (EHF) EURO 2020 held in Austria / Norway / Sweden.

The participating players provided informed consent before inclusion. The study was planned and performed in line with the Declaration of Helsinki, and approved by the Ethics Committee of the University of Alicante (registration number UA-2020-09-10).

Participants

Data were collected from 414 male elite handball players. A total of 1853 datasets out of 65 games were obtained. We excluded goalkeepers and observations from field players with less than 1 minute of playing time. The remaining 1596 datasets from 352 players were analyzed with regard to playing position (Figure 1).

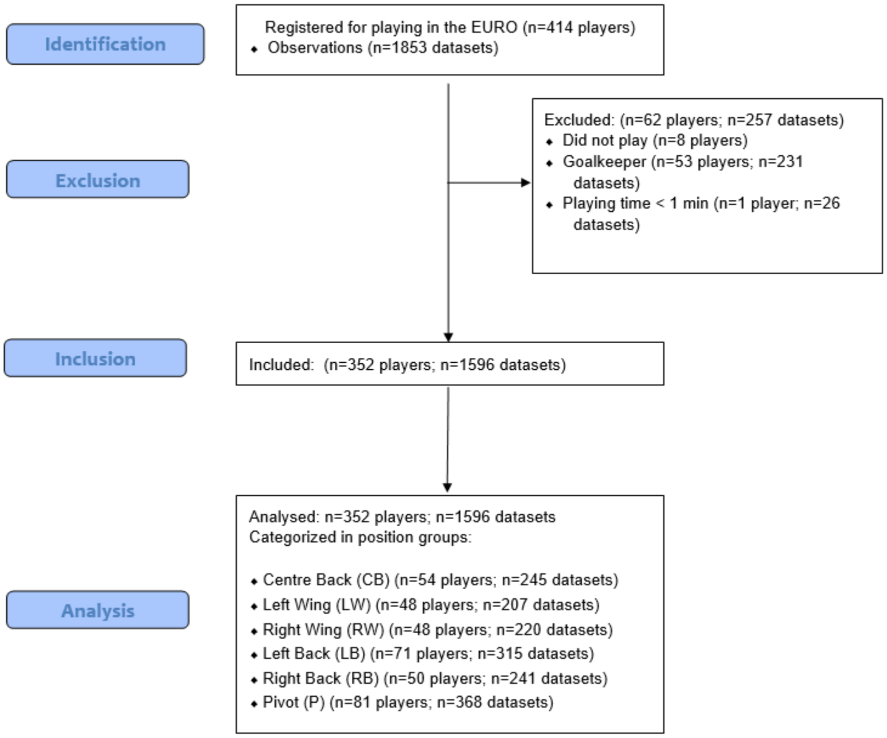

Fig. 1 Flow diagram

Instruments

Position data were continuously monitored using a local positioning system (LPS) (Kinexon Precision Technologies, Munich, Germany). Nine antennas were placed around the playing field which were connected to 10 anchor antennas distributed at 3 different levels above the ground in the arena. For a closer look at the setup, the reader is referred to Manchado et al. [3]. Player positions were recorded with a 16.6 Hz frequency by calculating the time-of-flight of ultra-wideband radio signals from the transmitter to the base stations. These time-of-flight measurement signals are smoothed with an Unscented Kalman Filter. Subsequently, the position was determined through triangulation. Speed and acceleration are calculated subsequently and filtered with a zero-phase shifting low pass Butterworth-filter of 3rd order with cut-off frequencies of 1 and 0.5 Hz, respectively. Recently the system has been validated [13,14] and was used for the analysis of movement patterns in ice-hockey and handball [15,16].

Data processing

To automate the calculation of net playing time, the player positions had to be at least 1 second and 0.8 m on the field to count as active. For substitutions, it had to be 0.4 m outside of the field for 1 second or more. The time in which the ball was not on the pitch, or when neither team had possession of the ball, was not included. Further, playing phases (offense/defense) were distinguished based on ball possession and overall player movement. Net playing time was calculated as the accumulated time of the offense and defense phases. LPS data of each single player were analysed for the periods of their individual net playing time and summed for further analysis. Total run distance was determined accordingly.

Energy costs and metabolic power data were calculated using previously outlined equations [10,17]. An energy cost of 4.46 J/kg/m was used for the handball players in this study, which differs from the 3.6 J/kg/m of running at constant speed on flat terrain that had originally been determined in endurance mountain runners [18]. Handball players, consistent with football players and generally active men not specialized in straight-forward running, run less economically compared to endurance runners; therefore, they need slightly more energy [19,20]. Further, the constant (KT) for running on grassy terrain in analyses of football match play and training sessions[10] was not included. Net estimated energy expenditure (above resting) above a high intensity threshold was quantified which was set at 35 W/kg.

Additionally, equivalent distance and the equivalent distance index were calculated. All data were processed in Matlab (R2020b).

Statistical analyses

All statistical analyses and plots were performed with R (4.0.4) [21].

We have applied and compared different linear regression models for the analysis of the relationships between various parameters: Metabolic power, energy expenditure, equivalent distance index, and summed high metabolic power energy were dependent variables (DV), while position and time played were defined as independent variables. To account for the nested data structure (repeated measures for players in teams), we used linear mixed models via the {lme4} package [22] (see our markdown script for dependencies and versions). Volume (DV: Energy expenditure) models did not include time, as we were interested in total time-independent exertion (random intercept). Intensity distribution analysis also did not include time (random intercept). The intensity (DV: average MP) models included time played and position as fixed effects, and players nested in teams as random effects, to account for multiple observations for players who played more matches (random intercept & random intercept/slope over time). Erraticness (DV: equivalent distance index) models also included time played and position as fixed effects and players nested in teams as random effects (random slope). Sensitivity was checked via a reduced data set (preliminary round) and a spline model with the {mgcv} [23]. We compared models via several criteria (p-value, Akaike-Information-Criterion, Bayesian-Information-Criterion) and their coefficients. Further, we compared the estimated means with 95% confidence intervals of our models for the positions (and time in intensity models). Heterogeneity was inspected via random slope/intercept coefficients. Assumptions were checked graphically via model residual plots (Q-Q, residuals vs. fit) (see appendix for further details).

Results

In sum, 1596 of 1853 datasets from 352 players met our inclusion criteria (Figure 1). Anthropometric characteristics and net playing time are given in Table 1. Wing players weighed less and pivot players weighed more to the respective other positions. Further, playing time was highest in wing players compared to the other positions (Table 1).

Table 1 Number of players and observations, anthropometric characteristics, and playing time for each position.

Position	n_{pl}	n_{obs}	Weight (kg)		Height (cm)		Time (min)	
			Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Center Back	54	245	90.6	6.9	189.7	5.8	24.9	13.6
Left Wing	48	207	84.4	7.9	186.9	5.7	32.1	17.0
Right Wing	48	220	83.1	6.3	184.6	5.4	30.0	18.4
Left Back	71	315	97.1	6.5	196.1	4.2	23.8	12.6
Right Back	50	241	95.8	8.9	194.4	5.8	24.5	13.3
Pivot	81	368	105.4	8.4	196.8	4.6	24.5	13.8
Total sample	352		94.3	10.5	192.4	6.7		

n_{pl} = number of players; n_{obs} = number of observations

Volume

Energy expenditure relative to body weight (random intercept) was highest in left wings, followed by right wings, center backs, left and right backs, and pivots (Figure 2A, Table 2). Absolute total energy expenditure (random intercept) was highest in left wings followed by pivots, center backs, right wings, and left and right backs (Figure 2A, Table 2). However, interindividual variability was high for relative and absolute total energy expenditure.

Since the equivalent distance is calculated from the energy expenditure by multiplying with a fixed value, equivalent distance was also highest in left wings, followed by right wings, center backs, left backs, right backs and pivots (Table 2. Data for mean total distances run in the matches are given in the appendix.

Left wings expended most energy in the high intensity category, followed by right wings, center backs, left backs, right backs and pivots (Table 2).

Intensity

Our random intercept and slope model performed best among other models (random intercept/slope vs. random intercept, AIC: 3635 vs. 3769, BIC: 3710 vs. 3823, p<.001) and yielded a plausible distinction between positional groups: Center Backs had the highest mean metabolic power, followed by right and left wings, left and right backs and pivots (Figure 2C).

Erraticness

Wings had the highest equivalent distance index values (random intercept/slope), followed by the center backs, the pivots, the left backs and the right backs (Figure 2D, Table 2).

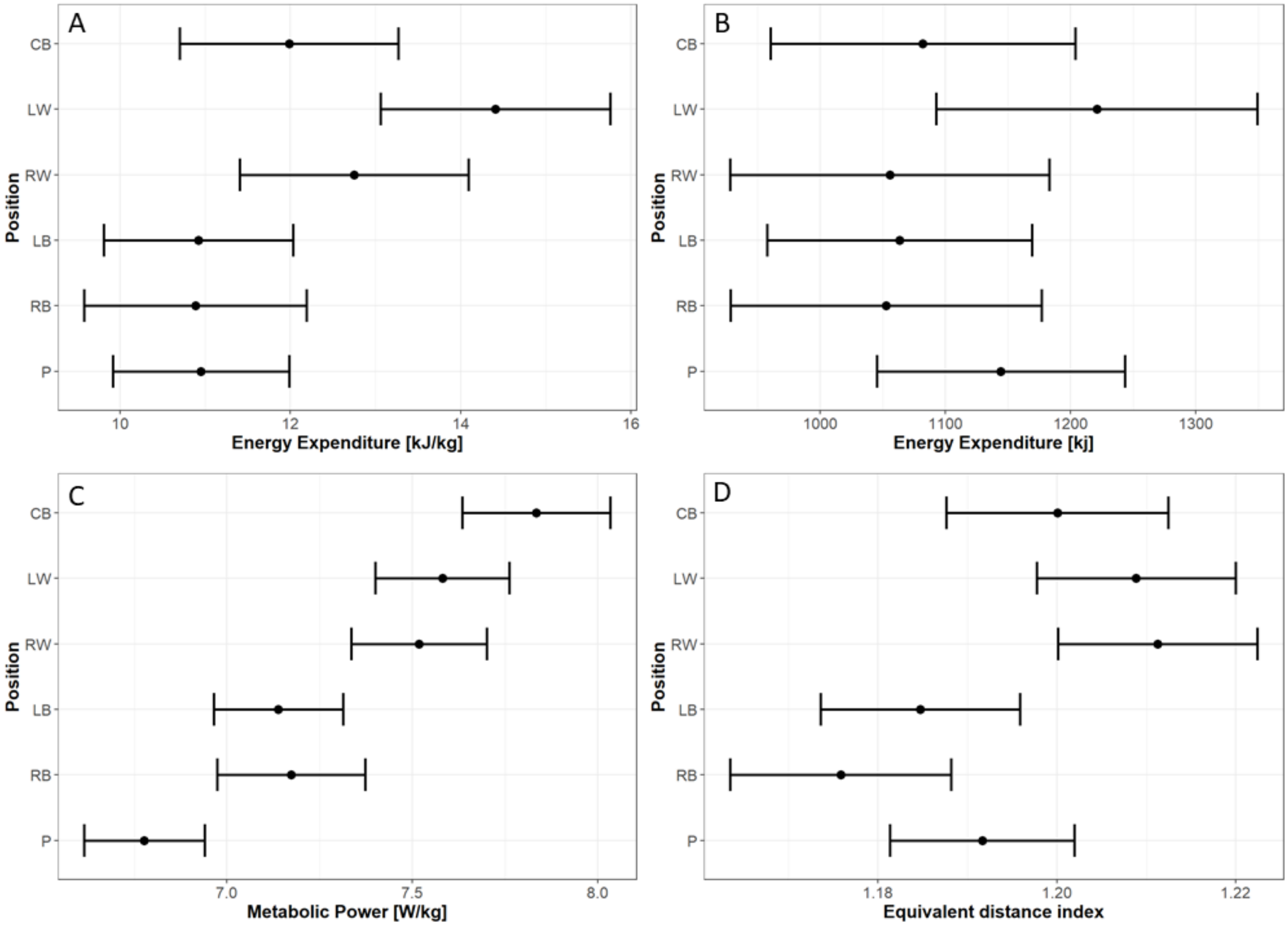

Fig. 2 TIE-fighter plots of estimated means with 95% confidence intervals
Relative (A) and absolute (B) total energy expenditure (random intercept), mean metabolic power (C) (random intercept/slope) and equivalent distance index (D) (random intercept/slope) CB: center backs; LW: left wings; RW: right wings; LB: left backs; RB: right backs; P: pivots

Impact of the time on the field

The linear model predicted a decrease in intensity of 2.5% (0.2 kJ/kg/s; $CI_{95\%}$ [0.17, 0.23]) per 10 minutes played. However, the decrease seems to be rather curvilinear with a stronger decrease in short playing times accompanied by higher variability (Figure 3). The random effects for teams suggests less variability between teams (range: -0.26 to 0.25), but rather high variability in individuals (range: -3.23 to 3.84) (see appendix for details).

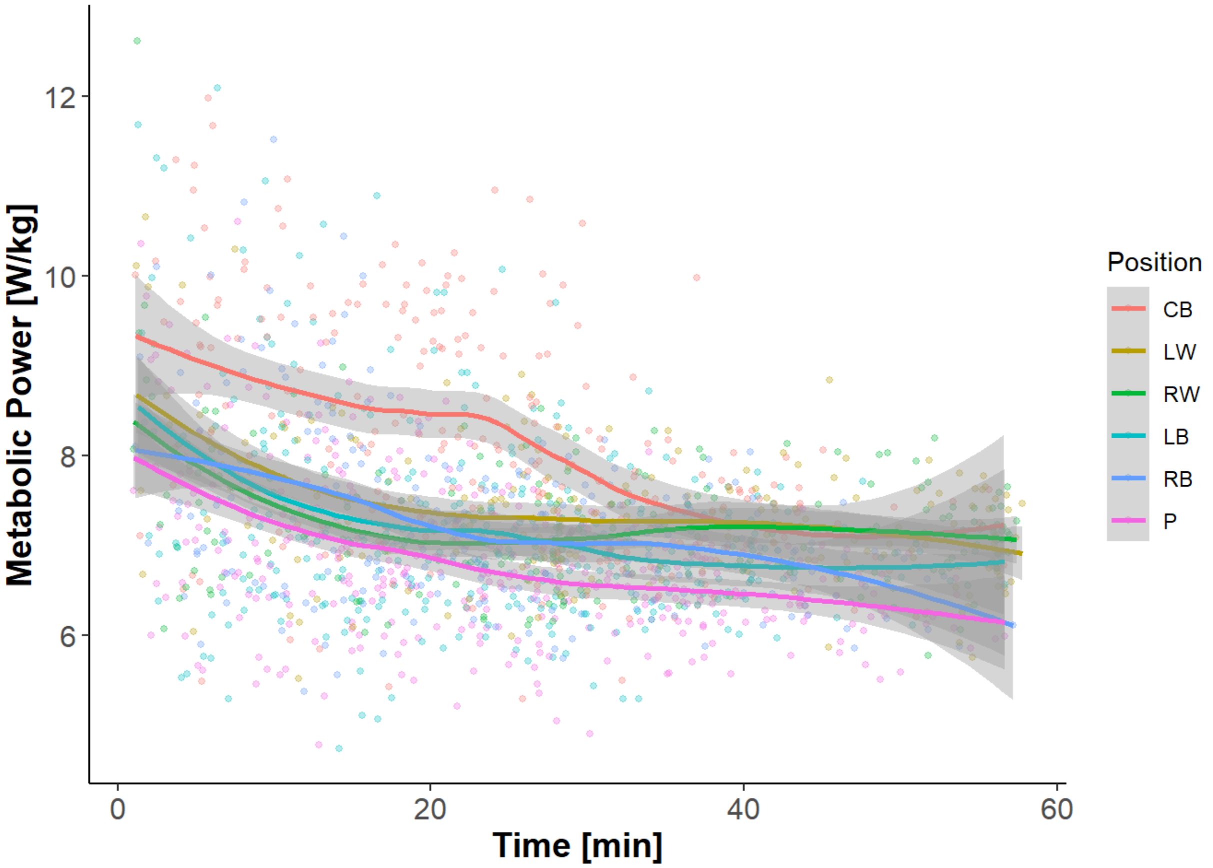

Fig. 3 Mean metabolic power in dependency of time played and position; each scatter presents one value for each player in each game played. CB: center backs; LW: left wings; RW: right wings; LB: left backs; RB: right backs; P: pivots

Table 2 Volume, intensity, erraticness, and energy distribution by positions, estimated means with 95% confidence intervals (random intercept mixed model)

		Center Back		Left Wing		Right Wing		Left Back		Right Back		Pivot	
	Unit	Mean	$CI_{95\%}$	Mean	$CI_{95\%}$	Mean	$CI_{95\%}$	Mean	$CI_{95\%}$	Mean	$CI_{95\%}$	Mean	$CI_{95\%}$
Energy Expenditure	kJ/kg	12.0	10.7; 13.3	14.4	13.1; 15.8	12.8	11.4; 14.1	10.9	9.8; 12.0	10.9	9.6; 12.2	11.0	9.9; 12.0
Energy Expenditure	kJ	1082	960; 1243	1221	1092; 1177	1056	928; 1169	1063	957; 1183	1053	928; 1349	1144	1045; 1204
Equivalent Distance	m	2854	2548; 3159	3430	3109; 3752	3036	2716; 3355	2600	2335; 2865	2592	2281; 2903	2608	2361; 2854
Mean Metabolic Power	W/kg	7.85	7.67; 8.03	7.51	7.35; 7.67	7.52	7.35; 7.68	7.16	7.00; 7.33	7.16	6.98; 7.35	6.77	6.62; 6.92
Equivalent Distance Index	ul	1.20	1.19; 1.21	1.21	1.20; 1.22	1.21	1.20; 1.22	1.18	1.17; 1.20	1.18	1.16; 1.19	1.19	1.18; 1.20
High Intensive Energy in MP >35 W/kg	J/kg	3.80	3.48; 4.11	3.34	3.03; 3.65	2.06	1.77; 2.35	1.70	1.40; 2.00	1.58	1.33; 1.84	1.57	1.33; 1.81

Discussion

The most important findings of the present investigation are 1) position-specific differences in net playing time; 2) a clear position dependency of most of the metabolic power parameters, and 3) a dependency of mean metabolic power and high intensity metabolic power on position and time played. The findings of differences (between positions and time-dependent play on court) in metabolic power, energy expenditure, equivalent distance index, and high metabolic power energy lead to verification of hypothesis (1) and a decrease of intensity verifies the secondary hypothesis.

Volume

The mean total energy expenditure of all players determined from horizontal movements on the field (~12 kJ/kg) was clearly lower compared to other team sports like football (~61 kJ/kg, [10]), Australian football (~63 kJ/kg, [24]), rugby league (~39 kJ/kg, [25]), and field hockey (~32 kJ/kg, [8]). We presume that total energy spent during a match on an elite national (and likely international) level is close to what a single player might invest from their individually well-developed muscular energy metabolism, regardless of the type of team sport they practice. Thus, there are various reasons for lower total energy expenditure determined by horizontal movements in handball compared to other sports. First, the duration of a match is shorter in handball (60 min) compared to football (90 min), Australian football (80 min), rugby league (80 min), and field hockey (70 min before 2019). Second, there are many interchanging activities in handball; some players are specialized for offensive or defensive parts of the match, and are substituted when the phases change [16], leading to an even shorter playing time in handball (between 24 and 32 min, Table 1). The third reason is a likely higher energy turnover from other handball-specific actions compared to other team sports and their respective sport-specific movements. Handball is characterized by a significant number of jumps, passes, throws, and duels [26–28]. Although it has not yet been systematically and exactly analyzed, these actions require high intensity energy. Considering the total energy per player for all sport-specific, high and low intensity actions are limited due to limited ATP rebuilding processes [29], the mentioned additional energy-demanding actions in handball inevitably reduce the energy turnover specific to horizontal run movements and vice versa, thus leading to the characteristic pattern of movements, actions, and recovery periods in handball [27].

As no other study used the metabolic power approach in handball up to this point, we have to compare metabolic power-derived volume parameters with conventional time-motion-derived volume parameters such as total distance, distance in different speed categories from other handball tournaments and matches. Although total energy expenditure, equivalent distance, and total distance correlate, the total distance is a correct estimate of the volume only if the speed is constant, which clearly is not true in handball.

In our investigation, wing players showed the highest total energy expenditure and the highest equivalent distance, followed by center backs, backs, and pivots. This is in line with a study using time-motion analyses of player movements from the same European Championships tournament [3] and with a study from the World Championships tournament 2015 [4] which was also showing the highest total run distance in wing players, followed by center backs, backs, and pivots. Two other studies from the German Bundesliga [2] and the Portuguese 1st league [26], analysing positions for both wing players and all three backcourt players together, revealed the highest run distance in wing players.

In regards to net energy expenditure at high intensity power, both wing positions expended more energy at high intensity compared to the other positions which is in line with distance covered at high speed [3]. Wings typically have more space to cover and are the preferred player to run a counterattack. We presume that the lower energy expenditure from horizontal movements in some handball position is "compensated" for with a significant amount of high intensity energy demanding actions, such as throws, jumps, passes, and duels.

As stated, energy expenditure from horizontal movements is only one component of the total energy expenditure in handball, where handball-specific high intensity actions such as jumps, stops, changes of direction, and duels occur [27,28]. The number of high intensity handball-specific actions remarkably differs between playing positions, with pivot players performing nearly double the high intensity actions as the wing players (~140 vs 75) [27]. When total energy per player is limited [29], the energy expenditure from horizontal movements is in relation to the energy turnover through other highly intensive actions: the more highly intensive handball-specific actions a player performs, the less total energy they will spend through horizontal movements, and vice versa. The individual relation between both energy consuming loads of a single player (namely, the loads from run-movements and handball-specific movements) is a matter of position, tactic, and individualized and position-specific training programs.

Intensity

The average metabolic power of all players determined from horizontal movements on the field (~ 7.3 W/kg, Figure 2, Table 2) was lower compared to other team sports such as field hockey (~ 11.2 W/kg, [8]), Australian football (~ 9.9 W/kg, [24]), and rugby league (~ 8.7 W/kg, [25]. In contrast to total energy expenditure, however, shorter playing time in handball should have led to higher mean metabolic power. Mean metabolic power declines with increasing playing time in handball (Figure 4). Thus, shorter duration of handball matches compared to other team sports, and generally shorter duration of playing time in handball should have led to a higher mean metabolic power from horizontal movements compared to other team sports. Although there is a lack of data in this study pertaining to the number of other handball-specific, energy-demanding movements (jumps, throws, passes and duels) from this tournament, the numbers are likely comparable to those reported for top-level handball matches previously [26]. As discussed, total energy production per time is limited for every single player. Therefore, many successive high-intensive handball-specific movements automatically lead to a reduction of mean metabolic power during horizontal movements. Without the knowledge of an individual players' aerobic capacity and profile for energy metabolism, this remains somewhat speculative.

We found a position-dependency of mean metabolic power with the highest values in center backs, followed by wing players, back players, and pivots (Figure 2, Table 2). No other study has analyzed metabolic power in handball so far; thus, we must compare this data with other intensity parameters. Manchado et al. [3] used mean running pace for describing the intensity of handball matches. They also found highest values for center back players. In their analysis, however, pivots had the second highest running pace, followed by left and right backs, and right and left wings. The position-specific differences between mean metabolic power and mean running pace indicate that running pace alone does not reflect intensity in handball correctly as it neglects accelerations. This assumption is further supported by the fact that wing players had a slightly higher equivalent distance index compared to other positions in our study. This indicates that their movements are more erratic compared to the pivots and backs. Further, in another study, center backs and wings had a slightly higher number of high intensity accelerations and decelerations per minute compared to backs and pivots (4.5, 4.0, 3.9, 3.8 min^{-1} for CB, W, B, and P, respectively [30]. Positive and negative accelerations, however, substantially increase energy demands [8], resulting in higher mean metabolic power in these positions, and should not be neglected. Our data suggest that position-specific conditioning drills are required to prepare for the specific requirements and energetic demands of match-play. These requirements cannot be defined by speed or acceleration analyses alone, as handball players like players in other team sports rarely cover the necessary distance to achieve top speed, therefore, they hardly reach their individual top speed level. Accordingly, the ability to accelerate - defined as the rate of change in velocity - is at least as important to successful performance as maximum velocity [31]. The metabolic power approach takes both into account.

Erraticness

The equivalent distance index reflects the erraticness of running [10,8] with a higher index, indicating that activities are more intermittent in nature. Mean equivalent distance index in our study was approximately 1.20 for all positions (1.18 – 1.21 for different positions). This figure is similar as it is for football (mean: 1.20 (1.13 – 1.33); [11]). The equivalent distance index in our investigation in handball, however, was clearly higher compared to Australian football (mean: 1.10 (1.09 – 1.11); [24]), though slightly lower compared to field hockey (mean: 1.24 (1.22 – 1.26); [8]), and much lower compared to rugby league (mean: 1.28 (1.27 – 1.30); [25]. This indicates that in handball compared to other team sports, players generally perform medium to high dynamic accelerated running.

Impact of the time on the field

Our model illustrates a decrease of intensity (mean metabolic power) of 2.5% per 10 minutes played, with a sharper decline in the first 5 minutes compared to longer playing time. This is in line with Büchel et al. [2] who reported a 7% higher mean speed for low playing-time players compared to high playing-time players. Similar results were reported in changes in average speed, relative time spent running, and high-intensity running between halftimes in handball [12,2] and field hockey[8] . Bradley et al. [32] showed that substitute players in football covered more distance at high intensity and performed more sprints. This supports the thesis that the less you play, the more intense you move. The higher decline in intensity for the lowest playing time players may also be due to the nature of substitution itself, as Büchel et al. [2] proposed. Players need to act according to the situation in the match. During substitution, they often need to rush on and off the court. Wing players appear to be less fatigued during the match from other movements, as they perform much less of these movements compared to players in other positions [26]. Another explanation may be a higher aerobic capacity of wing players compared to back and line players, which may assist in reducing fatigue during a match. However, as we do not have the individual data of the players' aerobic capacity, this remains speculative.

Practical relevance

The differences in metabolic power derived intensity and volume parameters between positions throughout handball match-play suggest that it is important to adapt the training to the positional profile of each player. The inclusion of metabolic power analysis in handball is useful and necessary for the advancement and development of the sport and further individualization of training programs. Metabolic power allows for the analysis of individualized high-intensity activities and the respective training adaptations when individual thresholds are included in the analysis. Especially so in handball, high intensity efforts are rather short bouts where time and distance cannot reflect these bouts accurately, and where adenosine triphosphate turnover can be extremely high [33].

Methodological considerations

In this study, we focused on the evaluation of positional differences. In handball, players change their position frequently in the offensive phases of the match; however, we did not account for variations in tactical behavior. Playing in different defensive systems (4-2; 5-1; 6-0), for example, may result in different values. Further, the metabolic power approach assumes movement of the center mass and is neglecting any movements from the limbs. Additionally, the sensor device was placed in a pouch between the shoulder blades, which may have amplified movements from the trunk from tackling or other handball specific movement patterns and may have overestimated metabolic power [8]. Further, as stated above, the volume and intensity of handball match-play are characterized by many jumps, throws, passes, and tacklings. All these actions yield a certain amount of high energy and influence energy expenditure from horizontal movements and vice versa. These actions are not considered in the metabolic power approach, though certainly require investigation and an eventual amendment to the formula of total energy analysis in handball.

Perspective

With our analyses, we propose modelling the physical demands (i.e., exercise volume and intensity) in handball using the metabolic power model, a phase-by-phase model to extract net playing time and linear mixed models in order to account for the observational character. This can be conceptually used in other studies and may add meaningfully to this growing body of literature. However, the metabolic power model is far from perfect in modelling the physical and physiological demands. Future research should implement demands of sport-specific actions such as passing, jumping, side-steps, body contact, etc. Despite this, we see advantages over the common speed/distance approach. Such metrics may give insight into the locomotion of handball players. Metabolic power appears to reflect the load and intensity more accurately, as it takes into account the cost of acceleration in activity comprising perpetual changes in speed. We suggest using intensity models with a time component to account for decreasing intensity throughout the game, particularly in sports where interchange is allowed.

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Declaration of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as potential conflict of interest.

Ethics Approval

The study was planned and performed in line with the Declaration of Helsinki, and approved by the Ethics Committee of the University of Alicante (registration number UA-2020-09-10).

Author Contributions

Conceptualization, J.V., R.S. and P.P.; Methodology, J.V., R.S. and D.N.; Software, R.S.; Formal Analysis, J.V. and R.S.; Resources, C.M.; Writing – Original Draft, J.V.; Writing – Review & Editing, J.V., R.S., D.N., C.M. and P.P.; Visualization, J.V. and R.S.; Supervision, P.P.

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