Monitoring external load in elite male handball players depending on playing positions

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ABSTRACT: Monitoring workload is critical for elite training and competition, as well as preventing potential sports injuries. The assessment of external load in team sports has been provided with new technologies that help coaches to individualize training and optimize their team's playing system. In this study we characterized the physical demands of an elite handball team during an entire sports season. Novel data are reported for each playing position of this highly strenuous body-contact team sport. Sixteen world top players (5 wings, 2 centre backs, 6 backs, 3 line players) were equipped with a local positioning system (WIMU PRO) during fourteen official Spanish first league matches. Playing time, total distance covered at different running speeds, and acceleration variables were monitored. During a handball match, wings cover the greater distance by high-speed running (> 5.0 m·s^{-1}): 410.3 ± 193.2 m, and by sprint (> 6.7 m·s^{-1}): 98.0 ± 75.4 m. Centre backs perform the following playing position that supports the highest speed intensities during the matches: high-speed running: 243.2 ± 130.2 m; sprint: 62.0 ± 54.2 m. Centre backs also register the largest number of high-intensity decelerations (n = 142.7 ± 59.5) compared to wings (n = 112.9 ± 56.0), backs (n = 105.2 ± 49.2) and line players: 99.6 ± 28.9. This study provides helpful information for professional coaches and their technical staff to optimize training load and individualize the physical demands of their elite male handball players depending on each playing position.

INTRODUCTION

Global positioning systems are widely used in outdoor team sports such as rugby or football [1, 2]. This system also carries an embedded inertial measurement unit (IMUs) (e.g. accelerometer, magnetometer) recorder with a good level of validity [3], and a wide range of metrics (e.g., distance and number of sprints), although GPS cannot be used indoors (the GPS signal is blocked). Recently, many companies have developed ultra-wide band systems to collect real-time data in indoor sports [4]. This new technology has led to a better understanding of the players' responses to training and competition. [5, 6, 7].

Although there are still limitations that should not be over-looked [3], technical staff can now adjust player workloads more

precisely according to game demands [8]. These aspects are essential in handball, since playing positions largely influence game demands [9]. As a result, coaches can design training content adapted to playing position and playing style, which should lead to better performance [5] and fewer injuries [10].

At present, despite greater access to technology, there are still few scientific contributions related to game demands in handball. Additionally, most of this research has been conducted with video tracking [11, 12] or hand notational analysis [13]. These technologies have been shown to be less adapted to recording explosive actions typical of handball than IMUs systems [8, 14]. In this indoor

context, despite the proven accuracy [3] and reliability [15] of IMUs, more studies applied to official competitions in elite male handball players are needed. Previous studies have provided specific information, but only based on game-simulated situations in elite women [5, 16], training sessions in adolescent male players [14], or during 30 minutes outdoors [8].

The evolution of the total player load (TPL) was also analysed, reporting, for the first time ever, the external load indicator for each player in relation to actual playing time, i.e., providing information on the intensity level achieved per unit of time. These studies did not report any information about player displacement (e.g. distance covered at different speeds), which is of paramount information to coaches [5, 16]. It is worth noting that game demands are gender-dependent in elite handball [17], which makes these results useless for male elite players. To our knowledge, the physical demands in an elite men's handball team have never been described during a sports season.

Thus, the aim of this study was to characterise position-specific physical demands in elite handball players by measuring external load during a competitive season to provide a benchmark for coaches and the related training staff to optimise player preparation.

MATERIALS AND METHODS

Experimental approach to the problem

We conducted a cross-sectional, observational study to determine the differences between each playing position: wings (W), centre backs (CB), backs (B) and line players (LP). Results correspond to the average of 14 competitive official home matches disputed in the 2017–18 ASOBAL league (Spanish national premier league). We collected 188 records from the 16 players selected from the 14 games (61 from W, 18 from CB, 68 from B and 41 from LP).

Subjects

We analysed 16 professional elite male players from the same team throughout the season. The team comprised five W (26.6 ± 6.3 years; 183.1 ± 4.4 cm; 83.2 ± 4.1 kg), two CB (32.0 ± 7.1 years; 192.8 ± 1.0 cm; 93.8 ± 4.9 kg), six B (26.3 ± 4.8 years; 195.3 ± 2.8 cm; 97.8 ± 5.1 kg) and three LP (28.3 ± 4.0 years; 198.0 ± 8.4 cm; 101.5 ± 4.9 kg). The data came from daily monitoring of all the players in the team throughout the season both in training and in competition. Consequently, the approval of an ethics committee was not required [18].

Competitive match monitoring

The study was carried out using the WIMU PRO system (RealTrack Systems S.L., Almería, Spain). Each device, whose dimensions were 81x45x16 mm (height/width/depth) and which weighed 70 g, was fitted to the back of each player with adjustable bibs (Rasán, Valencia, Spain). All the players were used to this type of device and the way it is fastened, as they had trained with this system all season (3, 4).

Playing time was only recorded when the players were on court. The time spent between player rotation, timeouts (a maximum of three per match), periods when the game was interrupted and the disciplinary sanctions typical of handball where the players must leave the court for two minutes were omitted.

As 14 games were monitored, all the players included in the study participated in the game for an average of approximately 60 minutes per game. The team's game model used mainly a 6/0 defence (six players aligned near the 6-metre zone) and was conducive to a remarkably high game pace with many counterattacks.

Data processing

The positioning data record was monitored in real time and subsequently analysed using the SPRO software version 937 (SPRO, RealTrack Systems, 2018). The system operates by means of triangulations between four antennas with patented ultra-wideband technology (18 Hz sampling frequency) placed 5 m away from each one of the corners of the court and at a height of 6 metres. These units include several sensors that record at different sampling frequencies. The sampling frequency used for 3-axis, accelerometer, gyroscope, and magnetometer was 100 Hz and 120 kPa for the barometer [3, 4].

A previous validation study found a total bias in the mean velocity measurement between 1.18 and 1.32 km/h while the bias in distance was between 2.32 and 4.32 m (19) In addition, good inter-unit and intra-unit reliability was reported (intraclass correlation coefficients > 0.93) (19).

The effective playing time (PT, in min), distance covered (TD, in m), maximum speed achieved (m·s^{-1}), average speed (m·s^{-1}) and high-speed running (HSR, distance covered in metres above 5.0 m·s^{-1}) [14, 20] were extracted from the raw data reported by the system using SPRO software. We retrieved the distance covered at different speeds: walking (0.0–1.7 m·s^{-1}), jogging (1.8–3.3 m·s^{-1}), slow running (3.4–5.0 m·s^{-1}), running (5.1–5.8 m·s^{-1}), high-intensity running (5.9–6.7 m·s^{-1}) and sprint (> 6.7 m·s^{-1}). The total number of accelerations, decelerations, high-intensity accelerations (HIA), high-intensity decelerations (HID) (in m·s^{-2}) and HIA/HID per min (m·s^{-2}·min^{-1}) were recorded. HIA and HID were defined as events above 2 g [7, 8]. We calculated the TPL (total player load). The TPL is a vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each one of the three planes divided by 100 in absolute [7] or relative time – TLP·min^{-1} [16, 21].

Statistical analysis

Descriptive statistics are presented as means and standard deviations (SD). Differences between playing positions were analysed using Cohen's effect size (ES) statistics and ± 90% CL. The criterion for determining the size of the ES was: < 0.2 | 0.2 to 0.59 | 0.6 to 1.19 | 1.2 to 1.99 | ≥ 2.0, considering these values as trivial, small, moderate, large and very large, respectively [22]. The percentage likelihood of difference between groups was calculated and regarded

TABLE 1. Effect size and statistically significant differences between playing positions in IMU variables.

Variables	Wings (W)	ES	Rating	Center Backs (CB)	ES	Rating	Backs (B)	ES	Rating	Line players (LP)
TPL·min (AU·min⁻¹)	1.1 ± 0.2			1.1 ± 0.2			1.1 ± 0.2			1.1 ± 0.2
		CB: 0.11	trivial		B: 0.20	trivial		LP: 0.08	trivial	
		B: 0.31	small		LP: 0.13	trivial				
		LP: 0.24	small							
MaxV (m·s⁻¹)	6.4 ± 0.6 ^{b}			6.3 ± 0.6			5.9 ± 0.8			6.2 ± 0.8
		CB: 0.12	trivial		B: 0.52 *	small		LP: 0.36 *	small	
		B: 0.62 **	moderate		LP: 0.14	trivial				
		LP: 0.25	small							
HSR (m)	410.3 ± 193.2 ^{ab}			243.2 ± 130.2 ^{c}			161.7 ± 110.1			172.4 ± 96.0
		CB: 1.10 ***	moderate		B: 0.66 *	moderate		LP: 0.05	trivial	
		B: 1.65 ***	large		LP: 0.65 *	moderate				
		LP: 1.66 ***	large							
HSR · min⁻¹ (m)	6.6 ± 2.3			3.7 ± 1.7			2.6 ± 1.6			3,2 ± 1.8
		CB: 1.64 ***	large		B: -0.50 *	small		LP: 0.20	trivial	
		B: -2.05 ***	very large		LP: -0.28	small				
		LP: -1.80 ***	large							
HSR (n)	39.6 ± 18.2			34.9 ± 18.1			23.4 ± 15.8			24.3 ± 11.2
		CB: 0.30	small		B: 0.64 *	moderate		LP: 0.04 *	trivial	
		B: 0.04 ***	moderate		LP: 0.69 *	moderate				
		LP: 1.02 ***	moderate							
HIA (m·s⁻²) (n)	134.8 ± 60.7			148.7 ± 59.2			121.2 ± 53.9			112.0 ± 33.6
		CB: 0.23	small		B: 0.49 *	small		LP: 0.21 *	small	
		B: 0.24	small		LP: 0.76 *	moderate				
		LP: 0.46 *	small							
HID (m·s⁻²) (n)	112.9 ± 56			142.7 ± 59.5			105.2 ± 49.2			99.6 ± 28.9
		CB: 0.51 *	small		B: 0.69 *	moderate		LP: 0.14	trivial	
		B: 0.15	trivial		LP: 0.91 **	moderate				
		LP: 0.30	small							
HIA·min⁻¹ (m·s⁻²·min⁻¹)	2.2 ± 0.8			2.3 ± 0.8			2.1 ± 0.8			2.0 ± 0.6
		CB: 0.06	trivial		B: 0.26	small		LP: -0.03	trivial	
		B: 0.24	trivial		LP: 0.32	small				
		LP: 0.46	small							
HID·min⁻¹ (m·s⁻²·min⁻¹)	1.8 ± 0.8			2.2 ± 0.8			1.8 ± 0.7			1.8 ± 0.5
		CB: 0.41 *	small		B: 0.50 *	small		LP: 0.05 *	trivial	
		B: 0.08	trivial		LP: 0.52 *	small				
		LP: 0.05*	trivial							

ES: effect size; substantial probability of difference between playing positions: * likely, ** very likely, and *** most likely. TPL: total player load; MaxV: maximum velocity; HSR: high-speed running; HIA: high-intensity acceleration; HID: high-intensity deceleration. Significant differences (p < 0.001): ^{a} line players; ^{b} backs; ^{c} wings.

as almost certainly not (< 0.5%), very unlikely (< 0.5%), unlikely (< 25%), possibly (25–75%), likely (> 75%), very likely (> 95%) or most likely (> 99.5%). A percentage likelihood of difference < 75% was regarded as a substantial magnitude. Threshold chances of 5% for substantial magnitudes were used, meaning that a likelihood of > 5% in both a positive and negative direction was considered unclear. We also calculated significant differences. The Kolmogorov-Smirnov test confirmed a non-normal distribution of all the variables analysed. The Kruskal-Wallis test was performed to compare the four playing positions, followed by the Wilcoxon signed-rank test with Holm adjustment to determine the differences between positions in pairs. In the statistical tests that required it, the significance level was $p < 0.05$. The statistical analysis was performed using the R Studio Software (v1.1.463 Studio, Boston, Massachusetts). The measurement errors of all the metrics we used are not available, so we could not include them in our statistical analysis.

RESULTS

The playing time did not present any significant difference between playing positions ($p = 0.06$), although CB (65.6 ± 12.6 min) played moderately more than LP (56.3 ± 12 min, ES = 0.75) and slightly more than B (59 ± 12.5 min, ES = 0.5) and W (60.8 ± 6.9 min, ES = 0.27). The total distances travelled were significantly different between playing positions ($p < 0.0001$). CB (4040 ± 1007 m) and W (3903 ± 1224 m) covered a moderately greater distance (ES = 1.06, $p < 0.001$ and ES = 0.77, $p < 0.0001$, respectively) than B (3571 ± 864 m) and LP (3149 ± 630 m) during a game.

The distance travelled per minute was significantly different between playing positions ($p < 0.0001$). W (64.5 ± 10.4 m·min^{-1}), CB (62.3 ± 11.6 m·min^{-1}) and B (61.8 ± 7.8 m·min^{-1}) travelled moderately faster on average than LP (56.5 ± 6.6 m·min^{-1}, ES = 0.91, 0.62 and 0.74 respectively).

TPL was significantly different between playing positions ($p < 0.05$). CB (71.2 ± 12.6 UA) bore moderately more TPL than LP (59.5 ± 12 UA, ES = 0.7), slightly more than B (62.3 ± 17.7 UA, ES = 0.5), although W had a similar load (68.1 ± 23.1 UA, ES = 0.15). The total number of accelerations and decelerations performed during a game were equivalent for W, CB and B (acceleration: 1167.5 ± 337, 1166.9 ± 203.9, 1125.9 ± 271.6, respectively, ES = 0.01 to 0.15; deceleration: 1164.4 ± 336.2, 1161.4 ± 203.9, 1120.7 ± 271.1, respectively, ES = 0.01 to 0.18). LP differ only slightly from CB in this aspect (acceleration: 1102.5 ± 264.1, ES = 0.22: deceleration: 1106.15 ± 263.4, ES = 0.21). The analysis of the total number of accelerations and decelerations did not present any significant ($p = 0.82$ and $p = 0.79$, respectively) or substantial differences.

Table 1 presents the external load variable and Figure 1 the distance travelled at different speeds.

DISCUSSION

To our knowledge, this is the first time that an elite men's handball team has been monitored by IMUs during 14 official matches from a top-level national regular league. The main findings are that CB and W differ substantially from B and LP. The external load differences
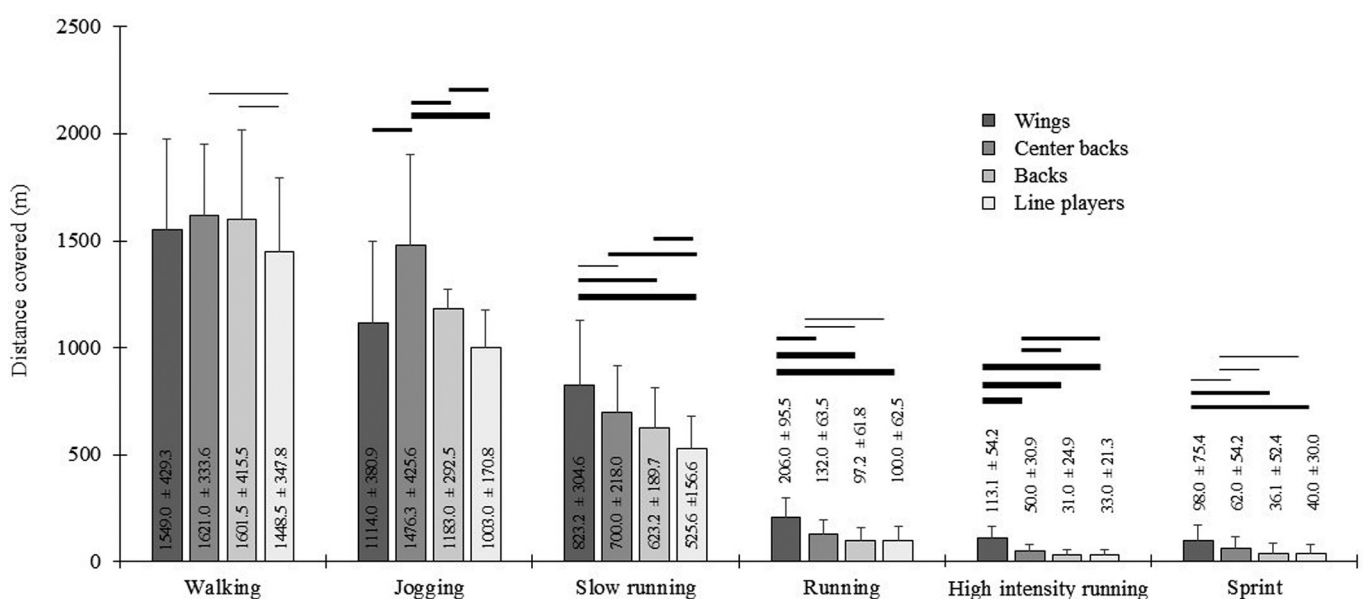

FIG. 1. Distance covered at different speeds according to each playing position.
Speed criteria: walking (0–1.7 m·s^{-1}), jogging (1.8–3.3 m·s^{-1}), slow running (3.4–5.0 m·s^{-1}), running (5.1–5.8 m·s^{-1}), high-intensity running (5.9–6.7 m·s^{-1}), sprint (> 6.7 m·s^{-1}). The thickness of the lines represents the magnitude of the difference (effect size) ▬ stands for a large, ▭ for a moderate and — for a small difference. Only effect sizes with a substantial probability of difference (> 75%) are shown.

between CB and B are as high as can be justified by a dedicated analysis.

Total distance, playing time and TPL

CB played more and travelled the greatest distance, followed by W, and LP had the lowest external physical load. Despite some controversies in the calculation and meanings of TPL, this metric is one of the most used variables to control external load during competition and training in team sports [6, 7, 15]. CB bore the highest TPL, followed by W, B and LP. To our knowledge, no study has been conducted with this metric.

One might think that time spent in the field (i.e. more opportunities to produce external load) should affect the TPL expressed by unit of time (minutes). Surprisingly, this metric was practically identical for all playing positions ($\approx 1.1 \pm 0.2$ AU·min^{-1}). This is a reminder of the complexity of the TPL formula, mainly based on acceleration, and therefore not simply dependent on effective playing time or distance covered [5, 15, 21]. Furthermore, it is difficult to compare the results of this paper with those from other handball studies, on account of different age [23], population type: level [5] and gender [6, 15] and game type: non-competitive games [8] and competitive games [6, 16, 21]. These results question the usefulness of this variable in assessing external load in handball.

Most of the works in the literature have merged CB and B [11, 20]. To our knowledge, only Cardinale et al. [12] and Barbero et al. [8] have studied CB separately, albeit with a different tracking technology or in non-ecological conditions. Our results confirm that the external loads borne by the CB are the highest and therefore call for a specific approach. The results obtained by the other players are consistent with previous studies conducted by video recording [9, 20].

Running pace, distance and running speed

Many authors have measured the distance travelled per minute in their work, although the different methodologies used to measure playing time (taking or not taking player rotations into account, team time out and actual playing time) have rendered this number virtually impossible to compare [8, 9].

Distance covered at different speeds is noteworthy since it is directly related to the game model. The technical staff can therefore use this indicator to design training content, particularly at the metabolic level. All players, regardless of position, covered between 70% and 78% of the total distance at a running pace of less than 3.3 m·s^{-1} (walking and/or jogging) and between 17% and 21% at between 3.3 and 5 m·s^{-1}. W covered a significantly greater distance above 5 m·s^{-1} compared to the other players. These results are consistent with those of previous studies [13, 24], although it should be borne in mind that hand notational technologies were used.

Sprint and high-speed running

Playing elite handball calls for a substantial volume of high-speed running [8]. As stated before, IMU could have validity and reliability concerns when measuring high-speed running (25); therefore our results and conclusions could not be definitive. However, these variables are extremely important for training and the prevention of injury. Previous studies [8] conducted with GPS during 30-minute outdoor training games reported higher sprinting speeds for W (6.9 ± 0.3 m·s^{-1} vs. 6.4 ± 0.6 m·s^{-1}), and similar results for CB (6.1 ± 0.3 vs. 6.3 ± 0.6 m·s^{-1}) and B (6.1 ± 0.3 vs. 5.9 ± 0.8 m·s^{-1}). LP reached a higher sprinting speed in our study (6.2 ± 0.8 vs. 5.5 ± 0.4 m·s^{-1}), which is even higher than B. Many factors could explain these differences, such as the team's game model, the individual characteristics of each player, fatigue (our data were collected during whole games) and a higher number of games (i.e., 14). On comparing the value of maximal sprinting speed expressed during games to sprint testing (e.g. 30-m straight-line sprinting) some substantial differences emerge. In our study, the mean maximal sprinting performed by W was about 17% (1.8 vs. 2.1 m·s^{-1}) lower than that which was obtained by players from the same level in a 30-m sprint [25]. This difference highlights the fact that it is highly likely that handball players do not frequently reach their maximal velocity during games. Coaches should consider this aspect.

W presented the greatest high-speed load, as they covered the greatest HSR distance each minute and performed the highest number of HSR. CB completed the highest number of HSR but with a low HSR value covered each minute (3.7 ± 1.7 HSR·min^{-1}). This paradox could be related to the technical and tactical demands of this playing position. CB are a in a central position in which they perform many short, high-intensity runs towards the goal.

It is also useful to know how many metres players travel in HSR during a match. These values are especially important for coaches to manage HSR volume during a training session or a microcycle. Previous research conducted by means of video analysis yielded similar results to our study, in which W covered the greatest distance at speeds above 5 m·s^{-1} [12, 20]. It is worth noting that the distance covered above 5.8 m·s^{-1} fluctuates greatly. The CV ranged from 46% for the high-intensity runs to 145% (for running, high-intensity running and sprinting). These variations reflect the unpredictable character of game demands in team sports [7] and/or the limits of the device in high speed running measurement. Before drawing any definitive conclusion regarding high speed running and sprinting, we need to be more confident about the validity and the reliability of the device.

Acceleration and deceleration

Players' ability to accelerate and decelerate is particularly important in meeting tactical and technical demands in handball. This is evident in the numerous changes of direction that take place during a match [9]. Our results indicate that all players perform a similar amount of accelerations and decelerations. CB performed the highest number of HIA (148.7 ± 59.2 n·s^{-2}) and HID (142.7 ± 59.5 n·s^{-2}). This should also be related to the technical and tactical demands of the playing position and the HSR per minute. When these values

were standardised by playing time (m·s⁻¹·min⁻¹), the results were similar (Table 1). These results coincide with those obtained in previous studies conducted by means of video recording [27], albeit not with others [8]. However, the comparison of both studies is once again difficult, either because they involved women or because they were based on GPS monitoring during outdoor training games, respectively. Decelerations lead to a significant eccentric demand on players, which could induce many negative effects (e.g., muscle damage) and injuries [28]. Thus, the technical staff should monitor this aspect. Even if the threshold is lower in our study (2 vs. 2.5 g), handball induces one of the highest deceleration loads for players in team sports [28].

Methodological considerations

In most studies, CB were included with the lateral backs (i.e., right and left) in the backs category [13]. This aspect is important, because this clustering potentially conceals some especially important information for the technical staff. Probably, physical demands on the court decrease for CB and increase for LB, so that it is difficult for the coach to adjust them. To our knowledge, only two studies have made a distinction between these players [8, 12].

Another important consideration is that neither video-based nor IMU analysis could measure the external load in handball extensively. The actions performed on the training field did not always produce a movement or an acceleration. For example, to block their opponent, LP use a high level of isometric strength and need to maneuverer vigorously with their arms to gain an advantageous position. IMUs could register some movement (e.g. acceleration) in these situations but their intensities are far from the level of isometric force required in this type of action. These activities produce a high cardiac output [24] but are not clearly observable with IMUs or video tracking.

While this study provides an analysis of the external load of male elite handball teams, it is limited to certain global metrics and does not provide a further insight into handball-specific movements such as sideways and backward displacements and jumps. Hence more work is necessary to elucidate these aspects further.

Limitations

A team can use different defensive systems (different spatial and functional organisation, e.g. 6/0, 5/1) depending on the coach's choice. These options rely on many factors (e.g., the opponents, coach philosophy and team characteristics). Each team chooses its own defensive system but also must contend with the opponent's. These tactical options are likely to have many consequences in terms of physical demands, although we are not aware of any study that confirms this hypothesis. The data presented in this investigation are based only on home games (with a predominantly 6/0 defensive system and an offensive game based on counterattack and speed) which can also affect game demands [29]. Since we monitored the same team over 14 games, it should be noted that many variables

could have influenced outcomes, such as the level of the opponents [30] and game plan [31]. Another issue is that player rotation is unlimited in handball, and most teams use offensive and defensive specialists with systematic changes. These constant rotations pose numerous difficulties in analysing game demands.

Practical applications

Our results could provide external load reference values for other male elite handball teams. CB and W present a similar level of external load. This is important in designing appropriate training content, particularly for high-speed running. These findings have certain direct implications for injury prevention. Technical staff should apply the same amount of speed training for CB and W. LP and B bear the smallest external load in our study, but it should be remembered that IMUs could not accurately measure LP performance. As a result, the needs of these two playing positions should be different. It is important to adapt training load and training content to each playing position and coaches should establish at least three different groups: 1) CB and W, 2) B, 3) LP.

CONCLUSIONS

The analysis of all the variables monitored with an IMU system suggests that both CB and W positions have the highest external load, while by contrast B and especially LP have the lowest load. W and CB perform a substantially greater number of sprints and high-speed running than the other players. Some methodological and technological issues limit the analysis of handball-specific movements (e.g., jumps and sideways and backward movements) and research that overcomes these difficulties is called for. Coaches and practitioners will also need to understand how contextual factors (e.g., level of the opponent, game location, score and game plan) affect physical game demands. This knowledge could lead to better training load management and the design of specific training content.

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