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Section III – Sports and Physical Activity

Evaluation of an IMU-Based Tracking System for Monitoring Physical Demands in German Junior Female and Male National Handball Players: Agreement with an Established LPS System and Application during Training

by
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Indoor tracking systems of varying technological complexity are commonly used to quantify physical demands in team-handball. However, there is a lack of research concerning IMU based tracking systems. Therefore, the aim of this study was to evaluate a recent IMU tracking system in team-handball. The evaluation steps included the examination of (i) the agreement between an established LPS+IMU and the IMU tracking system, (ii) the correlation structure of investigated variables, and (iii) differences between training drills using the IMU system. A total of 34 handball players from the female U18 and male U21 national teams of the German Handball Federation participated. Three training sessions including seven training drills and one simulated match were recorded using an established LPS+IMU and the recent IMU tracking system. Results showed that (i) the accumulated player load and time spent in the low speed zone presented substantial agreements (CCC > 0.95), (ii) the accumulated player load was highly correlated with total distance and time spent in very low, low, and very high speed zones (r ≥ 0.61), and (iii) accumulated player loads were highest in training drills covering the entire court. In German junior female and male national handball players, the recent IMU tracking system only allowed a valid assessment of variables that were directly assessed by the measurement technology, i.e., the accumulated player load. However, the player load indicated more the volume than the intensity of training and matches, which should be considered by coaches and scientists when monitoring physical demands in junior handball players.

***Keywords**: team sport games; inertial measurement unit; local positioning system; monitoring; training*

Introduction

For an evaluation of new technologies in sports science under externally valid conditions, knowledge of the respective sport is obligatory (Linke et al., 2018). In this context, team handball is a physically and technically-tactically demanding contact sport (Wagner et al., 2014). It is characterized by the individual performance of players (Garcia-Sanchez et al., 2023) and the overall tactical behavior of the team (Wagner et al., 2014). To design and optimize training drills and adaptation processes aimed at enhancing physical performance and preventing particularly overuse injuries in handball, it is essential to quantify the intensity and volume of key sport-specific activities such as running, jumping, throwing, rapid changes of direction, and physical contacts during training sessions and matches (Garcia-Sanchez et al., 2023). The quantification should enable coaches to compare competition and training demands and to distinguish between high-intensity phases of training drills based on

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running speed and acceleration. Indoor tracking systems are suitable for this purpose; although, they differ in their technological design and thus also in their provided variables (Garcia-Sanchez et al., 2023; Luteberget et al., 2018b; Torres-Ronda et al., 2022).

Local positioning systems (LPSs) combined with inertial measurement units (IMUs) are considered the state-of-the-art tracking technology in team handball (Blauberger et al., 2021). The technology allows the precise estimation of the player and the ball position from which instantaneous speed and acceleration can be calculated (Blauberger et al., 2021). The integration of IMU data enables the quantification of additional metrics, such as the jump count, impacts, and the player load, which are not captured by the LPS alone. Moreover, these metrics can provide valuable insights in team handball by capturing position-specific events, such as the number of impacts sustained by pivots (Garcia-Sanchez et al., 2023). Since the 2019/2020 season, combined LPS+IMU tracking systems have been permanently installed in all arenas of the first Handball division in Germany. Notably, the LPS+IMU tracking system requires the manual positioning of reference antennas and system calibration, which are time-consuming and require human resources that are often unavailable. This limitation hinders its practical use for training applications (Pino-Ortega et al., 2021). Alternatively, coaches and scientists can use recently developed IMU only tracking systems, which are more practical, have the same sensor size, and do not require antennas (Luteberget et al., 2018a). However, IMU tracking systems and their generated variables have been less frequently validated (Arlotti et al., 2022). In team handball, the IMU technology is potentially appropriate to identify and quantify sport-specific movements such as throwing (van den Tillaar et al., 2021), jumping, and running activities (Lentz-Nielsen et al., 2025). Attempts have also been made to estimate horizontal acceleration (Alexander et al., 2016) or instantaneous distance and running speed (Pillitteri et al., 2021). However, this remains challenging due to the inherent IMU sensor drift (Arlotti et al., 2022). Usually, when using IMU tracking systems, the player load (Dawson et al., 2024), the number of jumps (Saal et al., 2023), and also the number of high-intensity events (Luteberget et al., 2018c) are used to quantify physical demands in team handball. Literature regarding the validity of measuring jumps in handball using back-worn IMU technology is quite rare (Javanmardi et al., 2022). In contrast, the player load and its variations are well studied (Bredt et al., 2020). For instance, the player load, which reflects the changes in accelerations of all axes measured by the IMU, shows moderate to high correlations with the RPE and the session RPE ($r = 0.4$ to 0.8) (Casamichana et al., 2013; Choice et al., 2023; Helwig et al., 2023; Pedersen et al., 2023), high correlations with total distance covered ($r = 0.7$ to 0.9) (Choice et al., 2023; Oliva-Lozano et al., 2021), increases with the number of collisions, and includes information on horizontal acceleration and deceleration ($r^2 = 5$ to 10%) (Dalen et al., 2016). Furthermore, the accumulated player load above 2G correlates with high metabolic load distance ($r = 0.8$) (García-Sánchez et al., 2025).

Current IMU tracking systems offer comparable variables (e.g., time spent in speed zones) to LPS+IMU tracking systems. However, they are rarely used in team handball, for example to compare different training exercises. In one study, semi-professional female handball players wore IMU sensors during different drills. It was found that a higher player load and a greater number of high-intensity events (acceleration and change of direction events > 2.5 m/s) occurred during 3 vs. 3 compared to 6 vs. 6 drills (Luteberget et al., 2018c). Knowledge of the load during these drills could assist coaches in planning training sessions with appropriate intensity and volume. However, it can be noted that there is a lack of evaluation studies; particularly, in relation to the speed and acceleration-related variables provided by IMU tracking systems (Arlotti et al., 2022) under externally valid conditions.

Therefore, the aim of this study was to evaluate a recent IMU tracking system for measuring total distance, the accumulated player load, the number of high-intensity accelerations, time spent in speed zones, and the number of jumps in German junior national handball players. The evaluation steps included the examination of (i) the agreement between an established LPS+IMU and the IMU tracking system, (ii) the correlation structure of investigated variables, and (iii) differences between training drills using the IMU tracking system. Considering the literature body provided, we hypothesized that the agreement between metrics measured by an IMU and an LPS+IMU tracking system would be heterogeneous.

Methods

Participants

A total of 34 handball players from the female U18 (n = 19; age: 17 ± 0.7 years, body height: 175 ± 9 cm, body mass: 69 ± 10 kg) and male U21 (n = 15; age: 20 ± 0.4 years, body height: 190 ± 4 cm, body mass: 92 ± 9 kg) national teams of the German Handball Federation (DHB) participated in the study. According to McKay et al. (2022), players were classified as elite/international athletes (tier 4). Players were nominated on 02 June 2022 by the respective national coaches of the DHB and recruited for the study between 22 and 29 June 2022. Legal guardians were informed by the DHB as part of the nomination process and gave their written consent for athletes to participate in the study and performance diagnostics. All players were informed of the study aim, the procedures, and provided written informed consent on the day of the study. Furthermore, all players had to be free of acute musculoskeletal injuries and infections. This study was conducted following the principles of the Declaration of Helsinki, and approved by the local Ethics Committee of the Leipzig University, Leipzig, Germany (protocol code: 2022.06.09_eb_159; approval date: 21 June 2022).

Experimental Approach

In total, data from three training sessions (U18 female: two sessions in June 2022 and U21 male: one session in January 2023) were collected. All sessions were conducted in an indoor sports hall with a standard handball court. Two training sessions consisted of seven different training drills and a standardized warm-up for both teams and were performed in the morning. An additional training session included a simulated match (2 x 30 min) for the U18 female team in the afternoon. The standardized warm-up was conducted according to the DHB guidelines (MAPS, 2024) by a national coach at the beginning of all training sessions. All seven training drills had a match-based character with a 6-0 defense system and were conducted over eight minutes with two minutes of passive recovery in between to allow comparisons without time normalization. The training drills were part of the routine training practice (Dechechi et al., 2023) and varied in court size, the area played, the number of teams, the number of players per team, and the number of assisting players. The three training sessions were recorded using an established LPS+IMU (Kinexon Perform LPS) and a recent IMU (Kinexon Perform IMU) tracking system. For both systems, sensors were placed between the shoulder blades of the players in a thigh-fitting elastic shirt from the manufacturer. The LPS+IMU sensor was placed above the IMU sensor with the aim of minimizing the lever arm, which allowed simultaneous data recording and comparisons.

LPS and IMU Tracking Systems

The LPS+IMU tracking system (Kinexon Perform LPS, Version 4) collected 2D positional and 3D IMU (accelerometer, gyroscope, and magnetometer) data at 20 and 100 Hz, respectively. To briefly explain the measurement principle: 12 antennas were positioned around the playing field connected to one base station. A sensor (30 x 40 x 7 mm, 15 g) worn by athletes transmitted time signals via radio technology to the antennas and via a wide local area network to the base station. The used technology had been described in detail elsewhere (Hoppe et al., 2018; Manchado et al., 2020) and shown acceptable validity and reliability for distance covered, speed, and acceleration (Blauberger et al., 2021).

The IMU tracking system (Kinexon Perform IMU, 100 Hz, Version 4) collected 3D IMU (accelerometer, gyroscope, and magnetometer) data only, which were locally processed using proprietary algorithms by the manufacturer software to estimate distance covered along with time spent in particular speed zones (Kinexon, n.d.). The method to calculate the accumulated player load had been described in detail elsewhere (Saal et al., 2023).

Training Drills

Figure 1 shows the seven training drills. Briefly, in the first drill (2 vs. 2+2), two attacking players, including a pivot, played against two defending players on the half court (20 x 20 m) in the small central area (7.60 and 6.45 m from the 6-m and the 9-m line to sidelines, respectively). The attacking team had two assisting players, serving as pass receivers and passers only. In the second (4 vs. 3+2) and the third training drill (4 vs. 4+2), four attacking players, including a pivot played, against three or four defending players, respectively, on the half court in the large central area (4.00 and 1.80 m from the 6-m and the 9-m line to sidelines, respectively). In both training drills, the attacking team had two assisting players. In the fourth (4 vs. 3 vs. 3) and the fifth training drill (4 vs. 4 vs. 4), four attacking players, including a pivot, played against three or four defending players, respectively, on the full court (40 x 40 m) in the large central area. Both training drills were played with three teams, whereby after the end of an attack, the defending team was the new attacking team and played against the waiting defending team on the other courtside. The former attacking team stayed on the same courtside and acted as a new waiting defending team. In terms of the 4 vs. 3 vs. 3 drill, pivots only played in the attacking team and were otherwise off the court behind the sideline. In the sixth (6 vs. 5) and the seventh training drill (6 vs. 6), six attacking players played against five or six defending players, respectively, on the half court.

Statistical Analysis

Statistics were done using R 4.3.0 and included three following steps of analysis: (i) the agreement between the LPS+IMU and the IMU tracking system, (ii) correlation structure of the investigated variables using LPS+IMU data, and (iii) differences among the seven training drills using the IMU tracking system. To investigate the agreement of both tracking technologies, the following variables were considered: (i) total distance covered, (ii) time spent in different speed zones (very low: < 4 km/h, low: 4 to < 10 km/h, medium: 10 to < 16 km/h, high: 16 to < 22 km/h, and very high: ≥ 22 km/h), (iii) the accumulated player load, (iv) the number of high-intensity accelerations (accumulated player load ≥ 3.6 m/s^2 for ≥ 1 s), and (v) the number of performed jumps. These variables were chosen, because they were provided by both systems and represented common speed- and acceleration-related characteristics used in team sports such as handball (Garcia-Sanchez et al., 2023). A detailed description of the variables can be found elsewhere (Saal et al., 2023). The statistical agreement of the two tracking systems was quantified using the Lin's concordance coefficient (CCC), which combines both precision and accuracy and provides a comprehensive assessment of the agreement (Lin, 1989). Additionally, confidence intervals (95% CIs) for the paired mean differences and Cohen´s *d* were provided. Cohen´s *d* for paired means was interpreted as follows: $|d| < 0.2$ “negligible”, $|d| < 0.5$ “small”, $|d| < 0.8$ “medium”, and otherwise “large” (Cohen, 1988). Paired values were independently analyzed for the groups: the warm-up, training drills, and the simulated match. Outliers were defined as relative errors outside the lower (< 0.05) and the upper bound (> 0.95) of the sample probabilities. The CCC values were interpreted as follows: perfect (≥ 0.99), substantial (0.95 to 0.99), moderate (0.90 to 0.95), and low (≤ 0.90) (McBride, 2005). To explore the correlation structure of the investigated variables, LPS+IMU data of the three sessions were used. Moreover, we included two variables, i.e., the number of accelerations and the number of decelerations, which were not available in the IMU tracking system, to obtain additional information on training intensity. The Spearman’s rank correlation coefficient was calculated using the median at the subject level. Correlation coefficients were interpreted as follows: very small (< 0.1), small (0.1 to 0.3), moderate (0.3 to 0.5), and large (> 0.5) (Cohen, 1988). Subsequently, rows and columns of the correlation matrix were clustered (Ward’s method, hierarchical cluster) based on the similarity of their values (Kolde, 2019). The best number of clusters was determined by the silhouette method. Based on steps (i) and (ii), variables were chosen for analysis in terms of (iii) the aim, in which differences among the different training drills were examined using the IMU tracking system only. Data from assisting players in the training drills were excluded. To test the differences among the seven training drills, three linear mixed models with athletes as random effects were fitted and compared. Then, 95% CIs for all regressions models were computed using a bootstrap approximation.

Results

Agreement of Both Tracking Systems

Table 1 summarizes the agreement between the LPS+IMU and IMU tracking systems during the warm-up, training drills, and the simulated match. There were no statistically significant differences for total distance ($p = 0.10$, $d = 0.05$), time spent in the high ($p = 0.06$, $d = 0.12$) and the very high speed zone ($p = 0.13$, $d = 0.03$), the accumulated player load (p = 0.21, d = −0.03), and the number of high-intensity accelerations (p = 0.13, d = 0.05). The CCC ranged from 0.23 to 0.96. A substantial agreement was found for time spent in the low-speed zone (CCC = 0.96) and the accumulated player load (CCC = 0.95). A moderate agreement was observed for total distance covered (CCC = 0.93) and the number of high-intensity accelerations (CCC = 0.92), while a low agreement was found for time spent in very low (CCC = 0.82), medium (CCC = 0.82), high (CCC = 0.72), and very high speed zones (CCC = 0.71), as well as the number of jumps (CCC = 0.23).

Correlation Structure of Investigated Variables

Figure 2 shows the ordered correlation matrix based on a cluster analysis using data from the LPS+IMU tracking system. Determining the best number of clusters resulted in a two-cluster solution. The variables were grouped based on similarity in their correlations, using hierarchical clustering with the Ward's method (Kolde, 2019). The first cluster consisted of the accumulated player load, total distance, and time spent in very low, low, and very high speed zones, whereas the second cluster included the number of accelerations, time spent in medium and high speed zones, the number of jumps, high-intensity accelerations, and decelerations.

The following results were based on two IMU generated variables with high CCC values, namely the accumulated player load (CCC = 0.95) and the number of high-intensity accelerations (CCC = 0.92). The accumulated player load showed high correlations with total distance covered (r = 0.83) and time spent in low (r = 0.70), very low (r = 0.75), and very high (r = 0.61) speed zones within the first cluster. However, despite its high CCC, the number of high-intensity accelerations exhibited only low correlations (r ≤ 0.29) with the number of accelerations and decelerations, time spent in medium and high speed zones, and the number of jumps within the second cluster.

Differences among Training Drills

Based on the CCC outcomes, as an estimation for the agreement and also due to the results from the correlation structure, revealing that the number of high-intensity accelerations showed small, non-significant relationships with the other LPS+IMU variables (r < 0.32), only the accumulated player load of the IMU tracking system was used to compare the different training drills. Table 2 shows the descriptive statistics of the accumulated player load depending on the different training drills.

Figure 3 shows characteristics of the IMU tracking system based the accumulated player load depending on different training drills and both teams. Table 3 shows the summary output of the linear mixed models according to the accumulated player load. Adding the team significantly improved the fit of the model 3 compared to model 2 ($x^2(1)$ = 4.95, p = 0.02). The model's intercept, corresponding to type = 6 vs. 6 and team = U18 female, was at β = 36.6 a.u. Training drills on the full court (types 4 vs. 3 vs. 3 and 4 vs. 4 vs. 4) induced a significantly higher accumulated player load with an estimated effect of 25.9 and 24.9 a.u. This corresponded to an estimated load of 62.5 a.u. (36.6 + 25.9) for the 4 vs. 3 vs. 3 condition in the reference group (U18 female). Minor effects were found for team differences with larger values for the U21 male team by 8.3 a.u. and higher values in 2 vs. 2+2 of 8.7 a.u. compared to the reference level. Other formats (e.g., 4 vs. 3+2, 4 vs. 4+2, 6 vs. 5) showed no significant differences from the baseline.

Discussion

The aim of this study was to evaluate a recent IMU tracking system for measuring total distance, the accumulated player load, the number of high-intensity accelerations, time spent in particular speed zones, and the number of jumps in German junior national handball players. The evaluation steps included the examination of (i) the agreement between an established LPS+IMU and the IMU tracking system, (ii) the correlation structure of investigated variables, and (iii) differences among training drills using the IMU tracking system.

Our main findings showed (i) substantial agreements (CCC: 0.95 to 0.99) between the established LPS+IMU and the recent IMU tracking system for time spent in the low speed zone and the accumulated player load, (ii) large correlations of the accumulated player load with total distance covered (r = 0.83) and time spent in very low (r = 0.75), low (r = 0.70), and very high speed zones (r = 0.61), and (iii) the highest accumulated player load in full court training drills (p < 0.001).

Table 1. Agreement of the LPS+IMU and IMU tracking systems for monitoring physical demands during the warm-up, training drills, and the simulated match.

Variable	n	Obs.	IMU M ± SD	LPS+IMU M ± SD	*p*	*d*	95% $CI_{mean\ difference}$	CCC	95% CI_{CCC}
Total distance covered (m)	18	148	744 ± 715	709 ± 689	0.10	0.05	−7.6 to 77.2	0.93	0.90 to 0.95
Time spent in the very low (<4 km/h) speed zone (s)	13	109	671 ± 480	572 ± 375	< 0.001	0.21	51.7 to 145.3	0.82	0.75 to 0.86
Time spent in the low (4 to <10 km/h) speed zone (s)	13	109	211 ± 176	198 ± 171	<0.01	0.07	4.3 to 21.2	0.96	0.95 to 0.98
Time spent in the medium (10 to <16 km/h) speed zone (s)	13	99	51 ± 69	62 ± 83	0.01	−0.13	−19.7 to −1.8	0.82	0.75 to 0.87
Time spent in the high (16 to <22 km/h) speed zone (s)	13	97	16 ± 37	11 ± 22	0.06	0.12	−0.2 to 9.1	0.72	0.64 to 0.79
Time spent in the very high (≥22 km/h) speed zone (s)	13	89	0.9 ± 4.8	0.4 ± 2.1	0.13	0.03	−0.1 to 1.0	0.71	0.69 to 0.73
Accumulated player load (a.u)	18	148	93 ± 82	96 ± 82	0.21	−0.03	−7.0 to 1.5	0.95	0.93 to 0.96
Number of high intensity accelerations	18	141	12.3 ± 16.3	11.6 ± 13.9	0.13	0.05	−0.2 to 1.8	0.92	0.89 to 0.94
Number of jumps	18	132	3.8 ± 3.3	7.8 ± 9.5	< 0.001	−0.5	−5.5 to −2.5	0.23	0.14 to 0.31

Note: n = number of subjects; Obs = number of observations; M = arithmetic mean; SD = standard deviation; p = p value; d = Cohen´s d; 95% $CI_{mean\ differences}$ *= confidence interval related to the estimator; CCC = Lin's concordance coefficient; a.u. = arbitrary units; Variables without units are counts*

Table 2. Mean and standard deviation of the accumulated player load measured with the IMU tracking system depending on the different training drills by the team.

Training drills	Accumulated player load (a.u.) M ± SD	
	U18 female	U21 male
2 vs. 2+2	45.8 ± 12.6	52.7 ± 10.8
4 vs. 3+2	32.2 ± 10.3	50.4 ± 11.2
4 vs. 4+2	44.6 ± 8.1	41.3 ± 16.3
4 vs. 3 vs. 3	59.9 ± 13.4	73.2 ± 17.6
4 vs. 4 vs. 4	50.8 ± 15.8	79.3 ± 17.6
6 vs. 5	45.3 ± 9.9	38.3 ± 13.0
6 vs. 6	39.1 ± 16.7	41.1 ± 18.3

Note: M = arithmetic mean; SD = standard deviation; a.u. = arbitrary units

Table 3. Summary of three linear mixed models to predict the accumulated player load with the type of training drills and the team. Model 1 serves as a null model. Model 3 differs from model 2 by including the team.

Accumulated player load						
	Model 1 Value ~1 + (1∣type)		Model 2 Value ~ type + (1∣Name)		Model 3 Value ~ type + team + (1∣Name)	
Effect	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Fixed Effects (type)						
Intercept	50.5	43.3 to 58.3	41.1	35.5 to 46.4	36.6***	29.9 to 43.4
2 vs. 2+2			8.8	2.3 to 15.4	8.7*	1.7 to 16.1
4 vs. 3+2			1.8	−5.1 to 8.9	1.7	−4.9 to 8.3
4 vs. 4+2			0.9	−5.7 to 7.9	0.8	−5.6 to 7.6
4 vs. 3 vs. 3			25.8	19.7 to 32.7	25.9***	19.7 to 32.8
4 vs. 4 vs. 4			24.9	18.7 to 31.1	24.9***	18.4 to 31.6
6 vs. 5			−0.7	−7.3 to 5.8	−0.7	−6.8 to 5.3
U21 male					8.3*	1.5 to 15.1
Random Effect						
Residual	242.6		153.5		153.2	
Type	104.4					
Name			83.0		66.8	
AIC	1564.5		1516.7		1513.7	
BIC	1574.2		1545.6		1545.9	
R^2 (cond./marg.)	0.3/0.0		0.57 / 0.34		0.57 / 0.39	

*Note: type = training drills (group level); Name = player id (subject level); value = accumulated player load; Significance codes: '***' < 0.001, '**' < 0.01, '*' < 0.05*

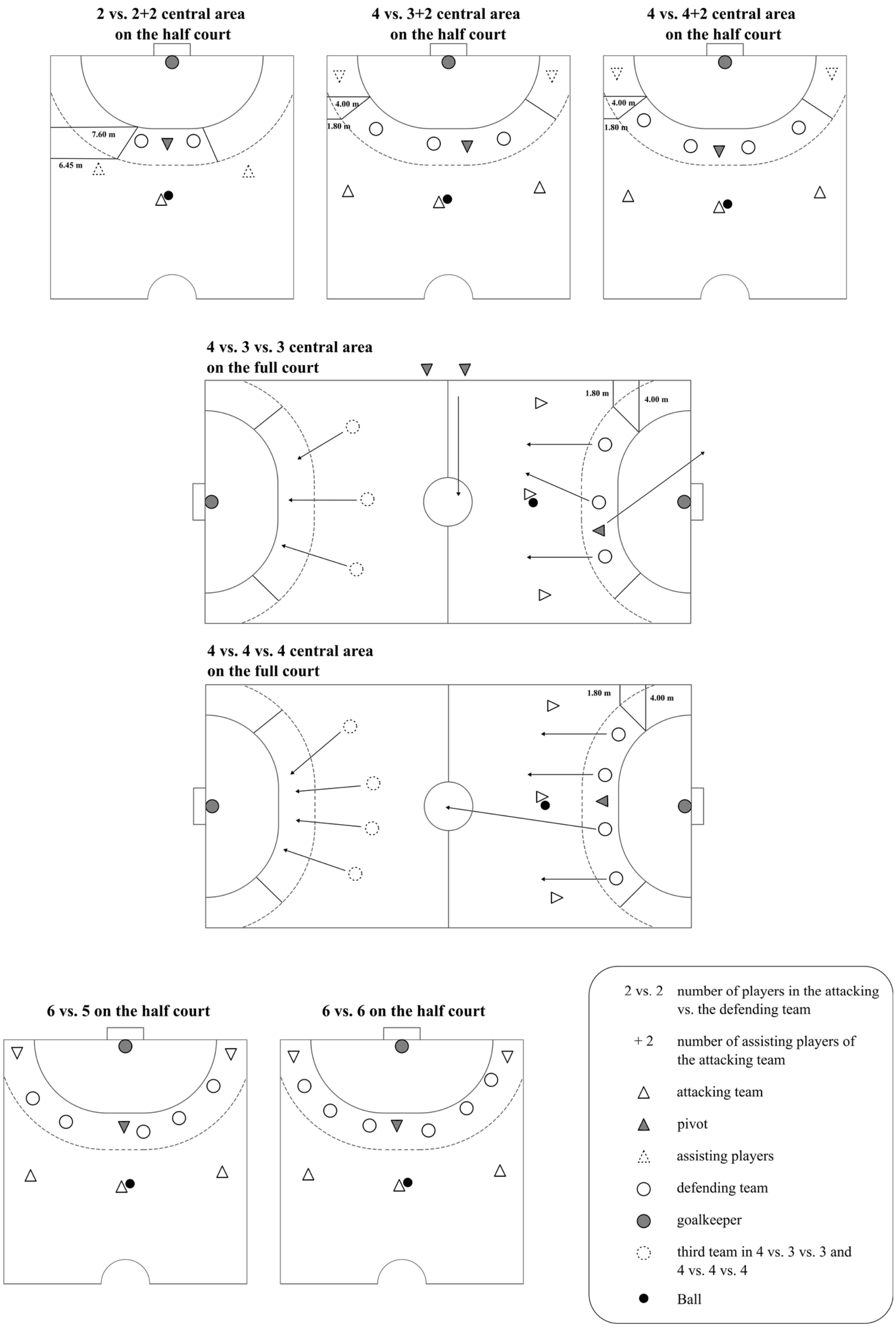

Figure 1. The seven training drills with different numbers of players and sizes of the court.

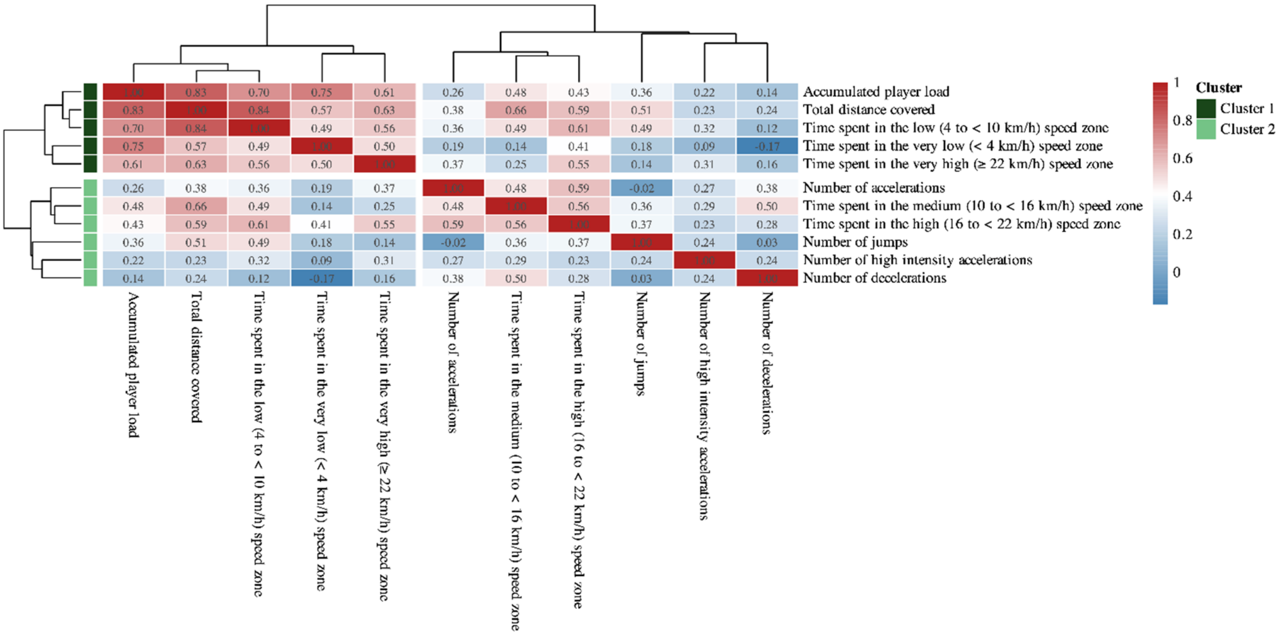

Figure 2. Ordered correlation structure based on two clusters for the investigated variables from the LPS+IMU tracking system. The heatmap color gradient reflects correlation strengths between variables, ranging from −0.17 (blue) to 1.0 (red). The white color corresponds to the midpoint of this range, approximately 0.4, rather than zero.

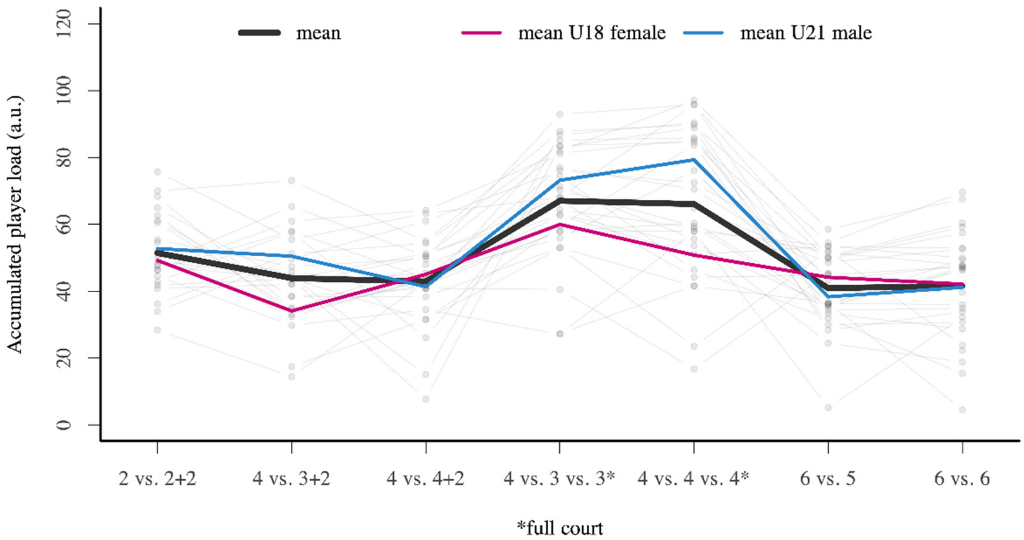

Figure 3. Characteristics of the IMU tracking system based on the accumulated player load depending on different training drills and both teams.

Regarding the first main finding, substantial agreements of the established LPS+IMU and the recent IMU tracking system were only found in two variables: time spent in the low speed zone and the accumulated player load (Table 1). Earlier studies had shown that IMU tracking systems tended to overestimate average speed and acceleration during high speed running compared to timing gates (Alexander et al., 2016) and differed in estimating average speed against a video based reference system with a CCC value of 0.80 (Pillitteri et al., 2021), which supports our findings (Table 1). A possible explanation could be the IMU drift, which is a known issue caused by the integration of sensor noise and bias over time, resulting in the progressive accumulation of errors in the position and orientation estimates (Arlotti et al., 2022). The accumulated player load showed a high level of agreement, as expected, since this metric was generated by the IMUs in both systems. The high level of agreement in the time spent in low-speed zones also seemed reasonable, considering the nature of the IMU drift: noise tends to increase with higher and abrupt changes in acceleration, making errors more likely during rapid movement changes. However, in our study, the observed non-significant bias in time spent in the very high speed zone should be interpreted with caution. In our dataset, only 8 out of 96 observations reached the threshold of ≥ 22 km/h. Hence, in 81 observations, both systems recorded zero seconds, which might explain the non-significant paired mean differences, requiring more research to be clarified. Considering the findings collectively, only the accumulated player load and time spent in the low-speed zone can currently be regarded as valid variables derived from the IMU tracking system.

The second main finding was that the accumulated player load showed strong correlations with total distance and time spent in different speed zones at the limits (very low, low, and very high), forming the first cluster with them (Figure 2). Other studies had also reported a large correlation between the player load and total distance covered (Casamichana et al., 2013; Choice et al., 2023; García-Sánchez et al., 2025; Oliva-Lozano et al., 2021) as well as low speed activities and high speed running (Gabbett, 2015), which supports our results. The cluster can be explained by the fact that acceleration decreases with increasing running speed (Sonderegger et al., 2016), whereby the highest acceleration occurs in medium to high running speed of ~7 to 14 km/h (Morin et al., 2021). Thus, due to the mathematical foundation of the player load (i.e., the summation of all rates of change in acceleration), the accumulated player load may be a preferred variable for monitoring running activities with low accelerations during training. Furthermore, the accumulated player load seems to be suitable to estimate the overall subjective perception, but it does not help determine "fine-structured loading" (Helwig et al., 2023). In contrast, variables from an IMU tracking system, such as the number of high-intensity accelerations, should be interpreted with caution due to their weak correlation with acceleration and deceleration counts obtained from the established LPS+IMU tracking system (Figure 2). Overall, these points suggest that the accumulated player load only reflects running activities with comparatively low proportions of high accelerations. Further studies are required to clarify the biomechanical and physiological meaning of the player load.

Regarding the third main finding, we found significantly higher accumulated player loads in training drills, when covering the entire court (Figure 3). The results are partly in line with previous studies where it has been reported that the total distance covered increased with increasing court sizes, while handball specific activities such as the number of team actions, passes, jumps, and change of directions did not increase (Dechechi et al., 2023). Also, the total distance, the player load, and high-intensity events increased with a decreasing number of players as it occurred in 3 vs. 3 or 2 vs. 2 training drills (Corvino et al., 2014; Luteberget et al., 2018c), indicating the high-intensity nature of small-sided games. However, in our study, the significant differences between 6 vs. 6 and 2 vs. 2+2 on the half court drills can be considered negligible due to the small effects indicated by the confidence interval (1.7 to 16.1) of the estimate of 8.7 a.u. (Table 3). An estimated accumulated player load of 70.8 a.u. over 8 min for the 4 vs. 3 vs. 3 condition in male U21 players appears realistic when compared to approximately 250 a.u. accumulated during a 60-min match in the German men's Bundesliga (Saal et al., 2023). These estimates can serve as a basis for prescribing training volume. Thus, and considering our previous main finding, the accumulated player load does not seem to be suitable for measuring the intensity of training drills in junior national team handball, which needs to be evaluated by further studies taking established intensity measures into account.

Although our study enhances the understanding of a recent IMU tracking system and its application in German junior national handball players, some limitations should be noted. First, our results regarding the agreement are not based on interchangeable repeated measures, which could have an influence on the estimators. To overcome this problem, an adapted concordance correlation coefficient for repeated measures might be useful (Carrasco et al., 2013). However, we used the original CCC (Lin, 1989) due to the convergence warnings, when calculating the CCC for repeated measures. Second, we tested the IMU tracking system under field conditions as we monitored training sessions. A standardized laboratory-based approach may provide further insights into the validity of the IMU tracking system, paving the way for additional validation studies. With regard to the elite sample, generalizability cannot be assumed, but the values could serve as a guide or a benchmark. A larger sample would also allow for a distinction to be made among the playing positions, which was not possible here. Third, due to the continuously ongoing technological process, all tracking systems are regularly optimized and updated by the manufacturer. In this context, we evaluated both systems without adding the latest software updates and hardware, which were available at the time of submission. However, we are confident that our results reflect the status quo of the systems during the mentioned time period of the data collection, meaning that further studies to evaluate the technological development of the tracking systems investigated in this study are needed.

Conclusions

In German junior female and male national handball players, the recent IMU tracking system provides reliable measurements only for directly assessed variables, such as the accumulated player load. However, while the accumulated player load strongly correlates with total distance covered and time spent in low-speed zones, it primarily reflects running activities with relatively few high accelerations. Consequently, the accumulated player load alone is insufficient for assessing the frequency and magnitude of accelerations and decelerations, which are crucial for optimizing handball training due to the rapid changes in speed and direction that frequently occur in team handball. Coaches and sports scientists should take this limitation into account when using IMU-derived metrics to monitor physical demands in junior national handball players. Future research should focus on the validation of IMU generated high-intensity measures.

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