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ORIGINAL RESEARCH

Characteristics of external loads in winning and losing matches in male professional volleyball players using wearable inertial sensors

Hongke Zhong[1], Xiangxiang Dou[1], Jiyoung Lee[2,*], Munku Song[3,4,*]

[1]Department of Physical Education, Shangqiu Medical College, 476000 Shangqiu, Henan, China
[2]Department of Physical Education, Gangneung-Wonju National University, 25457 Gangneung, Republic of Korea
[3]Department of Human Healthcare, Gyeongsang National University, 52725 Jinju, Republic of Korea
[4]College of Sport Science, Sungkyunkwan University, 16419 Suwon, Republic of Korea

***Correspondence**
jylee@gwnu.ac.kr
(Jiyoung Lee);
somogo@gnu.ac.kr
(Munku Song)

Abstract

Background: Volleyball requires dynamic activity, and the external load is related to winning or losing a game. This study aimed to compare external loads between won and lost matches and to describe position-specific load patterns in starters from the Korean men's professional volleyball league. **Methods**: A total of 212 individual data points (113 from won matches and 99 from lost matches) were collected across 36 matches during the 2022–2023 season from a single team, including setters, outside hitters/opposite spikers (OH/OS), and middle blockers (MB). External loads were measured using inertial sensor-based wearable devices (Catapult, Melbourne, Australia) and included playerload (PL), total jumps (TJ), low-band jumps (LBJ), mid-band jumps (MBJ), high-band jumps (HBJ), explosive efforts (EE), horizontal explosive efforts (HEE), and repeated high-intensity efforts (RHIE). **Results**: PL, TJ, HBJ, and EE were significantly higher in won matches ($p < 0.05$). In the positional analysis, OH/OS players showed significant differences in TJ, HBJ, and EE, while MB players showed significant differences in TJ, EE, and HEE (all $p < 0.05$). When comparing positions in won matches, all external load variables showed significant differences ($p < 0.05$). **Conclusions**: The greater external loads were observed in matches that were won, and distinct external load patterns across positions suggest that position-specific training considerations may be beneficial.

Keywords

Wearable device; Activity monitoring; Position demands; Match outcome; Performance analysis

1. Introduction

Volleyball is a team sport governed by a rule that allows each team up to three contacts per rally, which promotes rapid transitions between offense and defense and leads to highly dynamic gameplay [1, 2]. Within this structure, players often perform repeated high-intensity movements, including powerful jumps, dynamic landings, quick reactions, and explosive actions such as spiking and blocking [2–4]. Given these repeated physical demands, monitoring external load during matches is essential for managing fatigue and maintaining performance throughout the season [5–10]. In recent years, wearable microsensors equipped with global positioning system (GPS) and accelerometry have become widely used to quantify external load in both indoor and outdoor sports [7, 11, 12]. While previous studies have offered valuable insights into positional external load characteristics, they have rarely incorporated match outcomes as a variable, making it difficult to examine how external load may relate to match success [7, 13, 14].

In volleyball, each playing position is clearly defined by tactical roles, resulting in position-specific physical demands and corresponding differences in external load profiles [5, 12, 15]. For example, studies on National Collegiate Athletic Association women's volleyball players have shown that setters perform the highest number of medium-band jumps, middle-blockers engage in the most explosive efforts, and liberos record the highest playerload (PL) [12, 16]. Similarly, research involving professional male volleyball players has also reported distinct differences in external load variables depending on position [3, 17]. While these previous studies have provided meaningful insights by highlighting the characteristics and differences in positional external load, research that identifies the relative importance of this load required for each position to achieve match victory remains scarce or insufficient [12, 16, 17].

Beyond volleyball, studies in other team sports have reported that match outcomes can influence both internal and external load variables. For example, elite beach handball players exhibited significantly higher PL per minute, distance per minute, number of jumps, and accelerations in matches won compared to those lost [18]. In collegiate women's basketball, better-performing teams covered more total distance and recorded higher maximum heart rates [19]. Similarly, professional soccer players demonstrated higher frequencies of acceleration and deceleration in won matches [20]. Conversely, a study on male basketball players found no significant differences in external load between match outcomes, which may be attributed to the lack of position-specific activity analysis [21].

Identifying the external load characteristics of starting players in won matches may provide practical benchmarks for setting training loads that reflect competitive demands [19, 22, 23]. However, to date, no study has quantified whether the external load by position varies depending on the outcome of a volleyball match using wearable sensors. Given that prior studies confirmed positional external load differences but did not address how these relate to match success, a performance-oriented analysis is needed. Therefore, the purpose of this study was to quantify the load pattern by position in each sports position using wearable inertial sensor technology and investigate how activity characteristics differ according to game results. The researchers hypothesized that wearable inertial sensors would be useful for analyzing the activity characteristics of volleyball players, and that activity patterns would significantly differ depending on game results, and that these differences would also differ by position [18–21].

2. Materials and methods

2.1 Study participants

This study involved players from a single team in the Korean Men's Professional Volleyball League during the 2022–2023 season. The team, which placed third in the regular season standings, represented an upper-middle ranking level. A total of 19 athletes were on the team roster, of whom 12 starters who participated in official matches were included in the analysis. Starters were defined as players who were officially listed in the starting lineup for each match, and the data were collected by the team's coaching staff. The positional distribution consisted of 2 setters, 6 outside hitters/opposite spikers (OH/OS), and 4 middle blockers (MB) (Fig. 1). Before the study began, all participants were informed of the research purpose and procedures, and only those who voluntarily agreed to participate were included. All participants wore identical wearable devices during matches (Table 1). The study was approved by the Institutional Review Board of Sungkyunkwan University (an institution affiliated with one of the authors; approval number: 2024-05-028), and written informed consent was obtained from all participants after being informed of the purpose and procedures of the study.

2.2 Measurement and variables

External loads were measured using the Vector S7 device (Catapult Innovations, Melbourne, VIC, Australia), which integrates a triaxial accelerometer, gyroscope, and GPS (Fig. 2). The device was securely placed in a vest pocket located between the shoulder blades and was activated before the match began and deactivated immediately after the match. For each match, all players wore the same device, which was set up and attached in a consistent manner based on pre-instructed procedures. Although the Vector S7 includes a GPS module, all data used in this study were derived from its inertial sensor components (triaxial accelerometer and gyroscope). Match durations and rest periods between sets were accurately tracked using real-time radio-frequency technology. All data were analyzed using Catapult's proprietary software (OpenField, version 1.22.2, Catapult Group Holdings Limited, Melbourne, VIC, Australia).

The following variables were collected: match time, PL, total jumps (TJ), low-band jumps (LBJ; 10–30 cm), mid-band jumps (MBJ; 30–50 cm), high-band jumps (HBJ; ≥50 cm), explosive efforts (EE), horizontal explosive efforts (HEE), and repeated high-intensity efforts (RHIE). Match time was defined as the total active duration of play in minutes, excluding set intervals. PL was calculated as the vector sum of triaxial acceleration and is interpreted as a cumulative acceleration load. Jumps were recorded when players remained airborne for at least 320 milliseconds and were classified into LBJ, MBJ, and HBJ based on jump height. EE was defined as the number of accelerations exceeding 3.5 m/s^2 across any axis. HEE represented horizontal accelerations (x- and y-axes) over 3.5 m/s^2, primarily reflecting defensive lateral or forward-backward movement [24]. RHIE was defined as three or more high-intensity accelerations (≥2.79 m/s^2) occurring within 21 seconds, indicating bursts of sustained effort, and reflecting the frequency of repeated high-intensity movements that may contribute to fatigue accumulation [12].

2.3 Data processing

A total of 36 regular-season matches were included in the analysis, of which 19 were won and 17 were lost. External load data were collected for all starters in each match, resulting in 252 individual data points. Among these, 36 data points from liberos were excluded due to their restricted role, as liberos are not allowed to attack or block, making their jump-related load fundamentally different and not directly comparable to other positions. Additionally, four cases were excluded due to early substitutions caused by injury. Consequently, 212 data points were included in the final analysis: 36 for setter, 106 for OH/OS, and 70 for MB. Based on match outcome, 113 data points were from won matches and 99 from lost matches. Since volleyball matches can range from 3 to 5 sets, all external load variables were standardized on a per-set basis. Notably, because the fifth set in volleyball is played to 15 points instead of 25, it was weighted as 0.6 sets (15/25 = 0.6) to standardize the total number of sets played (*e.g.*, five-set matches were considered as 4.6 sets for analysis).

2.4 Data analysis

All variables were expressed as mean ± standard deviation. The Shapiro-Wilk test was used to verify the normality of the data. Independent *t*-tests were conducted to compare external load variables between won and lost matches. To examine positional differences in external loads, a one-way analysis of variance with linear contrast was first conducted, followed by Bonferroni *post-hoc* test to clarify the directional trend among positions. To evaluate the practical significance of the

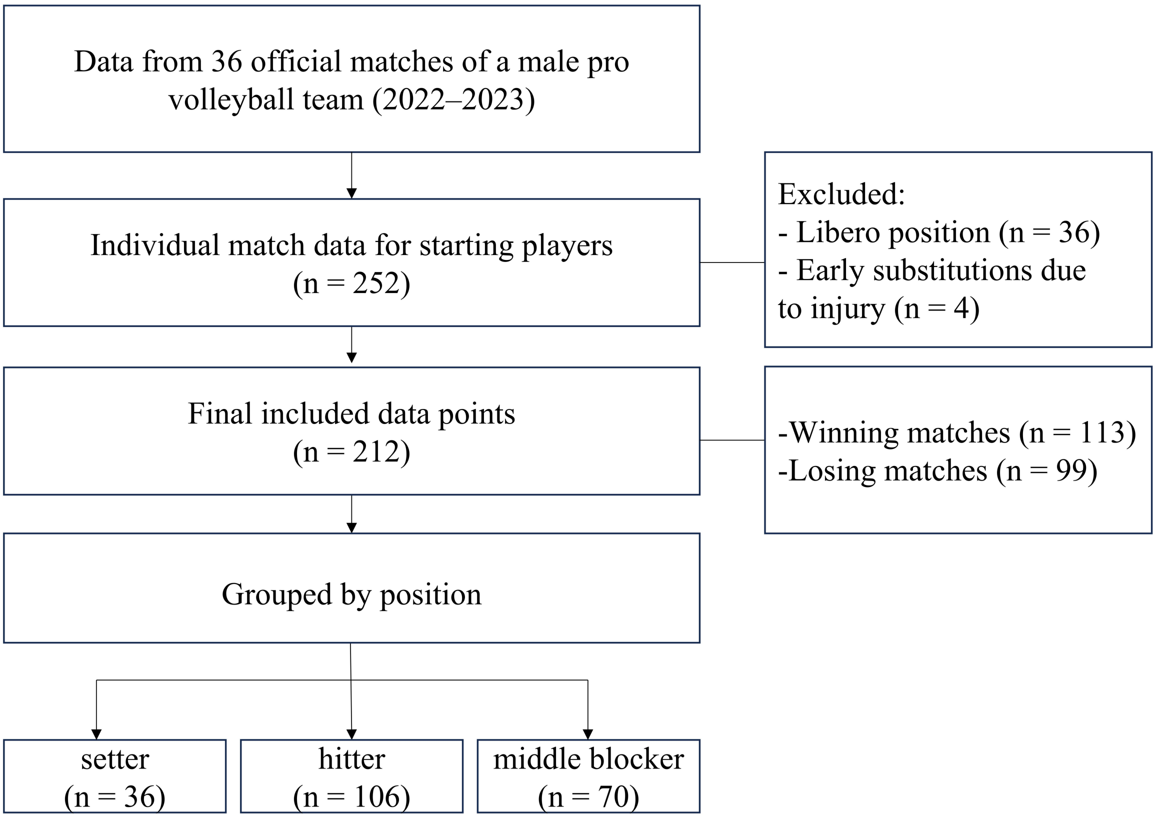

FIGURE 1. Flowchart of participant data selection and inclusion.

TABLE 1. General characteristics of the starters from 36 regular season matches.

Variables	Age (yr)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Career (yr)
Total (n = 12)	28.5 ± 4.6	196.0 ± 8.2	88.7 ± 8.2	23.1 ± 1.3	7.4 ± 4.1
Setter (n = 2)	25.5 ± 7.8	182.5 ± 0.7	80.0 ± 8.5	24.0 ± 2.4	6.0 ± 5.6
OH/OS (n = 6)	29.7 ± 3.6	197.7 ± 7.0	88.3 ± 8.8	22.5 ± 1.3	8.2 ± 3.1
MB (n = 4)	28.3 ± 5.3	200.3 ± 3.6	93.8 ± 2.2	23.4 ± 0.5	7.0 ± 5.7

BMI: body mass index; OH/OS: outside hitters/opposite spiker; MB: middle blocker.

FIGURE 2. Illustration of the wearable inertial sensor device and data collection process.

findings, effect sizes were calculated in addition to p-values. Specifically, Cohen's d was computed for independent t-tests, and partial η^2 was reported for Analysis of Variance (ANOVA) results. The magnitude of effect sizes was interpreted as small ($0.2 \leq d < 0.5$; $0.01 \leq \eta^2{}_p < 0.06$), medium ($0.5 \leq d < 0.8$; $0.06 \leq \eta^2{}_p < 0.14$), and large ($d \geq 0.8$; $\eta^2{}_p \geq 0.14$). All statistical analyses were performed using SPSS software (version 25.0, IBM, Armonk, NY, USA), with the level of statistical significance set at $\alpha < 0.05$.

3. Results

3.1 Comparison of external load by match outcome

Table 2 presents the comparison of external load variables per set between won and lost matches. Overall, PL (p = 0.037), TJ (p = 0.004), HBJ (p = 0.016), and EE (p = 0.008) were significantly higher in won matches. In contrast, no statistically significant differences were observed for LBJ, MBJ, HEE, or RHIE according to match outcome.

3.2 Positional subgroup analysis of external load by match outcome

Fig. 3 illustrates differences in external loads between won and lost matches for each position. For setter, external load values were generally higher in won matches, but none reached statistical significance. For OH/OS, TJ (p = 0.031), HBJ (p = 0.016), and EE (p = 0.039) were significantly higher in won matches, while HEE and RHIE showed no significant differences. For MB, TJ (p = 0.015), HEE (p = 0.011), and EE (p = 0.019) were significantly higher in won matches. Although HBJ tended to be higher in won matches, the difference was not statistically significant.

3.3 Positional comparison of external load in won matches

Table 3 presents the comparison of external load variables between positions based on won matches. While no significant difference was observed in match time, all other variables showed significant positional differences: PL ($p < 0.001$), TJ ($p < 0.001$), LBJ (p = 0.001), MBJ ($p < 0.001$), HBJ ($p < 0.001$), HEE (p = 0.001), EE ($p < 0.001$), and RHIE ($p < 0.001$). Specifically, S recorded significantly higher TJ and MBJ compared to other positions. The OH/OS showed the highest values in PL, LBJ, HEE, and EE, while MB recorded the highest values in HBJ and RHIE.

4. Discussion

This study is one of the first to examine how external load varies by match outcome among male professional volleyball starters using microsensor technology, while also analyzing positional differences. The findings revealed that won matches involved greater overall physical activity than lost matches, with these differences especially pronounced in OH/OS and MB. These results suggest that higher jump frequency and explosive actions—particularly those involving power and quickness—may be associated with successful performance in elite-level volleyball, where fast-paced rallies and physical dominance at the net often influence the match flow. These findings may serve as foundational data for developing position-specific training strategies aimed at improving performance.

In this study, PL, TJ, HBJ, and EE were significantly higher in won matches, indicating that greater overall physical activity was associated with match victories. Although no prior studies have investigated this topic specifically in volleyball, our findings align with those from other team sports, where higher external load—including PL—was reported in matches won compared to those lost [18–20]. PL reflects the combined intensity of movements such as jumping, direction changes,

TABLE 2. Comparison of external load variables per set between won and lost matches.

Variable	Won matches (n = 113)	Lost matches (n = 99)	t	p	Cohen's d
Match time, min	30.0 ± 1.8	30.8 ± 1.7	−3.104	0.002**	−0.46
Playerload, AU	105.2 ± 17.8	100.1 ± 17.9	2.100	0.037*	0.29
Jump, (n)					
TJ	23.5 ± 4.7	21.6 ± 4.7	2.934	0.004**	0.43
LBJ	4.0 ± 3.2	3.6 ± 3.3	0.887	0.376	0.12
MBJ	5.5 ± 5.3	5.3 ± 4.8	0.316	0.753	0.00
HBJ	13.9 ± 3.9	12.6 ± 3.8	2.425	0.016*	0.34
Effort, (n)					
HEE	5.2 ± 3.2	4.6 ± 3.0	1.391	0.165	0.18
EE	19.2 ± 5.1	17.2 ± 5.1	2.672	0.008**	0.39
RHIE	0.7 ± 0.6	0.5 ± 0.5	1.604	0.110	0.36

*TJ: total jumps; LBJ: low-band jumps; MBJ: medium-band jumps; HBJ: high-band jumps; HEE: horizontal explosive efforts; EE: explosive efforts; RHIE: repeated high-intensity efforts; AU: Arbitrary Unit. *p < 0.05, **p < 0.01.*

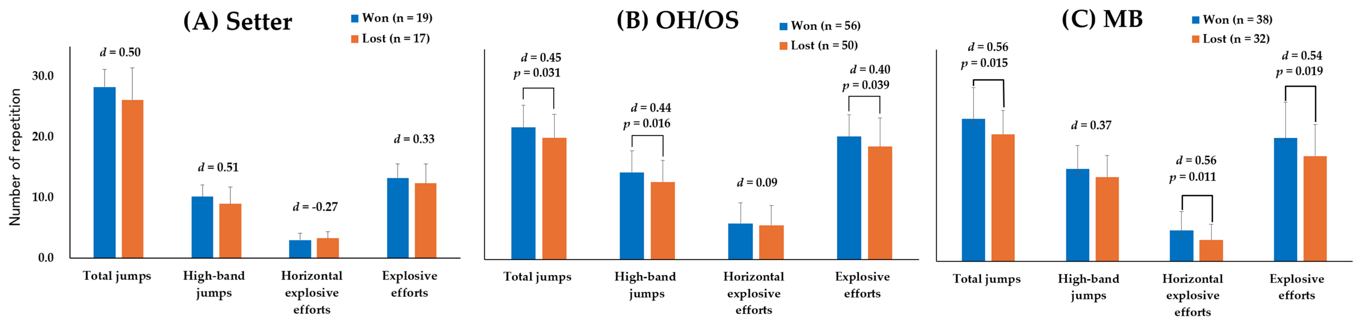

FIGURE 3. External load differences per set between won and lost matches by playing position. (A) Setter. (B) Outside hitter/opposite spiker. (C) Middle blocker. OH/OS: outside hitter/opposite spiker; MB: middle blocker. Cohen's *d* and *p* values are shown within the figure. Error bars represent standard deviations.

TABLE 3. Comparison of external load variables per set by playing position in won matches.

Variable	Setter (n = 19)	OH/OS (n = 56)	MB (n = 38)	F	p for trend	Partial η^2	Trend pattern
Match time, min	30.1 ± 1.9	30.0 ± 1.9	30.0 ± 1.9	0.000	>0.999	0.00	-
Playerload, AU	84.5 ± 7.0	113.9 ± 18.0	102.8 ± 10.9	29.994	<0.001***	0.35	b > c > a
Jump, (n)							
TJ	28.3 ± 2.9	21.7 ± 3.7	23.6 ± 5.1	17.675	<0.001***	0.24	a > b = c
LBJ	1.7 ± 0.6	4.8 ± 3.9	4.1 ± 2.3	7.446	0.01**	0.12	b = c > a
MBJ	16.4 ± 2.0	2.7 ± 1.7	4.2 ± 2.4	346.509	<0.001***	0.86	a > c > b
HBJ	10.2 ± 1.9	14.2 ± 3.6	15.3 ± 3.9	13.837	<0.001***	0.20	c = b > a
Effort, (n)							
HEE	3.0 ± 1.1	6.0 ± 3.4	5.1 ± 3.1	7.204	0.01**	0.12	b > c > a
EE	13.2 ± 2.4	20.3 ± 3.6	20.4 ± 5.9	20.845	<0.001***	0.28	b = c > a
RHIE	0.1 ± 0.2	0.6 ± 0.4	1.0 ± 0.7	22.186	<0.001***	0.29	c > b > a

OH/OS: outside hitters/opposite spiker; MB: middle blocker; TJ: total jumps; LBJ: low-band jumps; MBJ: medium-band jumps; HBJ: high-band jumps; HEE: horizontal explosive efforts; EE: explosive efforts; RHIE: repeated high-intensity efforts; AU: Arbitrary Unit.

***$p < 0.01$, ***$p < 0.001$. a: Setter; b: Outside hitter/opposite spiker; c: Middle blocker.*

and landing [12]; therefore, an increase in PL suggests greater total physical output during winning performances.

HBJ represents the frequency of high-intensity jumps, such as spiking and blocking [17], and its higher values in won matches may indicate a more dominant offensive strategy. Specifically, spike approaches—which involve rapid acceleration followed by a vertical leap—and block jumps during opponent attacks are key contributors to HBJ. EE refers to explosive movements near the net, including sharp directional shifts and quick jumps [25]. Elevated EE values suggest more active engagement in both attack and defense. Altogether, these results imply that winning matches involved more aggressive play, quicker transitions, and greater physical engagement, suggesting that external load may be related to match outcomes in volleyball.

Although several external load variables showed statistically significant differences between won and lost matches, the effect sizes were small in magnitude (Cohen's d = 0.12–0.46). These effect size results suggest that certain external load variables may contribute to match outcomes; however, the practical magnitude of their influence is limited. Collectively, these findings imply that although certain external load demands may contribute to match outcomes, reflecting that winning in volleyball is determined by multiple complex and multifactorial factors (*e.g.*, opponent strength, match duration, home or away conditions).

The positional subgroup analysis revealed that external load variables significantly differed between won and lost matches for the OH/OS and MB positions, reflecting the distinct physical demands of each role. This finding aligns with previous studies in other team sports, such as handball and soccer, where high-intensity activity by forwards or attackers was found to be a critical factor in match success [18, 20]. OH/OS players showed significant differences in TJ, HBJ, and EE, suggesting greater offensive and defensive involvement in matches that were won. MB demonstrated significant differences not only in TJ and EE, but also in HEE, which reflects rapid horizontal accelerations. These findings indicate that MB must frequently perform high-intensity efforts without sufficient recovery during matches, consistent with previous reports [17]. On the other hand, S generally recorded higher values in won matches across most external load variables, although these differences did not reach statistical significance. This suggests that setter's external loads may not be strongly influenced by match outcomes, as their main responsibility lies in orchestrating offensive plays rather than executing high-intensity physical actions [26]. However, due to the limited data and lack of prior research, it is premature to conclude that setter's external loads do not vary by match result, and further investigation is warranted. Nevertheless, this study is the first to provide detailed quantitative evidence of how position-specific loads contribute to match outcomes, thereby underscoring its significance.

When comparing external load across positions in won matches, setter exhibited significantly lower values in PL, EE, and RHIE compared to OH/OS and MB. This reflects that the quantity and type of physical demands differ depending on the tactical role of each position [3, 27]. In line with previous studies, OH/OS and MB demonstrated higher values in EE and RHIE, highlighting their exposure to continuous high-intensity efforts throughout the match [12, 17]. In contrast, although setter showed lower values in these high-intensity indicators, earlier research reported that setter performed the highest frequency of medium-band jumps, indicating that setter also engage in a distinct, position-specific activity pattern [16, 17]. These findings align with known positional characteristics and emphasize the need for position-specific load profiles rather than simple comparisons of total external load. Additionally, the consistently large effect sizes observed across all external load variables (partial η^2 = 0.12–0.86) further highlight the marked distinctions in positional activity demands.

This study objectively quantified external loads using wearable inertial sensors and showed that greater physical outputs were more frequently observed in matches that were won, suggesting that external load may be related to match outcomes in volleyball. Given the distinct physical demands of each position, position-specific load-based training strategies may be more effective than uniform approaches. Incorporating external load values observed in won matches into training programs could help optimize load management, mitigate fatigue, and reduce the risk of overuse injuries, ultimately supporting performance improvement.

This study has several limitations. First, it analyzed data from a single team and season, which limits the generalizability of the findings to all male professional volleyball players. Second, several contextual factors—such as opponent strength, match duration, and home/away conditions—may have acted as potential confounders but could not be fully controlled. These elements should be considered when interpreting the findings. Third, the L position was excluded, so defensive external load characteristics were not addressed. Lastly, conducting multiple univariate *t*-tests and ANOVAs across several interrelated variables may have increased the risk of Type I error, and thus the results should be interpreted with caution. Future studies should address the current limitations of analyzing a single team with a small sample size by incorporating data from multiple teams and seasons, and by conducting a more detailed analysis of libero and attacking positions (OH/OS). Moreover, expanding the research to account for external load differences according to team level could more effectively contribute to developing position-specific training strategies and enhancing performance.

5. Conclusions

This study quantitatively analyzed movement patterns and external loads in male professional volleyball starters using wearable inertial sensor technology, revealing significant differences according to match outcomes and playing positions. Higher values in high-intensity indicators such as TJ, HBJ, and EE were observed in won matches, suggesting that greater physical output may be associated with successful performance in volleyball. Moreover, the distinct external load patterns across positions highlight the need for tailored training strategies that reflect position-specific physical demands. OH/OS may benefit from training that emphasizes explosive and multi-directional efforts, MB may require recovery-focused training based on elevated RHIE, while setter may benefit from training that emphasizes mid-band jumps. Using position-specific load levels observed in won matches as training targets may help adjust training loads more efficiently and is expected to assist in reducing the risk of overuse injuries.

AVAILABILITY OF DATA AND MATERIALS

The data sets that were used and analyzed in the current study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

JL and MS—conceptualization; writing–review and editing; supervision. HKZ—methodology. XXD and MS—formal analysis; software. XXD and JL—investigation. MS—data curation. HKZ, JL and MS—writing–original draft preparation. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The research ethics committee of the Sungkyunkwan University Institutional Review Board reviewed and approved the study according to the Declaration of Helsinki (No. 2024-05-028). Informed consent was obtained from all study participants.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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