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ORIGINAL RESEARCH

Quantification of match and training workload by position in Korean professional men's volleyball players

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Abstract

This research aimed to quantify match workload by position among Korean Men's Professional Volleyball League (KOVO) players during the regular season. A secondary aim was to provide information about the workload requirements during pre-match warm-up and training sessions. This study involved three liberos (L), three setters (S), eight outside or right-side hitters (OH/RS) and five middle blockers (MB). Playing minutes (PM), total jumps, low-band jumps, medium-band jumps, high-band jumps, explosive efforts (EE) and repeated high-intensity efforts (RHIE) were objectively quantified as external workloads through a wearable activity monitor. During matches, S had the highest loads of total jumps ($p < 0.001$) and medium-band jumps ($p < 0.001$). MB performed the most high-band jumps ($p < 0.001$) with the highest EE ($p < 0.001$) and RHIE ($p < 0.001$). PM was shorter in training than in matches for all positions, but variables like medium-band jumps, EE and RHIE were higher in training compared to matches. S had the highest pre-match workload for total, low and medium band jumps ($p < 0.001$, $p < 0.001$ and $p < 0.001$, respectively). OH/RS had the highest high-band jumps ($p < 0.001$), while L had the highest load for EE ($p < 0.001$) and RHIE ($p < 0.001$). Our findings indicate that volleyball workload demands differ by position during matches and pre-match warm-ups, underscoring the importance of designing position-specific training programs.

Keywords

Volleyball; External workload; Activity monitor; Wearable device; Jump count

1. Introduction

Monitoring players' physical demands during practice and games is essential for developing effective training and recovery strategies for peak performance in competition [1]. The physical workload monitoring system assists coaches and practitioners in planning training and recovery strategies around congested schedules [2]. Wearable microsensors, such as global positioning systems (GPS) and accelerometers, have substantially contributed to the development of sports activity monitoring systems [3, 4]. Until the mid-2010s, GPS technology was used primarily in outdoor sports such as soccer [3], American football [5] and rugby [6]. Since then, wearable activity monitoring devices have gradually begun to be used for assessing physical demands in indoor sports [4, 7]. Researchers, for example, have used indoor sports activity analyzers such as Catapult's Optimeye T6 to study the training and match workload demands of basketball and volleyball players [8, 9]. The validity and reliability of an accelerometer-based player-tracking device are well-established [10].

Volleyball is a team sport that demands high skill and dynamic, multidirectional movements. Two teams of six players on each side, separated by a net, play volleyball on the 18-meter-by-9-meter court. Volleyball is a fast-paced sport in which each team is allowed three touches before placing the ball on the opposing team's court, and it requires different physical demands such as reacting, accelerating, jumping, landing, pivoting, decelerating and striking [11]. As a result, monitoring the workloads that athletes experience during training and competition is crucial, so they undergo constant evaluations to guarantee optimal performance [12]. Previous studies support the notion that performance analysis significantly improves the parameters that influence performance [13, 14].

The workload demands in volleyball vary depending on the player's position and the type of activity, such as training or a match [7, 15]. A study of 11 National Collegiate Athletics Association (NCAA) female volleyball players found that setters performed the most jumps; middle blockers (MB) made the most explosive efforts, and liberos had the highest player load [7]. Another study of 11 NCAA volleyball players found that setters made more than twice as many jumps in training as in matches [15]. Due to their specialized role in defense, liberos face additional internal workloads while seeing fewer jumps and RHIE than other positions [7, 15]. Studies on male players revealed that the internal and external workloads required during a match varied by position [16–18]. Nevertheless, previous studies that focused on male athletes had limited data collection [16] or relied on video-based time-motion analysis for data collection [17, 18].

Volleyball is a team sport that has clearly defined positional roles. Coaches and trainers can create position-specific training programs by quantifying the physical demands of matches and training sessions by position. According to our preliminary findings, volleyball players perform pre-match warm-up activities with nearly the same intensity as during the game. However, prior studies have frequently overlooked this aspect [15, 19]. Consequently, the need to assess the workload required for each position during matches and training for professional volleyball players was identified. The primary aim of this study was to quantify match workload by position among Korean Men's Professional Volleyball League (KOVO) players during the regular season. A secondary aim was to provide information about the workload requirements during training and pre-match warm-up sessions.

2. Materials and methods

2.1 Study participants

The 2022–2023 Korean Volleyball League (KOVO) regular season featured seven men's professional teams. The KOVO regular season usually starts in mid-October and ends in early March, with each team playing 36 official games. The data for this study were gathered prospectively from 19 players on one team during the 2022–2023 regular season, which included training sessions and games. The study participants had an average age of 28.2 $\pm$ 4.4 years, height of 191.4 $\pm$ 9.8 cm and weight of 84.5 $\pm$ 10.7 kg. The roster included three liberos, three setters, eight outside or right-side hitters (OH/RS), and five MB. The players' average professional career lasted 7.2 $\pm$ 4.0 years (median 7 years, range 2–15). The Institutional Review Board of Sungkyunkwan University reviewed and approved the research protocol (No. 2024-05-028). Before the study, all participants were fully informed of the research objectives and procedures, and each participant provided written informed consent.

2.2 Data collection and measurements

During the regular season, the player competed in all sessions, including team training and games, which provided external and internal workload data. The external workloads were measured using an indoor sports activity analysis device from Catapult (Vector S7, Catapult Innovations, Melbourne, VIC, Australia). This device includes a GPS, a three-axis accelerometer, a gyroscope and a magnetometer. The Vector S7 sensor was inserted into a padded pouch sewn into the sports bra between the player's scapulae, just below the neck, as instructed by the manufacturer. Movements on all axes were sampled at 100 Hz, and players used the same device throughout the season. The sensor was activated after stretching, at the start of on-court warm-ups with the ball, and then turned off at the end of the session. As in previous studies, we used radio frequency live tracking to precisely record the start and end times of the warm-up, as well as each event, such as training and matches [7]. Following each session, we analyzed the external workload variables with Catapult Sports specialized analysis software (OpenField, Catapult Innovations, Melbourne, VIC, Australia, version 1.22.2). The device's intra-device reliability has been assessed and reported [10].

Playing minutes (PM) refers to the length of time each match or training session lasted. Jumps on the craniocaudal (z) axis are defined as the number of times an athlete was airborne for more than 320 ms [15]. Jumps are classified into three categories: low-band jumps (less than 20 cm), medium-band jumps (20 cm to less than 50 cm) and high-band jumps (more than 50 cm). Explosive effort (EE) is defined as the number of accelerations greater than 3.5 m/s^2 along the mediolateral (x) and anteroposterior (y) axes [7]. Repeated high-intensity effort (RHIE) is the frequency with which an athlete performs three or more rapid acceleration actions ($>$2.79 m/s) with recovery periods of less than 21 s [15]. To account for gender differences, all bands were set 10 cm higher than those used in a prior study of NCAA female volleyball players [7, 15]. The internal workload was quantified using the session rating of perceived exertion (S-RPE). The monitoring tool assigns scores ranging from 0 to 10. Players voluntarily recorded their S-RPE immediately after completing the exercise. As previously stated, S-RPE was calculated as RPE $\times$ duration (PM) and reported in Arbitrary Units (AUs) [7]. The internal load S-RPE had an overall response rate of approximately 88.6%.

2.3 Data processing

The data collection period lasted 171 consecutive days, during which 36 official games (13 three-set games, 10 four-set games and 13 five-set games) and 106 team training sessions were held. The training workload analysis included data from all 19 players who participated in the study; however, data from one setter who played only two matches as a substitute during the season were carefully excluded from the game workload analysis. Data collected during periods when players could not practice or compete due to injury, including the S-RPE, were excluded from the analysis. The total number of observable events per player session was 529 for games and 1584 for training. Given the nature of volleyball, which allows for flexible player substitutions during games, analyzing all observations may understate the game's demands. To reduce this error, we excluded 64 instances where the in-game jump count was less than 10, resulting in a final analysis of 465 events. Simultaneously, after excluding six instances of abnormal data from the total training observations, we included 1578 training data entries in the final analysis. Team training sessions were full-team volleyball-related activities led by the coach, while individual training, strength and conditioning sessions were excluded from data analysis. This study defines the pre-match warm-up as volleyball activities performed with a ball immediately before the match, excluding stretching and strength exercises that activate stabilizers and mobilizers.

2.4 Data analysis

All variables were presented as means and standard deviations. The external workload variables included PM, jumps (total, low-band, medium-band, high-band), EE and RHIE, whereas the internal workload variable included S-RPE. A match was defined as one game session, including the pre-match warm-up. Match workload data were categorized based on the total number of sets played in each match, presented as 3-set, 4-set or 5-set matches. The average of all-set matches was used to compare the match workload between position groups and event types (match *vs.* training). One-way analysis of variance (ANOVA) with a linear contrast option was performed to compare linear trends in the workload variables across playing positions. An independent *t*-test was used to compare the workload differences between training sessions and matches. The pre-match warm-up loads were calculated as a percentage (%) of the individual match demands by position. The libero position was excluded from this process because jumping is not its primary responsibility. All statistical analyses were performed using SPSS-PC (version 25.0, IBM, Armonk, NY, USA) with a significance level of less than 0.05.

3. Results

3.1 Match workloads by playing position

Table 1 summarizes match workloads by position. Workloads for total jumps ($p < 0.001$), low-band jumps ($p < 0.001$), mid-band jumps ($p < 0.001$), high-band jumps ($p < 0.001$), EE ($p < 0.001$) and RHIE ($p < 0.001$) were significantly different by position. Specifically, setters made the most jumps and mid-band jumps, followed by MB, OH/RS and liberos in that order. OH/RS also made the most low-band jumps, followed by setters, MB, and liberos in that order. MB made the most high-band jumps, followed by OH/RS, setters and liberos, in that order. However, there was no statistically significant difference in S-RPE across positions. MB had the greatest EE load, followed by OH/RS, setters and liberos in that order. MB also had the highest RHIE load, followed by OH/RS, liberos and setters, in that order.

3.2 Training and match workloads by playing position

Table 2 displays the workload requirements for training sessions and matches by position. In an intra-position comparison, our study found that, while all players had significantly higher PM in matches than in training sessions, overall training sessions required more external workload than matches. Setters and MB made more total jumps in training than in matches (42.7% and 13.7%, respectively). Setters had more low-band jumps in training sessions than in matches (19.7%), whereas OH/RS and MB had more low-band jumps during matches (41.0% and 27.5%, respectively). Setters, OH/RS, and MB had higher medium-band jumps during training sessions than during matches (74.0%, 20.0% and 77.8%, respectively). Liberos, OH/RS, and MB had higher EE in training sessions than in matches (21.7, 9.5% and 13.8%, respectively). Setters, OH/RS, and MB had higher RHIE during training sessions than during matches (66.6%, 77.3% and 109.1%, respectively). Regardless of position, high jumps did not differ significantly between training sessions and matches. OH/RS and MB had higher S-RPE in matches than in training sessions (8.6% and 10.5%, respectively), while liberos and setters had similar S-RPE in both sessions. In the inter-position comparison, setters performed the most total jumps and medium-band jumps, while MB performed the most high-band jumps ($p < 0.001$) with the most EE and RHIE. There was no significant difference in PM, low-band jumps, or S-RPE.

3.3 Pre-match warm-up workloads by playing position

Table 3 shows the pre-match warm-up workloads by playing position. Setters exhibited the highest load of total, low-band and medium-band jumps, followed by MB and OH/RS ($p < 0.001$, $p < 0.001$ and $p < 0.001$, respectively). The OH/RS had the highest load of high-band jumps, followed by setters and MB in that order ($p < 0.001$). Liberos had the highest EE load, followed by OH/RS, setters, and MB, in that order. They also had the highest RHIE load, with setters, MB and OH/RS following closely behind.

4. Discussion

This study quantified male professional volleyball players' match and training workloads using wearable activity monitoring devices. Our study findings found that (1) the players' workloads differed significantly by playing position and activity mode and (2) pre-match warm-up workloads differed by playing position. Taken together, our study findings highlight the importance of designing position-specific training programs for peak performance in competition.

Concerning match workloads, our study findings about total and low-band jumps align with the results of previous studies [7, 15]. Previous studies consistently found that liberos perform most of the jumps within the low-band category [15]. Liberos, being defensive specialists, cannot serve, block or substitute during the entire six rotations of the game. These position-specific characteristics made liberos have higher internal workloads with lower RHIE than other positions [7, 15]. Our study findings about medium-band jumps are also consistent with those from previous studies, in which the setter performed the most total jumps and medium-band jumps [7, 15, 16]. Setters frequently perform these medium-band jumps due to the nature of their role. As the game's orchestrators, setters are responsible for the accurate delivery of the ball, so they strategically use the float serve to move quickly to the defensive position after serving [20]. Additionally, setters are responsible for blocking, which requires both mid- and high-band jumps. Our study findings about high-band jumps are consistent with previous studies reporting position-specific characteristics [17]. A study of skilled Austrian national team players found that elite male volleyball players have average spike jumps of 67 cm [21]. The high-band jumps are typical in offensive positions like MB and OH/RS [17]. Finally, our study found that EE and RHIE were high in the MB and OH/RS positions, consistent with previous research [7, 15]. These findings indicate that those positions require a significant number of intense movements throughout the game.

TABLE 1. Match workload demands by position (mean ± SD).

Variable	Playing minute	Total jump	Low-band jump	Medium-band jump	High-band jump	EE	RHIE	S-RPE
Libero (n = 88)								
3 set-match (n = 31)	136.1 ± 5.0	20.6 ± 6.7	16.4 ± 5.8	4.2 ± 2.1	1.1 ± 0.3	27.4 ± 13.4	1.9 ± 1.2	718.9 ± 181.9
4 set-match (n = 25)	171.1 ± 8.2	28.7 ± 11.2	22.8 ± 10.4	5.7 ± 2.1	1.0 ± 0.2	32.7 ± 15.5	1.7 ± 0.8	867.3 ± 244.7
5 set-match (n = 32)	187.6 ± 12.7	25.6 ± 11.3	20.0 ± 10.6	5.5 ± 2.8	1.0 ± 0.2	35.1 ± 18.2	2.2 ± 1.5	943.8 ± 296.5
match average	164.8 ± 24.1	24.7 ± 10.3	19.5 ± 9.4	5.4 ± 2.4	1.0 ± 0.2	31.7 ± 16.0	1.9 ± 1.2	844.4 ± 262.4
Setter (n = 59)								
3 set-match (n = 21)	136.2 ± 4.8	126.3 ± 34.3	28.8 ± 10.9	68.4 ± 20.6	29.2 ± 12.9	43.1 ± 14.9	1.9 ± 0.7	725.2 ± 125.6
4 set-match (n = 15)	169.3 ± 7.3	154.6 ± 48.9	40.2 ± 14.9	78.7 ± 23.7	35.7 ± 17.3	50.6 ± 20.1	1.5 ± 0.7	868.9 ± 144.8
5 set-match (n = 23)	188.2 ± 8.9	152.0 ± 59.5	31.0 ± 9.6	81.3 ± 36.0	39.7 ± 21.3	56.1 ± 23.6	2.0 ± 1.2	965.2 ± 216.3
match average	164.9 ± 23.9	143.5 ± 50.0	32.6 ± 12.3	76.0 ± 28.4	34.9 ± 17.9	50.1 ± 20.4	1.8 ± 0.9	853.4 ± 197.1
OH/RS (n = 203)								
3 set-match (n = 71)	136.1 ± 4.9	78.6 ± 19.7	31.1 ± 15.7	9.2 ± 6.8	38.3 ± 21.5	58.3 ± 27.3	1.9 ± 1.2	697.0 ± 179.4
4 set-match (n = 56)	170.4 ± 7.9	97.1 ± 32.5	39.9 ± 23.3	11.3 ± 6.7	46.1 ± 31.2	72.5 ± 40.9	2.5 ± 1.6	850.6 ± 178.9
5 set-match (n = 76)	188.5 ± 8.8	103.5 ± 29.5	41.3 ± 25.1	13.9 ± 8.2	48.5 ± 31.9	72.5 ± 39.0	2.1 ± 1.6	933.9 ± 268.9
match average	165.2 ± 23.7	93.0 ± 29.4	37.3 ± 22.1	11.6 ± 7.5	44.3 ± 28.7	67.5 ± 36.4	2.2 ± 1.5	829.3 ± 239.9
MB (n = 115)								
3 set-match (n = 35)	136.0 ± 4.8	87.9 ± 29.8	24.9 ± 11.5	18.1 ± 8.8	45.0 ± 20.4	61.0 ± 26.3	2.7 ± 1.8	786.7 ± 168.1
4 set-match (n = 37)	169.6 ± 10.0	89.9 ± 38.7	26.6 ± 11.9	16.3 ± 9.2	47.0 ± 29.1	65.1 ± 39.6	3.0 ± 2.9	875.3 ± 272.5
5 set-match (n = 43)	189.8 ± 8.8	103.9 ± 42.2	27.4 ± 12.7	20.6 ± 12.1	56.1 ± 30.6	77.7 ± 41.8	4.0 ± 3.4	932.0 ± 275.2
match average	166.9 ± 23.6	94.6 ± 38.0	26.4 ± 12.0	18.5 ± 10.3	49.8 ± 27.6	68.6 ± 37.4	3.3 ± 2.9	869.8 ± 252.4
Linear trends by position	$p = 0.907$ ($df = 3$, $F = 0.185$)	$p < 0.001$ ($df = 3$, $F = 169.054$) a < c = d < b	$p < 0.001$ ($df = 3$, $F = 25.975$) a < d < b = c	$p < 0.001$ ($df = 3$, $F = 474.159$) a < c < d < b	$p < 0.001$ ($df = 3$, $F = 81.165$) a < b < c = d	$p < 0.001$ ($df = 3$, $F = 31.097$) a < b < c = d	$p < 0.001$ ($df = 3$, $F = 12.937$) a = b < c < d	$p = 0.653$ ($df = 3$, $F = 0.614$)

OH/RS, outside hitter/right side hitter; MB, middle blocker; EE, explosive efforts; RHIE, repeated high-intensity efforts; S-RPE, session rating of perceived exertion. The units for jump, explosive effort, and repeated high-intensity effort are repetitions, while the unit for S-RPE is arbitrary. a = libero; b = setter; c = opposite hitter/right side hitter; d = middle blocker.

TABLE 2. Training and match workloads by position (mean ± SD).

Variables	Playing minute	Total jumps	Low-band jump	Medium-band jump	High-band jump	EE	RHIE	S-RPE
Libero								
Training (n = 269)	127.9 ± 25.8	27.8 ± 12.8*	20.9 ± 9.5	6.3 ± 4.4	0.6 ± 3.9	38.6 ± 20.0*	1.8 ± 1.9	750.1 ± 191.3
Match (n = 88)	164.8 ± 24.1*	24.7 ± 10.3	19.5 ± 9.4	5.4 ± 2.4	1.0 ± 0.2	31.7 ± 16.0	2.0 ± 1.2	844.4 ± 262.4
Total (n = 357)	136.9 ± 29.9	27.1 ± 12.3	20.6 ± 9.5	6.1 ± 4.0	0.7 ± 3.4	36.9 ± 19.3	1.9 ± 1.8	775.3 ± 215.7
Setter								
Training (n = 211)	129.3 ± 26.0	204.6 ± 55.0*	38.9 ± 20.0*	132.2 ± 45.9*	33.5 ± 19.1	55.4 ± 24.0	3.0 ± 2.5*	799.4 ± 220.4
Match (n = 59)	164.9 ± 23.9*	143.5 ± 50.0	32.6 ± 12.2	76.0 ± 28.4	34.9 ± 17.9	50.1 ± 20.4	1.8 ± 0.9	853.4 ± 197.1
Total (n = 270)	137.1 ± 29.5	191.3 ± 59.5	37.6 ± 18.7	120.0 ± 48.6	33.8 ± 18.9	54.5 ± 23.8	2.7 ± 2.3	881.3 ± 216.3
OH/RS								
Training (n = 620)	128.9 ± 25.7	87.6 ± 27.8*	26.4 ± 14.9*	13.8 ± 11.1*	47.5 ± 18.0	73.9 ± 22.9*	3.9 ± 2.9*	763.6 ± 241.9*
Match (n = 203)	165.2 ± 23.7*	93.0 ± 29.4	37.4 ± 22.1	11.5 ± 7.6	44.3 ± 28.7	67.5 ± 36.4	2.2 ± 1.5	829.3 ± 239.9
Total (n = 823)	137.9 ± 29.6	88.9 ± 28.3	29.1 ± 17.6	13.2 ± 10.4	46.7 ± 21.2	72.4 ± 27.0	3.5 ± 2.7	780.1 ± 243.0
MB								
Training (n = 478)	128.4 ± 25.5	107.5 ± 44.4*	20.7 ± 13.3*	32.9 ± 24.5*	53.9 ± 28.9	78.1 ± 40.0*	6.9 ± 6.0*	787.1 ± 264.4*
Match (n = 115)	166.9 ± 23.6*	94.6 ± 38.0	26.4 ± 12.0	18.5 ± 10.3	49.8 ± 27.6	68.6 ± 37.4	3.3 ± 2.9	869.8 ± 252.4
Total (n = 593)	135.9 ± 29.4	104.9 ± 43.5	21.8 ± 13.3	30.1 ± 23.2	53.1 ± 28.6	76.2 ± 39.7	6.2 ± 5.7	803.1 ± 263.9
Linear trends by position	$p = 0.659$ ($df = 3$, $F = 0.535$)	$p < 0.001$ ($df = 3$, $F = 1033.473$) a < c < d < b	$p = 0.140$ ($df = 3$, $F = 88.925$ a = d < c < b	$p < 0.001$ ($df = 3$, $F = 1699.021$) a < c < d < b	$p < 0.001$ ($df = 3$, $F = 496.738$) a < b < c < d	$p < 0.001$ ($df = 3$, $F = 160.907$) a < b < c = d	$p < 0.001$ ($df = 3$, $F = 124.108$) a < b < c < d	$p = 0.117$ ($df = 3$, $F = 1.964$)

OH/RS, outside hitter/right side hitter; MB, middle blocker; EE, explosive efforts; RHIE, repeated high-intensity efforts; S-RPE, session rating of perceived exertion. The units for jump, explosive effort, and repeated high-intensity effort are repetitions, while the unit for S-RPE is arbitrary. Asterisks (*) indicate within-position differences at <0.05. a = libero; b = setter; c = opposite hitter/right side hitter; d = middle blocker.

TABLE 3. Pre-match warm-up workload demands as a percentage (%) of the individual match demands by position.

Variable	Playing minute	Total jump	Low-band jump	Medium-band jump	High-band jump	EE	RHIE
Libero (n = 88)	24.0 ± 3.7	-	-	-	-	49.4 ± 19.0	28.7 ± 29.5
Setter (n = 59)	23.7 ± 3.6	50.3 ± 14.2	61.2 ± 27.3	54.6 ± 25.6	36.9 ± 27.3	32.3 ± 18.7	26.8 ± 24.8
OH/RS (n = 203)	23.8 ± 3.6	33.4 ± 15.9	37.9 ± 20.8	25.7 ± 23.8	43.5 ± 26.9	38.0 ± 20.1	13.7 ± 20.5
MB (n = 115)	23.6 ± 3.7	34.1 ± 12.8	49.8 ± 17.8	40.9 ± 17.9	29.0 ± 23.1	30.4 ± 20.8	14.5 ± 21.5
Linear trend by position	$p = 0.922$ ($df = 3$, $F = 0.161$)	$p < 0.001$ ($df = 2$, $F = 31.419$) c = d < b	$p < 0.001$ ($df = 2$, $F = 31.578$) c < d < b	$p < 0.001$ ($df = 2$, $F = 44.059$) c < d < b	$p < 0.001$ ($df = 2$, $F = 11.503$) d < b = c	$p < 0.001$ ($df = 3$, $F = 16.684$) d = b < c < a	$p < 0.001$ ($df = 3$, $F = 12.203$) d = c < b = a

OH/RS, outside hitter/right side hitter; MB, middle blocker; EE, explosive efforts; RHIE, repeated high-intensity efforts. The units for the variables "jump", "explosive effort" and "repeated high-intensity effort" are repetitions, while the unit for the variable "S-RPE" is an arbitrary unit. a = libero; b = setter; c = opposite hitter/right side hitter; d = middle blocker.

The position's high-intensity external workloads, such as EE, RHIE and high-band jumps, likely contribute to the relatively high S-RPE recorded for MB in this study, despite the need for further research. Taken together, the findings from the current and previous studies advance our understanding of the physical demands and jump heights unique to each position, providing critical information for effective training and match strategies.

Our study findings about training and match workloads are consistent with those of Kupperman *et al*. [15] who reported higher workloads during training than during matches. Although PM was shorter during training sessions than during matches, variables such as medium-band jumps, EE and RHIE were higher during training sessions compared to matches. The KOVO players who participated in this study rigorously simulated actual match situations during their training sessions, which may have contributed to these findings. In training, RHIE was significantly higher than in matches for all positions except libero, ranging from 1.7 to 2.1 times. These findings can be attributed to the fact that the KOVO players who participated in this study practiced the offensive and defensive moves required to score frequently during their training sessions, which has important implications for injury prevention and player management due to overuse.

Players must warm up before games to deal with workload demands while also improving and/or optimizing their performance. Warm-up routines stimulate temperature, metabolic, psychological and neuromuscular mechanisms, potentially improving players' readiness and neuromuscular performance prior to training or competition [22]. Thus, determining the amount of pre-match warm-up workload demands could aid in developing evidence-based warm-up routines for all playing positions. Our study findings showed that the relative pre-match warm-up loads of jumping actions and EE exceeded 30% of the match loads across playing positions. Specifically, setters had the highest pre-match warm-up workload demands in terms of total jumps (~50.3%), low-band jumps (~61.2%), and medium-band jumps (~54.6%). Liberos had the highest EE (49.4%) and RHIE (28.7%), while OH/RS and setters had the highest workload demands of high-band jumps (43.5% and 36.9%, respectively).

The significant increase in the number of jumps for the setter position is likely due to the setter's role of distributing the ball and setting up plays, which necessitates many jumps during warm-ups to coordinate with multiple attackers. The extensive pre-match warm-ups for EE and RHIE by Liberos, a defensive specialist with passing and digging responsibilities in the back row, may mirror the position's crucial role in volleyball [23]. Liberos must receive the ball at speeds of up to 130 km/h [23], so intensive defensive movement practice to improve reaction time may have contributed to the rise in RHIE rates. OH/RS demonstrated the greatest increase in high-band jumps, as well as a significant increase in EE. Attackers performed more spike jumps and receptions during the warm-up period to prepare for the match, which led to this increase. In conclusion, our study's findings demonstrate how the physical demands of match preparation can differ significantly depending on the playing position.

The study has the advantage of gathering objective and comprehensive data on the internal and external workloads of professional male volleyball players using a large sample size. At the same time, this study had some limitations too. First, we cannot rule out the possibility of overestimating setters' workloads by excluding data from one of the three setters who participated infrequently. Second, this study was unable to exclude non-playing time, such as timeouts, rest periods between sets and video review sessions, which can differ from match to match from total match time. Therefore, we may have overestimated the total playing time for both games and practice sessions. Because movements during non-playing time can cause an overestimation of workload, future research should carefully account for these non-playing periods. Third, the limited external validity of the conclusions may arise from this study's exclusive focus on the match and training data of a single team from the KOVO league. Future studies should address these limitations. Studies that investigate the relationship between external workload and factors such as injury or performance (*e.g.*, win-loss record) will highlight the significance of measuring external workload.

5. Conclusions

The current findings show that workload demands during volleyball matches vary by position type, with each position facing different workloads even during pre-match warm-ups and training sessions. These findings can help coaches and trainers better understand the physical demands of each position, emphasizing the importance of developing position-specific training programs. Setters who perform primarily mid-height jumps should focus on increasing their specific training within that range. In contrast, MB and outside hitters, who frequently perform explosive movements and high-intensity jumps, should prioritize these powerful training aspects while also emphasizing recovery strategies. Players can maximize their performance by tailoring pre-match warm-up protocols to each position.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and analyzed in the current study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

MS and HK—were responsible for the study concept and design, data collection and analysis, and drafting and revision of the manuscript. SYoo and SYoon—were responsible for the experimental concept and design, and data collection and analysis. All authors read and approved the final version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The Sungkyunkwan University Institutional Review Board's Research Ethics Committee reviewed and approved the study according to the Declaration of Helsinki (No. 2024-05-028). All study participants provided informed consent.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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