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RESEARCH

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Quantifying internal and external training loads in collegiate male volleyball players during a competitive season

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Abstract

Background The long-term monitoring of internal and external training load is crucial for the training effectiveness of athletes. This study aims to quantify the internal and external training loads of collegiate male volleyball players during the competitive season. The internal and external training load variables were analyzed across mesocycles and playing positions.

Methods Fourteen participants with age of 20.2 ± 1.3 years, height of 1.81 ± 0.05 m, and body weight of 70.8 ± 5.9 kg were recruited. The data were collected over a 29-week period that was divided into four mesocycles: preparation 1 (P1, weeks 1–7), competition 1 (C1, weeks 8–14, including a 5-day tournament in week 14), preparation 2 (P2, weeks 15–23), and competition 2 (C2, weeks 24–29, including a 6-day tournament in week 29). Each participant wore an inertial measurement unit and reported the rating of perceived exertion in each training session. The internal training load variables included weekly session rating of perceived exertion, acute: chronic workload ratio, and training monotony and strain. The external training load variables included jump count and height and the percentage of jumps exceeding 80% of maximal height.

Results C2 had the highest average weekly internal training load (3022 ± 849 AU), whereas P2 had the highest average weekly acute: chronic workload ratio (1.46 ± 0.13 AU). The number of weekly jumps in C1 (466.0 ± 176.8) was significantly higher than in other mesocycles. Weekly jump height was significantly higher in C1, P2, and C2. Internal training load was positively correlated with jump count ($\rho = 0.477$, $p < 0.001$). Jump count was negatively correlated with jump height ($\rho = -0.089$, $p = 0.006$) and the percentage of jumps exceeding 80% of maximal height ($\rho = -0.388$, $p < 0.001$). The internal and external training load variables were similar among different playing positions.

Conclusion The participants exhibited significantly higher internal training load in C2 and higher jump height after P1. A high jump count was associated with higher internal training load and lower jump height. Excessive jumps may result in fatigue and reduce height.

Keywords Acute:chronic workload ratio, Jump count, Session rating of perceived exertion, Wearable device

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Background

The long-term monitoring of training load is crucial for the training effectiveness of elite athletes. Sufficient intensity and volume are required to reach the optimal training outcomes. However, exceeding the training threshold excessively can result in overtraining, which can reduce athletic performance and increase the risk of injury [1]. Each athlete may have a unique response to a given training load. Consequently, long-term monitoring of training load and response in individual athletes is essential for manipulating training intensity and volume to elicit a positive response while allowing for adequate recovery [2]. External and internal variables may be used to assess the training load. The external training load is the physical stimulus imposed on the athletes, such as jump count and height, movement speed and distance, or the weight used in resistance training. Internal training load reflects the psychophysiological stress caused by external training load [3]. The methods for quantifying training load should be sensitive to the specific sport while being convenient enough to be used frequently.

One of the most practical and commonly used methods to estimate internal training load is session rating of perceived exertion (sRPE). This simple subjective evaluation correlates strongly with objective indicators of training load, such as heart rate reserve percentage and blood lactate concentration [4]. Additional variables derived from sRPE, such as acute: chronic workload ratio (ACWR), training monotony, and training strain, can provide additional insight into both positive and negative training outcomes [5].

ACWR, the ratio of weekly internal training load and rolling average of weekly internal training load in the preceding four weeks, represents the relative changes in the internal training load in the present week compared to the previous month. In numerous sports, including professional volleyball, an ACWR greater than 1.5 arbitrary unit (AU) has been associated with an increased risk of injury [1]. An ACWR between 1.00 and 1.49 AU posed the lowest risk for injury, compared to lower or higher levels, during a professional basketball season [6]. Another study found that an ACWR value greater than 1.5 AU was associated with an increased risk of injury in elite rugby league players, particularly when combined with an increased workload [7]. Similar outcomes were discovered for athletes in other sports [8, 9]. Therefore, the International Olympic Committee consensus statement recommends that weekly increases in training load should not exceed 10% to avoid negative effects [10].

A training monotony greater than 2 AU, indicating less variation among training loads in sessions, has been suggested to significantly increase the risk of injury and overtraining [11]. Higher training monotony was also linked to increased muscle soreness, stress, fatigue, sleep disturbances, and decreased perception of recovery and peak power in the lower limbs in male professional volleyball players [12–14]. Training strain denotes the cumulative stress induced by the workload throughout the week [11]. Elevated training strain has been associated with muscle soreness and a diminished sense of recovery in elite volleyball players [13, 14].

Volleyball is distinguished by its high-intensity and intermittent movements, with jumping being the primary offensive and defensive technique [15]. Consequently, the majority of research and practical applications on external training load and volleyball performance focus on jump count and height. In recent years, wearable inertial measurement devices have enabled coaches and researchers to collect real-time data on the vertical displacement of volleyball players during training and competition [16, 17]. The variations in jump demand in training and matches have also been explored in different playing positions with distinct offensive and defensive roles [18].

The combination of internal and external training load variables is required to comprehensively monitor the training response of individual athletes. However, research on volleyball players' internal and external training loads throughout an entire competitive season is limited. Furthermore, the relationships among internal and external training load variables are still unclear in volleyball players. This study aims to quantify the internal and external training loads using sRPE and wearable devices, respectively, of collegiate male volleyball players during a competitive season. We hypothesized that (1) internal and external training load variables are different across four mesocycles; (2) participants of different playing positions have different internal and external training load; and (3) internal and external training load are correlated.

Methods

Study design

The study utilized an observational cohort study design. Internal and external training load data in each tactical training session were collected during a 29-week competitive season.

Participants

Sixteen male athletes from a Division I university volleyball team in Taichung, Taiwan, were initially recruited through convenient sampling. Two participants withdrew from the study for personal reasons. The final data included 14 participants who were 20.2±1.3 years old, 1.81±0.05 m tall, and 70.8±5.9 kg in weight. The participants were separated into three groups according to their primary playing positions, hitters (outside hitters and opposite, n=7), middle blockers (n=5), and setters

($n=2$). Exclusion criteria included inability to train due to injuries or illness, cardiovascular or metabolic disease, or participation in fewer than two training sessions per week. Liberos were also excluded from the study because the jumping requirement is low in their primary defensive role. The study protocol was approved by the Research Ethics Committee, Jen-Ai Hospital, Taichung, Taiwan (110-03). Participants or legal guardians signed the informed consent document.

Procedures

The data of internal and external load were collected during a 29-week competitive season from September, 2021 to March, 2022. The season was divided into four mesocycles: preparation 1 (P1, weeks 1–7), competition 1 (C1, weeks 8–14, with a 5-day tournament in week 14), preparation 2 (P2, weeks 15–23), and competition 2 (C2, weeks 24–29, with a 6-day tournament in week 30). The final day of data collection occurred one day before the second tournament. The team usually held 3 to 4 tactical and technical training session per week throughout the season. A total of 78 training sessions were recorded. Weight training sessions, typically held 1 to 2 times per week depending on the mesocycles, were scheduled on different days than tactical and technical training. Data on these weight training sessions were not collected.

Internal training load

All players rated their effort on a 10-point scale approximately 15 min after each training session [19]. The sRPE was calculated by multiplying the RPE by the duration (in min) of the session. Subsequently, the following variables were calculated: (1) the internal training load, the sum of sRPE throughout the week; (2) ACWR, the ratio of weekly internal training load and rolling average of weekly internal training load in the preceding 4 weeks; (3) the training monotony, determined by dividing the mean sRPE achieved across all training sessions of the week by the standard deviation; and (4) the training strain, determined by multiplying internal training load by training monotony [11]. Throughout the duration of the study, all variables were computed on a weekly basis.

External training load

Jump count and height in each training session were measured by inertial measurement units (VERT wearable jump monitor, VERT COACH, Fort Lauderdale, FL, USA). Throughout each training session, the unit was secured to the participant's posterior superior iliac spine with a belt. The data were wirelessly transmitted via Bluetooth to the iPad application for the VERT COACH System. The jump count and average height were calculated for each training session.

One week prior to the start of week 1, the maximal attack jump height was measured for each participant using VERT. Each participant performed three attack jumps with greatest effort, and the highest result was recorded as their maximal jump height. The height of each jump during all training sessions was manually extracted from the VERT COACH System and divided by the respective participant's maximal jump height. The percentage of jumps exceeding 80% of their maximal jump height was then calculated.

Good inter-device reliability allows the VERT unit to record 99.3% of the jumps performed during volleyball practice and competition [17]. Although VERT overestimated jump height by an average of 5.5 cm, it is a convenient and acceptable measure of on-court jump count and height [17].

Statistical analysis

The average weekly internal and external training load variables in each mesocycle was used for analysis. The data were presented as the mean ± standard deviation format. As indicated by the Shapiro–Wilk test, the data were not normally distributed. Therefore, the Friedman test was used to compare internal and external training load variables across the four mesocycles. In the presence of a significant time effect, Wilcoxon post-hoc comparisons were conducted. Using the Kruskal–Wallis test, differences in internal and external load variables among participants of different playing positions were analyzed, followed by Wilcoxon tests for post-hoc comparisons if significant effects were observed. Spearman's rank correlation coefficient was used to analyze the correlation between internal training load, jump count and height, and the percentage of jumps exceeding 80% of maximal height. The significance level was set at $\alpha=0.05$, whereas the significance level in post-hoc tests was set at $p<0.05$ divided by the number of pairwise comparisons [20]. Effect sizes were measured using Kendall's W. Kendall's W values of 0.1 to <0.3 indicate a small effect, 0.3 to <0.5 indicate a moderate effect, and values ≥ 0.5 represent a large effect size [21]. Based on the sample size of 14, the effect size of 0.85 can be detected with the power of 0.8, as estimated using the software G*Power 3.1. The software SPSS for Windows version 23.0 (IBM, Armonk, NY, USA) was used for statistical analysis.

Results

Table 1 presents the internal training load variables for all participants and different positions across the four mesocycles. C2 exhibited the highest average weekly internal training load, which was significantly higher than that in P1 ($p=0.011$, Kendall's W = 0.327) and C1 ($p=0.001$, Kendall's W = 0.735). Meanwhile, P2 had the highest weekly average ACWR, which was significantly

Table 1 The weekly internal training load variables in participants of different playing positions during the four mesocycles

Position	Preparation 1	Competition 1	Preparation 2	Competition 2
Internal training load (AU)				
All	2205 ± 534	2426 ± 583	2652 ± 643	3022 ± 849†#
Hitter	2088 ± 555	2276 ± 619	2262 ± 687	2567 ± 861
Middle blocker	2122 ± 444	2421 ± 463	2994 ± 231	3426 ± 564
Setter	2846 ± 333	2961 ± 733	3160 ± 413	3604 ± 846
ACWR[a] (AU)				
All	1.25 ± 0.44	0.99 ± 0.10	1.46 ± 0.13†*	1.11 ± 0.16
Hitter	1.26 ± 0.37	0.98 ± 0.11	1.43 ± 0.17	1.07 ± 0.06
Middle blocker	1.31 ± 0.61	1.00 ± 0.11	1.50 ± 0.91	1.08 ± 0.09
Setter	1.03 ± 0.03	0.96 ± 0.64	1.46 ± 0.13	1.08 ± 0.09
Training monotony (AU)				
All	0.93 ± 0.24	1.07 ± 0.12	0.94 ± 0.10	0.97 ± 0.06
Hitter	0.93 ± 0.27	1.06 ± 0.16	0.92 ± 0.14	0.94 ± 0.07
Middle blocker	0.90 ± 0.26	1.06 ± 0.10	0.97 ± 0.06	0.98 ± 0.03
Setter	1.00 ± 0.12	1.10 ± 0.01	0.94 ± 0.10	1.02 ± 0.34
Training strain (AU)				
All	2341 ± 722	2919 ± 837	3141 ± 904	3020 ± 933
Hitter	2270 ± 834	2780 ± 977	2680 ± 1027	2528 ± 949
Middle blocker	2204 ± 668	2868 ± 681	3551 ± 433	3425 ± 584
Setter	2933 ± 294	3534 ± 787	3732 ± 729	3728 ± 1020

[a]ACWR: acute: chronic workload ratio; #$p < 0.05$ vs. Preparation 1; †$p < 0.05$ vs. Competition 1; *$p < 0.05$ vs. Competition 2

Table 2 Average weekly jump count and jump height among participants of different playing positions in each of the four mesocycles

Position	Preparation 1	Competition 1	Preparation 2	Competition 2
Jump count				
All	277.3 ± 128.1	466.0 ± 176.8†	283.3 ± 99.1	298.5 ± 102.5
Hitter	243.3 ± 66.0	392.5 ± 46.0	245.4 ± 60.6	272.7 ± 68.3
Middle blocker	213.9 ± 74.6	433.5 ± 145.1	280.4 ± 112.6	269.1 ± 72.1
Setter	538.6 ± 22.5	804.9 ± 107.1	423.3 ± 75.1	475.5 ± 127.3
Jump height (cm)				
All	49.82 ± 4.58	59.29 ± 8.87#	59.82 ± 10.43#	61.25 ± 10.42#
Hitter	51.40 ± 2.29	62.89 ± 7.92	62.32 ± 10.28	64.48 ± 9.59
Middle blocker	51.13 ± 3.82	58.79 ± 6.49	60.38 ± 7.50	62.09 ± 6.99
Setter	40.97 ± 0.52	47.90 ± 11.30	49.70 ± 17.46	47.81 ± 15.06
Jumps > 80% of max height (%)				
All	40.91 ± 12.28	41.56 ± 14.79	42.74 ± 15.80	44.74 ± 16.86
Hitter	47.05 ± 4.96	46.89 ± 6.95	45.90 ± 13.03	50.12 ± 8.97
Middle blocker	41.35 ± 11.51	48.83 ± 1.59	52.51 ± 1.76	53.93 ± 5.23
Setter	18.78 ± 0.98	11.96 ± 0.93	16.99 ± 6.34	12.09 ± 1.38

#$p < 0.05$ vs. Preparation 1; †$p < 0.05$ vs. other three mesocycles

higher than that in C1 ($p = 0.001$, Kendall's W = 1.000) and C2 ($p = 0.011$, Kendall's W = 0.735). Although these comparisons had Kendall's W larger than 0.5, indicating large effects, it is noteworthy that an effect size of 0.85 can be detected with a power of 0.8 given this sample size. Training monotony and strain did not differ significantly across the four mesocycles. Internal load variables exhibited consistent trends across positions, with the highest average weekly internal training load in C2 and the highest ACWR in P2. Furthermore, internal load variables did not show significant differences among participants of different playing positions across any mesocycle. Although it is noteworthy that setters reported a higher average internal training load than hitters and middle blockers in all mesocycles.

Weekly jump count and average jump height and the percentage of jumps exceeding 80% of maximal height for each mesocycles are presented in Table 2. C1 recorded a significantly higher weekly jump count than the other mesocycles (all $p < 0.001$, Kendall's W = 0.673). Setters showed a higher average jump count than hitters and middle blockers in every mesocycle, but the differences were statistically insignificant. Jump height gradually increased from P1 to C2, reaching its peak in C2. The jump height in C1 (p=0.002, Kendall's W=0.510), P2 (p=0.006, Kendall's W=0.327), and C2 (p=0.002, Kendall's W=0.735) was significantly higher than that in P1. No statistically significant difference in average jump height and percentage of jumps exceeding 80% of maximal height were observed among players of different positions, although setters exhibited the lowest levels in both categories.

A positive correlation was found between internal training load and jump count (ρ=0.477, p<0.001, Fig. 1A). Following the rest in week 15, the internal training load gradually increased beginning in week 16, reaching its peak in the week preceding the second tournament (week 29, 5437±1944) (Fig. 1A). Meanwhile, the weekly average jump count peaked in week 12 of C1 (651±278). Additionally, internal training load was negatively correlated with the percentage of jumps exceeding 80% of maximal height (ρ = –0.141, p<0.001, Fig. 1B).

A negative correlation was identified between jump count and jump height (ρ = –0.089, p=0.006, Fig. 2A). Weekly average jump height gradually increased during P1, plateauing from week 9 onwards. A negative correlation was also found between jump count and the percentage of jumps exceeding 80% of maximal height (ρ = –0.388, p<0.001, Fig. 2B).

Weekly ACWR, training monotony, and training strain are depicted in Fig. 3A and B, and 3C, respectively. The highest ACWR value occurred in week 17 (2.19±0.45; Fig. 3A), primarily as a result of the decreased internal training load in weeks 14–15. Training monotony peaked at 1.45±0.31 in week 11, and ranged between 0.57±0.02 and 1.35±0.11 in other weeks (Fig. 3B). The final week saw the highest training strain, at 5437±1944 (Fig. 3C).

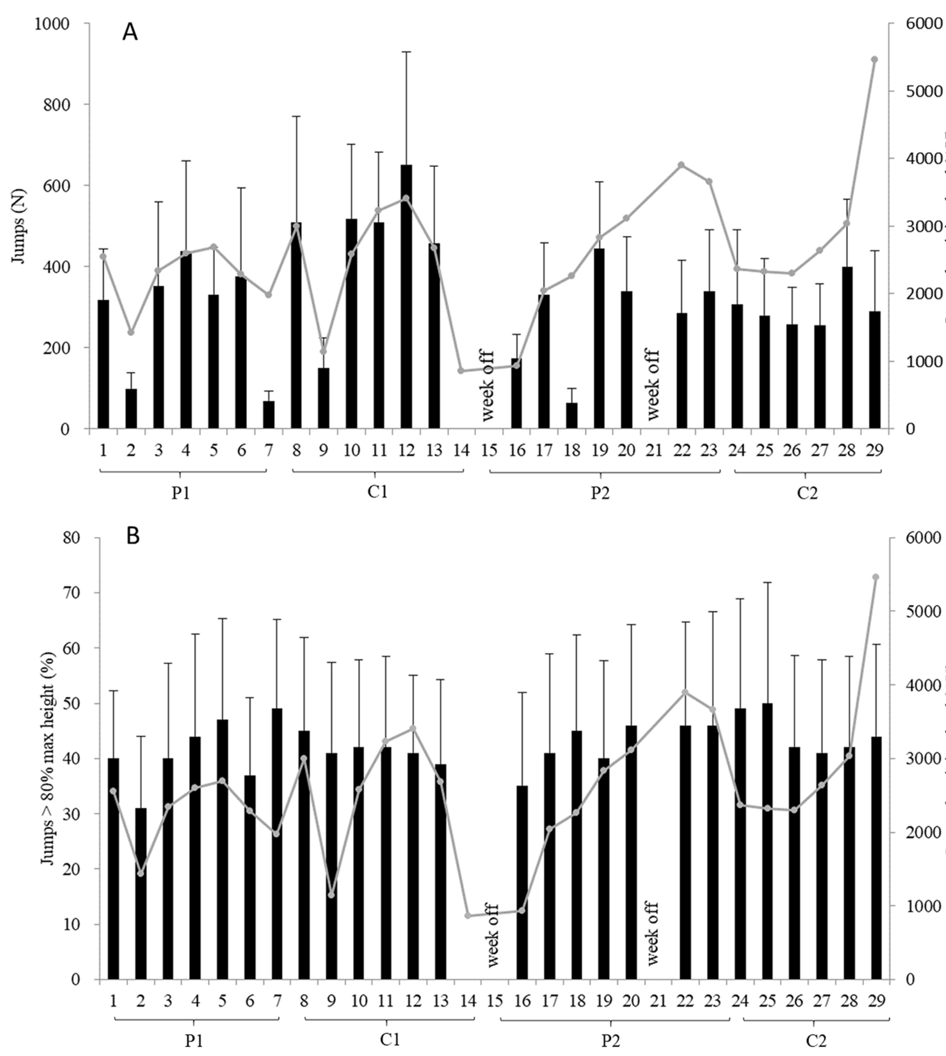

Fig. 1 (**A**) Weekly jump count (■) and internal training load (-●-), (**B**) weekly percentage of jumps exceeding 80% of maximal height (■) and internal training load (-●-) in the four mesocycles. C1: competition 1; C2: competition 2; P1: preparation 1; P2: preparation 2

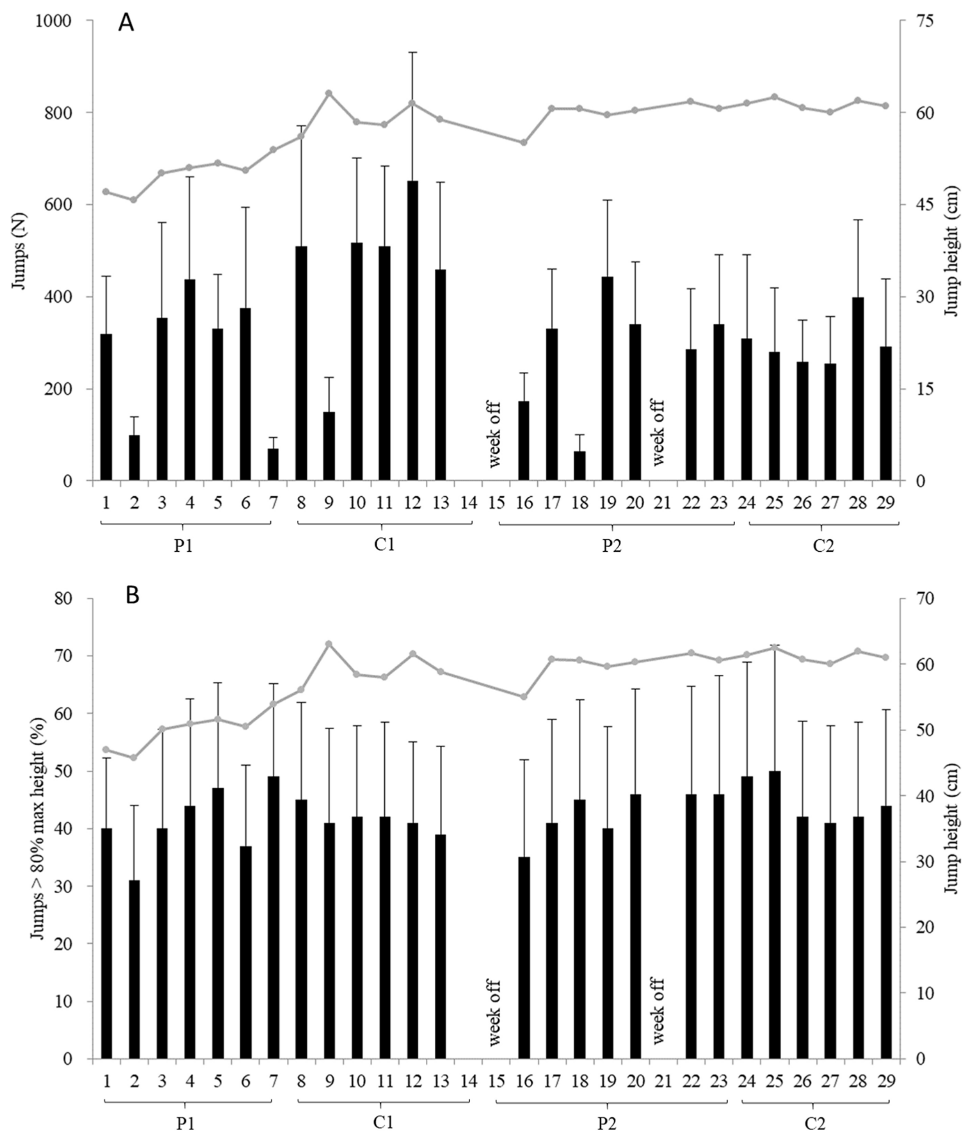

Fig. 2 (**A**) Weekly jump count (■) and average jump height (-●-), (**B**) weekly percentage of jumps exceeding 80% of maximal height (■) and average jump height (-●-) in the four mesocycles. C1: competition 1; C2: competition 2; P1: preparation 1; P2: preparation 2

Discussion

This study quantified the internal and external training load of collegiate male volleyball players during a competitive season. Internal and external training load variables did not show significant differences among participants across various playing positions in any mesocycle. The results revealed a significantly positive correlation between the internal training load, as measured by sRPE, and the external training load, as measured by jump count and the percentage of jumps exceeding 80% of maximal height. In addition, the presence of a negative correlation between jump count and height and the percentage of jumps exceeding 80% of maximal height implies that a higher frequency of jumps during training sessions may be associated with diminished jump height. Furthermore, ACWR was below 1.5 in the majority of weeks, which was likely to minimize injury risk.

The positive correlation between internal and external training load was consistent with a previous study that reported a positive correlation (r=0.49) between weekly sRPE and the number of jumps in professional male volleyball players [22]. Internal training load was also a strong predictor of heart-rate derived training impulse in collegiate female beach volleyball players [23]. In professional volleyball players, internal training load was significantly correlated with fatigue, sleep quality, muscle soreness, perceived recovery, psychological stress, well-being, and creatine kinase concentration [24–26]. Furthermore, sRPE was sensitive to the total number of repetitions in high-intensity whole-body movements [27]. These findings demonstrate that the convenient

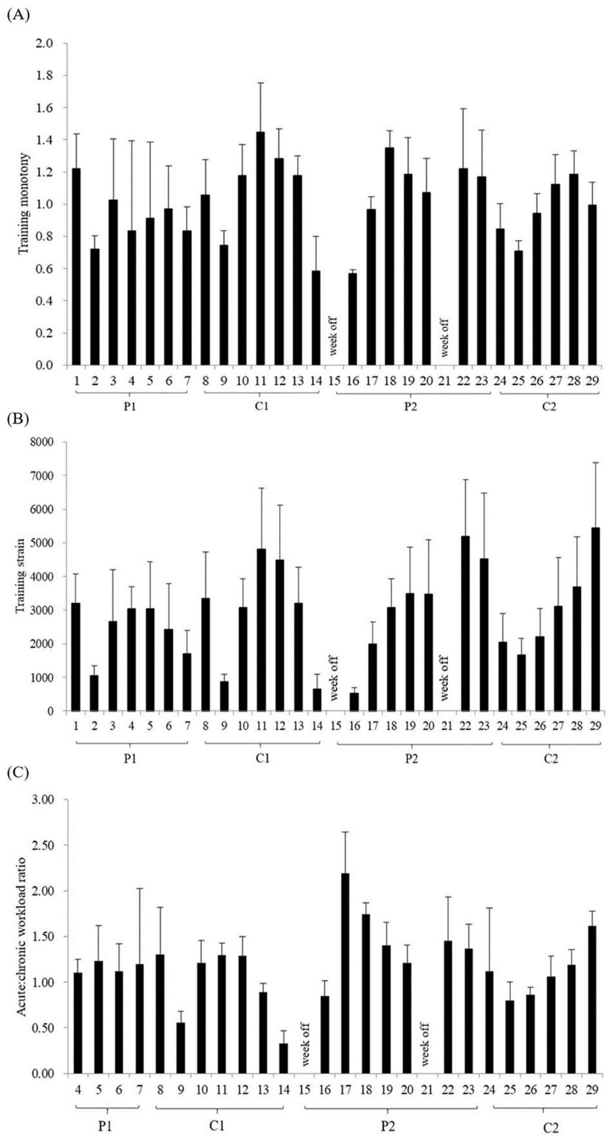

Fig. 3 (**A**) Acute: chronic workload ratio (ACWR), (**B**) training monotony, and (**C**) training strain in the four mesocycles. C1: competition 1; C2: competition 2; P1: preparation 1; P2: preparation 2

sRPE method was able to reflect external training load and recovery status.

The short tournament-style competition of the collegiate season contrasts with the longer, fewer-games-per-week format of the professional season. The relatively weaker five-day tournament in week 14 served as the qualifying round for the stronger second tournament in week 30. The top six teams from the six-day second tournament advanced to the third and final tournament. Each consecutive day, the team played one match in the tournaments. Therefore, the training program's objective was to achieve peak performance for the second tournament by gradually increasing the training load in P2 and C2 while maintaining a reasonable ACWR, monotony, and strain. The weekly internal training load in this group of collegiate volleyball players was lower than that in professional athletes [13, 26]. Despite a packed match schedule, the participants reported a relatively light internal training load during week 14 compared to previous weeks. This is consistent with a previous study which found that collegiate female volleyball players jump less during competition than during training [28]. The high internal training load in week 29, one week prior to the second tournament, was somewhat unexpected given that the total number of jumps had been reduced for the purpose of tapering. It is possible that the psychological pressure before the important tournament was reflected in RPE. Unfortunately, the investigated team failed to advance to the third and final tournament. This training program adopted by this collegiate team is different from that in professional volleyball seasons in which two or three matches were played in a week for several months. Professional teams typically had a lower training load during competitive mesocycles than that during preparatory mesocycles to ensure the optimal match performance [13].

An ACWR between 1.00 and 1.49 posed the lowest risk for injury, compared to lower or higher levels, during a competitive season [6]. It appeared that the training load was effectively managed in the present study because the average ACWR was below the 1.5 threshold in most weeks. Due to the light internal training load in weeks 14–16, the ACWR peaked in weeks 17 and 18. After a week of rest, the participants were eased into P2 mesocycle.

A weekly training monotony greater than 2, indicating a lack of variation among training loads in sessions, has been suggested to significantly increase the risk of injury and overtraining [11]. For example, a higher training monotony was associated with a greater likelihood of illness and traumatic injury among soccer players [29, 30]. In the present study, training monotony ranged between 0.57 and 1.45 in most weeks, indicating a reasonable variation in intra-week training loads. Although the training program appeared to be well-tolerated, the negative correlation between jump count and jump height suggests that elevated training load still led to fatigue in the particular session.

This study reveals that setters exhibited a trend of higher average jump counts during training sessions across playing positions, a pattern observed consistently at both collegiate and professional levels. Previous researches showed that setters perform more jumps during training sessions compared to middle blockers and outside hitters in collegiate [31] and professional volleyball teams [32]. The high frequency of jumps among setters during training aligns with their performance during collegiate [31] and professional matches [18, 32].

However, despite their higher jump frequency during both practice and matches, setters executed jumps with less intensity [18, 31, 32]. This study also showed that setters had only an average of 11.96–18.78% jumps exceeding 80% of maximal height during training in various mesocycles. It's worth noting that statistical comparisons to analyze jump count and height among various playing positions were not conducted in the aforementioned studies due to limited sample sizes [18, 31, 32]. Similarly, this study did not find statistically significant differences in jump count and height and the percentage of jumps exceeding 80% of maximal height across different playing positions.

Our results showed that the internal training load was comparable for players of different positions. The primary reason is that all participants followed the same training regimen and schedule. On the contrary, it has been shown that middle blockers experienced the highest internal training load [33], whereas another study indicated that middle blockers had lowest workload as measured by local positioning system among all positions in elite volleyball players [34]. This disparity may be a result of teams' varied playing tactics.

This research has several limitations. First, data were collected from a single team. Although it ensured that all participants followed the same training program, the results may not be extrapolated to other teams with varying training levels. Second, in this group of student athletes, RPE may be affected by factors other than volleyball training, such as academic load or part-time jobs. Third, horizontal movements were not quantified in this research, despite their importance to performance. Fourth, the lack of competition data could influence the training data. Lastly, due to the small sample size of participants and players in each playing positions, an effect size of 0.85 can be identified with the power of 0.8. Most comparisons had Kendall's W lower than 0.85 except for P2 having significantly higher weekly average ACWR than that in C1. Small sample sizes may also result in a lack of distinction between playing positions.

In conclusion, this study revealed a positive correlation between internal and external training loads in a collegiate team. In addition, internal and external training load variables did not show significant differences among participants across various playing positions in any mesocycle. Future research may incorporate horizontal motions to more precisely quantify the external training load.

Practical applications

Our findings provide coaches with practical methods for assessing internal and external training loads, facilitating the implementation of periodization and recovery strategies. Given the notable positive correlation between internal and external training loads, the simple sRPE can yield valuable insights into training stress even when inertial measurement units are unavailable. Coaches are advised to include weekly ACWR, training monotony, and strain assessments in their monitoring routines to prevent injuries and overtraining. In addition, coaches should be aware that a high jump count during a training session may lead to the feeling of fatigue and a reduction in jump height.

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Author contributions
HSL acquired, analyzed, and interpreted the data and drafted the manuscript. HJW conceptualized and designed the study and drafted the manuscript. CCW conceptualized and designed the study, interpreted the data, and drafted the manuscript. JYC acquired and analyzed the data. CCK conceptualized the study and edited the final draft. All authors read and approved the final manuscript.

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Data availability
The datasets generated and analyzed during the current study are available in the Figshare, https://doi.org/10.6084/m9.figshare.25514467.v1.

Declarations

Ethics approval and consent to participate
The study protocol was approved by the Research Ethics Committee, Jen-Ai Hospital, Taichung, Taiwan (110-03). Participants or legal guardians signed the informed consent document. This study was conducted in accordance with the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Timoteo TF, Debien PB, Miloski B, Werneck FZ, Gabbett T, Bara Filho MG. Influence of workload and recovery on injuries in elite male volleyball players. J Strength Cond Res. 2021;35(3):791–6. https://doi.org/10.1519/jsc.0000000000002754.
2. Burgess DJ. The research doesn't always apply: practical solutions to evidence-based training-load monitoring in elite team sports. Int J Sports Physiol Perform. 2017;12(Suppl 2):S2136–41. https://doi.org/10.1123/ijspp.2016-0608.
3. Impellizzeri FM, Marcora SM, Coutts AJ. Internal and external training load: 15 years on. Int J Sports Physiol Perform. 2019;14(2):270–3. https://doi.org/10.1123/ijspp.2018-0935.
4. Foster C, Boullosa D, McGuigan M, Fusco A, Cortis C, Arney BE, Orton B, Dodge C, Jaime S, Radtke K, et al. 25 years of session rating of perceived exertion: historical perspective and development. Int J Sports Physiol Perform. 2021;16(5):612–21. https://doi.org/10.1123/ijspp.2020-0599.
5. Williams S, Trewartha G, Cross MJ, Kemp SPT, Stokes KA. Monitoring what matters: a systematic process for selecting training-load measures. Int J Sports Physiol Perform. 2017;12(Suppl 2):S2101–6. https://doi.org/10.1123/ijspp.2016-0337.

6. Weiss KJ, Allen SV, McGuigan MR, Whatman CS. The relationship between training load and injury in men's professional basketball. Int J Sports Physiol Perform. 2017;12(9):1238–42. https://doi.org/10.1123/ijspp.2016-0726.
7. Hulin BT, Gabbett TJ, Lawson DW, Caputi P, Sampson JA. The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. Br J Sports Med. 2016;50(4):231–6. https://doi.org/10.1136/bjsports-2015-094817.
8. Hulin BT, Gabbett TJ, Blanch P, Chapman P, Bailey D, Orchard JW. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. Br J Sports Med. 2014;48(8):708–12. https://doi.org/10.1136/bjsports-2013-092524.
9. Blanch P, Gabbett TJ. Has the athlete trained enough to return to play safely? The acute:chronic workload ratio permits clinicians to quantify a player's risk of subsequent injury. Br J Sports Med. 2016;50(8):471–5. https://doi.org/10.1136/bjsports-2015-095445.
10. Schwellnus M, Soligard T, Alonso JM, Bahr R, Clarsen B, Dijkstra HP, Gabbett TJ, Gleeson M, Hägglund M, Hutchinson MR, et al. How much is too much? (part 2) international olympic committee consensus statement on load in sport and risk of illness. Br J Sports Med. 2016;50(17):1043–52. https://doi.org/10.1136/bjsports-2016-096572.
11. Foster C. Monitoring training in athletes with reference to overtraining syndrome. Med Sci Sports Exerc. 1998;30(7):1164–8.
12. Clemente FM, Mendes B, Palao JM, Silverio A, Carrico S, Calvete F, Nakamura FY. Seasonal player wellness and its longitudinal association with internal training load: study in elite volleyball. J Sports Med Phys Fit. 2019;59(3):345–51. https://doi.org/10.23736/s0022-4707.18.08312-3.
13. Debien PB, Mancini M, Coimbra DR, de Freitas DGS, Miranda R, Bara Filho MG. Monitoring training load, recovery, and performance of Brazilian professional volleyball players during a season. Int J Sports Physiol Perform. 2018;13(9):1182–9. https://doi.org/10.1123/ijspp.2017-0504.
14. Rebelo A, Pereira JR, Martinho DV, Amorim G, Lima R, Valente-Dos Santos J. Training load, neuromuscular fatigue, and well-being of elite male volleyball athletes during an in-season mesocycle. Int J Sports Physiol Perform. 2023;18(4):354–62. https://doi.org/10.1123/ijspp.2022-0279.
15. Sheppard JM, Gabbett T, Taylor KL, Dorman J, Lebedew AJ, Borgeaud R. Development of a repeated-effort test for elite men's volleyball. Int J Sports Physiol Perform. 2007;2(3):292–304. https://doi.org/10.1123/ijspp.2.3.292.
16. Borges TO, Moreira A, Bacchi R, Finotti RL, Ramos M, Lopes CR, Aoki MS. Validation of the vert wearable jump monitor device in elite youth volleyball players. Biol Sport. 2017;34(3):239–42. https://doi.org/10.5114/biolsport.2017.66000.
17. Skazalski C, Whiteley R, Hansen C, Bahr R. A valid and reliable method to measure jump-specific training and competition load in elite volleyball players. Scand J Med Sci Sports. 2018;28(5):1578–85. https://doi.org/10.1111/sms.13052.
18. Lima RF, Palao JM, Clemente FM. Jump performance during official matches in elite volleyball players: a pilot study. J Hum Kinet. 2019;67:259–69. https://doi.org/10.2478/hukin-2018-0080.
19. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, Doleshal P, Dodge C. A new approach to monitoring exercise training. J Strength Cond Res. 2001;15(1):109–15.
20. Atkinson G. Analysis of repeated measurements in physical therapy research: multiple comparisons amongst level means and multi-factorial designs. Phys Ther Sport. 2002;3(4):191–203.
21. Kendall MG, Gibbons JD. Rank correlation methods. 5th ed. Oxford, UK: Oxford University Press; 1990.
22. Lima RF, Silva A, Afonso J, Castro H, Clemente FM. External and internal load and their effects on professional volleyball training. Int J Sports Med. 2020;41(7):468–74. https://doi.org/10.1055/a-1087-2183.
23. Tometz MJ, Jevas SA, Esposito PM, Annaccone AR. Validation of internal and external load metrics in ncaa d1 women's beach volleyball. J Strength Cond Res. 2022;36(8):2223–9. https://doi.org/10.1519/jsc.0000000000003963.
24. Clemente FM, Silva AF, Clark CCT, Conte D, Ribeiro J, Mendes B, Lima R. Analyzing the seasonal changes and relationships in training load and wellness in elite volleyball players. Int J Sports Physiol Perform. 2020;15(5):731–40. https://doi.org/10.1123/ijspp.2019-0251.
25. Horta TAG, Bara Filho MG, Coimbra DR, Miranda R, Werneck FZ. Training load, physical performance, biochemical markers, and psychological stress during a short preparatory period in Brazilian elite male volleyball players. J Strength Cond Res. 2019;33(12):3392–9. https://doi.org/10.1519/jsc.0000000000002404.
26. Andrade DM, Fernandes G, Miranda R, Reis Coimbra D, Bara Filho MG. Training load and recovery in volleyball during a competitive season. J Strength Cond Res. 2021;35(4):1082–8. https://doi.org/10.1519/jsc.0000000000002837.
27. Falk Neto JH, Tibana RA, de Sousa NMF, Prestes J, Voltarelli FA, Kennedy MD. Session rating of perceived exertion is a superior method to monitor internal training loads of functional fitness training sessions performed at different intensities when compared to training impulse. Front Physiol. 2020;11:919. https://doi.org/10.3389/fphys.2020.00919.
28. Taylor JB, Kantor JL, Hockenjos TJ, Barnes HC, Dischiavi SL. Jump load and landing patterns of collegiate female volleyball players during practice and competition. J Sports Med Phys Fit. 2019;59(11):1892–6. https://doi.org/10.23736/s0022-4707.19.09650-6.
29. Putlur P, Foster C, Miskowski JA, Kane MK, Burton SE, Scheett TP, McGuigan MR. Alteration of immune function in women collegiate soccer players and college students. J Sports Sci Med. 2004;3(4):234–43.
30. Brink MS, Visscher C, Arends S, Zwerver J, Post WJ, Lemmink KA. Monitoring stress and recovery: new insights for the prevention of injuries and illnesses in elite youth soccer players. Br J Sports Med. 2010;44(11):809–15. https://doi.org/10.1136/bjsm.2009.069476.
31. Kupperman N, Curtis MA, Saliba SA, Hertel J. Quantification of workload and wellness measures in a women's collegiate volleyball season. Front Sports Act Living. 2021;3:702419. https://doi.org/10.3389/fspor.2021.702419.
32. Skazalski C, Whiteley R, Bahr R. High jump demands in professional volleyball-large variability exists between players and player positions. Scand J Med Sci Sports. 2018;28(11):2293–8. https://doi.org/10.1111/sms.13255.
33. Ungureanu AN, Brustio PR, Boccia G, Rainoldi A, Lupo C. Effects of presession well-being perception on internal training load in female volleyball players. Int J Sports Physiol Perform. 2021;16(5):622–7. https://doi.org/10.1123/ijspp.2020-0387.
34. Akyildiz Z, de Oliveira Castro H, Çene E, Laporta L, Parim C, Altundag E, Akarçeşme C, Guidetti G, Miale G, Silva AF, et al. Within-week differences in external training load demands in elite volleyball players. BMC Sports Sci Med Rehabil. 2022;14(1):188. https://doi.org/10.1186/s13102-022-00568-1.