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Article

Acute and Chronic Training Load Effects on Elite Volleyball Players

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Featured Application: Coaches and sports scientists can use the study's findings to better balance training loads, particularly during high-intensity or high-frequency jump sessions. Monitoring the number of jumps and recovery status can help prevent performance declines and reduce injury risks associated with excessive fatigue. The positive effects of post-activation performance enhancement (PAPE) suggest that carefully planned high-frequency jump sets can be integrated into training or warm-up routines to enhance performance. For instance, including PAPE-inducing exercises before competitions could improve vertical jump performance during games. Periods of high training loads should be followed by strategic recovery phases to mitigate residual fatigue effects, particularly in agility and jump performance. Periodization strategies that account for these findings can optimize performance peaks during key matches or tournaments. The maintenance or improvement of vertical jump height during training can serve as a practical and accessible indicator of an athlete's training status and overall adaptation. Coaches can incorporate regular jump performance assessments into their practice routines to gauge athletes' readiness and make real-time adjustments. Identifying and addressing the signs of residual fatigue—such as declines in jump height or agility—can help optimize athlete performance in subsequent sessions. Incorporating active recovery techniques, nutritional strategies, and adequate sleep can complement the training and recovery process.

Abstract: This study investigated the acute and chronic effects of training load on vertical jump height, agility, and recovery status in elite male volleyball players. Eleven athletes' internal load was monitored over two 3-week periods, with external load quantification and recovery status assessed in weeks 3 and 7. Countermovement jump and agility tests were conducted pre- and post-training sessions. Results showed higher training load in the first period compared to the second, influencing motor performance, with better outcomes observed in the second period. No negative acute effects on motor performance were found; two sessions showed post-session CMJ improvement, potentially influenced by jump frequency and quantity within those sessions. Periods of high or reduced TL impacted motor performance, specifically vertical jump height and agility. Vertical jump results proved sensitive to TL fluctuations, providing insights into training status, recovery, and motor performance. Reducing TL strategically during the season facilitated physical recovery and positive motor performance adaptations. This suggests managing training load strategically can optimize performance and recovery in elite volleyball players.

Keywords: volleyball; internal load; external load; vertical jump

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1. Introduction

Elite volleyball athletes face intense physical demands, performing repeated high-intensity movements like jumps, sprints, and rapid changes in direction throughout a long and grueling season [1]. Optimizing training is crucial for maximizing performance and minimizing injury risk [2]. This requires careful management of training load, encompassing both external loads, the measurable physical demands placed on the athlete (e.g., jump height, distance covered), and internal load, the individual psychophysiological response to those demands (e.g., perceived exertion, heart rate) [3].

The ability to jump high is a critical determinant of success in volleyball, influencing actions such as serving, attacking, and blocking [4,5]. However, the repetitive nature of these high-intensity movements can lead to fatigue, potentially impairing performance and increasing the risk of injury [6]. Effective training programs must carefully balance the application of training stimuli with adequate recovery to mitigate these risks [7].

Monitoring both EL and IL provides valuable insights into an athlete's training status and readiness [3]. Recent research has explored EL and IL in elite male volleyball, examining training session characteristics [8,9], weekly load distribution [10–12], and seasonal variations [13–15], using methods such as rate of perceived exertion (RPE) and jump count as the most commonly used [16,17]. These studies have revealed a correlation between increased TL and poorer recovery, well-being, and a heightened risk of injury [11,14,18]. Furthermore, EL varies among players depending on their specific roles and the associated movement demands [15,19].

Despite growing interest in TL monitoring, there remains considerable debate regarding the relationship between EL and IL [8,20,21], likely due to variations in experimental designs and participant characteristics across studies. The complex interplay of exercise structure, training objectives, session types, and the distribution of stimuli and recovery further complicates this relationship. Moreover, there is a limited understanding of how accumulated TL acutely and chronically affects performance, and how TL fluctuations relative to game day impact athletes.

This study investigates the acute and chronic effects of IL and EL on neuromuscular performance and recovery status in elite male volleyball athletes at two distinct points in the season. We aim to address the current knowledge gap by examining how these factors influence performance in vertical jumps and multidirectional movements, key determinants of success in modern volleyball. Furthermore, we will analyze the relationship between EL and IL to provide practical insights for optimizing training programs and enhancing athletic performance.

2. Materials and Methods

2.1. Sample

The sample consisted of 14 male elite volleyball athletes from the same team competing in Brazil's 1st division. Participants were non-randomly selected based on convenience, considering their acceptance and availability. Athletes (22.35 ± 4.14 years; 194 ± 9 cm; 89.15 ± 7.89 kg; 23.81 ± 2.16% body fat; 41.2 ± 5.62 cm CMJ) signed an informed consent form (ICF) after receiving verbal and written explanations about the study's risks, benefits, and procedures. This observational research was approved by the São Paulo University Research Ethics Committee (protocol: 23926919.9.0000.5659).

2.2. Study Design

The study monitored the second part of the competitive season, following the year-end break. The design comprised two 3-week periods (Period 1 [P1] and Period 2 [P2]), separated by a 1-week break, totaling 7 weeks. During this time, 53 training sessions (physical, technical, tactical, technical-tactical, and simulated games) and 6 official matches were conducted. Internal Load (IL) was monitored across P1 and P2. Additional analyses, including External Load (EL), motor tests (pre- and post-training), and recovery/well-being questionnaires, were performed during weeks 3 and 7. These analyses spanned three consecutive days (Tuesday, Wednesday, and Thursday) in each respective week. Three athletes withdrew for personal reasons, resulting in a final sample size of 11 participants.

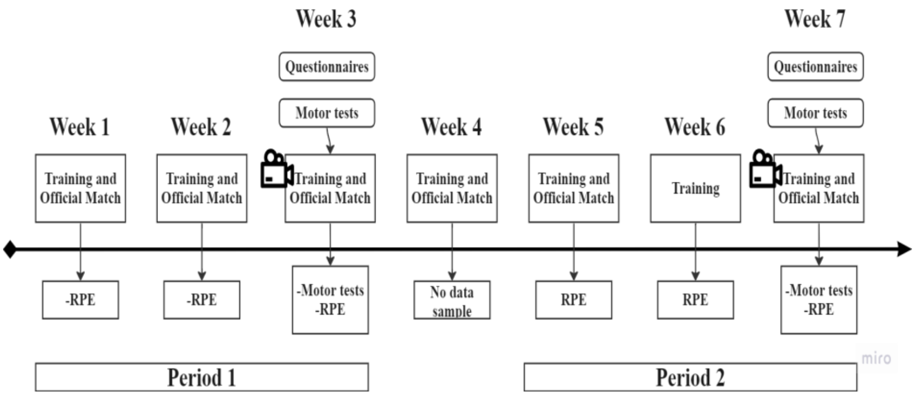

Figure 1. Study design.

2.3. Body Composition

Body composition was assessed using dual-energy X-ray absorptiometry (DXA) with a GE Lunar iDXA device (GE Healthcare, Madison, WI, USA) and Encore 2011 software (version 13.6). Total body mass, lean mass, and fat mass were measured to characterize the sample. All assessments were conducted by the same technician to ensure consistency, with the equipment calibrated before each session.

2.4. Internal Load

Internal Load (IL) was quantified using Foster's perceived exertion method (Borg CR-10 scale). Thirty minutes after each session, athletes rated their effort using the question: "How was your training?" IL metrics were calculated as follows:

- Session Load (sRPE): RPE × session duration (minutes).
- Daily Training Load (TL): Sum of all sRPE values for a day.
- Period Training Load (PTL): Sum of TL values across a period.
- Total Weekly Training Load (TWTL): Sum of TL values across a week.
- Monotony (Mnt): Weekly load average ÷ standard deviation (SD).
- Strain: TWTL × monotony.

Results were expressed in Arbitrary Units (AU).

2.5. External Load

External Load (EL) was quantified by counting jumps during training. Sessions were filmed using a GoPro Hero 5 camera (GoPro Inc., USA) positioned behind the court, ensuring an unobstructed view of the athletes. Jumps were classified based on their context (e.g., attacking, blocking, serving). An experienced evaluator performed the analysis, with reliability confirmed by a second evaluator. A randomly selected session (18% of total footage) demonstrated excellent inter- and intra-rater agreement (ICC = 0.99).

2.6. Motor Tests

Motor performance was assessed through vertical jump (CMJ) and agility tests conducted pre- and post-training. Athletes performed a standardized warm-up (flexibility exercises, multidirectional movements, and jumps) before testing. Each test was performed three times per session, and the average score was used for analysis [22].

- Vertical Jump: CMJ height was measured using the Jump System Pro contact mat (Cefise, Nova Odessa, Brazil) based on Bosco's protocol.
- Agility: The Pro Agility Test involved running specific distances and touching markers. Times were recorded using a Vollo VL1809 hand stopwatch (1/100-second accuracy).

Data collection followed established protocols for CMJ [23] and agility [24].

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2.7. Questionnaires

To evaluate recovery status and subjective perception of fatigue, athletes completed two questionnaires daily before the first training session during test weeks. Responses were collected via Google Forms (Google©, USA).

- Well-Being Scale (WB): This scale assessed five dimensions: overall fatigue, sleep quality, general muscle pain, mood, and stress levels. Athletes rated each item on a scale from 1 (worst perception) to 5 (best perception), based on their current condition at the time of response [25]. The overall well-being index was calculated as the sum of the scores across all dimensions, providing a comprehensive measure of athlete well-being.
- Total Quality Recovery (TQR): This visual analog scale evaluated the athletes' subjective perception of recovery. Scores ranged from 6 (very poorly recovered) to 20 (very well recovered) [26]. The athletes selected a single value corresponding to their recovery status, which was directly used for data analysis.

This standardized approach ensured consistent and reliable insights into the athletes' recovery and fatigue levels throughout the study.

3. Results

3.1. Analysis of Periods 1 and 2

The data for periods 1 and 2 are presented in Table 1. Statistical tests revealed significant differences in IL parameters between P1 and P2 ($p < 0.05$) and between weeks ($p < 0.01$). Post hoc analyses showed that RPE, TWTL, monotony (Mnt), and strain were higher in P1 compared to P2 ($p < 0.05$).

Within P1, there were no significant differences in PSE across weeks. However, TWTL and strain were higher in week 1 compared to week 2 ($p < 0.01$), while Mnt was lower in week 2 ($p < 0.02$). In P2, significant differences were found for RPE and Mnt in week 2 ($p < 0.01$), and TWTL and strain were higher in week 1 compared to weeks 2 and 3 ($p < 0.01$). Additionally, TWTL and strain in week 2 were lower than in week 3 ($p < 0.01$).

Pairwise week analysis indicated significant differences in TWTL ($p < 0.05$) and strain ($p < 0.01$) between weeks 1 and 2, Mnt between weeks 1, 2 ($p < 0.01$), and 3 ($p = 0.02$), and RPE in week 2 ($p < 0.01$).

Table 1. Periods 1 and 2 internal load values (mean ± SD).

Period 1*				**Period 2**		
	week 1	**week 2**	**week 3**	**week 5**	**week 6**	**week 7**
RPE	5,.6 ± 1,1	**5,5 ± 1,0a**	5.6 ± 0.7	5,8 ± 0,9	**3,8 ± 0,9****	5,6 ± 0,9
TWTL (AU)	**6.942,27 ± 1.361,68**b**	**5.121,82 ± 915,59b**	4.703.09 ± 587,86	**6.252,27 ± 902,11****	**4.453,64 ± 646,07!**	5.113,64 ± 848,92
Monotony	**1,8a**	**1,5a#**	**1,7c**	1,6	**0,9****	1,6
Strain (AU)	**1.2576,44 ± 2.861,07a****	**7.650,38 ± 1.473,77a**	8.152,36 ± 1.225,86	**9.972,98 ± 1.760,30****	4.182,43 ± 706,11	8.214,43 ± 1.847,89

RPE = Rating of Perceived Exertion; TWTL = Total Week Training Load, AU = Arbitrary units. * = difference ($p < 0.05$) between periods; ** = difference ($p < 0.01$) within period; # = difference ($p < 0.02$) within period, ! = difference ($p < 0.01$) to following week; a = difference ($p < 0.01$) to pared week; b = difference ($p < 0.05$) to pared week; c = difference ($p = 0.02$) to pared week.

3.2. Analysis of Test Weeks Results

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Data for Test Weeks 1 and 2 are shown in Table 2. In P1, PTL, average load, Mnt, and strain were significantly higher than in P2 ($p < 0.01$). Within-week comparisons in P1 revealed significant differences in RPE, sRPE, TL, and the number of jumps on paired days ($p < 0.01$).

During Test Week 1, TL for D1.1 was higher than D2.1 ($p < 0.01$). RPE for court training on D2.1 was higher compared to D1.1 ($p < 0.02$) and D3.1 ($p < 0.01$), while sRPE was lower on D3.1 ($p < 0.01$) and D2.1 ($p = 0.05$) compared to D1.1. The number of jumps and frequency of jumps were significantly higher on D1.1 ($p < 0.01$) and lower on D2.1 ($p < 0.01$) compared to D3.1.

During Test Week 2, TL was higher on D2.2 compared to other days ($p < 0.01$). RPE and sRPE for D1.2 were lower compared to D3.2 and D2.2 ($p < 0.05$). There were no differences in the number and frequency of jumps within the week.

Paired day comparisons between weeks revealed significant differences in RPE for D2 and D3 (D2.1 vs. D2.2 and D3.1 vs. D3.2) ($p < 0.01$). For sRPE, significant differences were observed in D1 ($p < 0.02$), D2, and D3 ($p < 0.01$). Differences were also found in CT for D1, D2, and D3 ($p < 0.01$) and in the number of jumps for D1 and D2 ($p < 0.01$).

Table 2. Internal and external load data from the testing weeks (weeks 3 and 7).

	Week Test 1						**Week Test 2**					
	Day 1.1		**Day 2.1**		**Day 3.1**	**Mean**	**Day 1.2**		**Day 2.2**		**Day 3.2**	**Mean**
TQR	14.70 ± 1.91		12.50 ± 3.02		14.38 ± 2.69		14.09 ± 2.39		14.18 ± 1.19		14.50 ± 2.04	
WB	15.10 ±1.78		13.80 ± 3.01		16.00 ± 2.52		15.91 ± 1.93		15.45 ± 2.15		16.64 ± 2.57	
Session Mode	Strength	Block + Technical	x	Fitness + Serve-receive	Strength	Technical + Attack-block	x	Block + Attack-block	Strength	Side out + simulated game	x	Side out/transitions + simulated game
Time (min)	60	88	x	86	60	68	x	80	60	85	x	71
RPE	5.18 ± 1.34	7.27 ± 0.86	x	**8.45 ± 1.16a!**	6.50 ± 1.15	6.27 ± 0.96	x	**6.55 ± 1.37b**	6.09 ± 1.16	7.27 ± 0.96	x	**7.91 ± 0.79!**
sRPE (AU)	310.91 ± 80.17	**640.00 ± 75,89**!**	x	**727.09 ± 99.51a!**	390.00 ± 68.89	426.55 ± 65.42	x	**523.64 ± 109.82b**	365.45 ± 69.85	618. 18 ± 81.78	x	**561.55 ± 56.27!**
Jumps		**112.3a!**	x	**39.3***		68.2	x	98.9		**75.9!**	x	75.4
Jump/min		**1.63a!**	x	0.94		1.10	x	1.40		1.10	x	1.30
TL (AU)	**950.91 ± 142.20a!**		**727.09 ± 99.51***		**816.55 ± 116.62!**		523.64 ± 109.82		**983.64 ± 139.95a!**			561.55 ± 56.27
PTL (AU)						**2494.55 ± 249.17#**						2068.82 ± 241.57
Mean TL (AU)						**831.52#**						689.61
Monotony						**3.34#**						2.85
Strain (AU)						**8324.64#**						4411.00

AU = arbitrary units; RPE = Rating of Perceived Exertion; sRPE = session Rating of Perceived Exertion; TL = daily Training Load; PTL = Period Training Load; TQR = Total Quality Recovery; WB = Well Being questionnaire. * = difference to following day ($p < 0.01$); ** = difference to following day ($p < 0.05$); a = difference within the week ($p < 0.01$); b = difference within the week ($p < 0.05$); ! = difference to pared day ($p < 0.01$); # = difference to week 2 ($p < 0.01$);.

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3.3. Analysis of the Training Effect on Motor Performance

Table 3 summarizes motor performance data. Differences in performance were observed between periods, with week 7 (P2) showing better vertical jump (CMJ) height ($p < 0.01$) and agility ($p < 0.02$).

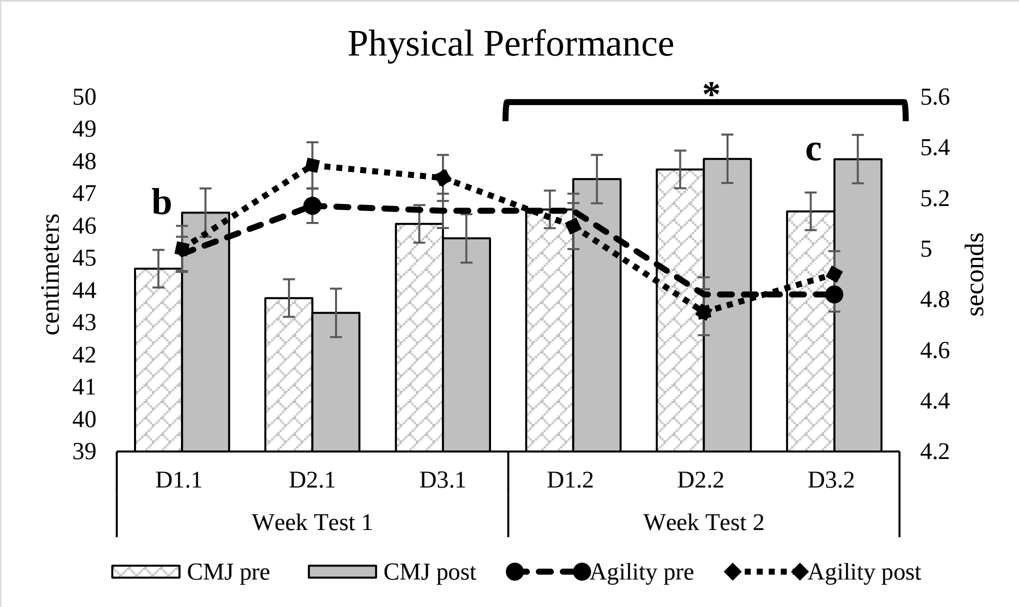
Within-week comparisons in week 3 revealed better CMJ performance on D1.1 compared to D2.1 ($p < 0.05$) and better agility on D1.1 compared to D2.1 and D3.1 ($p < 0.01$). In week 7, agility performance was worse on D1.2 compared to D2.2 and D3.2 ($p < 0.001$), with no differences in CMJ. Paired day comparisons showed differences in CMJ for D2 ($p < 0.001$) and agility for D2 and D3 ($p < 0.001$).

A training effect ($p < 0.03$) was identified for CMJ performance on D1.1 ($p < 0.01$) and D3.2 ($p < 0.04$), but no effect was observed for agility performance.

Table 3. Data from motor tests carried out before and after training sessions (mean ± SD).

		Week Test 1									
		Counter Movement Jump (cm)					**Pro Agility Test (s)**				
			95% CI	Δ%	ES	ICC		95% CI	Δ%	ES	ICC
Day 1.1	pre	**44.67 ± 6.45!**	40.34 – 49.01	3.7	0.27	0.96	**4.98 ± 0.39****	4.71 – 5.24	0.6	0.05	0.66
	post	**46.41 ± 6.40b**	42.11 – 50.72				**5.00 ± 0.30**	4.81 – 5.21			
Day 2.1	pre	43.76 ± 5.12	40.32 – 47.20	-2.6	0.09	0.95	5.17 ± 0.25	5.00 – 5.34	3.1	0.54	0.51
	post	43.30 ± 5.23	39.78 – 46.81				5.33 ± 0.33	5.11 – 5.55			
Day 3.1	pre	46.06 ± 4.86	42.79 – 49.33	-1.	0.09	0.99	5.15 ± 0.30	4.94 – 5.35	2.5	0.40	0.64
	post	45.61 ± 4.39	42.66 – 48.56				5.28 ± 0.35	5.04 – 5.52			
		Week Test 2									
		Counter Movement Jump (cm)					**Pro Agility Test (s)**				
			95% CI	Δ%	ES	ICC		95% CI	Δ%	ES	ICC
Day 1.2	pre	**46.51 ± 4.98**	43.17 – 49.86	3.2	0.16	0.96	**5.15 ± 0.21****	5.00 – 5.29	-1.0	0.28	0.85
	post	**47.45 ± 6.38**	43.16 – 51.74				**5.09 ± 0.21**	4.95 – 5.24			
Day 2.2	pre	**47.75 ± 5.68a**	43.94 – 51.57	2.0	0.05	0.98	**4.82 ± 0.19a**	4.69 – 4.95	-1.5	0.34	0.86
	post	**48.08 ± 6.52**	43.70 – 52.46				**4.75 ± 0,21**	4.61 – 4.89			
Day 3.2	pre	**46.45 ± 5.58**	42.71 – 50.21	3.0	0.27	0.95	**4.82 ± 0.31a**	4.61 – 5.03	1.6	0.31	0.84
	post	**48.07 ± 6.33c**	43.81 – 52.33				**4.90 ± 0.19**	4.77 – 5.02			

cm = centimeters; s = seconds; CI = Confident Interval, ES = Effect size, ICC = Intraclass correlation coefficient. * = difference to week test 1 ($p < 0.02$); ** = difference within the week ($p < 0.01$); ! = difference to following day ($p < 0.01$), a = difference to pared day ($p < 0.01$), b = difference between moments (pre x post) ($p < 0.01$), c = difference between moments (pre x post) ($p < 0.05$).



Graphic 1. Analysis of the acute and chronic effect of training load on athletes' motor performance (mean ± SE). * = difference to week test 1 ($p < 0.02$), b = difference between moments (pre x post) ($p < 0.01$), c = difference between moments (pre x post) ($p < 0.05$).

3.4. Correlations

Correlation analysis excluded libero players due to the low number of jumps performed. No significant correlation was found between the number of jumps and RPE or sRPE. A moderate correlation was observed between session duration and sRPE ($r = 0.59$; $p < 0.01$), TQR and WB scales with RPE ($r = -0.47$ and -0.40, $p < 0.01$), sRPE ($r = -0.45$ and -0.50, $p < 0.01$), and between TQR and WB ($r = 0.53$; $p < 0.01$).

The number of jumps on D1.1 showed a moderate correlation with WB on the following day (D2.1) ($r = -0.67$, $p < 0.05$). Weak correlations were found between CMJ and agility performance ($r = 0.30$; $p < 0.05$).

4. Discussion

This study analyzed the acute and chronic effects of training load on the motor performance of professional volleyball athletes, as well as the relationship between external load (EL) and internal load (IL). The main findings indicate that the training sessions analyzed did not acutely impair motor performance. On the contrary, the number and frequency of vertical jumps performed by the athletes contributed to improved jump height in some sessions. As a chronic effect, it was observed that periods of high training loads or significant load reductions influenced motor performance, particularly in terms of vertical jump height and agility.

Although no correlation was found between the number of jumps performed and the perceived IL of the athletes, IL was more closely related to the duration of the training session. Previous studies have indicated that intense training sessions may lead to energy depletion and intramuscular metabolite accumulation, resulting in expected performance reductions [27]. However, in this study, the recovery interval between stimuli (~30s) appeared sufficient to maintain motor performance, as corroborated by Guan et al. [28] and Carroll et al. [29].

The results showed that the significant number of jumps performed on D1.1 negatively impacted the recovery status reported by the athletes, affecting vertical jump performance on D2.1 and agility performance on D2.1 and D3.1. This residual fatigue effect was observed for at least 24 hours in vertical jump performance and 48 hours in agility. Previous studies, such as that of Thomas et al. [2],

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also indicated that intense stimuli like jumps or sprints could reduce neuromuscular function for similar periods.

Despite this, the positive results in vertical jump performance on D1.1 and D3.2 suggest an effect of post-activation performance enhancement (PAPE). The high frequency of jumps and maintenance of performance may be related to the athletes' adaptation to daily intense training, which promotes resistance to muscular fatigue and improvements in the stretch-shortening cycle [30]. Factors such as increased muscle temperature, enhanced blood flow, and higher firing frequency of alpha motor neurons may also contribute to improved performance [31,32].

Additionally, short intervals between actions (~30s) may be sufficient for partial recovery and performance maintenance in volleyball. This phenomenon aligns with studies showing that intermittent stimuli allow efficient recovery, particularly in well-trained athletes [33,34], and suggest that the ability to maintain or increase jump height after training serves as a training state marker.

Similar findings were reported by Berriel et al. [35], where a combination of strength and plyometric exercises before a 60-minute technical/tactical session led to improved vertical jump performance in athletes. Similarly, Villalon-Gasch et al. [36] analyzed the effect of PAPE in female volleyball players during a real game. Comparing a control group (normal warm-up) to an experimental group (strength stimuli), they measured vertical jump performance at various intervals: post-activation (8 min), pre-game (23 min), and across five sets (46, 68, 95, 120, and 123 min). The experimental group achieved peak jump height after the 2nd set (68 minutes post-activation), while the control group peaked after 90 minutes. However, by the 3rd set, both groups showed similar performance improvements, with the PAPE effect diminishing by the end of the match.

In our study, there was a difference between the loads and the motor performance of the analyzed periods, demonstrating that cumulative exposure to training sessions can both improve and impair athletic readiness. In week 6, the team had three consecutive days off, and there were no official matches, allowing for a significant reduction in chronic TL and strain. In this context, the lower demand condition led to improved motor performance in the test week, functioning as a tapering period [37]. Regarding the accumulation of vertical jumps performed by volleyball players, de Leew et al., [38] found that performing a large number of jumps in the week before the game is related to worse reception performance, possibly due to neuromuscular fatigue interfering with fine control of technical movement and can be an indicator of the cause of injury [39]

The correlation between TQR and WB scale results with RPE values reinforces that athletes' recovery status influences their perception of effort. Although no direct influence of training load on next-day motor performance was observed, excessive jump loads did have an impact. Monitoring chronic load accumulation is essential to adjust planning, optimize performance, and reduce injury risk [12].

Finally, our findings highlight that maintaining or improving vertical jump performance after training sessions can serve as a key marker of training status in volleyball. Load management strategies should be refined to maximize performance and prevent adverse effects of fatigue accumulation.

5. Limitations

This study is not without limitations, and among these, we can list: (i) only one volleyball team was evaluated, which hinders the extrapolation of data regarding the load effect; (ii) the results reflect the analysis of a few weeks of training in the second part of the season; (iii) the analysis was performed considering the team and was not divided by positions and game functions.

6. Conclusions

In our study, it was found that vertical jump measures are effective in assessing the athletic readiness of elite volleyball players. In this sense, it was observed that sessions with EL involving a large number of vertical jumps can enhance jump height performance through mechanisms related

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to the PAPE effect. This effect can last until the end of sessions lasting around 90 minutes, provided that fatigue does not surpass potentiation, and this balance is related to individual variables such as strength level, task adaptation, and athletic condition. On the other hand, sessions with large quantities of vertical jumps should be avoided up to 3 days before an official game since the residual effect can impair athletes' physical and cognitive performance. Thus, volleyball training sessions should be divided into sessions capable of promoting sufficient stimuli for the activation of potentiation mechanisms and sessions to develop/maintain specific motor endurance for the sport.

Accumulated load has an effect on athletes' motor performance, and a week with reduced training load near the end of the season was able to provide subsequent improvement in vertical jump performance and agility. No correlation was observed between the IL analyzed by RPE and the EL of vertical jumps, a fact that has already been observed in scientific literature, including questioning the adequacy of terms for their purpose.

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Conflict of Interest: The authors declare no conflicts of interest that could influence the research outcome.

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