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ORIGINAL ARTICLE
EXERCISE PHYSIOLOGY AND BIOMECHANICS

Jump performance and mechanics after a regular training bout in elite volleyball players

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ABSTRACT

BACKGROUND: Volleyball is a complex intermittent sport characterized by short explosive technical movements, many of which involve vertical jumping. The assessment of mechanical jumping variables in relation to both injury prevention and performance enhancement through the use of wearable technologies is becoming a new training tool among professional volleyball players.

METHODS: The present study aimed to assess the vertical jumping mechanics before and after a controlled load (volume and intensity) of a routine volleyball training session among male professional players. Twelve male elite professional volleyball players (23.7±4.9 years, 198.1±6.2 cm, 92.2±10.3 kg) of national and international level belonging to the same Brazilian first league team were recruited. Biomechanical analysis of vertical unilateral countermovement jump (CMJ) and bilateral CMJ tests were performed before and after a routine training session of these players at their usual training court. An inertial orientation sensor placed at the third lumbar vertebra was employed for biomechanical data collection.

RESULTS: In relation to the unilateral CMJ, a 10% decrease ($P=0.02$) in the vertical ground reaction force after training compared to pretraining values was observed. However, no significant differences were observed in the remaining outcomes. Regarding the bilateral CMJ, no significant differences were observed in all assessed outcomes.

CONCLUSIONS: Our findings showed no evidence of fatigue after a controlled regular in season volleyball training session in professional players. In addition, this volleyball training session induced a significant reduction in the vertical ground reaction force during unilateral CMJ in volleyball players.

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KEY WORDS: Fatigue; Education; Team sports.

Volleyball is a complex intermittent sport characterized by short explosive technical movements, many of which involve vertical jumping. In numerous defensive (blocking) and offensive (attacking, passing, and serving) movements, players are required to jump vertically as high as they are capable of doing, as the game revolves around a net at 2.43 and 2.24 meters above the floor for men and women respectively.[1] International male volleyball players usually perform a minimum of one jump movement during a rally of an average length of 11 s (range: 3 to 40), interspersed with rest periods of an average length of 14 s (range: 4 to 38),[2] requiring players to repeatedly perform lower-limb explosive jumping actions. Thus, the capacity to generate lower-limb explosive power is critical in obtaining success during a game or competition.[3] The modern sport demands have imposed greater vertical jump ability, improving the technical jumping offensive and defensive movements in elite volleyball. These factors are critical to the success of a team, considering that most of the points scored during a match occurred with jump activities.[4] Consequently, an excellent jumping performance, as well as an adequate repeated jumping capacity, is required in professional volleyball in order to cope with the competitive game demands.[5] This jump capabilities are often attenuated in response to fatigue during training or competition, reducing the squad performance and increasing the injury risk. Measurement of jumping performance can be utilized as a functional tool to measure fatigue within a training session.[6] In this context, assessing jumping performance changes cross training sessions are of paramount importance to avoid undesirable training-induced fatigue in professional male volleyball players, once this measurement is able to identify the athlete's neuromuscular status at each training session.

Fatigue is a complex, interactive, and multifactorial physiological process in which neuromuscular capacity is decreased over time causing feeling of weariness with prolonged muscular activity.[7-9] These physiological processes are usually reflected in sport physical performance decrements, including decreased isometric strength,[10] impaired movement control,[11] delayed reaction capacity[12] misalignment of the lower extremities, impaired dynamic joint stability,[11] decreased joint proprioception[11] and decreased ability for jump landing.[11] Moreover, in recent years, new testing devices have been developed in order to evaluate jumping mechanics of athletes in their habitual training environment.[13] These tools enable the coaches and sport clinicians to objectively quantify several jumping mechanical variables allowing the monitoring and evaluation of the level of fatigue and injury risk during training sessions.

Recently, a framework by Vanrenterghem *et al.*[14] has proposed to quantify separately physiological and biomechanical training loads across the training routine. In light of this, the on-field monitoring of the external load and fatigue level are of overriding importance due to: 1) fatigue is one of the main injury incidence risk factors in volleyball;[15] and 2) the monitoring of external load and associated fatigue may optimize the neuromuscular training-induced adaptations.[4, 14, 16] It is important to select the optimal training load (*i.e.* adequate intensity and volume) in order to promote an adequate training stimulus to safeguard the implementation of under- or overload during the training intervention.[16] Ankle and knee joint injuries are not infrequent in volleyball,[15] especially during jump-landing tasks within the context of training with muscular fatigue.[11, 15] Considering that an excellent jumping performance and repeated jumping capacity are required in professional volleyball, and the lack of data concerning the changes in jump performance and mechanics after a regular training session among elite male volleyball players, the current study aimed to assess the vertical jumping mechanics before and after a load controlled (*i.e.* number of jumps) volleyball training session among male professional players. The study hypothesis was that in the presence of neuromuscular fatigue, several biomechanical adaptations such as an increased vertical ground reaction force (VGRF) or a jumping performance decrease would be observed in the training court itself through the utilization of an ISU based biomechanical evaluation of the unilateral CMJ and bilateral CMJ tests.

Materials and methods

Participants

Twelve male elite professional volleyball players (23.7±4.9 years, 198.1±6.2 cm, 92.2±10.3 kg) of national and international level belonging to the same Brazilian first league team were recruited. The study was approved by the local ethics committee, in accordance to the Helsinki Declaration. All players were informed about the testing protocol and the possible risks/benefits and signed a consent form. All the testing players were injury free at the time of the experimental testing.

Jump performance testing protocol

After anthropometric measurements (*i.e.*, body mass and height) and a standardized general warm-up, participants performed the vertical jumping tests battery. The athletes were instructed to keep their hands on their hips during the execution of each maneuver. No added technical instructions about the jumping modality were given to the athletes to avoid modifications during the hopping task execution. Participants performed a testing familiarization including three submaximal repetitions for each type of jump before the tests (only before the training session) Therefore, the highest jump was selected for individual (within player) analysis.

Participants started the tests in the orthostatic position, and then performed three consecutives bilateral CMJ repetitions interspersed by 10 sec rest between attempts. Thereafter participants performed three unilateral CMJ with each limb, holding a balanced position at landing. Participants were vigorously encouraged to perform maximally in every jump. For each jump, the vertical (Z axis) velocity *versus* time curve was depicted and used to determine the

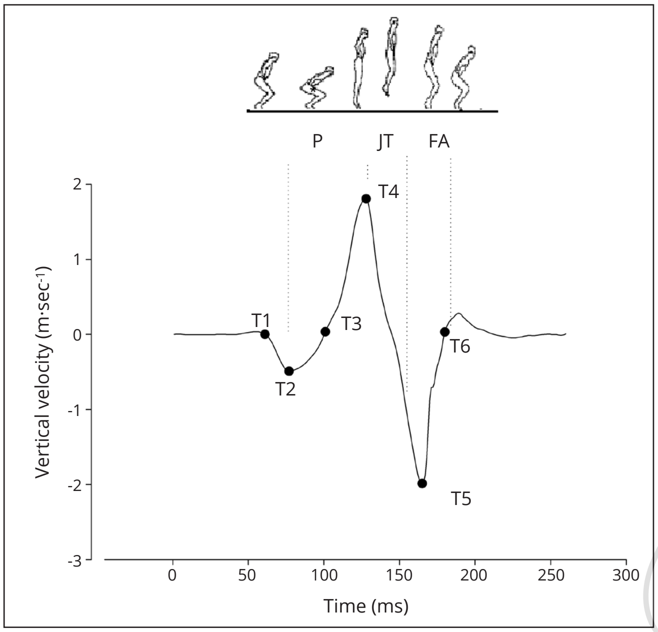

Figure 1.—Speed-time curve of a CMJ jump, extracted from the publication of Setuain *et al.*[13]
P: Propulsive phase; JT: jumping time; FA: final attenuation.

jumping phases, as illustrated in Figure 1.[13] The recorded variables for both bilateral and unilateral jump tasks were: preload negative exerted force (VF1), peak vertical ground reaction force at landing (VF2), propulsive vertical impulse (PVI), power output (P) and jump height (H). Data regarding unilateral CMJ was expressed as a mean of the two limbs. The reliability of the calculation of these variables through the employment of an ISU has been previously validated by Setuain *et al.*.[13] After completion of the training session, the battery of jump tests was replicated. The onset of fatigue was considered as a decrease in the jump height of the players greater than a 10% from baseline to post-training jump test values. The 10% decrease in jump height has been shown to have a high correlation with fatigue onset in sport.[17] An inertial orientation sensor (ISU) (MTx, 3DOF Human Orientation Tacker, XSens Techonolgies BV Enschede, Enschede, the Netherlands) placed at the third lumbar vertebra was employed for biomechanical data collection. The technical explanation about the ISU based biomechanical evaluation has been previously detailed.[13, 18] Briefly, direct mechanics-based procedures were used to estimate the center of mass displacement and to detail the jumping biomechanics. The direct mechanics procedure is based on the description of the subject as a mechanical system and the estimation of movement and actuation of forces through displacement of the center of mass.[13] The positioning of the ISU at the lumbar spine level, the presumptive location of the human center of gravity,[13] and the vertical velocity by time descriptive curves were both based on this approach.

Training session load monitoring and ratings of perceived exertion data recording

A routine in-season volleyball training session was carried out. Although twelve athletes were assessed pre and post training session, seven players were monitored across the training session, and had their jump performance (frequency and height) assessed by wearing an ISU (Vert Classic, Mayfonk Athletic, Fort Lauderdale, FL, USA) placed at their lumbar spines during the training routine. Validity and reliability of this ISU device has been investigated and publish elsewhere.[19] These athletes' positions were two middle blockers, one opposite, three outsiders, and 1 setter. The athletes also monitored during the training were chosen to use the ISU because they were usually game starters. The rest of the assessed athletes had only their number of jumps monitored by visual counting by the team staff. The number of jumps was controlled despite the positions having different number of jumps in training and games. The athletes changed their positions, through relays, then keeping the number of jumps similar among all the athletes throughout the training. In addition, the training proposed and conducted by the coach provided a similar distribution of lifting for both teams, that is, the teams had a similar distribution in attack and blocking actions, in order to balance the number of jumps. The training session was focused on developing playing strategies and was mainly based on small-sided games with technical and tactical specific objectives. Some other skill activities or volleyball tasks, always with ball, were also conducted. Volleyball nonspecific endurance or resistance training was not performed in the evaluated training session. The training session lasted 120 minutes. Nevertheless, in the case the players individually achieved the number of 110 jumps recorded with the ISU device, they were positioned to perform the post-training jumping test protocol. The number of 110 jumps was selected based on several previous observations performed, in which the team staff observed that 110 induced no losses or up till 2% of losses in the jump performance, whereas 120 jumps induced losses ranging from 10 to 15% of decreases in jump height among these players.

Following procedures previously described:[20, 21] 10-min after completion of the training session a rating of the perceived exertion of the whole training session was solicited from each participant using the modified[20] 0–10-point Borg's ratings of perceived exertion (RPE Scale). We explained to participants that we wanted a global rating of the entire training session, using whatever cues they felt appropriate, aiming to get an uncomplicated response reflecting players' global workout impression. We delayed securing session-RPE for 10 min so that particularly difficult or particularly easy segments toward the end of the exercise bouts would not excessively influence participants' ratings.[22] Players' RPE was obtained without the presence of any other player. Participants were familiarized with the use of the 0-10-point scale before data collection.

Design and procedures

Biomechanical analysis of vertical unilateral CMJ and bilateral CMJ tests were performed before and after a routine training session of professional male volleyball players in Brazil at their usual training court. Firstly, anthropometric data were collected. Secondly, the players were orthostatically positioned for the jumps tests, where ISU reference system was established. The reference frame sensor was aligned with the Z axis (vertical axis), X axis (mediolateral axis) and Y axis (anteroposterior axis). Each jump was broken down into different phases to enable a more comprehensive biomechanical analysis. Different events were defined on the basis of vertical velocity recordings. Once the different events of the jumping maneuvers were identified, the different phases could be defined, and the peak acceleration and orientation variables of each jump were analyzed by jump phase and jump type. For the VUCMJ, the action (the T1 event) began when the first negative Z-acceleration was produced. Next, negative passive and active work (prestretch) was performed during the "propulsive phase." The subsequent T2 event was determined when the maximum vertical negative velocity was reached (lowest position of the center of mass). T3 was denoted by the instant the vertical velocity first passed through zero in the transition between the initial absorption (countermovement in the case of VUCMJ) and the propulsive phases of the jump. The T4 event corresponded to the instant at which the maximum positive vertical velocity was achieved. Subsequently, the T5 event occurred when the vertical (Z-axis) velocity again reached a maximum value, and the final T6 event was denoted by the point when the vertical velocity reached zero after the jump (Figure 1).[13] For every cycle, the Z-velocity signal was used to distinguish the peak from the transition phases of each jump (for example, subject moving upwards ¼ positive Z-velocity at the propulsive phase; subject moving downwards ¼ negative Z-velocity at the landing phase). All of the information was combined to define the boundaries between the different relevant phases: initial absorption, propulsive, and final absorption for the drop jumps (bilateral and unilateral) and propulsive and final absorption for the countermovement jumps (Figure 1).[13] Further description can be found elsewhere.[13]

Once the reference system was established, a general warm-up was performed including three familiarization repetitions for each of the evaluating jumping tasks. Thereafter, the baseline unilateral CMJ and bilateral CMJ tests were performed. Three repetitions for each trial were recorded for statistical analysis. After, a routine in-season volleyball session was then performed. After completion of the training session, the jumping battery test was replicated. In summary, the timeline was conducted as follow: 1) anthropometric measurements and warm-up; 2) bilateral CMJ test; 3) unilateral CMJ test; 4) the load-controlled training session with a limited number of jumps; 5) ratings of perceived exertion (RPE) scale measures; 6) bilateral CMJ test; and 7) unilateral CMJ test.

Statistical analysis

Standard statistical methods were used for calculation of the means, standard deviations (SD), and confidence intervals (95% CI). Data were analyzed using parametric statistics following confirmation of normality by the Shapiro-Wilk Test (N.<50). Differences between pre- and post-training measures were evaluated by two-tailed Student's paired *t*-test. The magnitudes of the differences were assessed using 95% CI and Hedges' *g* effect sizes (ES). Differences were considered non-substantial if the 95% CIs overlapped zero. ES values of 0.2, 0.5, and >0.8 were considered to represent small, moderate and large differences, respectively. Significant level was considered P<0.05 for all analysis. The IMB SPSS Statistics 22 (IBM Corp.; Armonk, NY, USA) software was used. Descriptive statistics are reported as means (±SD).

Results

The participants subjectively reported a mean RPE of 5.4±1.6 after the training session. During the training session players performed 101.7±19.9 jumps (confidence interval 95%: 84, 110) of a mean height of 55.5±9.6 cm (confidence interval 95%: 54, 57).

In relation to the unilateral CMJ, a 10% decrease (P=0.02) in the vertical ground reaction force (VF2) after training compared to pretraining values was observed.

Table I.—*Unilateral CMJ biomechanical outcomes (N.=12).*

Outcome	Pre- Mean (SD)	Post- Mean (SD)	P value (*t*-test)	% Individual changes pre- *vs.* post-	ES Cohen's *d*
(VF1) (N.)	366.4 (149.9)	320.9 (182.6)	0.12	-10.9 (29.6)	0.4
(VF2) (N.)	3766 (1018)	3375 (1051)	0.02(*)	-10.0 (19.0)	0.3
PVI (N./kg/s)	2.3 (0.2)	2.3 (0.3)	0.78	-0.11 (9.5)	0
PO (W/kg)	14.0 (1.9)	14.3 (2.8)	0.63	2.9 (20.4)	0
Jump height (cm)	23.9 (2.3)	23.6 (3.0)	0.5	-1.2 (9.2)	-0.2

VF1: Preload negative exerted force; VF2: peak vertical ground reaction force at landing; PVI: propulsive vertical impulse; PVO: power output and jump height.

Table II.—*Bilateral CMJ biomechanical outcomes (N.=12).*

Outcome	Pre- Mean (SD)	Post- Mean (SD)	P value (*t*-test)	% Individual changes pre- *vs.* post-	ES Cohen's *d*
(VF1) (N.)	732.7 (373.7)	734.1 (261.4)	0.17	30.6 (68.9)	0.0
(VF2) (N.)	4095 (1211)	4033 (1638)	0.56	-2.0 (33.9)	0.0
PVI (N./kg/s)	3.06 (0.2)	3.07 (0.5)	0.5	0.31 (12.1)	0
PO (Watts/kg)	27.4 (5.3)	27.7 (4.8)	0.45	6.9 (27.9)	-0.1
Jump height (cm)	45.0 (5.4)	43.8 (4.6)	0.30	-1.3 (8.3)	0.2

VF1: Preload negative exerted force; VF2: peak vertical ground reaction force at landing; PVI: propulsive vertical impulse; PVO: power output and jump height.

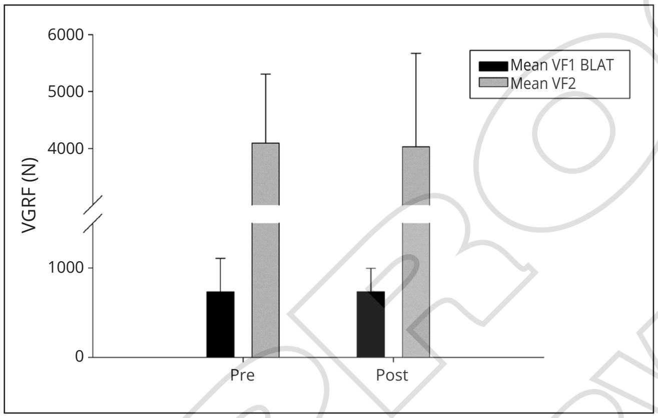

Figure 2.—Bilateral CMJ vertical ground reaction forces (VGR) from pre- to post-training.

However, no significant differences were observed in the remaining variables (Table I). Regarding the bilateral CMJ, no significant changes were found in all the analyzed variables (Table II, Figure 2). When looking for within player alterations, a 17 and 14% jumping performance reduction was observed on player 8 on bilateral and unilateral CMJ respectively (Figure 3).

Discussion

The present study aimed to investigate the influence of a volleyball training session with controlled volume and intensity on different jump performance outcomes among male professional players. The main finding of the present investigation was that no significant changes occurred

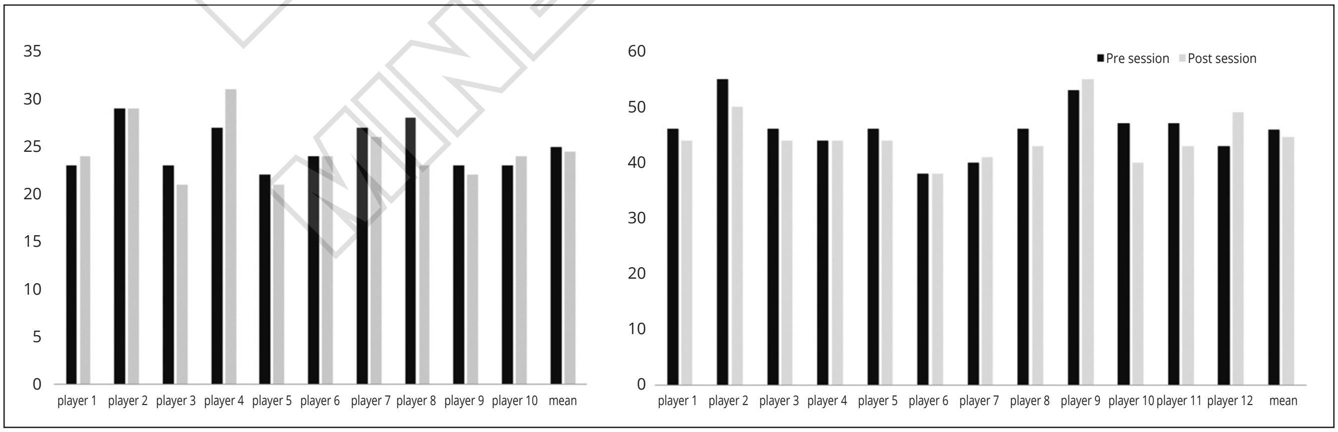

Figure 3.—Jumping performance reduction.

on jumping performance in relation to the training session monitored. In contrast, a significant reduction on the vertical ground reaction force at the landing phase of the unilateral CMJ was observed. No further significant changes were observed in the remaining analyzed variables. This finding suggests that a well-controlled training-load (~100 jumps and ~5 points of RPE) was able to preserve most outcomes of jump performance in top-elite volleyball players during a regular in-season training session. Fatigue onset was not demonstrated during the evaluated training session since there were no significant jumping performance reductions from baseline to post training tests. At an individual level, only one player reported a 14 and 17% jumping performance reduction while the others, remained below the 10%of jumping performance loss considered as indicative for fatigue (Figure 3). Whether this player was suffering from cumulative training volume or may be, he could not cope that session properly was not perceived on RPE reports. On behalf of the observed results, the training session evaluated in the present research could represent an adequate training stimulus with the avoidance of fatigue onset in these players.

The participants of this study exhibited similar bilateral CMJ mean values (≈44 cm; Table II) compared to other elite athletes from Spain,[23] Belgium,[24] and Slovenia[3] as well as slightly lower (-7%) mean values compared to National Teams.[25] In addition, it has been shown a similar bilateral CMJ performance in a previous study investigating another volleyball team of the Brazilian national league.[26] Furthermore, the mean height of the jumps recorded in the volleyball training session of this study (≈55.5 cm) is similar to the mean height of vertical block and attacking jumps test records (≈56.8 cm) reported for Slovenian national level players.[3] Comparisons of our results with those reported in other studies measuring vertical jumping performance in national level volleyball players of similar age are imprecise due to, mainly, the different testing procedures and the measuring devices utilized. It is important to mention that, although small, our study sample is composed of top-elite volleyball players and there are few athletes around the world at this level, especially because Brazilian national team have been part of elite world class volleyball in past decades.

The improvement in the ground reaction force absorption in the unilateral CMJ in these volleyball elite players during the training session may be explained due to the fact that the training session, composed predominantly by stretch-shortening cycles (SSC) resulted in a neuromuscular stimulation.[23] It is possible that the applied repeated jumping bouts could have induced a transient enhanced force absorption during the eccentric phase in the players, without reaching fatigue. Indeed, it has been shown that a previous neuromuscular exercise may improve different jump performance tasks.[23] This could indicate that the unilateral CMJ could be more sensitive to training- and/or fatigue-induced changes in relation to vertical ground reaction force management of the players.[27] These results, along with the absence of a decrease in the jumping performance is also an indicator of the control over the training load. The rigorous control of the training load by team's staff could have attenuated the onset of fatigue, and therefore, possible negative changes on the jumping mechanical variables measured in this study.

Several investigations have been carried out focusing on the biomechanical effects of fatigue in sport; and a decrease in jump height[28] has been observed after a fatigue-inducing training protocol.[28] However, the training load of the session performed by our elite volleyball players was well-controlled, as indicated by the mean number of jumps performed (≈102 jumps) and mean RPE response (≈5 a.u.). Because the training session lasted 120 min, athletes performed one jump every 70 s, while in competitive games there is a large range in the number of jumping actions (*i.e.*, serve, attack, block), depending on the position (*i.e.*, middle blockers, setters, hitters), time playing and rally duration.[2] For example, while in the frontcourt, setters usually perform a minimum of 1 jumping movement in a rally lasting 11s [2]. Regarding players position, it has been shown across different official matches that middle blocker executed 50.2 jumps per hour, setters performed 76.8 jumps per hour, and outside hitters executed 32.3 jumps per hour.[29] The RPE response was also classified as moderate[30] and was ≈30-40% lower in comparison with other professional volleyball training sessions.[26]

The ideal training dosage has traditionally been, and still is, a subject of much debate along sport scientific and professional practitioners. However, only a few studies aimed to assess the training-load dose-response for obtaining acute fatigue changes, although athletes and sport practitioners would benefit from this kind of information to optimize performance and reduce the risk of injury.[16] The present study which had ~120 minutes of volleyball training, ~5 points of RPE and ~100 jumps (1 every 70 sec of training) did not impair our elite volleyball players' jumping performance within the training session. It is interesting to point out that the mean height of all the jumps performed during the 120 min training session (≈55.5 cm) was similar to the mean height of blocking and attacking maximal vertical jump test recordings (≈56.8 cm) of players of similar volleyball level and similar bilateral CMJ performance.[3] Along with the maintenance of jump performance along the pre- and post-training tests, these results indicated that the jumping frequency utilized in this training session prevents a decrease in these players' jumping performance. The present study could become a precedent to open new lines of research in order to improve the training load management to avoid fatigue onset during volleyball training sessions. We assessed biomechanical changes produced in a professional male Volleyball team during an actual official training session, without carrying out standardized research protocols which are not related to the actual load that athletes are exposed to. Moreover, most studies have tested collegiate and amateur athletes, findings that are not always transferable to elite athletes.[15, 28] Another aspect to consider is the reliability and validity of ISU devices allowing scientific procedures to be transferred to the on-field collection of objective data, and vice versa. This equipment enables sport scientist and athletic coaches to analyze different biomechanical variables in an uncontrolled environment, approaching the study of sports gestures to real game situations that take part in the competitive games.

A training session in which a fatigue onset is present would generate an increase in the vertical ground reaction force at landing due to the inability in the production of eccentric work during the impact absorption, as a consequence of the reduced angular excursion caused by fatigue.[13] This result shows that the training load dose of this study (*i.e.*, RPE, number of jumps, and jump height control) did not negatively affect CMJ jumping mechanics. The training data reported could represent important and useful information for conditioning coaches who are seeking for avoidance of fatigue in male elite volleyball training sessions.

Limitations of the study

The present study has some limitations. Our findings cannot be extrapolated to other volleyball teams of different performance level, since the records were carried out during an official in-season training session of a professional male volley team. However, this scenario reinforces the functional and practical value of the present study. This study is a field-based study conducted during regular in-season volleyball training, and hence, the study design might have enhanced the applicability of the results. It is also necessary to emphasize that, by material means, the training load of all the players could not be measured by the ISU, since 7 models were only available, although 12 athletes had their mechanical and jump performance assessed before and after training. Moreover, it should be taken into account that all the evaluations were governed by parameters obtained on the vertical axis (Z axis), because they are the most relevant parameters in the vertical jump and in the sports gesture typical of volleyball. However, sports actions and injury mechanisms are described as three-dimensional movements, and further studies on the effects of an official in-season training session using different axis are needed.

Conclusions

In summary, the current investigation shows no evidence of jump performance impairment in a training setting with high-sensibility measures in elite volleyball players. In addition, our findings suggest that the regular in season volleyball training session may have induced a significant reduction in the vertical ground reaction force during unilateral CMJ in these athletes. Our findings expand the body of knowledge on the acute effects of a controlled load session on jump performance and vertical jumping mechanics in elite professional volleyball players. Controlled jumping exposure may serve as a preventive measure to avoid fatigue onset in regular training sessions among professional volleyball players. This fact could help to enhance performance for the game and prevent musculoskeletal injuries. Future studies should test mid-long-term approaches to assert whether these adaptations are maintained over time and whether this kind of training-load would be able to promote chronic positive changes if repeatedly utilized along a competitive volleyball season.

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