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RESEARCH

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Lower limb dynamic balance, strength, explosive power, agility, and injuries in volleyball players

Jiaoqin Wang[1], Zhikai Qin[1], Qiang Zhang[1] and Junsheng Wang[1*]

Abstract

Purpose This study explores the relationship among lower limb dynamic balance, lower limb strength, explosive power, agility, and sports injuries in male volleyball players.

Method The study involved thirty-one male volleyball athletes assessed for lower limb dynamic balance using the Y Balance Test Kit™. Muscle strength in the hip, knee, and ankle was measured using the Isomed 2000 isokinetic dynamometer. Power performance was evaluated through squat jump, countermovement (CMJ) jump, and drop jump tests using the Kistler force platform. Agility measurements were conducted using timing gates and a stopwatch.

Results Our findings revealed a significant correlation between interlimb asymmetry in the anterior reach of the Y balance test and non-contact injuries ($r=0.597$, $P<0.01$). Additionally, there were significant correlations between the Y balance test and lower limb strength ($r=0.356$ to 0.715, $P<0.05$), vertical jumping performance ($r=0.357$ to 0.672, $P<0.05$), and agility ($r=-0.379$ to -0.702, $P<0.05$).

Conclusion Based on these findings, It is recommended that interlimb asymmetry in the anterior reach direction of the Y Balance Test be considered as one of the indicators for potential non-contact lower limb injuries among elite male volleyball players. The lower limb muscle strength of the hip, knee, and ankle joints and power and agility are associated with lower limb dynamic balance capabilities. Additionally, dynamic balance may contribute to overall physical performance. Targeted strength training for unilateral muscles and incorporating various explosive exercise modes may support athletic performance and reduce the risk of sports-related injuries.

Keywords Volleyball, Lower limb dynamic balance, Muscle strength, power, Agility

*Correspondence:
Junsheng Wang
wangjunsheng@cupes.edu.cn
[1]Capital University of Physical Education and Sports, Beijing 100191, China

Introduction

Volleyball is a demanding team sport characterized by intricate technical and coordinated movement variations [1]. Among the crucial attributes, jumping ability and dynamic balance emerge as pivotal elements in an athlete's repertoire [2]. Dynamic balance, a cornerstone in athletic performance, refers to the capacity to maintain stable bodily posture during task execution [3], encompassing spatial orientation and precise positioning relative to body segments and the surrounding environment [4].

In sports, mastery of balance skills is paramount, facilitating various athletic maneuvers such as directional changes, swift starts and stops, manipulation of moving objects, and sustaining specific body positions [2]. Especially in volleyball, the efficiency of aerial actions—like spiking, blocking, and serving—directly impacts scoring [5]. During the aerial phase, athletes must control their body's posture and trajectory to optimize attacking force [6, 7]. Moreover, beyond airborne maneuvers, performance in non-aerial actions such as setting, receiving, and defense hinges on a player's postural stability and movement precision [8, 9]. For example, elite volleyball matches witness spiking velocities ranging from 50 to 112 km/h [10], demanding defensive players to swiftly adjust body positions in response to the ball's trajectory while maintaining impeccable posture control upon contact [11]. Failure to promptly readjust and regain balance within a short time frame can impede optimal execution, affect tactical performance, and heighten the risk of sports-related injuries [12].

Balance, power, strength, and agility are fundamental for optimal volleyball performance. Studies show that better scores in countermovement jump (CMJ) and attack jump (AJ) tests are linked to increased symmetry in Y Balance Test composite scores, suggesting that balance enhances force transmission and jump performance in volleyball players [13, 14]. While strength is crucial for tasks like spiking and blocking, it does not solely account for the dynamic stability needed for effective performance [15, 16]. Particularly in explosive tasks, such as hops and single-leg landings, dynamic balance is pivotal in stabilizing the body during flight and landing phases [17]. These demands are amplified during single-leg landings, which require enhanced neuromuscular control for postural stability. Research indicates that neuromuscular activity in muscles like the vastus medialis and biceps femoris during the hop test mirrors the requirements for dynamic stabilization [18]. Higher dynamic stability improves landing mechanics in single-leg hops, reducing injury risks and enhancing performance [19]. Paterno et al.(2010) further emphasized the importance of dynamic stability for more excellent performance in hop tests, reinforcing the necessity of combining power, balance, and coordination for optimal volleyball performance [20].

Strength and balance are closely interconnected. Several studies demonstrate that strength training can improve static and dynamic balance [21–23]. Strength training enhances lower extremity muscle strength, activates fast-twitch motor units, and improves muscle coordination, enhancing balance [23]. Additionally, strength training reduces neural inhibition and increases muscle spindle stimulation, contributing to better proprioception and postural control [24]. This heightened spindle sensitivity improves joint position sense, which is crucial for balance during dynamic movements.

Balance also plays a critical role in agility, directly impacting skills such as blocking [25]. Agility tasks require rapid directional changes, and balance is key to maintaining stability and facilitating effective movement transitions. Miller et al. suggested that improved balance and body control during complex movements enhance agility [26], supporting studies in handball and basketball, where dynamic balance training improved agility performance [27, 28].

Beyond performance, balance training has notable benefits for injury prevention. Maintaining stability is crucial for executing complex sports skills, reducing injury risks, and minimizing recurrence [29, 30]. Maintaining a stable position is vital for successfully executing extreme sports skills in official competitions and is key to injury prevention [31].

However, findings on the relationship between these physical attributes and overall sports performance are inconsistent. While studies by Tapanya et al. [32] and Izquierdo et al. [33] suggest that dynamic balance and lower limb strength are pivotal for neuromuscular adjustments necessary for explosiveness, other research, including that by Lee et al. [21]and Hallagin et al. [34], present conflicting results. Similarly, Gadre et al. [35] and Rokaya et al. [36] report improvements in agility through dynamic balance training in volleyball and soccer players, respectively, yet studies by Kin-Isler et al. [37] do not find a definitive correlation in professional sports. Additionally, Çakmak et al. [38] and Kartal et al. [39] found no significant correlation between balance and performance metrics in female and adolescent soccer players, underscoring the variability of balance's impact across different sports and populations. These findings suggest that the influence of balance on sports performance may vary significantly across different sports and athlete populations.

The inconsistencies in current research highlight the need for targeted studies on the impact of dynamic balance on sports performance, particularly its relationship with performance and injury prevention in volleyball players. This study investigates the association between dynamic balance and key physical attributes—strength, power, and agility—while exploring its potential role in reducing injury risk. Dynamic balance, a fundamental component of athletic performance, is hypothesized to enhance postural stability and neuromuscular control during high-intensity movements. The following hypotheses are proposed: (1) Performance Correlation Hypothesis: Dynamic balance positively correlates with key physical attributes such as strength, power, and agility in volleyball players. (2) Injury Risk Hypothesis: Volleyball players with superior dynamic balance demonstrate a lower risk of sports-related injuries due to improved postural stability and neuromuscular coordination.

Materials and methods

Subjects

According to previous studies [40, 41], the sample size was calculated using G*Power Software. Considering a power of 85%, an effect size of 0.47, α of 0.05, based on these inputs, GPower suggested a 30 minimum sample size necessary to achieve sufficient power to detect statistically significant results. This study involved 31 elite male volleyball players, comprising nine middle blockers, eight outside hitters, six setters, four liberos, and four opposites. Before the testing sessions, the athletes and their coaches were informed about the purpose and requirements of the tests. The study followed the guidelines of the Helsinki Declaration. All participants signed informed consent forms before participating in the research protocol. The Ethics and Ethics Committee of the Capital University of Physical Education and Sports has approved this study—examination and approval number 2023A075.

All participants willingly volunteered for this research; the dominant side for all athletes was the right side. The inclusion criteria for the testing required that the participants had no trunk or limb joint injuries in the month leading up to the tests and could participate in regular training sessions. Exclusion criteria included a recent report (<3 months) that indicated a musculoskeletal or head injury that could have affected their performance during testing. (Table 1).

Experimental procedure

All athletes participated in four experimental sessions separated by at least 48 h. Before all laboratory tests, the athletes had to perform a warm-up on a running machine for 10 min and dynamic stretching for 5 min. In the first session, dynamic balance tests were measured in the laboratory. In the second session, muscle strength was measured by an isokinetic dynamometer in the laboratory. Counter-movement, squat, and drop jumps were tested during the third session. In the final session, T-test and volleyball special agility test were measured on the volleyball court. The test sequence was randomized to prevent order biasing.

Table 1 Anthropometric data for participants

Age/year	Height/cm	weight/kg	Lower limb length/cm	training years/year
20.1 ± 1.2	191.4 ± 6.1	81.2 ± 10.6	96.6 ± 5.0	7.1 ± 2.2

Dynamic balance test

The Lower Quarter Y Balance Test (YBT-LQ) assessed trunk and lower extremity function [42]. This test measures the range of motion, strength, and neuromuscular control in the lower limbs, and numerous prior studies have demonstrated its utility in evaluating lower limb balance, especially in athletes [43, 44]. Moreover, the YBT-LQ test is reliable, with a high Intraclass Correlation Coefficient (ICC) ranging from 0.80 to 1.00 [45]. It also demonstrates good internal consistency, with kappa values ranging from 0.86 to 0.95 for individual raters and 0.64 to 0.65 for repeated measurements [46]. YBT-LQ test was measured in the following order: anterior, posteromedial, and posterolateral, on both the dominant and non-dominant limbs. The dominant limb is the one the athlete puts most of their weight on during a hitting approach, which is typically the same side as the arm used to hit the ball. Participants were instructed in the YBT-LQ protocol through verbal cues and demonstrations [43]. The Y Balance Test Kit™ for measurements was used. All participants wore shoes during testing and started on their dominant limbs. If they raised their heel or toe or lost balance, it counted as a trial error, and they repeated the trial. Each participant had at least three practice trials in each direction before recording the best of three formal trials. During the test, subjects reached as far as they could in three directions: anterior, posteromedial, and posterolateral [47]. The best reach distance value of three formal test results was recorded in the raw value (in cm) and the standardized value (in %). The standardized reach value is calculated by dividing the raw value by the lower limb length and multiplying it by 100%. The lower limb length is measured from the anterior superior iliac spine to the most distal point of the medial malleolus using a tape measure. Furthermore, the composite score's standardized value is calculated as (average of reach distances in all directions / lower limb length)×100%. YBT-LQ test asymmetries were calculated for all tasks defining the dominant (D) (the limb with the better functional test) and ND limb, using the following formula: asymmetry index=(D-ND)/D ×100 [48].

Muscle strength

Before measuring, the players completed general warm-up exercises, which included running on a running machine for 5 min at 8 km/h, and 5 min of dynamic stretching exercises, which included a downward dog, walking quad, and word's most excellent stretch. The unilateral strength of the concentric action of the ankle, knee, and hip extensors and flexors was measured using an isokinetic dynamometer ISOMED 2000 (D. & R. Ferstl GmbH, Hemau, Germany).

Angular velocities of $60°\cdot s^{-1}$ were used for ankle, knee, and hip unilateral strength. The test mode was chosen as "concentric, concentric." For the ankle joint test, the athlete took the supine position, fixed the upper body with the strap, fixed the thigh of the tested limb with the auxiliary adapter, and the axis of the rotation of the dynamometer was aligned with the lateral condyle of the ankle joint; for the hip joint test, the athlete also took the supine position, fixed the upper body with the strap, and the lower edge of the pad of the dynamometer was fixed in the thigh at the distance from the knee at the place of 2–3 cm. The dynamometer's rotation axis was aligned with the femoral joint. For the knee joint test, the upper body was fixed with straps; the athlete was in a sitting position, the upper body and thighs were fixed with straps; the subject's hands gripped the handles on both sides of the test chair, the axis of the rotation of the dynamometer was aligned with the lateral condyle of the femur, and the lower edge of the pad of the dynamometer arm was fixed in the calf at a distance of 2–3 cm from the lateral condyle of the ankle joint. The range of motion was set to 10–90°of knee and hip (0°= full extension), and the range of motion was set to -20°-50°of ankle (0°= the foot was perpendicular to the calf).

The testing protocol consisted of one set for $60°\cdot s^{-1}$ of the hip, knee, and ankle. In the warm-up set, the players performed three concentric/concentric reciprocal actions with a progressive rise in the muscle action until a maximum action was performed. After a 30-second rest, the players performed a set of five maximum repetitions. The testing sequence was as follows: the right side was tested in the sequence of the ankle, hip, and knee joint, while the left side was tested in the sequence of the knee, hip, and ankle joint. This order is structured for the sake of expediency and ease of administration. There was a 5 min interval between different joints on the same side and a 7 min interval between the left and right sides. The players received concurrent visual feedback during the testing through an isokinetic strength curve displayed on the dynamometer monitor. Regarding the players' weight, relative peak torque (PT, Nm/kg) was used for analysis.

Jump test

Vertical jump tests are a commonly employed method for evaluating lower limb power in athletes [49]. Following a preliminary warm-up, participants completed a series of three distinct jumps on a force platform (Kistler 9281CA; Winterthur, Switzerland). These jumps include squat jumps (SJ), countermovement squat jumps (CMJ), and drop jumps (DJ), with a resting interval of 1–2 min between each set [50]. The SJ test was initially conducted, in which individuals assumed a half-squat position with hands on their hips on the force platform, maintaining their knees at about 90°angle [51]. Following a 3-second pause, they were instructed to perform a maximal vertical jump upon the initiation command without any preparatory squat motion. Subsequently, CMJ testing was administered. Upon the beginning command, subjects expeditiously executed a squat down to about 90°before promptly initiating an upward jump [51]—Finally, the drop jump (DJ) assessment. Participants stepped forward from a 30 cm-high platform, positioned their hands on their hips, took a small step forward, and descended vertically with both feet. They executed an explosive vertical jump upon landing on the force platform [52]. Throughout all jump tests, participants were required to maintain an upright knee position during the flight phase. The most successful attempt, determined by jump height, among the three trials was selected for subsequent statistical analysis.

Data was captured at 1000 Hz through BioWare software (Version: 5.3.2.9, Kistler 9281CA, Switzerland) and then imported into V3D (V6 Professional, C-motion, Germantown, Maryland, USA). A fourth-order 15 Hz low-pass filter was employed to process the data, and metrics such as jump height (cm), rate of force development (RFD), and reactive strength index (RSI) for CMJ, SJ, and DJ were subsequently computed. Jump height was determined using the formula: 0.5 * 9.81 * (flight time/2)^2 [53]. The rate of force development (RFD) was calculated as the peak force divided by the time required to attain peak force [54]. The reactive strength index (RSI) was calculated as jump height divided by the ground contact time [55].

T-test

The T-test was conducted using a standardized version as reported in previous literature [55]. The measurements were converted from yards to meters, forming a distance of 10 × 10 m. The testing route employed in this study was based on the work of Miller et al. (Fig. 1) [55]. Throughout the testing procedure, participants continuously faced forward. The timing gates (Smart Speed; Fusion Sport Pty Ltd, Australia) were placed 0.75 m above the synthetic track and on either side of the starting line, with a 3-meter separation between them. Timing started when the participants passed through the timing gates and stopped when they returned to the finish line. Three trials were conducted, with a rest interval of 3–5 min between each trial, and the best performance was recorded.

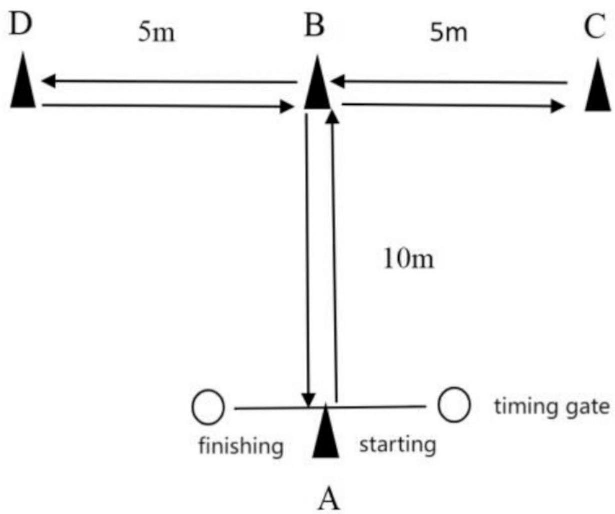

Fig. 1 Schematic representation of T-test

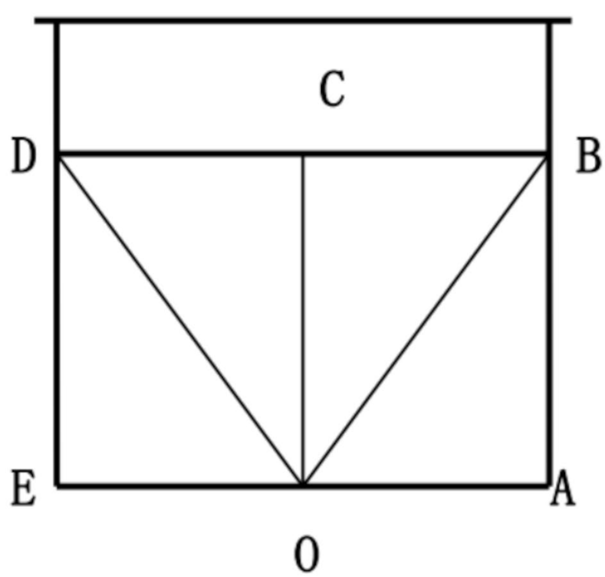

Fig. 2 Schematic representation of volleyball special agility test

Volleyball exceptional agility

The volleyball special agility test was measured on the volleyball court, with its starting point "O" at the midpoint of the end line, and points C, B, and D positioned at the intersections of the midpoint of the attack line, and the attack line with both sidelines, forming the shape of an isosceles right triangle (Fig. 2). A water-filled mineral water bottle was placed at each endpoint. The athlete initiated the timing by pushing down the bottle at point O using a stopwatch (Tianfu PC894, Shenzhen, China). The test was conducted sequentially along the OA-OB-OC-OD-OE path, with the final timing recorded when the bottle at point O was pushed down. The participant had to return and retry if any bottle was not pushed down. Each athlete completed three trials, and if a failure to topple a bottle or a miss occurred, a retry was permitted after a rest period. Three judges conducted timing, and the best median time was recorded.

Injury surveillance

Over eight months following initial baseline assessments, participants were monitored for lower limb injuries that did not result from direct contact. Team coaches used a standardized injury report form developed based on previous studies [56, 57]. The research team confirmed all reported injuries, categorizing them as lower extremity medical conditions that occurred during noncontact activities in volleyball, hindering the athletes' further involvement in training or games [58]. Injuries caused by direct contact with other players or objects, such as net posts and contusions from floor contact, were excluded. If a participant experienced multiple injuries, only the initial incident was documented to prevent the potential influence of subsequent injuries [59]. The study's research coordinator collected the completed injury reports from coaches and athletic trainers every quarter.

Statistical analysis

Statistical analysis was performed using SPSS v.20.0 (SPSSInc., IBM, China). The data in tables were presented as mean ± standard deviation. The Shapiro-Wilk test assessed the normality of the data distribution. Non-normally distributed data underwent square root transformation prior to further examination. Bonferroni correction was applied for pairwise comparisons to mitigate the risk of Type I error due to multiple comparisons. Alternatively, where appropriate, the False Discovery Rate (FDR) method was used to control for the number of false positives across multiple tests. The relationship between the Y-balance test and leg strength, power, and agility was assessed by the Pearson product-moment correlation coefficient (R). The magnitude of the effect for the correlations was based on the following scale. Small: ≤0–0.30, moderate: 0.31–0.49, large: 0.50–0.69, very large: 0.70–0.89, and nearly perfect: ≥0.90 [60]. The Y-Balance Test (YBT) asymmetry between limbs was evaluated using paired-sample t-tests to identify interlimb differences within athletes. Independent t-tests were conducted to compare YBT scores and asymmetry variations between injured and non-injured athletes, assessing whether injury status influenced balance performance or asymmetry. Spearman's correlation analysis examined the potential relationships between YBT asymmetry measures and injury status. Spearman's correlation was selected for its suitability for analyzing non-linear relationships and ordinal or non-normally distributed data. An alpha level of $p < 0.05$ was set as the threshold for statistical significance.

Table 2 Test results of Y balance of lower limbs of men's volleyball players

Test direction	Original value(cm)		Standard value		Composite value	
	D	ND	D	ND	D	ND
Anterior	67.50 ± 6.27	64.81 ± 5.50	0.70 ± 0.06	0.67 ± 0.06	0.97 ± 0.06	0.96 ± 0.07
Posteromedial	103.90 ± 7.79	103.13 ± 7.30	1.08 ± 0.10	1.07 ± 0.08		
Posterolateral	112.40 ± 7.60	110.02 ± 8.21	1.17 ± 0.10	1.14 ± 0.09		

Note: D: dominant Side, ND: Nondominant Side

Table 3 Descriptive raw standard value for asymmetry index of YBT_test between Dominant Side and Nondominant Side

Performance test	Mean ± SD	Mean Difference between limbs	Asymmetry index(%)
D_A_YBT	0.70 ± 0.06**	0.04 ± 0.02	5.61 ± 2.59
ND_A_YBT	0.67 ± 0.06		
D_PM_YBT	1.08 ± 0.10	0.02 ± 0.04	4.90 ± 3.44
ND_PM_YBT	1.07 ± 0.08		
D_PL_YBT	1.17 ± 0.10	0.03 ± 0.02	3.61 ± 3.37
ND_PL_YBT	1.14 ± 0.09		
D_YBT_composite score	0.97 ± 0.06	0.02 ± 0.05	4.84 ± 4.17
ND_YBT_composite score	0.96 ± 0.07		

Note: D: dominant Side, ND: Nondominant Side, A = anterior; PM = posteromedial; PL = posterolateral, **= $P < 0.01$

Results

Relationship between YBT-LQ test and injury

In YBT-LQ Test, a total of 51 instances (31 participants) showed asymmetry in all three directions, with differences in reach exceeding 4 cm. Specifically, 19 instances (37.3%) exhibited anterior asymmetry, 14 instances (27.5%) showed posterior-medial asymmetry, and 18 instances (35.3%) displayed posterior-lateral asymmetry. Further analysis of individuals with observed asymmetry revealed that 27 participants exhibited asymmetry in both lower limbs, constituting approximately 87.1%. Among these, 19 participants (about 70.4%) displayed anterior direction asymmetry, 14 (about 51.7%) demonstrated posterior-medial asymmetry, and 18 (about 66.7%) exhibited posterior-lateral asymmetry. Regarding composite scores, 12 athletes (38.7%) scored below 0.94 on both the left and right sides. Notably, 10 of these participants with a composite score below 0.94 on the right side also had low scores on the left side, and almost all of them had differences of over 4 cm between the left and right sides in one specific direction, except for one individual (Table 2). These findings suggest that volleyball players commonly exhibit asymmetry in their lower limb balance ability, with a relatively even distribution across various directions.

In the 8-month follow-up study, 13 athletes sustained noncontact lower limb injuries, with an average age of 20.15 ± 1.35 years, height of 190.38 ± 6.935 cm, body weight of 79.69 ± 12.59 kg, and training experience of 8.08 ± 2.72 years. Conversely, the 18 uninjured athletes had an average age of 20 ± 1.03 years, height of 192.11 ± 5.44 cm, body weight of 82.22 ± 9.14 kg, and training experience of 6.39 ± 1.42 years. The most frequent injury types were muscle strains and sprains, predominantly affecting the ankle (30%) and knee (23.1%).

Table 4 Descriptive raw standard Value Data for Y Balance Test in Injured and non-injured athletes

Performance test	Injured	Non-injured	*p*
D_A_YBT	0.70 ± 0.08	0.73 ± 0.08	0.24
ND_A_YBT	0.65 ± 0.07	0.70 ± 0.08	0.06
D_PM_YBT	1.20 ± 0.16	1.12 ± 0.13	0.14
ND_PM_YBT	1.14 ± 0.17	1.07 ± 0.12	0.16
D_PL_YBT	1.30 ± 0.12	1.21 ± 0.13	0.07
ND_PL_YBT	1.26 ± 0.13	1.16 ± 0.14	0.06
D_YBT_composite score	1.09 ± 0.12	1.02 ± 0.10	0.07
ND__YBT_composite score	1.04 ± 0.12	0.97 ± 0.09	0.10

Note: D: dominant Side, ND: Nondominant Side, A = anterior; PM = posteromedial; PL = posterolateral

Table 3 shows the YBT test performance of the D and ND limbs and the percentage of asymmetry for each task. Significant differences between D and ND limbs were only found in YBT_ANT ($P < 0.01$). Table 4 shows the analysis of YBT test performance through an independent t-test, contrasting injured athletes with their non-injured counterparts. The results showed no statistically significant difference in the same-limb YBT test performance across both groups. However, Fig. 3 elucidates that the injured athletes exhibited significantly greater asymmetry indices than non-injured athletes in the direction of anterior reach(YBT_ANT), with asymmetry indices of 7.31 ± 2.06% for injured athletes compared to 4.39 ± 2.25% for non-injured. Additionally, the analysis demonstrated a significant correlation between inter-limb asymmetry in YBT_ANT and non-contact injuries, with a correlation coefficient of $r = 0.597$ and a p-value less than 0.01 (Fig. 4).

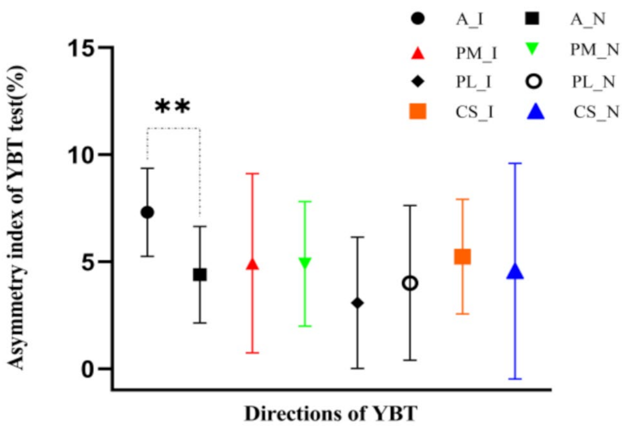

Fig. 3 Interlimb Asymmetry Index of YBT_test between injured and Non-injured athletes
Note: I = injured athletes; N = non-injured athletes; A = anterior; PM = posteromedial; PL = posterolateral; SC = YBT composite score, *= $P<0.05$; **= $P<0.01$

Relationship between YBT-LQ test and relative peak torque

Figure 5 illustrates that, during non-dominant leg support, the reach distance of the non-dominant leg in the anterior direction is moderate to highly positively correlated with muscle strength in the hip, knee, and ankle extensors and flexors of both the dominant and non-dominant legs, as well as with the dorsiflexion of the ankle ($r=0.414$ to 0.624, $P<0.05$ or $P<0.01$). Similarly, the posteromedial and posterolateral reach distances of the non-dominant leg showed moderate to high positive correlations with the muscle strength of the same muscle groups (posteromedial: $r=0.356$ to 0.463; posterolateral: $r=0.359$ to 0.548, $P<0.05$ or $P<0.01$). The composite score of the non-dominant leg was also positively correlated with these muscle strengths ($r=0.470$ to 0.677, $P<0.01$).

Furthermore, Fig. 4 reveals that during dominant leg support, the anterior reach distance of the dominant leg is positively correlated with the muscle strength of the hip, knee, and ankle extensors and flexors and the dorsiflexion of both the non-dominant and dominant legs ($r=0.375$ to 0.607, $P<0.05$ or $P<0.01$). The posteromedial and posterolateral reach distances of the dominant leg showed moderate to high positive correlations with the muscle strengths of the same muscle groups (posteromedial: $r=0.435$ to 0.691; posterolateral: $r=0.378$ to 0.715, $P<0.05$ or $P<0.01$). The dominant and non-dominant leg composite score also demonstrated a moderate positive correlation with these muscle strengths ($r=0.476$ to 0.709, $P<0.01$). (Fig. 4). These correlations are statistically significant ($P<0.05$ or <0.01). However, there was

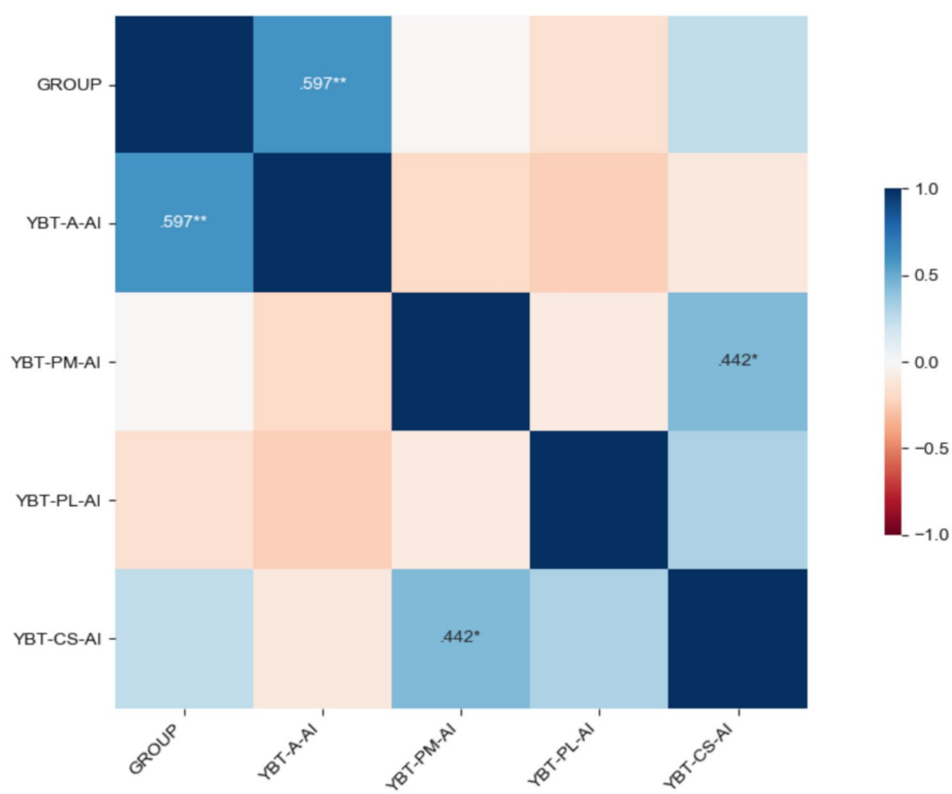

Fig. 4 Spearman's correlation of the Interlimb Asymmetry Index from the YBT test between injured and non-injured athletes
Note: GROUP = injured athletes and non-injured athletes; AI = asymmetry index; A = anterior; PM = posteromedial; PL = posterolateral; SC = YBT composite score, *= $P<0.05$; **= $P<0.01$

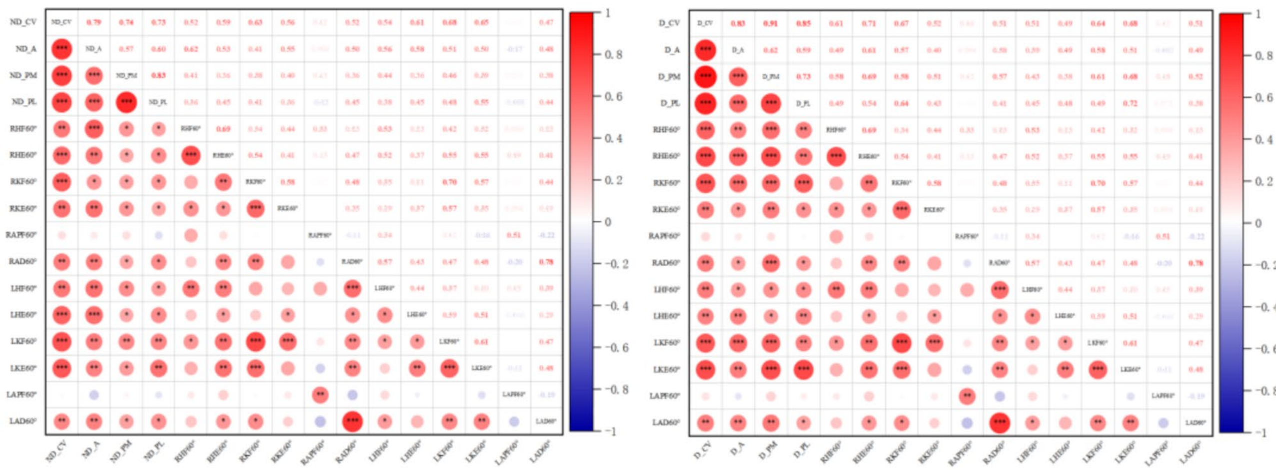

Fig. 5 The relationship between YBT-LQ Test and isokinetic hip, knee, and ankle muscle strength
Note: *** $P<0.001$, ** $P<0.01$, * $P<0.05$. D: dominant Side, ND: Nondominant Side. A: anterior, PM: posteromedia, PL: posterolateral, CV: composite value. RHF: right hip flexion, RHE: right hip extension, RKF: right knee flexion, RKE: right knee extension, RAPF: right ankle plantar flexion, RAD: right ankle dorsiflexion, LHF: left hip flexion, LHE: left hip extension, LKF: left knee flexion, LKE: left knee extension, LAPF: left ankle plantar flexion, LAD: left ankle dorsiflexion

no correlation between the YBT-LQ test and the ankle flexors relative to PT of the dominant and nondominant limb at 60°/s.

Relationship between YBT-LQ test and lower limb power

Alternatively, in the non-dominant limb, the YBT-LQ test's anterior direction score had a significant positive connection with CMJ height, CMJ-RFD, SJ height, SJ-RFD, DJ height, and DJ-RSI, with correlation values ranging from moderate to high ($r=0.410$ to 0.611, $P<0.05$ or $P<0.01$). Similarly, there was a moderate positive correlation between the posteromedial direction score of the YBT-LQ test and these physical performance metrics ($r=0.379$ to 0.555, $P<0.05$ or $P<0.01$). However, there was no positive correlation between the posterolateral direction score and CMJ height ($r=0.353$, $P=0.051$), but a moderate positive correlation with other measurements ($r=0.357$ to 0.534, $P<0.05$ or $P<0.01$). The composite score displays moderate positive correlations with CMJ height, CMJ-RFD, SJ height, SJ-RFD, DJ height, and DJ-RSI ($r=0.367$ to 0.672, $P<0.05$ or $P<0.01$).

On the other hand, for the dominant limb, the YBT-LQ test's anterior direction score was moderately positively correlated with CMJ height, CMJ-RFD, and SJ height ($r=0.358$ to 0.470, $P<0.05$ or $P<0.01$). Additionally, the posteromedial direction score of the YBT-LQ test showed a high positive correlation with CMJ height, CMJ-RFD, SJ height, SJ-RFD, DJ height, and DJ-RSI $r=0.482$ to 0.564, $P<0.05$ or $P<0.01$). There was also a moderate positive correlation between the posterolateral direction score and CMJ height, CMJ-RFD, SJ height, and SJ-RFD ($r=0.365$ to 0.461, $P<0.05$ or $P<0.01$). Furthermore, the composite score was moderate to strongly positively correlated with CMJ height, CMJ-RFD, SJ height, SJ-RFD, DJ height, and DJ-RSI ($r=0.413$ to 0.613, $P<0.05$ or $P<0.01$) (Fig. 6).

Relationship between YBT-LQ test and agility

Alternatively, in the non-dominant limb, there was a significantly negative correlation between the YBT-LQ test's anterior direction score and the T-test as well as the volleyball special agility test, with correlation values ranging from moderate to high (r = -0.381, r = -0.643, $P<0.05$, $P<0.01$, respectively). Similarly, the posteromedial direction score of the YBT-LQ test had a moderate negative correlation with the T-test and volleyball special agility test (r = -0.379, r = -0.3815, respectively, $P<0.05$). Also, the posterolateral direction score of the YBT-LQ test had a moderate negative correlation with the T-test and volleyball special agility test (r = -0.428, r = -0.370, respectively, $P<0.05$). The composite score of the YBT-LQ test showed a moderate to high negative correlation with the T-test and volleyball special agility test (r = -0.451, r = -0.702; $P<0.05$ or $P<0.01$).

Furthermore, for the dominant limb, a noticeable negative correlation was observed between the YBT-LQ test's anterior direction score and the T-test as well as the volleyball special agility test (r = -0.411, r = -0.531; $P<0.05$, $P<0.01$, respectively). Likewise, the posteromedial direction score of the YBT-LQ test showed a moderate negative correlation with the T-test and volleyball special agility test (r = -0.455, r = -0.424, respectively, $P<0.05$). Additionally, the posterolateral direction score of the YBT-LQ test demonstrated a high negative correlation with the T-test and volleyball special agility test (r = -0.381, r = -0.537, $P<0.05$, $P<0.01$, respectively).

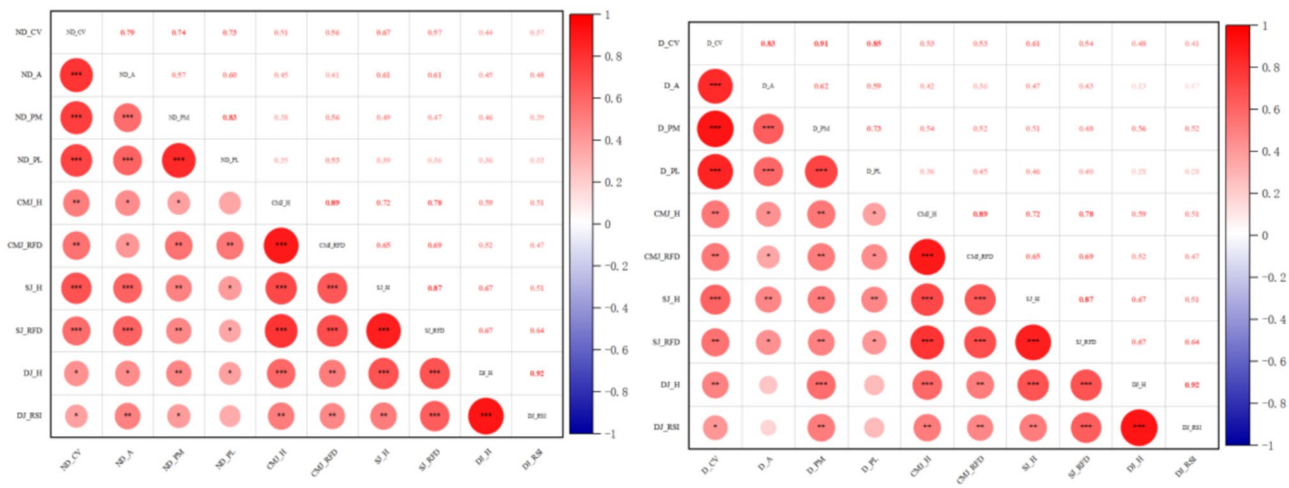

Fig. 6 The relationship between YBT-LQ Test and lower limb power. (left/ right)
Note: *** $P<0.001$, ** $P<0.01$, * $P<0.05$. D: dominant Side, ND: Nondominant Side, H: height, A: anterior, PM: posteromedial, PL: posterolateral, CV: composite value

Table 5 The relationship between YBT-LQ test and agility

	Direction	T-test	volleyball special agility test
ND	A	−0.381*	−0.643**
	PM	−0.379*	−0.381*
	PL	−0.428*	−0.370*
	CV	−0.451*	−0.702**
D	A	−0.411*	−0.531**
	PM	−0.455*	−0.424*
	PL	−0.381*	−0.537**
	CV	−0.492**	−0.550**

Note: ** $P<0.01$, * $P<0.05$. A: anterior, PM: posteromedia, PL: posterolateral, CV: composite value

The composite score of the YBT-LQ test showed a high negative correlation with the T-test and volleyball special agility test (r = -0.492, r = -0.550, $P<0.05$, $P<0.01$, respectively). See Table 5.

Discussion

The study investigated the relationship between dynamic balance (YBT), physical performance, and injury among male volleyball players. The main result was the consistent correlations found between YBT variables and other athletic performance measures. A particularly noteworthy finding was the significant correlation between interlimb asymmetry and non-contact injuries, as measured by YBT_ANT. This finding underscores the potential importance of identifying and addressing asymmetries to help reduce the risk of non-contact injuries in sports.

Relationship between YBT-LQ test and injury

Our study identified a significant correlation between asymmetry in the Y Balance Test-Anterior (YBT-ANT) and the likelihood of non-contact injuries. This finding aligns with research by Smith et al. [61], who reported a strong association with an odds ratio of 2.33, and Plisky et al. [62], who found that asymmetries exceeding 4 cm were associated with an increased risk of injury. However, Butler et al. [63] and Lai et al. [64] found no significant correlation, indicating that variations in sample characteristics or injury definitions may influence these results. Our study also presents findings that diverge from those of Brumitt et al. [65]. The differences between our results and those of Brumitt et al. may stem from variations in study design. While our prospective study followed subjects without impairments over 8 months to analyze injury profiles using statistical methods, including independent samples t-tests based on YBT scores, Brumitt et al. employed a retrospective design, analyzing data from individuals with a prior injury history. This methodological difference may explain discrepancies in the findings, particularly regarding the potential role of the YBT in identifying factors associated with injury risk. In addition, it is important to note that our findings do not suggest that the YBT can definitively predict injuries. Instead, there is a significant correlation between asymmetry in the YBT-ANT and the occurrence of non-contact injuries. Our results indicate that the YBT may not consistently detect performance deficits in athletes previously classified as 'healthy' but with an injury history. Moreover, the homogeneity of our sample, composed of athletes from the same school and team with comparable competition levels, may also contribute to the observed differences in findings.

Non-contact injuries are common in volleyball, particularly ankle injuries. Bhat et al. found a relatively high injury risk of 52%, which is notable given that volleyball is considered a non-contact sport [66]. In our study, ankle injuries were the most frequently reported, aligning with findings from previous research (Aagaard & Jorgensen, 1996; Aagaard et al., 1997; Bahr & Bahr, 1997) [67–69]. The significant relationship between asymmetry in the Y Balance Test-Anterior (YBT-ANT) and injury risk is mainly due to the test's ability to assess ankle stability and anterior thigh muscle control. Studies by Butler et al. [50], Witchalls et al. [53], and Overmoyer et al. [54] have shown that deficiencies in the tibialis anterior muscle are associated with biomechanical dysfunctions, which can result in excessive ankle inversion or eversion during dynamic movements, as noted by Hertel et al. [55], increasing the risk of sprains. These biomechanical issues may also place abnormal stress on the knee and other structures in the kinetic chain, raising the overall risk of injury. Our study further identified a positive correlation between YBT-ANT asymmetry and ankle dorsiflexion strength, with correlation coefficients of r_{D_leg} = 0.487 and r_{ND_leg} = 0.480 ($P<0.01$ for both). These findings suggest an association between asymmetry in the YBT and ankle dorsiflexion strength, which may help assess injury risk. However, it is important to emphasize that these correlations do not imply causality but rather reflect a relationship between the two variables.

However, we must recognize that excluding contact injuries limits the scope of our study, as it does not account for the injury mechanisms associated with direct contact, such as collisions or impacts during blocking and spiking. This exclusion may influence the generalizability of our findings, particularly regarding the role of balance in injury prevention during contact situations. Future studies could benefit from including contact injuries to explore how dynamic balance relates to these injury types and provide a more comprehensive understanding of injury risks in volleyball.

Relationship between dynamic balance and muscle strength in volleyball athletes

Our results demonstrated moderate to high positive correlations between the Y-balance test scores on the nondominant and dominant sides of young volleyball athletes and the bilateral hip and knee joint flexor-extensor torque and ankle dorsiflexor torque ($r=0.470$–0.682, $p<0.05$), which are consistent with previous studies. Cinarli et al. tested healthy young males to examine the relationship between maximal strength in hip extension muscles and Y-balance performance. They found that maximal strength in unilateral hip extension muscles was moderately correlated with dynamic balance ($r=0.466$–0.757, $p<0.01$) [70]. Similarly, Guirelli et al. tested 25 adolescent volleyball players using the Y-balance test and isometric muscle strength assessments of hip and knee extension muscles, finding moderate correlations between anterior Y-balance testing and knee extension strength and between posterior-lateral Y-balance testing and hip extension strength [71]. Dong-Kyu Lee et al. also found a significant relationship between strength in hip extension, knee flexion, and hip abduction muscle groups and Y-balance test results in adult females ($r>0.7$, $p<0.05$) [18]. Other studies have reported significant relationships between stabilizing and extensor muscle strength in the hip, knee, and ankle joints and Y-balance performance [32, 72]. Muscles like the quadriceps, hamstrings, and gastrocnemius strongly correlate with dynamic balance. Strengthening the unilateral strength in these muscle groups among volleyball athletes can enhance their dynamic balance and improve their athletic performance. Volleyball players require both strength and balance control to perform successfully. For instance, they must maintain proper body mechanics when landing after a spike or block, necessitating effective balance control. In other words, balance control and their developed strength are essential for optimal performance [73].

Relationship between dynamic balance and lower limb power in volleyball athletes

In our current study, we observed moderate to high positive correlations between lower limb balance abilities on both the nondominant and dominant sides of young volleyball athletes and their performance in squat jump (SJ), countermovement jump (CMJ), and drop jump (DJ) heights and rate of force development (RFD) ($r=0.470$–0.682, $p<0.05$). This finding aligns with previous research. González-Badillo et al. found that single-leg jumping tests were associated with single-leg dynamic balance [74]. Booysen et al. conducted Y-balance and strength tests on university students and professional soccer players, reporting a significant correlation between lower limb dynamic balance and CMJ performance ($r=0.4$–0.56, $p<0.05$) [75]. The observed correlations can partly be explained by lower limb muscle strength. The SJ primarily reflects the power of the hip and knee extensors. At the same time, the CMJ involves both the rapid extension-flexion capacity of these muscle groups and the influence of the myotatic reflex and elastic potential energy. The reactive jump emphasizes ankle dorsal flexor strength. The Y-balance and lower limb power tests, such as SJ, CMJ, and DJ, rely on strong quadriceps, hamstrings, gastrocnemius muscles, and specific squatting movements, underpinning the significant relationships observed.

These findings suggest that dynamic balance may influence spike jump performance in volleyball players. Practical spike jumping depends on approach velocity, foot positioning, and the ability to convert velocity through the dominant leg—factors tightly linked to neuromuscular coordination and lower limb control. Balance is foundational, enhancing dynamic stability and enabling precise, powerful movements. The determinants of spike jump performance include approach velocity, foot positioning, and the velocity conversion strategy through the dominant leg [76]. This strategy is directly tied to neuromuscular activation in the lower limbs [1]. By incorporating differential jump training, which provides continuous proprioceptive and neuromuscular stimuli, athletes can improve their balance. Enhanced balance performance is an operational measure of injury prevention [77]. Reduced balance is associated with an increased risk of injury [78], and both injury prevention and balance performance are influenced by the proprioceptive and neuromuscular systems [79–81]. Therefore, improvements in balance from such training may also positively impact spike jump execution by enhancing dynamic stability and neuromuscular control.

Relationship between dynamic balance and agility in volleyball

In the current study, a significant correlation was observed between dynamic balance and agility(T-test, the volleyball special agility test), particularly between the Y-balance test and the volleyball special agility test(r=-0.702, $P < 0.05$). This may be because the T-test evaluates linear acceleration, deceleration, and lateral agility. In contrast, the volleyball special agility test involves multidirectional agility and dynamic body postural changes, including repeated single-leg cutting maneuvers, better reflecting dynamic balance performance. These results are consistent with previous studies. Gadre et al. found that dynamic balance training equally improved agility in male and female volleyball players [35]. Similarly, Saraswat et al. observed significant improvements in the T-test performance of basketball players after a 4-week dynamic balance training program [82]. However, Armstrong et al. cautioned that the predictive ability of the Y-balance test for the T-test is limited and may be influenced by factors such as sport, gender, and limb length [83].

Our findings suggest that dynamic balance may be key in volleyball players' blocking and defensive performance. Effective defense requires rapid direction, speed, and body posture changes, demanding efficient acceleration and deceleration within short time frames. Gouttebarge et al. noted that volleyball players must often change direction mid-air to adjust to the ball, requiring rapid and precise movements [35].

Practical applications

The practical implications of this research extend across multiple areas within sports science and athletic training. Our study emphasizes the utility of the Y Balance Test-Anterior (YBT-ANT) in assessing asymmetry patterns that may be associated with lower limb injury risks in elite male volleyball players. Practitioners are encouraged to monitor asymmetries during YBT-ANT assessments to identify athletes at higher risk of injury. To support dynamic balance, strength and conditioning coaches can apply these insights to design targeted training programs that improve unilateral muscle strength, particularly in the hip, knee, and ankle joints. Previous studies have demonstrated that structured and progressive interventions can influence musculoskeletal injury rates and enhance neuromuscular function. For example, Augustsson et al. (2011) reported that a 26-week individualized resistance training program was associated with a notable reduction in musculoskeletal injuries among young volleyball players [84]. Similarly, a four-month preventive program targeting anterior knee pain, incorporating isometric strength exercises, plyometrics, and eccentric load exercises, showed a decreased odds ratio for knee pain in volleyball players [85]. Verhagen et al. (2005) noted the potential benefits of proprioceptive training, indicating that a 36-week balance exercise program, including balance boards and balls, was linked to reduced ankle injury risks [86]. Building on these findings, exercises like single-leg squats or lunges on unstable surfaces (e.g., stability balls or Bosu balls) may help improve lower limb strength and neuromuscular coordination, which are important for dynamic movements. Additionally, emphasizing soft, controlled landings during plyometric exercises may improve dynamic balance and reduce injury risks. A combination of strength, proprioceptive, and plyometric training within a progressive framework can support injury prevention and enhance athletic performance.

Conclusions

This study establishes a significant correlation between lower limb dynamic balance and key physical attributes such as strength, power, and agility in volleyball athletes. Notably, inter-limb asymmetry, as measured by the Y Balance Test Anterior (YBT_ANT), was significantly correlated with the incidence of non-contact injuries. The findings indicate that the muscle strength of the hip, knee, and ankle joints, along with power and agility, may be associated with lower limb dynamic balance capabilities. Additionally, dynamic balance may play a role in overall physical performance. Based on these insights, volleyball athletes' training programs are recommended to monitor dynamic balance and incorporate targeted strength training for unilateral muscles. Including various modes of explosive exercises could further support athletic performance and potentially reduce the risk of sports-related injuries.

Limitations

We acknowledge several important limitations in our study that could influence the interpretation and generalizability of our findings. First, while dynamic balance is a key physical attribute that influences volleyball performance, our study did not establish a direct link between dynamic balance and volleyball-specific technical or tactical performance. This gap emphasizes the need for future research to explore this potential connection more precisely. Additionally, our study excluded contact injuries, which may limit the scope of the findings. We recognize that including contact and non-contact injuries in future studies would provide a more comprehensive understanding of injury risks in volleyball. Furthermore, while our research identified correlations between lower limb dynamic balance and attributes such as strength, power, and agility, the study's cross-sectional design prevents us from making causal inferences. Future longitudinal or intervention-based studies are needed to establish causality and better inform training protocols to enhance performance and reduce injury risks. Our study did not account for position-specific demands, individual differences, training history, or physiological variables, which could significantly influence dynamic balance and injury outcomes. Therefore, future studies should consider these factors to improve the applicability of the findings. Finally, to broaden the generalizability of our results, future research should include gender comparisons and age-specific analyses, as these factors may influence dynamic balance, strength, and injury risk in volleyball players.

Author contributions

J.Q. mainly wrote the manuscript. Z.K. and Q.Z. are mainly responsible for the data collection and submission of the paper. J.S. is mainly responsible for the guidance and revision of the whole paper.

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Data availability

All data and materials can be accessed by contacting the corresponding author.

Declarations

Ethics approval and consent to participate

The study followed the guidelines of the Helsinki Declaration. All participants signed informed consent forms before participating in the research protocol. The Ethics and Ethics Committee of the Capital University of Physical Education and Sports has approved this study—examination and approval number 2023A075.

Consent for publication

All authors gave consent for the publication. Informed consent to publish was obtained from the subjects and their legal guardians. All photos are published with permission for open publication and with the subject's or their parent's permission.

Competing interests

The authors declare no competing interests.

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