

Article

Analysis of Balance Characteristics in Female College Volleyball Players Based on Joint Range of Motion

Yang Liu ¹ and Xiaoqin Zhao ^{2,*}

¹ Organization and Personnel Department, Shanxi Sports Vocational College, Taiyuan 030032, China; 19935171780@163.com

² School of Physical Education and Health Engineering, Taiyuan University of Technology, Jinzhong 030600, China

* Correspondence: zhaoxiaoqin@tyut.edu.cn

Abstract

Objective: Volleyball athletes require well-developed balance control during spiking, blocking, rapid movement, and landing. Joint range of motion (ROM) may also influence limb extension, support adjustment, and center-of-mass control. Previous studies have usually examined balance ability and joint ROM as separate factors related to volleyball performance. However, the associations between dynamic balance, static balance, and multi-joint ROM in the upper and lower limbs remain insufficiently understood. This study therefore aimed to examine the relationship between balance performance and upper- and lower-limb joint ROM in female college volleyball athletes. **Methods:** Thirty-five female college volleyball athletes were included. Dynamic balance of the upper and lower limbs was assessed using the Y-Balance Test, and static balance was evaluated under eyes-open and eyes-closed conditions using a static balance platform. Upper- and lower-limb ROM was measured using an electronic goniometer and the knee-to-wall test. Paired-sample *t*-tests were used to compare bilateral differences and differences between visual conditions. Pearson correlation analysis was performed to examine associations between joint ROM and balance performance, and false discovery rate (FDR) correction was applied to account for multiple comparisons. **Results:** (1) No significant bilateral difference was observed in upper-limb YBT-UQ performance ($p > 0.05$); for lower-limb YBT-LQ performance, a significant difference was found only in the anterior direction, with the right side showing higher values than the left side ($p < 0.01$). (2) Static balance parameters under the eyes-closed condition were significantly poorer than those under the eyes-open condition ($p < 0.01$); under the same visual condition, only the total sway path length of the right foot was significantly shorter than that of the left foot ($p < 0.05$). (3) The ranges of motion of right shoulder flexion, shoulder horizontal adduction, shoulder external rotation, elbow flexion, and knee-to-wall distance were significantly greater than that of the left side (all $p < 0.05$), and right hip internal rotation ROM was also significantly greater than that of the left side ($p < 0.01$). (4) Dynamic balance was correlated with selected joint ROM measures. Specifically, the anterior reach direction of the right YBT-LQ was positively correlated with hip flexion ROM ($r = 0.593$, $p < 0.01$) and knee-to-wall distance ($r = 0.653$, $p < 0.01$), and these correlations remained statistically significant after FDR correction. (5) Static balance parameters were correlated with selected lower-limb joint ROM measures in the original correlation analysis; however, these correlations did not remain significant after FDR correction. **Conclusions:** Female college volleyball athletes demonstrated a certain degree of bilateral asymmetry in dynamic balance and a pronounced de-

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pendence on visual input during static balance tasks. After FDR correction, the associations between the anterior reach direction of the right YBT-LQ and both hip flexion ROM and knee-to-wall distance remained stable, suggesting that these ROM measures may be related to anterior dynamic balance performance. These findings may provide a reference for postural control assessment and the development of sport-specific training programs for female volleyball athletes.

Keywords: balance; joint range of motion; volleyball; female; injury

1. Introduction

Volleyball is a team sport that requires the integration of technical skills, tactical execution, and physical fitness. Balance performance, defined as the ability to maintain body stability under static or dynamic conditions, is closely related to the control and accuracy of key volleyball skills, including spiking, blocking, defense, and serve reception. During volleyball-specific actions, athletes frequently transition among rapid starts, sudden stops, jumps, aerial hits, and single- or double-leg landings, during which the body's center of mass changes continuously. Therefore, balance is relevant not only to static standing stability but also to center-of-mass control and limb positioning during jumping, aerial hitting, rapid movement, and landing. Recent evidence indicates that unilateral vertical jump performance and postural sway control are important indicators of volleyball-specific neuromuscular function [1]. Balance is influenced by multiple factors, including proprioception, visual processing, vestibular input, coordination, and joint range of motion (ROM). Among these factors, joint ROM is particularly important because it affects movement amplitude, joint coordination, center-of-mass transfer, and postural control [2]. Previous studies have suggested that upper-body joint mobility contributes to force production and angle control during serving and spiking, whereas lower-body flexibility is important for rapid movement and jumping [3,4]. Insufficient or asymmetrical joint ROM may also limit sport-specific performance and may be related to potential injury-related factors in volleyball athletes [5]. Thus, ROM and balance should not be considered isolated factors; instead, they may jointly contribute to postural control and volleyball-specific movement performance.

Although both balance performance and joint ROM influence volleyball-specific performance, previous studies have generally examined these factors separately. Research on balance has mainly focused on its role in enhancing athletic performance. For example, Wang et al. reported that balance is positively associated with strength, power, and agility in volleyball players [5]. Sebastia-Amat et al. found that 12 weeks of balance training significantly improved posture control in beach volleyball athletes [6]. Research on joint ROM has largely explored its relationship with volleyball players' strength, speed, flexibility, and sport-specific performance. Klumkool found that a pre-match massage significantly increased volleyball players' ROM and jumping performance [7], while Ai confirmed that PNF stretching effectively improved joint flexibility and increased passing and serving success rates [8]. These findings suggest that both balance and joint ROM are closely related to volleyball-specific performance. However, most existing studies have focused on the effects of balance training or ROM improvement alone. The association patterns between joint ROM and different balance performance measures remain unclear. In particular, systematic evidence is still limited regarding the multidimensional relationships among dynamic balance, static balance, upper- and lower-limb ROM, and bilateral

differences in female volleyball players. Clarifying these relationships may help characterize postural control in female volleyball athletes and provide evidence for optimizing sport-specific training and injury prevention strategies.

Therefore, the present study examined the relationship between ROM and balance performance in female college volleyball athletes using multi-joint assessment, multiple balance tasks, and bilateral comparisons. We hypothesized that balance performance would be associated with multi-joint ROM and that these associations would differ according to task type, limb region, and side. The findings may provide a reference for postural control assessment, sport-specific training program design, and future injury-related research in female volleyball athletes.

2. Research Subjects and Methods

2.1. Research Subjects

Thirty-five college volleyball athletes were recruited as participants in this study. All participants had achieved at least the Chinese National Second-Class Athlete level and had experience in volleyball-specific training. The participants were recruited from three different universities, and all tests were conducted under unified testing procedures, testing requirements, and evaluation criteria.

The exclusion criteria were as follows: (1) athletes who had sustained acute sports injuries of the upper or lower limbs within the past six months; (2) athletes with a history of chronic ankle instability, shoulder pain, rotator cuff injury, or other shoulder disorders; (3) athletes with vestibular dysfunction, neurological disorders, or other conditions that could affect balance ability or joint range of motion testing; and (4) athletes who experienced obvious pain or fatigue before testing or were unable to complete the tests as required.

The basic characteristics of the athletes are presented in Table 1. This study was approved by the Ethics Committee of Taiyuan University of Technology, with the approval number 2024121601. All participants were informed of the study's purpose, testing procedures, and potential risks before testing, and provided written informed consent.

Table 1. Subjects' basic information (M $\pm$ SD).

N	Age/Years	Height/cm	Weight/kg	Training Duration/Years	Upper-Limb Length/cm	Lower-Limb Length/cm
35	20.31 $\pm$ 1.08	175.23 $\pm$ 5.00	66.34 $\pm$ 7.02	6.74 $\pm$ 1.38	86.64 $\pm$ 4.72	97.81 $\pm$ 6.57

2.2. Research Methods

2.2.1. Y-Balance Test

The Y-Balance Test (YBT) is one of the functional testing methods commonly used to assess dynamic balance and neuromuscular control in athletes [9]. The YBT consists of the upper-quarter Y-Balance Test (YBT-UQ) and the lower-quarter Y-Balance Test (YBT-LQ). Before testing, the examiners received professional training. Prior to the formal test, participants were instructed on the testing procedures and completed two practice trials with corrective feedback. Each participant then completed three formal trials in each testing direction, and the mean value of the three trials was used for statistical analysis.

YBT-UQ Test Method

Upper-limb length was measured from the C7 spinous process to the tip of the middle finger. Participants performed the test in a single-arm push-up position with the feet shoulder-width apart. The third metacarpophalangeal joint of the supporting hand was

aligned with the center of the testing device. With the non-supporting hand, participants pushed the reach indicator as far as possible in the medial, superolateral, and inferolateral directions without interruption. Both upper limbs were tested, with three trials for each side and a 30 s rest interval between trials. Participants were required to maintain a stable three-point support position involving both feet and the supporting hand throughout the test. A trial was considered invalid and repeated if the non-supporting hand touched the ground, the participant leaned on the equipment, the elbow of the supporting arm flexed, the knee flexed, or momentum was used to push the indicator [10].

YBT-LQ Test Method

Lower-limb length was measured in the supine position from the anterior superior iliac spine to the distal edge of the medial malleolus. During the test, participants stood on one foot on the testing board with their toes aligned with the baseline, while the non-supporting foot was positioned lightly behind the board. While maintaining balance, participants reached the non-supporting foot as far as possible in the anterior (AT), postero-medial (PM), and posterolateral (PL) directions. Both lower limbs were tested, with three trials for each side and a 15 s rest interval between trials. A trial was considered invalid and repeated if the non-supporting foot touched the ground, the heel of the supporting foot lifted from the ground, the hands left the hips, or balance was lost.

The normalized maximum reach distance was calculated as follows: reach distance (cm)/upper- or lower-limb length (cm) $\times$ 100%. The normalized composite score was calculated as follows: mean maximum reach distance across all directions/upper- or lower-limb length (cm) $\times$ 100%.

2.2.2. Static Balance Acquisition

This study used a plantar pressure gait analysis system (Podomed, shanghai, China) to collect participants' plantar pressure data and static balance parameters, with a sampling frequency of 100 Hz. Before testing, all participants stood barefoot on the testing platform and completed static single-leg standing tasks according to standardized testing procedures. The test conditions included four static standing tasks: eyes-open left-foot stance, eyes-closed left-foot stance, eyes-open right-foot stance, and eyes-closed right-foot stance. Each task lasted 10 s [11]. During testing, participants were required to maintain body stability. If obvious movement of the supporting foot, contact of the non-supporting foot with the ground, or loss of balance occurred, the trial was considered invalid and was repeated. All tests were conducted under the same experimental conditions to minimize the potential influence of differences in footwear, standing posture, and testing conditions on the results. The plantar pressure testing system can be used to evaluate plantar pressure distribution and static postural control performance, and has demonstrated a certain degree of test stability [12].

2.2.3. Measurement of Joint Range of Motion

Joint Range of Motion

Joint ROM was measured using an electronic goniometer. Before testing, all participants completed standardized preparation under the same experimental conditions and were instructed to avoid additional stretching or strenuous exercise. During the measurements, participants were tested in standardized positions, and the examiner stabilized the adjacent body segments to minimize compensatory movements of the trunk, pelvis, or limbs. Specifically, during upper-limb joint measurements, the trunk, shoulder girdle, or forearm was primarily stabilized, whereas during lower-limb joint measurements, the pelvis, thigh, or lower leg was primarily stabilized. Active ROM was measured for the shoulder, elbow, wrist, hip, and knee joints [13]. All variables were measured bilaterally, with three repeated measurements performed on each side, and the mean value was used for statistical analysis.

Knee-to-Wall Test

The knee-to-wall test was used to assess weight-bearing ankle dorsiflexion, expressed as knee-to-wall distance. Testing method: Participants stood barefoot, with the toes of the tested foot facing the wall. While keeping the heel on the ground, participants bent the knee as far as possible to touch the wall with the knee, and the distance from the toes to the wall was recorded in centimeters (cm). If the knee could not reach the wall, the test was repeated by adjusting the initial distance between the foot and the wall. Each side was measured three times, and the mean value was used for statistical analysis. The knee-to-wall test has been shown to have good test reliability [14].

2.2.4. Statistical Analysis

A priori sample size estimation was performed using G*Power 3.1.9.2. Because the primary aims of this study were to examine the relationship between joint ROM and balance performance in female college volleyball athletes and to compare differences in related variables between the left and right sides and under different visual conditions within the same participants, sample size estimation was mainly based on paired-sample *t*-tests and Pearson correlation analysis. A two-tailed test was used, with the significance level set at $\alpha = 0.05$ and statistical power set at $1 - \beta = 0.80$. This approach supports the robustness and reliability of the sample size estimation [15]. Based on the paired-sample *t*-test, assuming a medium effect size of $d_z = 0.50$, the estimated minimum required sample size was approximately 34 participants. Based on Pearson correlation analysis, assuming an expected correlation effect size of $r = 0.45$, the estimated minimum required sample size was 35 participants. Finally, 35 female college volleyball athletes were included in this study, which met the sample size requirements for the primary statistical analyses.

Statistical analyses of participants' age, height, years of training, and test variables were performed using SPSS 26.0 software. Results are presented as mean $\pm$ standard deviation ($M \pm SD$). Paired-sample *t*-tests were used to compare bilateral YBT results, bilateral joint ROM, and static balance indicators under eyes-open and eyes-closed conditions. Pearson correlation analysis was used to assess the relationships between joint ROM and dynamic and static balance indicators. The standard interpretation of the correlation coefficient *R* was defined as follows [16]: 0–0.30 indicates low correlation, 0.31–0.60 indicates moderate correlation, 0.61–0.89 indicates high correlation, and 0.90–1.00 indicates near-linear correlation.

To account for multiple Pearson correlation analyses involving joint ROM and balance indicators, the Benjamini–Hochberg false discovery rate (FDR) correction method was applied. After correction, $q < 0.05$ was considered statistically significant.

3. Results

3.1. YBT-UQ/LQ Test Results

The YBT-UQ/LQ results are shown in Table 2. No significant differences were observed between the left and right hands of female college volleyball athletes in the medial, superolateral, and inferolateral reach directions or in the composite score, suggesting good bilateral symmetry in upper-limb dynamic balance performance. Female college volleyball athletes scored significantly lower in the anterior reach direction with the left foot than with the right foot ($p < 0.05$). No significant differences were observed between the left and right feet in the posteromedial direction, posterolateral direction, or composite score ($p > 0.05$). A significant bilateral difference was observed in the anterior reach direction of the YBT-LQ, with the right side showing higher values than the left side. The side-to-side difference was 4.17 cm, slightly exceeding the 4 cm reference threshold, suggesting a certain degree of anterior dynamic balance asymmetry.

Table 2. The test results of YBT-UQ/LQ of college female volleyball players (M $\pm$ SD).

Test Items	Direction	Left	Right	<i>p</i>
YBT-UQ	Medial (cm)	77.26 $\pm$ 8.93	78.09 $\pm$ 5.44	0.641
	Superolateral (cm)	63.80 $\pm$ 13.08	63.14 $\pm$ 8.93	0.807
	Inferolateral (cm)	79.11 $\pm$ 10.92	79.29 $\pm$ 10.13	0.946
	Composite score (%)	84.94 $\pm$ 9.37	84.90 $\pm$ 7.21	0.981
YBT-LQ	Anterior (cm)	63.03 $\pm$ 6.13	67.20 $\pm$ 6.48	0.007
	Posteromedial (cm)	102.74 $\pm$ 11.31	106.06 $\pm$ 9.65	0.192
	Posterolateral (cm)	103.49 $\pm$ 7.90	105.14 $\pm$ 9.72	0.436
	Composite score (%)	91.99 $\pm$ 6.73	95.01 $\pm$ 6.92	0.690

3.2. Static Balance Test Results

Under the eyes-open condition, female college volleyball athletes showed no significant bilateral differences in sway area, anteroposterior sway distance, mediolateral sway distance, or sway velocity. However, total sway path length was significantly shorter for the right foot than for the left foot ($p < 0.05$). For both feet, sway area, anteroposterior sway distance, mediolateral sway distance, total sway path length, and sway velocity were significantly lower under the eyes-open condition than under the eyes-closed condition ($p < 0.01$).

Under the eyes-closed condition, no significant bilateral differences were observed in sway area, anteroposterior sway distance, mediolateral sway distance, or sway velocity. However, total sway path length remained significantly shorter for the right foot than for the left foot ($p < 0.05$) (Table 3)

Table 3. Test results of the static balance of female college volleyball players (M $\pm$ SD).

Balance Function Parameters	Eyes Open		Eyes Closed	
	Left	Right	Left	Right
Sway Area (mm ²)	3.97 $\pm$ 1.79	3.98 $\pm$ 1.76	22.57 $\pm$ 5.38 ##	20.88 $\pm$ 6.80 ▲▲
Anteroposterior sway distance (cm)	1.65 $\pm$ 0.50	1.54 $\pm$ 0.47	3.35 $\pm$ 1.16 ##	3.10 $\pm$ 0.94 ▲▲
Mediolateral sway distance (cm)	0.91 $\pm$ 0.42	0.95 $\pm$ 0.29	1.96 $\pm$ 0.70 ##	1.89 $\pm$ 0.52 ▲▲
Total sway path length (mm)	25.03 $\pm$ 6.44	22.08 $\pm$ 5.06 *	53.88 $\pm$ 10.14 ##	48.63 $\pm$ 1.09 *▲▲
Sway velocity (cm/s)	3.26 $\pm$ 0.83	3.14 $\pm$ 0.73	6.28 $\pm$ 1.57 ##	6.15 $\pm$ 1.32 ▲▲

Under the same visual condition, compared with the left foot, * $p < 0.05$; under different visual conditions, compared with the left foot, ## $p < 0.01$; compared with the right foot, ▲▲ $p < 0.01$.

3.3. Joint Range of Motion Measurement Results

The joint ROM results are shown in Table 4. Significant bilateral differences were observed in shoulder flexion, shoulder horizontal adduction, shoulder external rotation, elbow flexion, and weight-bearing ankle dorsiflexion (all $p < 0.05$), with greater values on the right side. A highly significant bilateral difference was also observed in hip internal rotation ($p < 0.01$), again with a greater value on the right side. No significant bilateral differences were found in the ROM of the other joints.

Table 4. Measurement results of upper- and lower-limb joint range of motion and knee-to-wall distance in female college volleyball players (M $\pm$ SD).

Joint	Direction of Motion	Left-Side Value	Right-Side Value	<i>p</i>
Shoulder	Flexion	142.15 $\pm$ 15.80	153.45 $\pm$ 13.37	0.020
	Extension	53.00 $\pm$ 6.07	53.33 $\pm$ 6.47	0.831
	Abduction	166.18 $\pm$ 8.26	166.23 $\pm$ 10.13	0.980
	Horizontal abduction	45.93 $\pm$ 11.85	49.56 $\pm$ 14.82	0.261
	Horizontal adduction	120.40 $\pm$ 10.39	125.71 $\pm$ 8.35	0.021
	External rotation	79.46 $\pm$ 6.80	84.52 $\pm$ 7.73	0.049
	Internal rotation	61.69 $\pm$ 9.04	63.60 $\pm$ 8.20	0.355
Elbow	Flexion	144.71 $\pm$ 8.66	150.63 $\pm$ 7.92	0.04
	Pronation	80.79 $\pm$ 8.74	79.83 $\pm$ 5.91	0.592
	Supination	90.32 $\pm$ 9.08	91.22 $\pm$ 10.74	0.705
Wrist	Palmar flexion	76.97 $\pm$ 9.61	79.08 $\pm$ 11.42	0.406
	Extension	74.92 $\pm$ 9.97	73.96 $\pm$ 8.95	0.672
	Ulnar deviation	42.58 $\pm$ 6.59	44.40 $\pm$ 5.44	0.212
	Radial deviation	32.70 $\pm$ 6.10	32.47 $\pm$ 5.54	0.873
Hip	Flexion	101.95 $\pm$ 12.79	104.06 $\pm$ 5.46	0.374
	Extension	32.35 $\pm$ 10.06	30.17 $\pm$ 8.18	0.322
	Abduction	60.82 $\pm$ 8.14	58.10 $\pm$ 3.55	0.77
	Adduction	25.76 $\pm$ 5.43	25.10 $\pm$ 0.59	0.481
	External rotation	43.00 $\pm$ 50.68	34.73 $\pm$ 4.96	0.340
	Internal rotation	42.87 $\pm$ 5.33	47.05 $\pm$ 1.49	0.001
Knee	Flexion	129.98 $\pm$ 9.38	126.54 $\pm$ 9.38	0.90
Ankle	Dorsiflexion ROM	29.07 $\pm$ 4.90	27.76 $\pm$ 6.90	0.362
	Plantar flexion	39.98 $\pm$ 9.49	40.47 $\pm$ 9.53	0.830
	Inversion	31.29 $\pm$ 5.30	31.57 $\pm$ 6.66	0.849
	Eversion	20.60 $\pm$ 6.36	20.19 $\pm$ 4.22	0.753
	Knee-to-wall distance (cm)	14.30 $\pm$ 3.53	15.90 $\pm$ 1.67	0.015

3.4. Correlation Analysis Between YBT Distance and Joint Range of Motion

Pearson correlation analysis was used to examine the relationships between YBT reach distances and joint ROM, and the Benjamini–Hochberg FDR method was further applied to correct the correlation results. The Pearson correlation analysis showed that the correlations between YBT-UQ reach distances and upper-limb joint ROMs were mainly observed in the right upper limb. Specifically, the superolateral reach direction of the right YBT-UQ was positively correlated with wrist palmar flexion ROM and wrist extension ROM, while the inferolateral reach direction was positively correlated with wrist radial deviation ROM. The composite score of the right YBT-UQ was negatively correlated with forearm supination ROM. No obvious correlations were observed between left-hand YBT-UQ performance and upper-limb joint ROM. After FDR correction, none of the correlations between YBT-UQ reach distances and upper-limb joint ROM remained statistically significant.

YBT-LQ reach distances showed certain correlations with lower-limb multi-joint ROMs, mainly involving the hip, knee, and ankle joints. Specifically, the anterior reach direction of the left YBT-LQ was positively correlated with knee flexion ROM and knee-to-wall distance. The anterior reach direction of the right YBT-LQ was positively correlated with hip flexion ROM, knee flexion ROM, ankle dorsiflexion ROM, and knee-to-wall distance. In addition, the posteromedial reach direction of the right YBT-LQ was positively correlated with hip flexion, adduction, and internal rotation ROM, as well as ankle eversion ROM and knee-to-wall distance.

After further FDR correction, only the correlations between the anterior reach direction of the right YBT-LQ and hip flexion ROM ($r = 0.593$, $p < 0.01$) and knee-to-wall distance ($r = 0.653$, $p < 0.01$) remained statistically significant. These findings suggest that hip flexion ROM and knee-to-wall distance may have relatively stable associations with right-side anterior dynamic balance performance. The Pearson correlation results between YBT reach distances and lower-limb joint ROM are presented in Table 5.

Table 5. Correlation between YBT reach distances and joint ROM/knee-to-wall distance.

Joint		Left				Right			
		Medial/Anterior	Superolateral/Posteromedial	Inferolateral/Posterolateral	Composite Score	Medial/Anterior	Superolateral/Posteromedial	Inferolateral/Posterolateral	Composite Score
Shoulder	Flexion	0.029	0.185	−0.209	−0.181	−0.217	0.255	0.117	−0.196
	Extension	0.003	0.317	0.132	0.083	0.021	0.185	−0.052	−0.141
	Abduction	−0.134	0.163	−0.011	−0.108	−0.007	0.224	0.176	0.158
	Horizontal abduction	−0.156	0.159	0.327	0.163	−0.263	0.228	0.047	−0.021
	Horizontal adduction	−0.016	0.007	0.180	0.025	−0.063	0.020	−0.083	−0.091
	External rotation	0.072	−0.058	0.016	0.042	−0.073	−0.042	0.037	−0.034
	Internal rotation	0.046	−0.143	−0.201	−0.123	−0.105	0.161	0.093	0.137
Elbow	Flexion	0.183	−0.012	0.188	0.159	0.063	−0.230	0.063	−0.094
	Pronation	0.000	0.194	−0.167	−0.254	−0.197	0.148	−0.132	−0.308
	Supination	0.025	0.030	−0.181	−0.266	−0.167	0.159	−0.122	−0.347 *
Wrist	Palmar flexion	0.136	0.154	0.239	0.137	−0.168	0.352 *	0.016	−0.042
	Extension	0.114	−0.139	−0.068	−0.052	0.054	0.479 **	0.155	0.264
	Ulnar deviation	−0.222	−0.052	−0.214	−0.162	−0.309	−0.100	−0.290	−0.326
	Radial deviation	0.295	0.304	0.209	0.246	0.120	0.286	0.343 *	0.226
Hip	Flexion	0.084	−0.191	−0.219	−0.118	0.593 **†	0.403 *	0.329	0.154
	Extension	0.239	−0.022	−0.124	0.069	−0.062	−0.057	−0.074	0.123
	Abduction	−0.049	−0.064	−0.076	−0.062	−0.045	0.154	0.425 *	−0.011
	Adduction	0.306	0.419 *	0.370 *	−0.034	0.099	0.541 **	0.329	0.408 *
	External rotation	0.070	0.013	0.005	0.027	−0.002	−0.331	−0.098	0.014
	Internal rotation	0.262	0.091	0.208	−0.159	0.276	0.470 **	0.291	0.398 *
Knee	Flexion	0.424 *	0.023	0.014	0.122	0.396 *	0.064	0.000	0.158
Ankle	Dorsiflexion	0.280	−0.019	0.029	0.104	0.418 *	0.221	0.231	0.012
	Plantar flexion	0.074	−0.334	−0.094	−0.345 *	0.254	−0.143	0.074	−0.074
	Inversion	0.128	0.147	0.174	0.007	0.224	0.143	0.227	−0.067
	Eversion	0.260	−0.001	0.125	−0.105	0.170	0.413 *	0.137	0.360 *

Knee-to-wall distance	0.446 **	0.270	0.328	0.093	0.653 **†	0.470 **	0.287	0.157
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Pearson correlation coefficients (r) are reported in the table. * $p < 0.05$ and ** $p < 0.01$ indicate statistical significance based on uncorrected p -values; † indicates statistical significance after Benjamini–Hochberg false discovery rate (FDR) correction ($q < 0.05$).

3.5. Correlation Analysis Between Static Balance Parameters and Lower-Limb Joint Range of Motion

Pearson correlation analysis was used to examine the relationships between static balance parameters and lower-limb joint ROM, and the Benjamini–Hochberg FDR method was further applied to correct the correlation results. The Pearson correlation analysis showed that, under the eyes-open condition, some static balance parameters were correlated with hip abduction ROM, hip internal rotation ROM, ankle plantarflexion ROM, ankle eversion ROM, and knee-to-wall distance. Under the eyes-closed condition, some static balance parameters were correlated with knee flexion ROM, ankle plantarflexion ROM, ankle inversion ROM, ankle eversion ROM, and knee-to-wall distance. Overall, the uncorrected correlations were mainly concentrated in lower-limb joint ROM measures involving the hip, knee, and ankle joints. After FDR correction, none of the correlations between static balance parameters and lower-limb joint ROM under either the eyes-open or eyes-closed condition remained statistically significant. The Pearson correlation results between static balance parameters and lower-limb joint ROM are presented in Table 6.

Table 6. Correlation between static balance parameters and lower-limb joint ROM/knee-to-wall distance.

Balance Function Parameters		Hip						Knee			Ankle		Knee-to-Wall Distance
		Flexion	Extension	Abduction	Adduction	External Rotation	Internal Rotation	Flexion	Dorsiflexion	Plantar Flexion	Inversion	Eversion	
Eyes open	L-sway area (mmq)	0.056	−0.016	0.117	−0.045	−0.168	−0.124	0.162	−0.103	−0.218	0.110	0.065	0.205
	L-AP sway distance (cm)	−0.117	−0.156	0.034	0.042	−0.131	−0.058	0.021	0.021	−0.068	0.123	0.060	0.304
	L-ML sway distance (cm)	0.327	0.168	−0.387 *	0.176	−0.229	−0.352 *	0.014	0.024	−0.002	0.110	−0.383 *	0.013
	L-total sway path length (mm)	0.063	−0.056	0.299	−0.056	−0.153	−0.051	0.297	0.037	−0.462 **	−0.134	0.066	−0.047
	L-sway velocity (cm/s)	0.332	−0.031	−0.171	−0.089	−0.024	0.165	0.318	0.048	−0.389 *	−0.319	0.007	−0.099
	R-sway area (mmq)	0.078	−0.217	0.133	0.024	0.069	−0.095	−0.053	0.051	−0.015	0.307	−0.077	0.160
	R-AP sway distance (cm)	0.014	−0.186	0.275	−0.322	0.096	−0.228	−0.069	0.079	0.084	0.192	−0.042	0.121
	R-ML sway distance (cm)	−0.062	0.189	0.108	0.130	−0.077	0.095	0.275	−0.035	−0.178	−0.088	−0.501 **	−0.369 *
	R-total sway path length (mm)	0.177	−0.087	0.121	−0.012	−0.004	−0.115	−0.010	0.093	−0.370 *	0.192	−0.301	0.032
R-sway velocity (cm/s)	0.036	−0.280	0.195	0.201	−0.097	−0.011	−0.121	−0.045	−0.229	0.216	0.160	0.218	
Eyes close	L-sway area (mmq)	−0.046	−0.149	0.010	0.035	−0.053	−0.015	−0.160	0.055	−0.147	0.191	0.230	−0.055
	L-AP sway distance (cm)	0.037	0.011	0.060	0.192	−0.118	0.226	−0.167	0.107	−0.133	0.325	0.195	−0.108
	L-ML sway distance (cm)	0.069	0.025	0.175	0.274	−0.217	0.170	−0.162	0.108	0.002	−0.438 **	−0.392 *	0.132
	L-total sway path length (mm)	−0.109	−0.030	−0.301	0.036	0.141	−0.273	−0.166	−0.022	−0.263	0.117	−0.423 *	0.101
	L-sway velocity (cm/s)	0.083	−0.087	0.091	−0.019	−0.207	−0.114	−0.188	−0.032	−0.158	0.068	−0.480 **	0.116

R-sway area (mmq)	−0.241	−0.231	−0.065	0.067	0.005	−0.266	0.114	−0.109	0.115	−0.011	−0.060	−0.149
R-AP sway distance (cm)	0.062	−0.136	0.177	0.086	0.156	−0.176	−0.009	−0.035	−0.063	0.194	−0.041	−0.011
R-ML sway distance (cm)	0.286	0.226	0.114	0.160	−0.086	0.127	0.215	−0.067	0.013	0.152	0.400 *	−0.439 **
R-total sway path length (mm)	0.163	−0.309	0.012	−0.017	−0.112	−0.188	−0.043	0.004	−0.368 *	−0.350 *	−0.018	0.077
R-sway velocity (cm/s)	0.107	−0.084	−0.075	−0.020	−0.053	0.145	−0.464 **	0.153	0.107	0.238	−0.441 **	−0.516 **

* $p < 0.05$; ** $p < 0.01$.

4. Discussion

4.1. Dynamic Balance Characteristics and Potential Mechanisms

4.1.1. Bilateral Symmetry in Upper-Limb Dynamic Balance

The YBT-UQ test is of great importance for evaluating upper-limb dynamic balance and injury prevention. In this study, no significant differences were observed in YBT-UQ reach distances between the left and right upper limbs across the three directions in female college volleyball athletes, indicating good bilateral symmetry in upper-limb dynamic balance performance. This finding is consistent with studies on baseball and softball athletes [17] and healthy adults [18]. In addition, single-arm jump tests have also shown no bilateral differences in upper-limb performance among soccer and wrestling athletes [19]. These studies suggest that healthy athlete populations typically demonstrate good bilateral symmetry in upper-limb dynamic stability tests. For female volleyball athletes, although serving and spiking are mainly performed with the dominant side, the non-dominant side also plays an important role in maintaining body balance, assisting arm swing, and completing defensive movements, which may help maintain overall symmetry in upper-limb dynamic stability.

4.1.2. Anterior Lower-Limb Asymmetry: Sport-Specific Adaptation and Assessment Implications

The YBT-LQ test can effectively reflect lower-limb dynamic postural control and may predict injury risk [20]. Although previous studies have reported no significant bilateral differences in YBT-LQ performance across the three directions among female volleyball players in different playing positions [21], our study found that female college volleyball athletes showed significant bilateral differences only in the anterior reach direction, with the dominant side performing better than the non-dominant side. The side-to-side difference exceeded the 4 cm reference threshold reported in previous studies [22]. Because this study did not collect injury incidence or prospective injury data, this difference cannot be directly interpreted as an increased injury risk; rather, it should be considered a reference for dynamic balance assessment and training monitoring. This may result from functional adaptations in neuromuscular control strategies induced by repeated, high-intensity use of the dominant side, namely the right leg, during sport-specific actions such as spiking and jumping. More importantly, this study showed that only the composite score of the non-dominant, namely left, lower limb in female volleyball athletes was below the clinical reference threshold of 94% [23], suggesting relatively insufficient dynamic postural control of the left lower limb. This may be related to asymmetry in bilateral muscle strength and neuromuscular control [24].

Although previous studies have shown that volleyball athletes demonstrate better lower-limb YBT performance than combat sports athletes, such as judo and taekwondo athletes [25], and that female athletes tend to exhibit greater asymmetry [26], the present

study further highlights significant asymmetry in the anterior reach direction and a relatively low composite score in the left lower limb. These findings suggest that greater attention should be paid to targeted training of the non-dominant, namely left, lower limb, particularly with respect to dynamic balance control in the anterior reach direction.

4.2. Visual Dependence in Static Balance Control

Static balance ability serves as the foundation for dynamic performance, and bilateral asymmetry in this capacity increases postural instability and injury risk. No significant differences were observed in most static balance indicators between soccer players, basketball players, swimmers, and non-athletes [27]. This study similarly found that female college volleyball players exhibited no significant differences in most static balance metrics between their left and right feet. However, the total swing trajectory length of the dominant (right) foot was significantly shorter than that of the non-dominant side. This may be related to superior plantar flexion ROM in the ankle joint, enabling more efficient postural microadjustments.

A more notable finding of this study was that female volleyball athletes demonstrated significantly poorer static balance performance under the eyes-closed condition than under the eyes-open condition, as indicated by higher values in several static balance parameters, including total sway path length and sway velocity. This finding suggests a pronounced reliance on visual feedback during postural control. It is consistent with previous studies on other visually demanding sports, such as soccer and basketball [28]. Balance control depends on the integration of visual, vestibular, and proprioceptive information. Volleyball requires athletes to continuously judge ball trajectory, offensive and defensive positioning, and jump timing; therefore, long-term sport-specific training may reinforce the use of visual information in postural regulation. When visual input is restricted under eyes-closed conditions, athletes must rely more on ankle-foot proprioception and vestibular regulation to maintain stability. The marked decline in balance performance observed under the eyes-closed condition in this study suggests that female volleyball athletes may still need to improve their non-visual sensory integration ability when visual input is limited. Therefore, future training may appropriately incorporate balance exercises under eyes-closed, visual-interference, or unstable-support conditions to promote proprioceptive function and multisensory integration ability [29].

4.3. Adaptive Changes in Joint Range of Motion and Their Potential Implications

4.3.1. The Dual Nature of Adaptation and Risk in the Increased Range of Motion of the Dominant Upper Limb

Adequate upper-limb joint ROM is essential for volleyball skill execution and injury prevention. The present study showed that female college volleyball athletes generally had normal upper-limb joint ROM, but significant bilateral asymmetry was observed. Specifically, the dominant side, namely the right side, exhibited significantly greater ROM in shoulder flexion, shoulder external rotation, and elbow flexion than the left side. This asymmetry may result from adaptive increases in joint mobility on the dominant side due to repeated serving and spiking movements during long-term sport-specific training. In addition, this asymmetry may suggest potential injury-related concerns. Previous research has indicated that insufficient shoulder external rotation ROM is directly associated with shoulder injury risk and may also affect the elbow [1]. However, greater ROM on the dominant side does not directly indicate better sport-specific performance or a lower injury risk, and should be interpreted comprehensively in relation to bilateral differences and the specific movement demands of volleyball. Therefore, upper-limb ROM assessment should be combined with targeted training to support sport-specific performance and reduce potential injury risk.

4.3.2. Characteristics and Impact of Asymmetric Range of Motion in the Lower-Limb Hip and Ankle Joints

Lower-limb joint ROM plays an important role in the technical performance of volleyball athletes. Hip joint ROM not only determines the extent of lower-limb extension during takeoff and landing, but also directly contributes to stability control [30]. Hip internal rotation ROM can influence knee joint alignment and overall movement performance [31], while knee and ankle joint ROM jointly contribute to cushioning and stability during landing [32]. The present study found that the overall lower-limb joint ROM of female volleyball athletes was within the normal range; however, a significant bilateral difference was observed in hip internal rotation ROM, with the right side showing greater ROM than the left side. This asymmetry may be related to the greater reliance of volleyball athletes on the right leg during technical movements such as spiking and sudden stops in competition, whereby long-term repetitive right hip internal rotation may lead to adaptive increases in ROM. In addition, asymmetry in hip internal rotation ROM may indicate potential movement-related risks. Restricted hip internal rotation may disrupt kinetic-chain coordination, whereas insufficient control of internal rotation may lead to excessive femoral internal rotation, thereby altering knee joint mechanical loading and increasing injury risk [33]. Therefore, training related to hip joint ROM should not focus solely on increasing mobility but should also emphasize hip stability and gluteal control to improve lower-limb control during takeoff, landing, and change-of-direction movements.

Weight-bearing ankle dorsiflexion, as reflected by knee-to-wall distance, plays an important role in jumping performance, landing cushioning, and injury prevention in volleyball athletes. During landing, ankle dorsiflexion absorbs approximately 37.0–50.0% of the total kinetic energy [34]. Limited ankle dorsiflexion ROM may reduce shock absorption efficiency, thereby increasing ground reaction forces and knee joint loading [35]. In the present study, the knee-to-wall test showed that female volleyball athletes had significantly greater ankle dorsiflexion ROM on the right side than on the left side. In addition, bilateral asymmetry or insufficiency in ankle dorsiflexion ROM may affect athletic performance and increase injury risk, which may be related to asymmetrical force-generation patterns resulting from previous injuries or overuse of the plantar flexors [36]. Therefore, bilateral differences in ankle dorsiflexion ROM among female volleyball athletes should be considered in lower-limb functional assessments and may be combined with balance stability training and landing technique training to improve lower-limb dynamic control and reduce potential injury risk.

4.4. Associations Between Joint ROM and Balance Control

4.4.1. Characteristics of the Relationship Between Upper-Limb Dynamic Balance and Joint Range of Motion

The present study did not find stable correlations between YBT-UQ reach distances and shoulder or elbow ROM in female college volleyball athletes, which differs from findings reported in male volleyball athletes [13]. This suggests that upper-limb dynamic balance in female volleyball athletes may not be primarily determined by shoulder and elbow ROM, but may instead be influenced by multiple factors, including shoulder girdle stability, core control, upper-limb strength, and multi-joint coordination [37–39].

Notably, Pearson correlation analysis showed that, in female volleyball athletes, the YBT-UQ reach distance of the dominant side, namely the right hand, in the superolateral direction was moderately positively correlated with wrist palmar flexion ROM and wrist extension ROM, while the reach distance in the inferolateral direction was moderately positively correlated with wrist radial deviation ROM. These findings suggest that wrist ROM may be associated with distal upper-limb support and hand position adjustment on

the dominant side. However, after FDR correction, these correlations did not remain statistically significant, indicating that the relationship between wrist ROM and YBT-UQ performance requires further verification. Based on these findings, upper-limb dynamic balance assessment and training in female volleyball athletes should not focus solely on increasing shoulder and elbow ROM but should also consider shoulder girdle control, core stability, and overall upper-limb coordination.

4.4.2. Task-Specific Relationships Between Lower-Limb Dynamic Balance and Hip and Ankle Range of Motion

Hip and knee flexion ROM measures are among the important joint-related factors influencing anterior reach performance in the YBT. Pearson correlation analysis showed that the anterior reach direction of the right YBT-LQ was positively correlated with several hip, knee, and ankle ROM measures. After FDR correction, only the correlations between the anterior reach direction of the right YBT-LQ, hip flexion ROM and knee-to-wall distance remained statistically significant. This finding is generally consistent with previous studies in young adults [36] and patients with chronic ankle instability [40], which reported that ankle dorsiflexion ROM influences anterior reach performance in the YBT. Previous research has also shown that fatigue may reduce YBT performance and is accompanied by decreases in sagittal-plane hip and knee joint ROM [41]. Therefore, hip flexion ROM and knee-to-wall distance may represent two relatively stable joint-related factors associated with anterior dynamic balance performance in female volleyball athletes.

This finding is biomechanically reasonable. The anterior reach direction of the YBT-LQ requires athletes to perform lower-limb reaching, trunk control, and forward center-of-mass displacement while maintaining single-leg support. Hip flexion ROM may influence the forward reach range of the swing leg, pelvic position adjustment, and trunk forward-lean control. Knee-to-wall distance is closely related to forward tibial progression on the stance side, ankle joint stability, and the ability to shift the center of mass forward. Therefore, the stable correlations of hip flexion ROM and knee-to-wall distance with anterior dynamic balance may reflect key joint demands during single-leg support and forward center-of-mass control in female volleyball athletes.

The uncorrected results also showed that the posteromedial and posterolateral reach directions of the YBT-LQ were correlated with selected hip and ankle ROM measures, and the correlated variables were not completely consistent between the left and right sides. These findings are partly consistent with previous evidence suggesting that the posteromedial direction may be influenced by hip function [42]. However, these correlations did not remain significant after FDR correction, which may be because the posteromedial and posterolateral directions of the YBT-LQ depend more heavily on hip strength, core stability, trunk control, and multi-joint coordination.

In summary, the relationship between lower-limb dynamic balance and joint ROM in female volleyball athletes did not show a broad and consistent correlation pattern, but instead demonstrated certain task-specific and joint-specific characteristics. After FDR correction, the stable findings were mainly concentrated in the relationships between the anterior reach direction of the right YBT-LQ, hip flexion ROM, and knee-to-wall distance. Therefore, when assessing and training dynamic balance in volleyball athletes, attention may be focused on single-leg support control in the anterior direction and the coordination of hip and ankle joint ROM. Other uncorrected correlations should be further verified in studies with larger sample sizes.

4.5. Characteristics of the Relationship Between Static Balance and Range of Motion in Lower-Limb Joints

The hip joint is widely recognized as playing a central role in postural control. Pearson correlation analysis showed that some static balance parameters were correlated with hip abduction ROM and hip internal rotation ROM, which is partly consistent with previous studies suggesting the involvement of hip function in postural control [43]. As the ankle joint is a primary joint for responding to postural perturbations, its multiplanar mobility plays an important role in balance control. Some static balance parameters were correlated with ankle plantarflexion, inversion, eversion, and knee-to-wall distance, suggesting that multidirectional ankle joint ROM may contribute to postural fine-tuning during single-leg standing. In addition, under the eyes-closed condition, some static balance parameters were also correlated with knee flexion ROM, indicating that knee and ankle joint ROM may be involved in postural regulation when visual input is restricted. However, none of these correlations remained statistically significant after FDR correction, suggesting that the explanatory power of single-joint ROM for static balance performance may be limited.

In summary, static balance parameters showed certain correlations with lower-limb joint ROM in the uncorrected analyses, but these correlations did not remain significant after FDR correction. Therefore, the present study should not interpret the relationship between static balance and any specific ROM measure as a core finding. Static single-leg standing may be influenced by multiple factors, including visual input, proprioception, fine ankle-foot control, muscle strength, and neuromuscular regulation, and the explanatory power of single-joint ROM for static balance performance may be limited. Future studies with larger sample sizes, muscle strength assessments, and kinematic analyses are needed for further verification.

4.6. Limitations

(1) This study used a cross-sectional design and can only reveal associations between joint ROM and balance performance; therefore, causal relationships between these variables cannot be inferred. In addition, injury incidence was not recorded, and no prospective injury follow-up was conducted. Thus, the relationships among ROM asymmetry, differences in balance performance, and actual injury occurrence should be further verified in future longitudinal studies.

(2) The sample size of this study was relatively limited, and the participants were restricted to female college volleyball athletes. Male athletes and athletes of different competitive levels were not included; therefore, the generalizability of the findings requires further validation. Moreover, the participants were recruited from three different universities, and differences in training content, training frequency, and training load across universities may have influenced their balance ability and joint ROM characteristics to some extent. Future studies may conduct stratified analyses by considering factors such as training years, training load, competitive level, and playing position.

(3) This study involved correlation analyses between multiple balance indicators and joint ROM measures. Although the FDR method was used to correct for multiple comparisons, some results that reached statistical significance in the uncorrected analyses may still have been influenced by the relatively small sample size and multiple testing. Therefore, this study focused primarily on the findings that remained significant after FDR correction as relatively stable results, while correlations that did not survive correction were interpreted with caution.

5. Conclusions

Based on cross-sectional correlation analysis, this study found that female college volleyball athletes showed a certain degree of bilateral asymmetry in dynamic balance and pronounced visual dependence in static balance. After FDR correction, the correlations between the anterior reach direction of the right YBT-LQ, hip flexion ROM and knee-to-wall distance remained relatively stable, suggesting that hip–ankle joint ROM may be associated with anterior dynamic balance performance. In training and assessment, attention may be given to the dynamic balance of the non-dominant lower limb, postural control under visually restricted conditions, and the relationships among hip flexion ROM, knee-to-wall distance, and dynamic balance. The findings of this study may provide a reference for postural control assessment and the development of sport-specific training programs for female volleyball athletes; however, these results should be further verified in studies with larger sample sizes and prospective designs.

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