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SYSTEMATIC REVIEW

Understanding biomechanical demands during volleyball spike and block landings: A systematic review

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Abstract

Volleyball is a sports discipline that involves complex technical movements, where the phases of movement are closely related to kinematic parameters. Spike and block actions play a crucial role in determining match outcomes, as volleyball players perform numerous jumps and subsequent landings throughout a game. This review therefore aims to clarify the biomechanical insights derived from studies examining the kinetic and kinematic parameters during the landing phases of spike and block techniques, which are fundamental skills in volleyball. A systematic review was conducted using four databases (Web of Science, PubMed, Scopus, Science Direct) with the keywords "landing mechanics in volleyball," "landing kinematics in volleyball," "landing mechanics of spike technique in volleyball," and "landing mechanics of block technique in volleyball." As a result of the database screening, fourteen articles (n=14) were included in the study. In conclusion, it was observed that studies on landing mechanics in volleyball are predominantly focused on the landing phase following the block action. It was found that the most critical kinematic variables affecting landing mechanics are valgus-varus angles, joint angles, joint moments, range of motion, ground reaction force, muscle stiffness, and muscle strength. Additionally, the findings consistently indicated that female volleyball players have greater joint range of motion and higher knee valgus angles, which are associated with increased injury risk.

Introduction

Volleyball is one of the most played team sports in the world, and its popularity has been steadily increasing in recent years (De Bleecker et al., 2024). The high tempo of competition, coupled with the rapid execution of complex motor skills, enhances the overall spectator experience (Mikołajec et al., 2025). However, the complex structure of the game also brings many challenges, especially for elite players. Volleyball players perform an average of 80 to 150 jumps per match, sometimes reaching up to 200, depending on their expertise, the number of sets played, and the duration of the match (Öz, 2017). In five-set volleyball matches, the number of jumps varies significantly depending on the players' positions. The highest average number of jumps is seen among setters (136 jumps), followed by middle blockers (97 jumps), opposites (88 jumps), and outside hitters (65 jumps) (Borras et al., 2011). Elite players perform approximately 40,000 attacks (and consequently jumps) per year with 16-20 hours of training per week (Tillman et al., 2004). These jumps can be used in almost all technical movements (set, spike, block, and serve), but they are mostly used for high jumps when performing spike and block movements (Rebelo et al., 2024). The substantial magnitude of jump load highlights the necessity of developing not only jump height but also jump endurance in training, while underscoring the importance of thoroughly analysing landing mechanics following each jump (Taylor et al., 2019).

Landing predominantly occurs following spike and block jumps, which correspond to offensive and defensive manoeuvres (Afonso et al., 2021; Li et al., 2021). Approximately 63% of musculoskeletal injuries observed in volleyball occur during the landing phase

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following jumps, which represents a fundamental component of spiking and blocking (Augustsson et al., 2006; Goodwin et al., 2016). In volleyball, jumps-and-landings are performed approximately 60 times per hour, during which the lower extremities are exposed to vertical ground reaction forces (GRF) equivalent to one to five times body weight (Garcia et al., 2022). In addition, it has been reported that the experience gained by players during regular training sessions, as well as the use of different landing strategies depending on the type of jump, may play a significant role in reducing GRF (Bathe et al., 2023). Optimal landing kinematics are characterized by strategies that minimize knee valgus moment and facilitate controlled interaction with the ground (Zahradnik et al., 2014). Preferring a two-leg landing, which reduces angular loading on the knee and hip joints, has been emphasized as particularly important for achieving both controlled plantar flexion and adequate hip and knee flexion during spike landings (Garcia et al., 2022; Xu et al., 2022). In effective spikes, increases in knee and hip angular velocities, vertical center-of-mass (CoM) velocity, and arm-swing amplitude lead to significant improvements in jump and spike height (Sarvestan et al., 2020). In successful blocks, players with superior lower-extremity coordination and adequate leg-knee stiffness have been reported to perform more efficient landings (Hughes & Watkins, 2008).

Techniques that are not executed optimally inevitably increase the risk of injury. Considering that the majority of injuries in volleyball occur during landings following jumps, a precise and detailed analysis of landing kinematics becomes indispensable. Previous research in volleyball has mainly addressed landing mechanics, with an emphasis on their association with sport-related injuries (Obara et al., 2022; Vermeulen et al., 2023; Zaki et al., 2025). (a) examining spike and block landings from kinetic and kinematic perspectives, and (b) determining their variations based on sex and experience level. Considering that landing mechanics are a critical factor in enhancing performance and reducing injury risk, this study is expected to contribute to a deeper understanding of landing mechanics and, consequently, support coaches, athletes, and researchers in designing more effective training programs and in better identifying key elements to be emphasized during technical instruction.

Methods

Search Strategy

This systematic review encompasses studies that have investigated the mechanics of spike and block landings in volleyball. To achieve this aim, articles published in peer-reviewed scientific journals and indexed in Web of Science (WoS), PubMed, Scopus, and ScienceDirect were systematically searched up to September 27, 2025. In the literature review, the following keywords were used to identify studies examining spike and block landing mechanics in volleyball: "landing mechanics in volleyball", "landing kinematics in volleyball", "landing kinetics in volleyball", "landing mechanics of spike technique in volleyball" and "landing mechanics of block technique in volleyball". During the search process, keyword combinations were created using Boolean operators ('AND' and 'OR'), and a comprehensive search strategy was employed by combining relevant terms in accordance with the purpose of the study. Only studies published in English were included, and no restrictions were applied regarding publication year. The search outputs were screened at the title, abstract, and full-text levels, and studies were selected based on predefined eligibility criteria.

Eligibility Criteria

The inclusion criteria for the review were as follows: (a) being an original research article, (b) addressing landing mechanics following spike or block actions in volleyball, (c) employing spike or block techniques within a research design that reflects the ecological demands of volleyball, and (d) focusing on indoor volleyball. The exclusion criteria were as follows: (a) studies published in languages other than English, (b) studies for which the full text was not accessible, (c) studies focusing primarily on injuries rather than volleyball-specific mechanics, and (d) articles classified as traditional reviews, systematic reviews, or meta-analyses.

Study Selection

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2015). After identifying articles in each database, the abstracts were screened, followed by a full-text assessment of studies that met the preliminary eligibility criteria.

Data Extraction

Data from the included studies were systematically collected using a pre-structured data extraction form. The extracted information included: first author's name, year of publication, sample characteristics and size, sex, age (mean values), type of task (spike or block action), measurement instruments (3D motion-capture systems, force platforms, video cameras), and kinematic outcomes (jump height, linear and angular velocities of the CoM, joint range of motion (RoM), lower-limb flexion angles, GRF, etc.). The data extraction process was conducted independently by two researchers, and any discrepancies were resolved through discussion.

Quality Assessment and Risk of Bias

The quality of the included studies was assessed using a customized STROBE-based quality evaluation tool, adapted from previous systematic reviews involving movement analysis (Lempereur et al., 2014; Oliveira et al., 2020; Peters et al., 2010) (Table 1). The quality assessment tool used in this review was developed in accordance with the primary research objectives. For each study, an overall quality score was calculated using a three-point scale in which each item was rated as zero (no description), one (limited description), or two (adequate description). Studies were classified as having 'limited' quality (total score <70%), 'good' quality (total score <80%), or 'high' quality (total score ≥80%). A Quality Index (QI) score was generated for each study and the overall quality level was expressed as a percentage by dividing the score achieved by the maximum possible score and multiplying the result by 100. All data were processed using a Microsoft Excel 2016 spreadsheet (Microsoft Corporation, Redmond, WA, USA).

In cases of disagreement between the two reviewers, a third independent researcher was consulted to reach consensus. For studies relevant to the topic but lacking quantitative data, the corresponding authors were contacted via email to request additional information. Studies for which no response was obtained, and missing data could not be retrieved were excluded from the analysis.

Results

Search Results

The search across the aforementioned databases initially identified 1,028 records relevant to the topic. After removing review articles, conference papers, non-English publications, records without accessible full text, and duplicates, 578 records remained for title and abstract screening. Based on the exclusion criteria, 102 records were deemed eligible for full-text assessment. Following the full-text review, 88 studies were excluded for not meeting the inclusion criteria. Consequently, 14 studies were included in this systematic review and were used in the final analysis (Figure 1).

Table 1
Quality analysis form used in the systematic review.

Q1	Is there in the abstract an explication of what has been done and found?
Q2	Is the scientific context clearly explained?
Q3	Are the objectives clearly stated?
Q4	Is the sampling size stated?
Q5	If yes, is the sampling size statistically justified?
Q6	Are the characteristics of the subjects (height, weight, sex, athlete, healthy or pathologic subject) described?
Q7	Is the motion analysis system described?
Q8	Are marker locations accurately described?
Q9	Is the spatial model defined?
Q10	Are the movement tasks defined?
Q11	Is the accuracy/reliability computation described?
Q12	Is the mathematical sequence for angular calculation (e.g. Cardan, Euler, Quaternions) described?
Q13	Is the data processing (filter, normalization, derived) described?
Q14	Are the statistical tools used to show significant differences?
Q15	Are the results about the accuracy/reliability described?
Q16	Are the results interpretable?
Q17	Are the limitations of the study discussed?
Q18	Is the conclusion clearly stated?

Questions were scored as follows: 0: No description; 1: Limited description; 2: Adequate description.

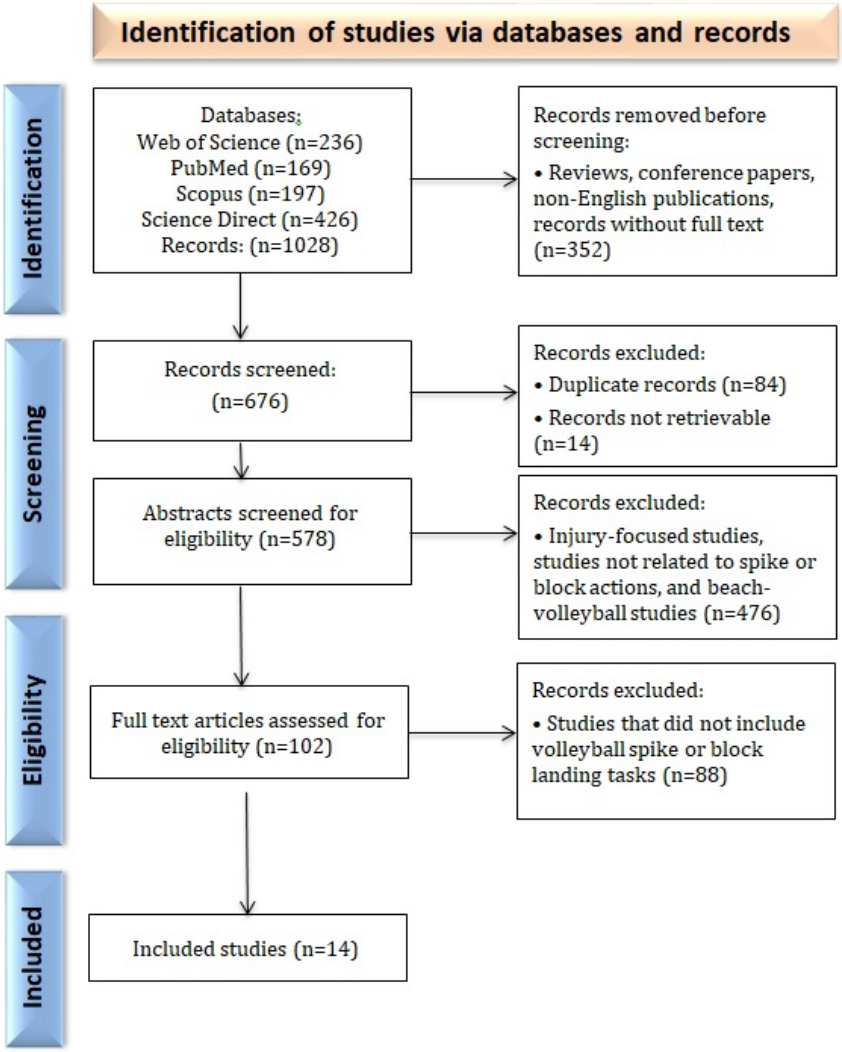

Figure 1. PRISMA (Preferred Reporting Items for Systematic reviews and Meta-analyses) flow chart.

Quality of Included Studies

The results of the quality assessment indicated that the methodological rigor of the included studies varied across the sample. Based on a maximum achievable score of 36 points, the QI scores ranged from 19 to 33 points, corresponding to quality percentages between 52.8% and 91.7%. Overall, seven studies were classified as high quality (≥80%), five studies demonstrated good quality (70–79%), and two studies showed limited quality (<70%). The highest scoring studies typically provided comprehensive descriptions of participant characteristics, motion analysis procedures, marker placement, task definitions, and data processing steps. Conversely, the lower scoring studies frequently lacked sufficient detail in areas such as sampling justification, reliability or accuracy reporting, and mathematical procedures used for angular calculations. Despite these variations, most studies consistently met the criteria related to describing the motion analysis system, defining the experimental tasks, and presenting key kinetic and kinematic outcomes. A detailed summary of the individual QI scores (points and percentages) is presented in Table 2.

Characteristic of the Included Studies

The characteristics of the included studies are shown in Tables 3 and 4. The 14 studies included in this systematic review comprised a total of 287 volleyball players, of whom 161 were male and 126 were female. The mean ages of the participants ranged from 13 to 27 years. All studies were experimentally designed to reflect the execution of spike and block techniques under conditions representative of real match scenarios. Regarding the measurement systems employed, 10 studies used both force platforms and motion-capture systems (Garcia et al., 2022; Hughes et al., 2008, 2010a, 2010b; Hughes & Watkins, 2008; Janssen et al., 2012; Marquez et al., 2009; Mercado-Palomino et al., 2020; Salci et al., 2004; Xu et al., 2022), 1 study used only a

force platform (Molla et al., 2023), 2 studies relied on video-camera systems (Lobietti et al., 2010; Parsons & Alexander, 2012), and 1 study incorporated electromyography (EMG) (Wang & Zhao, 2023). When categorized according to technical focus, 3 studies examined landing mechanics following both spike and block actions (Garcia et al., 2022; Lobietti et al., 2010; Salci et al., 2004), 7 studies focused exclusively on block landings (Hughes et al., 2008, 2010a, 2010b; Hughes & Watkins, 2008; Janssen et al., 2012; Mercado-Palomino et al., 2020; Molla et al., 2023), and 4 studies investigated landings performed after spike actions (Marquez et al., 2009; Parsons & Alexander, 2012; Wang & Zhao, 2023; Xu et al., 2022).

Spike Landing Mechanics

Among the studies included in this review, seven focused on spike landing mechanics. 2 studies were grouped under the category of gender-based differences (Lobietti et al., 2010; Salci et al., 2004). A summary of the remaining 5 studies is provided below (Garcia et al., 2022; Marquez et al., 2009; Parsons & Alexander, 2012; Wang & Zhao, 2023; Xu et al., 2022):

Studies investigating spike landing mechanics have reported findings across a variety of kinetic and kinematic parameters. These investigations commonly assessed horizontal and vertical CoM velocities and hip flexion at initial ground contact (IC) (Marquez et al., 2009), hip, knee, and ankle joint RoM (Garcia et al., 2022; Marquez et al., 2009), dorsiflexion/plantarflexion and knee flexion (Parsons & Alexander, 2012), GRF and ankle angle at IC (Garcia et al., 2022), peak knee and hip abduction moment as well as internal and external rotation moment (Xu et al., 2022), and electromyography (EMG) activations (Wang & Zhao, 2023).

Table 2
Quality analysis of the selected studies (n=14).

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Total (max:36)	% Quality
Salcı et al. (2004)	2	2	2	2	0	2	2	2	0	2	2	1	2	2	1	2	2	2	30	83.3
Hughes et al. (2008)	2	2	2	2	0	2	2	2	0	2	2	0	2	2	1	2	0	2	27	75
Hughes and Watkins (2008)	2	2	2	2	0	2	2	2	0	2	2	2	2	2	1	2	2	2	31	86.1
Marquez et al. (2009)	2	2	2	2	0	2	2	2	2	2	2	2	2	2	1	2	0	2	31	86.1
Lobietti et al. (2010)	2	2	2	2	0	0	0	0	0	2	2	0	0	2	1	2	0	2	19	52.8
Hughes et al. (2010a)	2	2	2	2	0	2	2	2	0	2	2	2	2	2	1	2	0	2	29	80.6
Hughes et al. (2010b)	2	2	2	2	0	2	2	0	2	2	2	2	2	2	1	2	0	2	29	80.6
Parsons et al. (2012)	2	2	2	2	0	2	2	0	2	1	2	0	2	2	1	2	2	2	28	77.8
Janssen et al. (2012)	2	2	2	2	0	2	2	2	2	2	2	2	2	2	1	2	0	2	31	86.1
Mercado-Palomino et al. (2020)	2	2	2	2	0	2	2	0	1	2	2	2	2	2	1	2	2	2	30	83.3
Garcia et al. (2022)	2	2	2	2	0	2	2	2	2	2	2	2	2	2	1	2	2	2	33	91.7
Xu et al. (2022)	2	2	2	2	0	2	2	2	2	2	2	1	2	2	1	2	2	2	32	88.9
Wang and Zhao (2023)	2	2	2	2	0	2	2	0	2	2	2	0	2	2	1	2	2	2	29	80.6
Molla et al. (2023)	2	2	2	2	2	2	2	0	1	2	2	0	2	2	1	2	2	2	30	83.3

Note: Studies presented in the table are ordered chronologically by year of publication.

Table 3
Characteristics of the included studies.

No	Title	Year	Authors	Journal of Publication
1.	Comparison of landing maneuvers between male and female college volleyball players	2004	Salcı et al.	Clin Biomech (Bristol)
2.	Gender differences in lower limb frontal plane kinematics during landing	2008	Hughes et al.	Sports Biomech
3.	Lower limb coordınation and stiffness during landing from volleyball block jumps	2008	Hughes and Watkins	Res Sports Med
4.	The effects of jumping distance on the landing mechanics after a volleyball spike	2009	Marquez et al.	Sports Biomech
5.	Landing techniques in volleyball	2010	Lobietti et al.	J Sports Sci Med
6.	Differences between the sexes in knee kinetics during landing from volleyball block jumps	2010a	Hughes et al.	Eur J Sport Sci
7.	The effects of opposition and gender on knee kinematics and ground reaction force during landing from volleyball block jumps	2010b	Hughes et al.	Res Q Exercise Sport
8.	Modifying spike jump landing biomechanics in female adolescent volleyball athletes using video and verbal feedback	2012	Parsons et al.	J Strength Cond Res
9.	Lower extremity kinematics and kinetics when landing from unloaded and loaded jumps	2012	Janssen et al.	J Appl Biomech
10.	Can kinematic and kinetic differences between planned and unplanned volleyball block jump-landings be associated with injury risk factors?	2020	Mercado-Palomino et al.	Gait Posture
11.	Comparison of landing kinematics and kinetics between experienced and novice volleyball players during block and spike jumps	2022	Garcia et al.	BMC Sports Sci Med Rehabil
12.	Temporal kinematic and kinetics differences throughout different landing ways following volleyball spike shots	2022	Xu et al.	J Sports Engineering and Technology
13.	Analysis of volleyball players' force generation during jump spike from the perspective of electromyographic characteristics	2023	Wang & Zhao	Acta Bioeng Biomech
14.	Relationship between impulse and kinetic variables during jumping and landing in volleyball players	2023	Molla et al.	BMC Musculoskelet Disord

Note: Studies presented in the table are ordered chronologically by year of publication.

Various motion-analysis software programs have been used as measurement methods in the studies reviewed. 2 studies employed the VICON motion-analysis system (Marquez et al., 2009; Xu et al., 2022), 1 study used the Dartfish software (Parsons & Alexander, 2012), and another utilized the Qqus motion-analysis program (Garcia et al., 2022). 1 study focused primarily on kinetic variables and used the Noraxon Ultium EMG system (Wang & Zhao, 2023). Additionally, 2 studies integrated force platforms concurrently with motion-analysis systems (Marquez et al., 2009; Xu et al., 2022). The reviewed studies mainly focused on male volleyball players (Garcia et al., 2022; Marquez et al., 2009; Wang & Zhao, 2023; Xu et al., 2022). While the participants included in these studies represented varying levels of experience, 2 studies specifically compared professional and amateur player groups (Garcia et al., 2022; Wang & Zhao, 2023). Most investigations examined comparative conditions such as different approach distances, experience levels, and foot-preference strategies during landings (Garcia et al., 2022; Wang & Zhao, 2023; Xu et al., 2022), whereas 1 study focused on the effects of verbal and visual feedback intervention (Parsons & Alexander, 2012).

Block Landing Mechanics

10 studies examined kinetic and kinematic aspects of block landing mechanics (Garcia et al., 2022; Hughes et al., 2008, 2010a, 2010b; Hughes & Watkins, 2008; Janssen et al., 2012; Lobietti et al., 2010; Mercado-Palomino et al., 2020; Molla et al., 2023; Salci et al., 2004), although 6 of these were categorized under sex-based differences (Hughes et al., 2008, 2010a, 2010b; Hughes & Watkins, 2008; Lobietti et al., 2010; Salci et al., 2004). Details regarding the remaining four studies are presented below (Garcia et al., 2022; Janssen et al., 2012; Mercado-Palomino et al., 2020; Molla et al., 2023).

Studies examining block landing mechanics have generally assessed variables such as jump height and hip flexion angles (Janssen et al., 2012); dominant and non-dominant leg energy absorption (EA) (Mercado-Palomino et al., 2020); lower-limb RoM, ankle dorsiflexion angles at IC, and GRF (Garcia et al., 2022). All studies examining block landings utilized force platforms. Motion analyses were performed using the Oqus motion-analysis system in 2 studies (Garcia et al., 2022; Mercado-Palomino et al., 2020), and the VICON system in 1 study (Janssen et al., 2012). Similar to the studies on spike landing mechanics, research on block landings has also predominantly been conducted on male volleyball players (Garcia et al., 2022; Janssen et al., 2012; Molla et al., 2023). While several studies focused primarily on kinetic variables (Garcia et al., 2022; Mercado-Palomino et al., 2020; Molla et al., 2023) 2 studies reported kinematic data (Garcia et al., 2022; Janssen et al., 2012).

Gender-Based Comparison of Spike and Block Landing Mechanics

Six of the studies included in this review reported kinetic and kinematic data related to gender-based differences in spike and block landing mechanics (Hughes et al., 2008, 2010a, 2010b; Hughes & Watkins, 2008; Lobietti et al., 2010; Salci et al., 2004). Information regarding these studies is provided below.

The studies primarily examined variables such as peak knee and hip flexion angles, GRF, and peak quadriceps and hamstring muscles torque (Salci et al., 2004); knee valgus, inter-knee distance, and inter-ankle distance (Hughes et al., 2008); lower-limb joint RoM, dorsiflexion and plantar flexion angles at IC, and leg stiffness (Hughes & Watkins, 2008). Additional variables included athletes' preferences for single- or double-leg landings (Lobietti et al., 2010); normalized knee moments (Hughes et al., 2010a); and valgus angles (Hughes et al., 2010b). With the exception of 1 study (Lobietti et al., 2010), all investigations employed both force platforms and motion-analysis systems as measurement instruments (Hughes et al., 2008, 2010a, 2010b; Hughes & Watkins, 2008; Salci et al., 2004). The VICON motion-analysis system was the most commonly used motion-analysis instrument (Hughes et al., 2008, 2010a, 2010b; Hughes & Watkins, 2008). 1 study conducted its assessments using match-video analyses (Lobietti et al., 2010). Most of the studies included collegiate volleyball players (Hughes et al., 2008, 2010a, 2010b; Hughes & Watkins, 2008; Salci et al., 2004). Block-related protocols were designed using various conditions, including different jump heights (Salci et al., 2004); blocking against an attack (Hughes et al., 2008, 2010a; Hughes & Watkins, 2008a); with or without an opponent (Hughes et al., 2010b); and comparisons between single- and double leg landings (Lobietti et al., 2010).

Table 4
Overview of the findings from the included studies.

No	Authors (Year)	Participants (n)	Gender (n, age)	Design	Instruments	Kinetic and kinematic outcomes				
							Female		Male	
1	Salcı et al. (2004)	Collegiate Athletes (n=16)	Male (n=8, age 22.3±2.5) Female (n=8, age, 20.5±1.9)	Landing mechanics of spike and block actions from varying heights (40 cm and 60 cm) measured on a force plate	Bertec force plate, Isokinetic dynamometer and KISS (local motion analysis software)	*Spike*	40 cm	60 cm	40 cm	60 cm
						MKF°	(59.3±9.5)	(76.2±7.6)	↑ (79.6±17.9)	↑ (87.9±16.7)
						MHF°	(44.9±11.3)	(61.4±10.0)	↑ (60.3±22.6)	↑ (72.0±19.3)
						GRF (n/kg)	(4.6±0.6)	(5.7±1.0)	↓ (3.3±0.5)	↓ (3.9±0.7)
						Block				
						MKF°	(63.8±7.1)	(75.7±8.1)	↑ (72.7±14.3)	↑ (84.9±3.2)
						MHF°	(52.8±9.8)	(68.9±13.2)	↑ (67.3±17.0)	↑ (74.2±14.4)
						GRF (n/kg)	(5.1±0.7)	(6.2±1.3)	↓ (3.6±0.5)	↓ (4.4±1.1)
						MQT (60°/s)	(195.2±32.1)		↑(302.5±90.7)	
						MHT (60°/s)	(95.4±21.3)		↑ (127.8±27.5)	
							Female		Male	
2	Hughes et al. (2008)	Collegiate Athletes (n=12)	Male (n=6, age (21.6±3.3) Female (n=6, age 21.2±1.3)	Landing mechanics of blocks performed in response to an attack, on force plates positioned in front of the net	AMTI force plate, VICON motion analysis software	+Var/-Val° ROM°	(-10.4±7.7)		↓ (-2.9±7.9)	
						IKD (mm /%ht)	(27.9± 18.0)		↓ (10.2± 16.5)	
						IAD (mm /%ht)	(23.7±16.5)		↑(41.6± 27.4)	
							Female		Male	
3	Hughes and Watkins (2008)	Collegiate Athletes (n=10)	Male (n=5, age 21.0±3.5) Female (n=5, age 21.8±0.5)	Landing mechanics of blocks performed in response to an attack, on force plates positioned in front of the net	AMTI force plate, VICON motion analysis software	MHF°	(39.07±11.89)		↓ (29.16±7.91)	
						KF° (IC)	(14.77 ± 6.30)		↑(19.58 ± 6.38)	
						RoM°				
						KF°	(53.13 ± 13.75)		↓ (42.97 ± 14.40)	
						AF°	(56.50 ± 11.13)		↓ (48.49 ± 12.28)	
						+Dorsi/-Plantar° (IC)	(−25.05 ± 9.34)		↓ (−17.09 ± 10.31)	
						GRF(N)	(1659.3 ± 411.3)		↑ (2501.2 ± 692.0)	
						LS (kN/m)	(10.29 ± 3.56)		↑ (15.02 ± 8.82)	
							Normal Distance		Long Distance	
							Vertical	Horizontal	Vertical	Horizontal
4	Marquez et al. (2009)	Collegiate Athletes (n=6)	Male (n=6, age 19.6±0.7)	Landing mechanics of spikes directed at a target from varying distances of balls delivered by the setter, measured on a force plate	Force plate, VICON motion analysis software	CoM m/s (IC)	(3.69±0.24)	(1.52±0.26)	↑ (3.88±0.33)	↑(2.39±0.16)
						HF° (IC)	(150.2± 19.8) (L)		↓ (125.8±13.8) (L)	
						RoM° (Left)				
						HF°	(11± 11)		↓ (7.3±11.1)	
						KF°	(22.2± 5)		↓ (16.0±4.1)	
						AF°	(36.7 ±16.6)		↓ (23.2±12.7)	
						MFV m/s				
						AV m/s (Left)	(1408.6±64.1)		↓ (1142.5±259.9)	
						HV m/s (Right)	(517.5±111.7)		↑ (715±99.5)	

Table 4 - Continued

						Female			Male			
						DLE	LL	RL	DLE	LL	RL	
5	Lobietti et al. (2010)	Professional Volleyball Players in the Italian League (n=96)	Male (n=48) Female (n=48)	Analysis of landing styles in six matches played in the Italian leagues during the 2004–2005 season	Video analysis	*Spike* (%)	(74.7)	(23.7)	(1.6)	↓(60.0)	↑(31.5)	↑(8.5)
						Position 4	DLE (68.7)	SL (31.3)		DLE ↓(29.9)	SL ↑(70.1)	
						Position 6	(38.2)	(61.8)		↓(21.4)	↑(78.6)	
						Block (%)	(58.7)	(19.4)	(21.9)	↓(51.2)	↑(25.6)	↑(23.2)
							DLE	LL	RL	DLE	LL	RL
						Left side block	(67.2)	(17.4)	(15.4)	↑(71.6)	↓(11.9)	↑(16.5)
						Right side block	(90.7)	(8.1)	(1.0)	↓(68.9)	↑(24.4)	↑(6.7)
							Female			Male		
6	Hughes et al. (2010a)	Collegiate Athletes (n=12)	Male (n=6, age 22.2±2.6) Female (n=6, age 21.7±1.5)	Landing mechanics of blocks performed in response to an attack, on force plates positioned in front of the net	Force plate, VICON motion analysis software	+Var/-Val°	(-6.79±4.50)			↓(-1.38±9.20)		
						NKM (BW x height)	(0.0208±0.0199)			↓(0.0116±0.0170)		
							Female			Male		
7	Hughes et al. (2010b)	Collegiate Athletes (n=12)	Male (n=6, age 21.6±3.3) Female (n=6, age 22.2±1.3)	Comparison of landing after blocked attacks with and without an opponent	Force plate, VICON motion analysis software		Without opponent	With opponent		without opponent	With opponent	
						MKF°	(78.0±8.1)	↑(68.2±12.2)		(67.2±12.9)	↓(62.1±11.6)	
						KF° (ROM)	(58.6±7.4)	↑(53.1±13.1)		(46.9±14.9)	↓(42.7±13.9)	
						+Var/-Val°	(-13.9±11.3)	↑(-10.4±7.7)		(-2.2 ±5.3)	↓(-2.9±7.9)	
						GRF (N)	(1.457±0.477)	↓(1.631±0.427)		(1.561±0.663)	↑(1.861±0.595)	
							Pre-Intervention			Post-Intervention		
8	Parsons & Alexander (2012)	Middle school players (n=19)	Female (n=19, age 13.2±0.4)	Changes in spike landing mechanics through verbal and visual feedback	4 Canon digital video camera, Dartfish motion analysis software		Right	Left		Right	Left	
						+Dorsi/-Plantar°	(13.0±7.5)	(14.4±7.8)		↑(20.8±8.4)	↑(24.2±7.0)	
						KF°	(66.6±7.2)	(71.9±10.3)		↑(84.9±12.0)	↑(89.0±13.0)	
							Unloaded			Loaded		
9	Janssen et al. (2012)	Australia Youth National Team (n=10)	Male (n=10, age 17.10±0.99)	Effects of a weighted vest on block landing mechanics	2 force plate, VICON motion analysis software	HF° (IC)	(32.3±5.19)			↓(30.0±4.68)		
						JH (m)	(0.57±0.09)			↓(0.51±0.08)		
							Planned			Unplanned		
							ND	D		ND	D	
10	Mercado-Palomino et al. (2020)	Semi-professional volleyball players (n=13)	Female (n=13, age 20.43 ± 2.17)	Kinematic differences in planned versus unplanned blocks and blocks performed from dominant versus non-dominant sides	2 force plate Oqus motion analysis software	EA(j/kg)						
						Hip (NDL)	(1.75±1.49)	(3.45±2.59)		↓(1.31±0.99)	↓(2.73±2.69)	
						Hip (DL)	(0.15±0.249)	(0.262±0.239)		↑(0.238±0.249)	↑(0.276±0.199)	
						Knee (NDL)	(1.046±0.363)	(0.661±293)		↓(0.993 ±0.36)	↓(0.493±0.19)	
						HF° (IC)	(21.30±5.09)	(23.76±6.35)		↑(24.44±4.24)	↑(24.13±4.97)	
						MKF	(63.53±9.64)	(69.55±10.06)		↓(62.92±11.19)	↓(67.52±8.06)	

Table 4 - Continued

						Professional		Amateur	
						Spike	Block	Spike	Block
11	Garcia et al. (2022)	Professional (n=15) and amateur (n=15) volleyball players	Professional male (n=15, age 28.7±7.1) Amateur male (n=15, age 27.6±5.4)	Comparison of landing mechanics after blocks and spikes between professional and amateur volleyball players	4 force plate Oqus motion analysis software	GRF (bw)	(3.70±1.02)	(2.76±0.74)	↓(3.58±0.64)	↑(2.83±0.41)
						RoM°				
						Hip°	(33.7±16.3)	(33.2±17.1)	↓(27.1±12.7)	↓(21.9±14.8)
						Knee°	(63.1±11.8)	(56.5±11.7)	↓(57.6±9.6)	↓(45.9±10.7)
						Ankle°	(47.1±6.9)	(51.0±8.1)	↓(35.4±10.6)	↓(45.9±7.6)
						AF° (IC)	(-22.4±7.4)	(-20.9±9.1)	↓(-11.4±13.9)	↓(-18.2±8.3)
						Max	Double Leg		Single Leg	
12	Xu et al. (2022)	Semi-professional volleyball players (n=13)	Male (n=13, age 22.5±2.6)	Kinematic differences between single- and double-leg landings after a spike	Force plate VICON motion analysis software	KABA°(+)	(16±3)		↓(6±2)	
						HABA° (+)	(19±3)		↓(9±2)	
						MHIR° (-)	(-10±3)		↓(-5±3)	
						Moment (Nm/kg)				
						KADA (-)	(-0.89±0.20)		↓(-0.16±0.23)	
						KIR (+)	(1.46±0.38)		↓(0.79±0.19)	
						KER (+)	(-0.60±0.33)		↓(-0.22±0.11)	
						HIR (-)	(-2.20±0.54)		↓(-0.88±0.30)	
						HER (+)	(3.50±0.52)		↓(1.16±0.35)	
						iEMG (µVs)	Professional		Amateur	
13	Wang and Zhao (2023)	Professional (n=10) and amateur (n=10) volleyball players	Male (n=20)	Comparison of landings after cross spikes from the position 4 in professional and amateur players	Noraxon Ultium EMG device	Gluteus max.	(5.43 ± 2.45)		↑(10.53 ± 3.09)	
						MAL (%)				
						Gluteus max.	(22.33 ± 2.12)		↓(12.21 ± 3.46)	
						Rectus fem.	(23.88 ± 2.24)		↓(14.56 ± 1.38)	
						Vastus med.	(25.51 ± 1.89)		↓(16.33 ± 1.26)	
						Vastus lat.	(23.22 ± 2.11)		↓(13.21 ± 2.07)	
						Biceps fem.	(28.97 ± 1.15)		↓(14.37 ± 2.64)	
						Impuls (N.s) (β)	T		P	
14	Molla et al. (2023)	Professional volleyball players (n=18)	Male (n=18)	Analysis of block jumps and landings performed without the ball	Force plate	RFD (con) (N/Kg/s)	0.537		p=0.02*	
						TPPC (ms)	0.424		p=0.04*	

*AF: ankle flexion angle, AV: ankle velocity, Biceps fem.: Musculus biceps femoris, BW: body weight, CoM: center of mass velocity, DL: dominant leg, DLE: double leg, +Dorsi/-Plantar: dorsiflexion/plantar flexion, EA: energy absorption, Gluteus max.: Musculus gluteus maximus, GRF: ground reaction force (vertical), HABA: hip abduction angle, HER: hip external rotation angle, HF: hip flexion, HV: hip velocity, IAD: inter-ankle distance (mm), IC: initial contact, IKD: inter-knee distance (mm/%ht), iEMG: integrated electromyography (µVs), JH: jump height, KABA: knee abduction angle, KADA: knee adductıon angle, KER: Knee external rotation angle, KF: knee flexion, KIR: knee internal rotation angle, LL: left leg, LS: leg stifness, MAL: muscle activation level, MFV: maximum flexion velocity, MHF: maximum hip flexion, MHIR: maximum hip internal rotation angle, MHT: maximum hamstring torque, MKF: maximum knee flexion, MQT: maximum quadriceps torque, NDL: non-dominant leg, NKM: normalized knee moment, Rectus fem.: Musculus rectus femoris, RL: right leg, RFD: rate of force development, RoM: range of motion, SL: single leg T: (t-statistic), TPPC: time to peak power concentric, +Var/-Val: Varus/Valgus angle. Vastus med.: musculus vastus medius, Vastus lat.: Musculus vastus lateralis, ↑: This symbol represents a significant increase, ↓: This symbol represents a significant decrease, *: This symbol represents a significant difference, p: This symbol represents a p value p<0.05.*

Discussion

Spike and block landings in volleyball involve different biomechanical demands due to the distinct movement objectives of these tasks. Spike landings typically occur after a forward attacking movement, requiring athletes to dissipate both vertical and horizontal momentum during landing (Tillman et al., 2004; Wagner et al., 2010). In contrast, block landings are generally characterized by more vertically oriented jumps performed close to the net, where maintaining postural stability and rapidly repositioning for subsequent actions are essential (Sheppard et al., 2008). In this context, the present systematic review comprehensively examined the kinetic and kinematic parameters associated with spike and block landing mechanics in volleyball. Across the included studies, the primary factors affecting landing mechanics were identified as knee, hip, and ankle flexion angles; flexion angles at IC; ankle plantarflexion/dorsiflexion angles; knee valgus–varus angles and moments; GRF; leg stiffness; joint RoM; and CoM velocities. These variables were reported to differ substantially according to both gender and experience level. Additionally, the studies highlighted the impact of different experimental approaches and task conditions on landing mechanics.

Spike Landing Mechanics

Based on the findings of this review, GRF appears to be a key mechanical factor in spike landings. A considerable number of studies have reported findings related to GRF. Garcia et al. (2022), documented an average GRF of 3.70 body weights during spike landings performed by professional male volleyball players. Similarly, Salcı et al. (2004), reported GRF values of 3.9 body weights during spike landings from a height of 60 cm among collegiate volleyball athletes, and 3.58 body weights during landings performed from 40 cm. GRF levels appear to vary depending on players' performance and conditioning status. Therefore, it may be inferred that professional athletes are exposed to greater vertical impact forces during landings, particularly as a function of jump height (Zaheri et al., 2024).

The studies included in this systematic review demonstrated that the spike jump height and approaching distance of spike have significant effects on landing kinematics. An increase in maximum knee flexion (MKF), maximum hip flexion angle (MHF), and GRF values was observed in both female and male athletes following spike jumps executed with a 20 cm height differential (Salcı et al., 2004). Additionally, in a study involving male players, Marquaez et al. (2009) found that greater approach distances during spike execution led to higher CoM velocities in both the horizontal and vertical planes, accompanied by significant reductions in lower-limb joint RoM. Collectively, these findings suggest that spike take-off height and variations in approach distance directly influence the loading patterns experienced by lower-limb joints during landing.

Another variable reported in the studies examining spike landing mechanics is the level of muscle EMG activation. Wang and Zhao (2023) reported that professional players exhibited significantly higher quadriceps and hamstring muscle EMG activation levels compared with amateur players. This difference may be attributed to training-induced morphological adaptations in the musculature. Augmented muscle activation not only enhances force absorption during landing but also positively influences several performance-related outcomes, such as jump performance and stabilization capacity (Chen et al., 2025). Moreover, another study observed that verbal and visual feedback provided to female athletes resulted in significant improvements in landing mechanics (Parsons & Alexander, 2012). This finding suggests that technical feedback plays an important role in improving landing quality, particularly among female players. Nonetheless, further research involving larger sample sizes and players with varying levels of experience is needed to strengthen these conclusions.

Block Landing Mechanics

This systematic review revealed that the existing literature has mainly focused on block landing kinematics. Mercado-Palomino et al. (2020) reported that energy absorption and lower-limb flexion angles during unplanned block actions are lower compared with planned blocks. This decline in performance during unplanned blocks may be explained by the demands of rapid decision-making under time pressure and the reduced motor preparation time, which can impair the neuromuscular system's ability to employ optimal jump and landing strategies. Another study demonstrated that block landings performed while wearing weighted vests resulted in reductions in lower-limb kinematic measures (Janssen et al., 2012). The increased segmental mass distribution associated with external loading may shift the athlete's CoM, thereby increasing the mechanical load placed on the knee and hip joints during landing. Similarly, Makaruk and Sacewicz (2011) reported that jumping and landing under additional load negatively affected motor control

and weakened postural stability. Another study comparing block landings across different experience levels reported that amateur volleyball players exhibited lower lower-limb joint RoM and lower GRF compared with professional athletes (Garcia et al., 2022). This may pose both technical and functional disadvantages. Supporting this interpretation, Zahradnik et al. (2017) found that landings performed with knee flexion angles below the critical threshold of 30° resulted in higher GRF values and increased joint stiffness, indicating that insufficient knee flexion is associated with technical inadequacy and elevated mechanical loading. Finally, it has been reported that rapid and forceful concentric muscle actions during block landings increase the resulting impulse, which in turn serves as a strong predictor of landing performance (Molla et al., 2018). Impulse, derived from the force–time curve, is one of the fundamental mechanical variables and plays a crucial role in determining landing quality and jump height (Linthorne, 2001).

Gender-Based Comparison of Spike and Block Landing Mechanics

Findings from studies comparing gender-based differences indicate that male volleyball players demonstrate greater inter-ankle distance, higher GRF, and increased leg stiffness, whereas female players exhibit greater knee valgus during blocking against an attack, along with larger lower-limb joint RoM and greater inter-knee distance. Additionally, during block jumps performed with and without an opposing attack, female volleyball players showed a broader range of alterations in lower-limb kinematics compared with males, suggesting that their landing mechanics may be more adversely affected under varying task constraints (Hughes et al., 2008, 2010b, 2010a; Hughes & Watkins, 2008). Another study comparing gender-based differences in spike landing mechanics similarly reported that female players exhibited greater knee valgus angles than their male counterparts (Kurt, 2024). The researchers noted that during block landings, females showed higher hip, knee, and ankle flexion angles, greater joint RoM, and increased knee valgus angles and moments compared with males (Hughes et al., 2008, 2010a, 2010b; Hughes & Watkins, 2008). These biomechanical characteristics may elevate the likelihood of excessive loading on the medial and lateral structures surrounding the tibia, thereby increasing injury risk among female players. Another study examining single- and double leg landings in male and female volleyball players reported that female players tended to land with two feet when spiking from position 4, but primarily adopted single leg landings when attacking from position 6. In contrast, male players showed a higher tendency to land on a SL from both positions (Lobietti et al., 2010). This finding aligns with previous research on the asymmetrical nature of the spike technique (Afonso et al., 2021; Wang at al., 2025). The differing landing strategies observed in female players across the two positions may be attributed to factors such as the planar distribution of the spike motion, approach angle, jump distance, dominant leg preference, and positional habits. In particular, spike executions from position 6 are performed with greater momentum, which may naturally predispose players to SL landings (Xu et al., 2021). Furthermore, Xu et al. (2022) reported that male players exhibited significantly lower hip and knee abduction angles, peak hip internal rotation, and knee and hip internal/external rotation moments during SL landings compared with double leg landings. These kinematic distinctions suggest that SL landings may represent a less stable landing strategy and may also increase certain injury risks. The same study also noted that during right- and left-side blocks, both male and female players primarily preferred double leg landings (Xu et al., 2022). For female players, this preference may represent a reflexive strategy aimed at achieving a more stable distribution of load upon ground contact.

In summary, the findings indicate that experience level influences movement patterns, with the majority of studies reporting that professional players exhibit more controlled joint kinematics and lower joint loading compared to amateur players. This trend was consistent across variables such as knee flexion angle and ground reaction forces, although a small number of studies reported no significant differences. Regarding gender differences, most studies consistently reported that female players demonstrate greater knee valgus, larger joint range of motion, and less favorable landing mechanics compared to males, whereas male players exhibit higher ground reaction forces and leg stiffness. Regarding task conditions, differences in landing strategies (single-leg vs. double-leg) and contextual factors (planned vs. unplanned blocks) consistently affected joint angles, joint moments, and energy absorption, with unplanned conditions generally associated with less favorable biomechanical patterns. However, some inconsistencies were observed depending on the specific variable and task constraints.

This review synthesized the findings from studies that examined spike and block landing mechanics using

methods aligned with the ecological demands of volleyball. One notable observation concerns the publication years of the included research. Many recent studies have focused on landing mechanics following tasks such as drop jumps and countermovement jumps and were therefore excluded due to limited ecological validity. Additionally, the small sample sizes reported in the included studies limit the strength of the inferences that can be drawn from their findings, representing a notable limitation of the current review. Because biomechanical assessments involve complex data collection, instrumentation, and labor-intensive processing procedures, studies in this field often rely on smaller participant groups. However, with recent advances in measurement and analytical technologies, improvements in data acquisition and processing efficiency may enable future research to include larger samples, thereby enhancing the generalizability of biomechanical findings in volleyball.

This review has several limitations that should be acknowledged. First, the temporal distribution of the included studies indicates that a considerable proportion of the available literature was published before 2012. This situation may be related not to limitations in the search strategy but rather to the relatively limited number of studies specifically examining sport-specific landing mechanics during volleyball spike and block techniques. Many studies in the broader biomechanics literature investigate landing mechanics using standardized tasks such as drop jumps or countermovement jumps. However, these protocols were not included in the present review because they do not directly reflect the technical and ecological context of volleyball-specific movements. Consequently, the strict inclusion criteria focusing on sport-specific spike and block landings may have reduced the number of eligible recent studies. Second, the methodological quality of the included studies was assessed using a checklist commonly applied in sports biomechanics research. Nevertheless, some items within this checklist (e.g., detailed mathematical sequences for angular calculations or specific modelling approaches) are not mandatory reporting elements for all biomechanics studies. Therefore, certain studies may have received relatively lower methodological quality scores due to reporting differences rather than actual methodological weaknesses. These aspects should be considered when interpreting the quality assessment results.

Conclusion

This systematic review demonstrated that the kinetic and kinematic parameters observed during spike and block landings in volleyball vary substantially depending on gender, experience level, landing strategy, task height, and movement planning. The review revealed that research has largely focused on block landing kinematics. Across spike and block landings, the most frequently examined mechanic variables included knee, hip, and ankle flexion angles; flexion angles at IC; ankle plantarflexion/dorsiflexion angle; knee valgus–varus angles and moments; GRF; leg stiffness; joint RoM; and CoM velocities. Evidence indicates that higher knee valgus angles and greater lower-limb joint RoM in female volleyball players contribute to increased injury risk. While male volleyball players tend to utilize SL landing strategies, female players more commonly adopt double leg landings, likely reflecting a preference for greater stability. These observed differences in landing strategies across spike and block actions underscore the need to tailor training programs according to gender, experience level, and task-specific demands. Especially training programs for female volleyball players should place greater emphasis on exercises that enhance gluteal muscle activation and promote safe single-leg landing techniques in order to better control knee valgus during block landings. Future research incorporating larger sample sizes, gender-based comparisons, and field-based analyses that preserve ecological validity will strengthen the existing knowledge base and support the development of more effective strategies for optimizing performance while managing injury risk in volleyball. In addition, integrating volleyball-specific landing tasks with advanced musculoskeletal modeling approaches may enable more realistic simulations of ACL injury risk and contribute to a deeper understanding of injury mechanisms.

Author Contributions

All authors contributed equally to the conception, design, data collection, analysis, and writing of the manuscript.

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