



Review

Unilateral versus Bilateral Landing after Spike Jumps in Male and Female Volleyball: A Systematic Review

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Abstract: *Background:* The spike is a key action in volleyball, and the landing technique and its asymmetries are commonly associated with an increased risk of injury. *Objectives:* The aim of this systematic review was to assess how male and female volleyball players land (i.e., unilaterally, or bilaterally) after spike jumps in matches and analytical settings (field or laboratory). *Methods:* The Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 guidelines were followed, with eligibility criteria defined according to participants, interventions, comparators, study design (PICOS): (p) healthy indoor volleyball players of any sex, age group, or competitive level; (i) exposure to landing after spike actions during official matches AND/OR simulated 6 vs. 6 games AND/OR analytical training conditions AND/OR laboratorial experiments; (c) not mandatory; (o) data on landing mechanics after spike actions, including reporting of whether the landing was unilateral or bilateral; (s) no restrictions imposed on study design. Searches were performed in seven electronic databases (Cochrane Library, EBSCO, PubMed, Scielo, Scopus, SPORTDiscus, and Web of Science) on 23 April 2021. *Results:* Automated searches provided 420 results. Removal of 119 duplicates resulted in 301 records being screened for titles and abstracts. A total of 25 studies were eligible for full-text analysis. Of these, eight studies were deemed eligible for inclusion in the review. Studies showed that (i) attackers landed asymmetrically 68% of the times (61% left leg, 7% right leg); (ii) bilateral asymmetries were observed for the hip, knee, and ankle joints; (iii) bilateral asymmetries were

observed even when players were instructed to land evenly on two feet; (iv) landing contact of the leg opposite to the hitting arm preceded the contact of the homolateral leg. One match analysis study showed that men landed more often on the left (31.5%) or right foot (8.5%) than women (23.7% and 1.6%). *Conclusions:* Studies analyzing spike landing showed a prevalence of unilateral landings (mostly the left leg first, for right-handed players) in men and women but more prevalently in men. Registration INPLASY202140104, DOI: 10.37766/inplasy2021.4.0104.

Keywords: volleyball; asymmetric kinematics; biomechanics; injury risk; match analysis; strength-shortening cycle; symmetry

1. Introduction

Volleyball is a team sport played by six players on each side of the court, divided by a net; the ball cannot be grabbed, and each team is limited to three contacts with the ball in each turn (with few exceptions where four contacts are allowed). In this sport, there are more symmetrically biased actions (e.g., set, pass) and predominantly asymmetric actions (e.g., the serve, the spike). The game has different phases, termed game complexes [1,2], that present distinct game patterns and have their own functional specificities (for a modern overview and synthesis, see Figure 1 in Martins et al. [3]). A major feature of volleyball is the predominant role played by vertical jumps [4,5]. In this context, muscles can be used as force dissipators in jump landings [6], which are common in volleyball (e.g., after spiking, blocking, serving, and setting) [4,7,8]. Strategies associated with energy dissipation patterns are relevant for understanding performance and injury risk [6], and in volleyball, an improper landing might be associated with noncontact ACL injuries [9–12].

Volleyball players regularly land unilaterally after a spike action [13], due to a shift in the center of gravity arising from the asymmetric technique that is required by the spike jump [14]. The asymmetric biomechanics of the trunk and upper limb in volleyball increase the likelihood of the right-handed players landing on the left leg first [15]. Even when the landing seems symmetric, the left leg usually plays a more prominent role in absorbing the impact for right-handed players [16]. Therefore, spike jumps are more strongly associated with unilateral landing than other volleyball jumps [13]. Unilateral landing seems to be associated with an increased risk of ACL injury [17]. In professional women volleyball players, 61.7% of ACL injuries occurred after landing from a spike jump, and the left knee was the most injured (64.7%) [12], suggesting the presence of asymmetry in how players land after spike jumps. Landing mechanics can be altered by surface and shoe type [18–20]. While the focus of our work relies on indoor volleyball, different surface features and shoe types may interact with landing dynamics and—perhaps—with the consequences of landing for the knee and other joints, but this issue is beyond the scope of our current work.

A study sampling two matches among four National Collegiate Athletic Association (NCAA) Division IA women volleyball teams revealed that players landed on the left foot after a spike jump in 35% of occasions, the right foot in 10% of actions, and symmetrically (on a rough visual inspection) in 55% of occasions [11]. Another study assessed 12 volleyball matches from the Italian men's and women's A1 and A2 professional leagues [13], analyzing video footage to categorize the landing techniques into unilateral or bilateral. After a spike jump, men fell 31.5% of times with left foot first, 8.5% with the right foot first, and 60% of the time with both feet (again, through visual inspection of video footage). For women, the values were 23.7%, 1.6%, and 74.7%, respectively, with significant sex-based differences. This is at odds with the greater incidence of ACL injuries reported in female athletes [10,21] since men were more asymmetric in landing after a spike jump and raises doubts on whether asymmetric landing is causally linked with noncontact ACL injuries in volleyball. Regardless of the exact relationships between unilateral landing mechanics, performance, and injury risk, it seems that women volleyball players are exposed differently than men to unilateral landing.

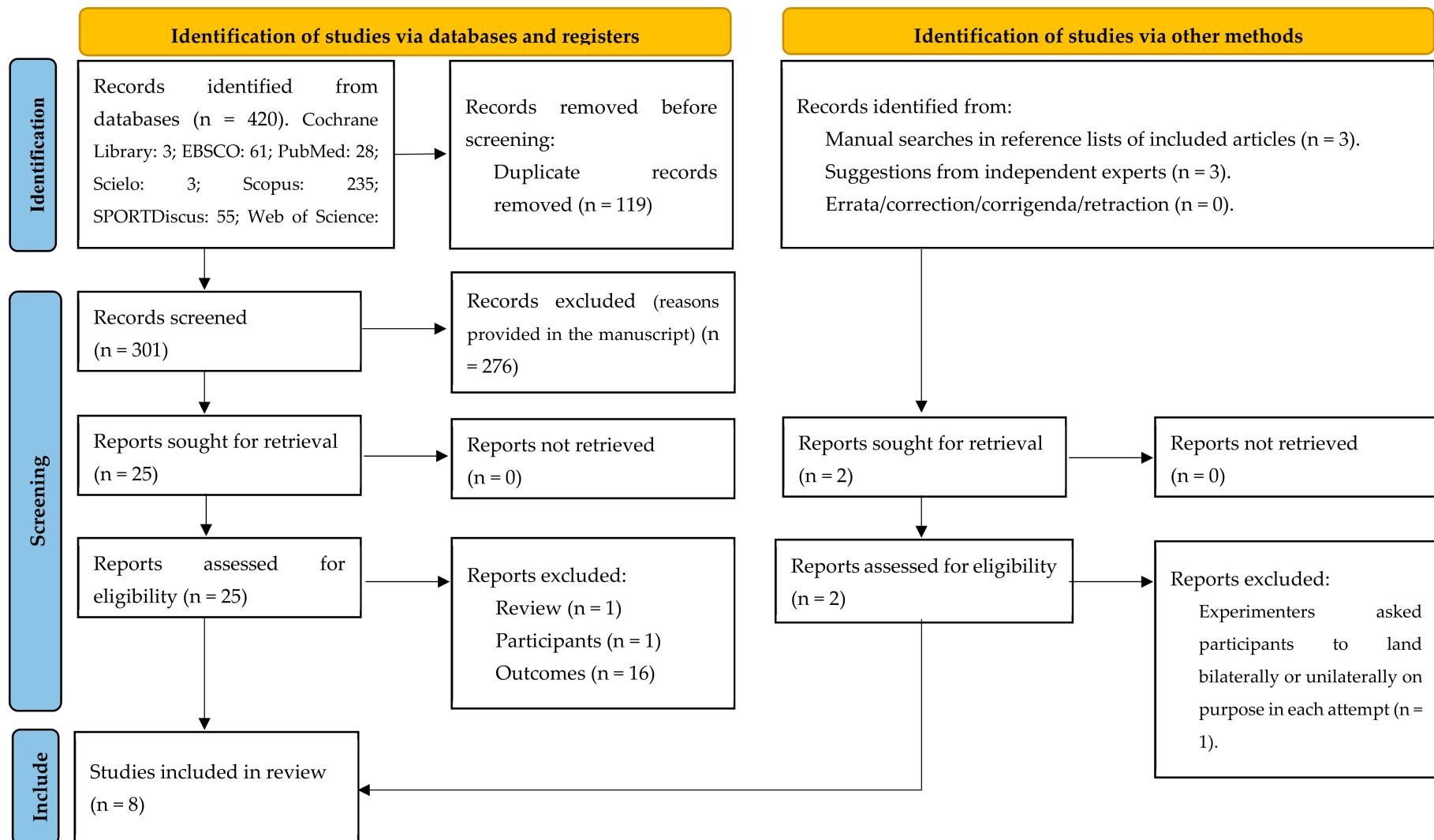


Figure 1. PRISMA 2020 flow diagram.

The landing technique may also be influenced by the attack zone [13]: men more often landed on one foot when attacking from positions 4 and 6, and on two feet when attacking from positions 1, 2, and 3. For women, landing on one foot was predominant when attacking from position 6, and landing on two feet was more common for all other positions [13]. Only in attacks from position 4 were the differences between men and women significant, leading to a more asymmetric landing in men [13]. In the same study, quicker attack tempos were associated more strongly with asymmetric landing [13]. These results suggest that, beyond the asymmetric constraints imposed by the spike action, the landing technique may depend on attack zone and tempo, and again denote subtle, but potentially relevant gender-based differences. This couples landing mechanics with task-related constraints and renders conscious control of landing a difficult undertaking, especially under time-constrained and real-match conditions.

In a laboratorial context, Xu, Jiang, Cen, Baker and Gu [14] collected vertical ground reaction forces upon landing after a spike action in 12 semi-professional male volleyball players. A tosser (i.e., thrower) sets the ball for the spiker, with no variability in ball trajectory constraints and no opposition. Landing on a single leg presented smaller knee flexion ($-74.3 \pm 15.2^\circ$ vs. $-99.8 \pm 17.6^\circ$) and hip flexion ($-43.0 \pm 12.8^\circ$ vs. $-74.3 \pm 10.9^\circ$) angles and greater ankle plantarflexion angle ($-19.9 \pm 8.8^\circ$ vs. $-8.6 \pm 8.3^\circ$) than landing on both legs, as well as the greater knee (-42.8 ± 5.8 vs. -29.4 ± 5.6 W/kg) and hip power (-57.9 ± 10.5 vs. -30.5 ± 6.9 W/kg). The authors stated that players should consciously increase hip and knee flexion when landing with one foot to avoid ACL injuries [14]. However, this study had no data on ACL injury, and it is doubtful that players can consciously focus on their landing (i.e., using an internal attentional focus) in real-match scenarios (where they will be attending external cues, e.g., ball trajectory, blockers). Additionally, as the match progresses, fatigue sets in, altering both unilateral and bilateral landing kinematics [22].

Concerning the internal or external focus in the landing technique, one study assessed the effects of a single session of video and verbal feedback on the spike jump landing technique in 19 female volleyball players (age, 12–14 years) [9]. Four weeks after the single feedback session, the 10 players in the intervention group had increased maximal hip and trunk flexion in landing after a spike action, in comparison with the control group (no feedback), while differences in knee flexion and ankle dorsiflexion were nonsignificant. However, the control and experimental groups were recruited from different teams and schools; therefore, confounding effects may have occurred [23]. The conditions under which the athletes performed the spike, and the landing were highly standardized, reducing the external validity of the study. Another study with 14 male adult volleyball players [24] showed that a drop landing and landing from a spike jump had substantial differences in lower limb biomechanics, raising the issue of the validity of the laboratory test used to assess landing biomechanics. Considering the diversity of study designs and findings, systematizing the existing body of knowledge may provide relevant information and point to future directions for research and practice.

According to the relevance of the spike action in volleyball, as well as the different outcomes obtained from different training or competitive contexts, our main goal was to systematically review studies assessing how male and female volleyball players land (i.e., unilaterally, or bilaterally) after spike jumps in matches or analytical settings (field or laboratory), and to assess gender-based differences. The working hypothesis was that unilateral landings were more common than bilateral landings, especially in official matches and in men. Based on a preliminary overview of the literature, data are scarce to generate a hypothesis concerning injury risk.

2. Materials and Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [25]. The review methods were established before initiating the research, and protocol registration preceded the search.

2.1. Eligibility Criteria

Studies were eligible if providing original research within the scope of this review and published in peer-reviewed journals, without limitations concerning language or publication date. Excluded records included conference abstracts, books and book chapters, editorials, letters to the editor, trial registrations, all types of reviews, essays, or original research in nonpeer-reviewed journals. Following PRISMA guidelines, inclusion and exclusion criteria were defined according to participants, interventions, comparators, outcomes, and study design (PICOS) (see Table 1).

Table 1. Inclusion and exclusion criteria based on scope and PICOS.

Rule	Inclusion Criteria	Exclusion Criteria
Participants	Indoor volleyball players of any sex, age group, or competitive level.	Players of sports other than indoor volleyball (i.e., sitting volleyball, beach volleyball). Unhealthy or injured indoor volleyball players. Physical education students.
Interventions	Exposure to landing after spike actions during official matches and/or simulated 6 vs. 6 games and/or analytical training conditions and/or laboratorial experiments.	No exposure to landing after spike actions. Spiking actions performed starting from a box or following incomplete executions (i.e., only a part of the full action). Landing after jumps other than spike actions (e.g., block, jump serve). Landing conditioned by the researchers (e.g., mandatory to land with only one foot on the force platform).
Comparators	Not mandatory.	No study was excluded on the basis of comparators.
Outcomes	Data on landing biomechanics after spike actions, including reporting of whether the landing was unilateral or bilateral. If available, data were collected on the degree of asymmetry in joints degree of flexion, and reaction forces.	Absence of data characterizing landing after spike actions as being unilateral or bilateral. Data on bilateral differences was compromised by the authors (e.g., excluding asymmetric landings from the analysis).
Study design	No restrictions imposed on study design.	No study was excluded on the basis of study design.

2.2. Information Sources

Searches were performed in seven electronic databases (Cochrane Library, EBSCO, PubMed, Scielo, Scopus, SPORTDiscus, and Web of Science) on 23 April 2021, after protocol registration. Following the selection of articles to be included, a manual search was conducted in their reference lists to retrieve additional studies that fit our eligibility criteria. Then, the list of included articles and the inclusion criteria were sent to two independent experts to help identify additional relevant articles. We established two criteria that experts had to fulfill, namely, (i) hold a PhD in sports sciences; (ii) have peer-reviewed publications in volleyball in journals with impact factor according to the Journal Citation Reports®. The experts were not provided with our search strategy, to avoid biasing their own searches. Upon completion of all these steps, on 1 May 2021, the databases were again consulted in search of errata or retractions of any included study [23].

2.3. Search Strategy

Code lines used in Cochrane Library, PubMed, Scopus, SPORTDiscus and Web of Science: ["volleyball" (title/abstract)] AND ["spik*" OR "attack*" OR "smash*" OR "hit" OR "hitting" (all fields)] AND ["land*" (all fields)]. Code lines used in Scielo and EBSCO: ["volleyball" (all fields)] AND ["spik*" OR "attack*" OR "smash*" OR "hit" OR "hitting"

(all fields)] AND ["land*" (all fields)]. Search results were exported to EndNote 20.0.1 for Mac (Clarivate Analytics). No filters or limits were applied.

2.4. Selection Process

J.A. and F.M.C. performed searches, removed duplicates, screened titles and abstracts, and analyzed full texts independently. No disagreements were found at this stage. The process was repeated for searches within reference lists and suggestions provided by the external experts.

2.5. Data Collection Process

Relevant data items were defined a priori, to avoid biasing the analyses [26]. L.L. and R.F.L. completed initial data extraction independently. In case of discrepancies, J.A., R.A., and A.P. discussed the situation until consensus was achieved. Data were recorded in Excel spreadsheets created specifically for this review.

2.6. Data Items

Outcomes consisted of data relative to how players landed after spike actions. These data include, if available, (i) the number of jumping actions; (ii) number and characteristics of unipodal versus bipodal landings; (iii) attack zone; (iv) attack tempo; (v) straight run-up versus feints; (vi) action immediately preceding the attack action (e.g., defense, block, serve reception, waiting); (vii) positional status (i.e., wing-spiker, opposite, middle-blocker, setter).

Additional information concerning study characteristics was extracted as follows: (i) sample size and features (e.g., age group, sex, level of the competition, number of players or teams; if available, number of right- and left-handed players); (ii) intra- and/or inter-observer reliability of the observations; (iii) study design; (iv) funding sources and potential conflicts of interest.

2.7. Study Risk of Bias Assessment

Upon inspection of the literature, the authors felt that no scale for assessment of methodological quality and risk of bias was appropriate for the review purposes, especially considering the possibility that many retrieved studies would use an observational design. For observational studies, the reported intra- and interobserver reliability were assessed. For nonrandomized studies, ROBINS-I was planned [27], and RoB 2 for randomized studies [28]. J.A. and F.M.C. independently assessed the risk of bias. There were no disagreements to report.

2.8. Effect Measures

The main outcomes of interest were unipodal and bipodal landing biomechanics.

2.9. Synthesis Methods

No meta-analysis was planned. A narrative synthesis of the results was provided.

2.10. Reporting Risk of Bias Assessment

Since no meta-analysis was planned, reporting risk of bias assessment could not be performed.

2.11. Certainty Assessment

The authors considered that no existing scale for assessing methodological quality was appropriate for observational studies addressing the research question. Therefore, for observational studies, The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist was provided [29], while the certainty of the evidence was assessed subjectively. A.G.-d.-A., G.d.C.T.C., and H.d.O.C. independently assessed observational studies. For multiarm studies, certainty was assessed using the Grading of

Recommendations Assessment, Development, and Evaluation (GRADE) [30–32]. J.A. and F.M.C. assessed multiarm studies. In case of disagreements, A.P., R.F.L., and J.A. intervened to provide a final decision.

3. Results

3.1. Study Selection

Automated searches provided 420 results (Cochrane Library: 3; EBSCO: 61; PubMed: 28; Scielo: 3; Scopus: 235; SPORTDiscus: 55; Web of Science: 35). Removal of 119 duplicates resulted in 301 records being screened for titles and abstracts. At this stage, 276 studies were excluded (85 were not original research; 191 failed to comply with one or more PICOS criteria). In total, 25 studies were eligible for full-text analysis, of which 16 were excluded due to not meeting participants [24] or outcome-related criteria [33–47]. Even when assessing landing after a spike jump (which not every study performed), usually only one lower limb was assessed, which detracted from assessing bilateral differences in landing mechanics. For example, in the study of Bisseling, Hof, Bredeweg, Zwerver, and Mulder [33], only one lower limb could contact the force platform upon landing, while in the study of Cronin, Bressel, and Finn [34], all jumps with asymmetric landing were excluded from the analysis. A study was excluded because it was a review, despite the abstract suggesting it was original research [48]. Finally, the study of Xu, Jiang, Cen, Baker, and Gu [14] (cited in the introduction) was excluded because athletes performed landings on a single leg in one experimental condition, and on both legs in another condition (i.e., not an unconstrained spiking action).

The reference lists of the seven studies that were deemed eligible were searched for retrieving relevant studies that had not emerged in the automated searches. Three potentially relevant titles were retrieved, of which two were excluded upon inspection of the abstracts. One study required full-text analysis but was excluded because the players had to land bilaterally or unilaterally on request [49]. Two independent experts suggested three additional studies, of which two had not emerged during our initial searches: one study only assessed the upper limbs, but the other study fulfilled eligibility criteria and was added to the review [50]. Errata, corrigenda/correction, and retractions were searched for the included studies, to ensure that the most correct versions of the data were considered [23], but none was found. In sum, eight studies had data on unilateral and bilateral landing and were deemed eligible for analysis [9,11,13,16,50–53]. The process is summarized in the PRISMA 2020 flow diagram [25] (Figure 1).

3.2. Study Characteristics

Study characteristics are detailed in Table 2. Five studies used laboratorial/field analytical approaches to assess landing from spike jumps under controlled conditions, of which four used an observational design [16,50,51,53], and one adopted a randomized design to assess the effects of a single session of augmented feedback in landing from a spike jump [9]. Three studies used match analysis to assess landings in official matches [11,13,52]. Samples ranged from 4 players [52] to 92 players [13]. Four studies assessed male players [16,51–53], three assessed female players [9,11,50], and one assessed both [13]. The fact that only one study assessed both men and women strongly constraints gender-based comparisons. One study assessed adolescents [9], while all others assessed adult players [11,13,16,50–53], with competition level in adults ranging from university-level players [16] to elite players of the World Championships [52]. In five studies, all players were right-handed [9,13,16,51,52], one study had 16 right-handed and 2 left-handed players [53], and two studies did not report on handedness [11,50]. Two studies analyzed outside hitters [16,52], two analyzed all attackers [11,13], and four studies did not report on the positional role [9,50,51,53]. Only one study attempted to correlate spike jumps with attack zone and tempo [13].

Table 2. Study characteristics and main results.

Study and Purpose	Study Design and Sample	Main Outcomes
<p>Adams, Kiefer, Panchuk, Hunter, MacPherson, and Spratford [51] Funding sources and competing interests: Unreported.</p>	<p>Experimental study with four conditions: hop jump (single leg), drop landing, spike jump, and augmented reality (augmented reality—smart glasses displayed a visual animation of a virtual nonplayer character setting) spike were carried out during the testing session). Twelve male right-handed volleyball players volunteered (age: 18.8 ± 3.2 years; height: 1.87 ± 0.8 m; body mass: 81.2 ± 8.9 kg); 6 from the Centre of Excellence program at the Australian Institute of Sport, 6 from an Australian Volleyball League. Positional role of the players was not detailed.</p>	<p>Bilateral differences on landing from a spike jump: 68% of participants landed asymmetrically, with 61% making initial contact on the left leg and 7% on the left foot.</p>
<p>Bermejo, Palao, and Valadés [50] Funding sources and competing interests: Unreported.</p>	<p>Observational study of the spike jump (Camcorder used to record the movement and Known3D software to analyze the spike jump). All subjects executed 5 consecutive spike jumps in practice context. 10 female volleyball players from Spanish Super League (age: 23.7 ± 5.7 years; height: 1.82 ± 0.1 m; body mass: 73.6 ± 5.0 kg). All subjects had played in international competitions. Handedness and positional role of the players was not detailed.</p>	<p>Bilateral differences on landing from a spike jump for ankle flexion and knee flexion. Leg of dominant hand: ankle flexion $139.2 \pm 11.1^\circ$; knee flexion $159.2 \pm 7.4^\circ$. Leg of nondominant hand: ankle flexion $130.4 \pm 9.8^\circ$; knee flexion $153.1 \pm 10.5^\circ$. Unclear if the bilateral differences achieved statistical significance.</p>
<p>Lobiatti, Coleman, Pizzichillo, and Merni [13] Funding sources and competing interests: Unreported.</p>	<p>Match analysis of official matches. 6 women's and 6 men's professional volleyball matches of the 1st Italian league. 48 men and 48 women (of whom 45 and 47, respectively, were right-handers; data restricted to right-handed players). Age, height, and body mass: unreported by the authors. All types of attacker were considered.</p>	<p>Men landed more often on the left (31.5%) or right foot (8.5%) than women (23.7% and 1.6%). Men landed more often unilaterally than bilaterally after attacking in zones 4 (70.1%) and 6 (78.6%), but not in zones 2 (15.8%), 1 (17.6%) and 3 (24.2%). Women landed more with one foot when attacking in zone 6 (61.8%), less when attacking in zones 1 (35.7%), 4 (31.3%), 3 (17.1%), and 2 (13.3%). Men landed unilaterally in 78.7% of quick attacks in zone 4, and in 53.6% of slow attacks. Women landed unilaterally in 44.5% of quick attacks in zone 4, and in 21.0% of slow attacks.</p>

Table 2. Cont.

Study and Purpose	Study Design and Sample	Main Outcomes
Marquez, Masumura, and Ae [16] Funding sources and competing interests: Unreported.	<p>“Simulated Court”: landing tasks on force platform. Normal and long jumping were assessed.</p> <p>Six male, university, right-handed, outside hitters (age: 19.6 ± 0.7 years; height: 1.86 ± 0.0 m; body mass: 78.3 ± 5.5 kg).</p>	<p>Normal landing</p> <p>Angle at the instant of the initial contact with the floor—right versus left foot: $29.5 \pm 3.1^\circ$ vs. $32.7 \pm 3.6^\circ$; right versus left ankle: 124.4 ± 15.7 vs. $124.4 \pm 12.4^\circ$; right versus left knee: $161.7 \pm 6.0^\circ$ vs. $160.0 \pm 7.5^\circ$; right versus left hip: $149.1 \pm 26.2^\circ$ vs. $150.2 \pm 19.8^\circ$.</p> <p>Range of motion—right versus left foot: $16.5 \pm 4.7^\circ$ vs. $25.3 \pm 4.7^\circ$; right versus left ankle: $30.2 \pm 13.9^\circ$ vs. $36.7 \pm 16.6^\circ$; right versus left knee: $17.9 \pm 4.2^\circ$ vs. $22.2 \pm 5.0^\circ$; right versus left hip: $7.9 \pm 7.2^\circ$ vs. $11.0 \pm 11.0^\circ$.</p> <p>Maximal flexion velocity—right versus left foot: $886.6 \pm 66.1^\circ/\text{s}$ vs. $981.9 \pm 105.7^\circ/\text{s}$; right versus left ankle: $1396.3 \pm 107.2^\circ/\text{s}$ vs. $1408.6 \pm 64.1^\circ/\text{s}$; right versus left knee: $798.3 \pm 98.4^\circ/\text{s}$ vs. $852.1 \pm 94.9^\circ/\text{s}$; right versus left hip: $517.5 \pm 111.7^\circ/\text{s}$ vs. $603.7 \pm 109.6^\circ/\text{s}$.</p> <p>Long landing</p> <p>Angle at the instant of the initial contact with the floor—right versus left foot: $26.3 \pm 6.6^\circ$ vs. $24.7 \pm 2.8^\circ$; right versus left ankle: 119.7 ± 20.9 vs. $125.8 \pm 12.2^\circ$; right versus left knee: $158.6 \pm 9.8^\circ$ vs. $160.0 \pm 6.8^\circ$; right versus left hip: $131.6 \pm 22.2^\circ$ vs. $125.8 \pm 13.8^\circ$.</p> <p>Range of motion—right versus left foot: $15.3 \pm 10.2^\circ$ vs. $17.1 \pm 4.5^\circ$; right versus left ankle: $19.9 \pm 13.7^\circ$ vs. $23.2 \pm 12.7^\circ$; right versus left knee: $18.2 \pm 7.1^\circ$ vs. $16.0 \pm 4.1^\circ$; right versus left hip: $11.8 \pm 21.6^\circ$ vs. $7.3 \pm 11.1^\circ$.</p> <p>Maximal flexion velocity—right versus left foot: $797.2 \pm 223.4^\circ/\text{s}$ vs. $785.9 \pm 179.7^\circ/\text{s}$; right versus left ankle: $1323.6 \pm 265.5^\circ/\text{s}$ vs. $1142.5 \pm 259.9^\circ/\text{s}$; right versus left knee: $973.5 \pm 139.6^\circ/\text{s}$ vs. $1041.6 \pm 122.2^\circ/\text{s}$; right versus left hip: $715.0 \pm 99.5^\circ/\text{s}$ vs. $754.1 \pm 89.9^\circ/\text{s}$.</p> <p>For all cases, unclear if bilateral differences were statistically significant.</p>

Table 2. Cont.

Study and Purpose	Study Design and Sample	Main Outcomes
Marquez, Masumura, and Ae [52] Funding sources and competing interests: Unreported.	Videotaped with two high-speed VTR cameras during the Men's World Championship of 2006. 4 male right-handed outside hitters (age: 24.8 ± 3.4 years; height: 1.98 ± 0.1 m; body mass: 91.0 ± 7.0 kg).	Eleven of the twelve landings (91.6%) were left-footed first, with the right leg elevated at floor contact.
Parsons and Alexander [9] Funding sources: Manitoba Health Research Council Studentship. Competing interests: Unreported.	Kinematic measurements on spike jump task. A repeated measures design was used (4 week time frame). Five successful spikes were performed. Sixteen healthy female right-handed volleyball players from 2 middle schools (age: 13.2 ± 0.4 years in intervention group and 13.1 ± 0.3 in controls; height and body mass: unreported by the authors). Positional roles of the players unreported by the authors.	Both groups showed bilateral asymmetries in landing for hip and knee flexion, and ankle dorsiflexion (i.e., all the assessed variables). Intervention group—right versus left ankle dorsiflexion: $17.3 \pm 6.9^\circ$ vs. $15.3 \pm 9.3^\circ$; right versus left knee flexion: $85.3 \pm 23.2^\circ$ vs. $86.4 \pm 24.3^\circ$; right versus left hip flexion: $69.6 \pm 30.1^\circ$ vs. $59.4 \pm 18.8^\circ$. Unclear whether these differences reached statistical significance.
Pavlov and Buzhinskiy [53] Funding sources and competing interests: Unreported.	Laboratorial-based spike task. Eighteen male volleyball players from a University team (age: 19.9 ± 0.9 years, height: 1.91 ± 0.2 m, body mass 89.3 ± 1.4 kg), of which 16 were right-handed and 2 left-handed. Positional role of the players was not detailed.	Indoor condition: Contact of the opposite leg on landing, in comparison with the homonymous leg: delay of 2 ± 0.6 ms.
Tillman, Hass, Brunt, and Bennett [11] Funding sources and competing interests: Unreported.	Recordings of two matches among four National Collegiate Athletic Association Division IA female volleyball teams. Number of players assessed and handedness: unreported by the authors. Age, height, and body mass: unreported by the authors. All types of attacker were considered.	Bilateral landing = 55%; right-foot landing = 10%; left-foot landing = 35%.

3.3. Risk of Bias in Studies

Only one study was randomized (cluster-randomized) [9]. Accordingly, RoB 2 (extension for cluster randomization) was used to assess the risk of bias. There were some concerns in risk of bias arising from randomization, due to insufficient information concerning how randomization was achieved and assessment of baseline differences, and no information concerning allocation sequence concealment. Low risk was identified in bias arising from the timing of identification or recruitment of participants. Some concerns were identified in risk of bias due to deviations from the intended intervention, as participants and people delivering the intervention were aware of the intervention. There was a high-risk bias due to missing outcome data: the two groups were small (10 in the intervention group and 9 in the control group), and three participants quit (1 in the intervention group, 2 in the control group). Since two were from the smaller group, this created an imbalance between intervention and controls, and there was no attempt to demonstrate that the result was not biased by missing data. There was a high risk of bias in the measurement of the outcome: assessors were not blinded, and the assessments had some subjectivity, confirmed by reported intraclass correlation coefficients <0.75 . Additionally, there was a high risk of bias in the selection of the reported results, since there was no pre-registered protocol, certain outcomes were excluded after being collected due to poor reliability (e.g., knee valgus angle), and the choice of average values was carried out a posteriori (again, due to problems with the reliability of measurements). This study was assessed with an overall high risk of bias.

For the remaining seven studies, which were observational, information was extracted concerning if and how they performed intra- and/or interobserver reliability. Four studies (57.1%) conducted laboratorial/field analytical experiments [16,50,51,53]. None of these studies reported intra- or interobserver reliability, not even indirectly (e.g., reporting reliability values of previous studies). For the automated devices and processes, no reference values were provided (e.g., typical error, standard error of measurement), except in one study (14.3%), which reported a 0.5 mm calibration error [50]. No study had blinded assessors. Three studies (42.9%) performed match analysis [11,13,52]. Two of them (28.6%) did not report intra- or interobserver reliability of the observations, and one study (14.3%) [52] reported the maximum relative error of the automated analysis through direct linear transformation (1.7% for width, 0.4% for length, and 4.2% for height). However, in this study [52], only three actions were selected for each subject; two researchers performed this selection, but there was no reporting of interobserver reliability for the choices that were made.

3.4. Results of Individual Studies

The results of individual studies are also compiled in Table 2 (see above). Laboratorial studies showed that (i) attackers landed 68% of the times asymmetrically (61% of times on the left leg, 7% on the right leg) [51]; (ii) bilateral asymmetries were present (unclear if statistically significant) in ankle flexion and knee flexion [50], as well as in foot and hip angles, and range of motion and maximal flexion velocity of the foot, ankle, knee and hip [16]; (iii) bilateral asymmetries in hip and knee flexion in both experimental and control groups (unclear whether statistical significance was reached), despite instructions to land evenly on two feet [9]; (iv) landing contact of the leg opposite to the hitting arm preceded the contact of the homolateral leg (no mention if statistically significant) [53]. Since the laboratorial studies only included men or women (but not both) and had very different study designs, gender-based comparisons could not be established.

A match analysis study with men showed that 91.6% of the landings after a spike jump occurred with the left foot first [52], and another showed that women landed 35% of times on the left foot, 10% on the right foot, and 55% bilaterally [11]. The authors stated that the majority of unilateral landings occurred in zone 4 but provided no data, and the player role was unreported [11].

Another match analysis study showed that men landed more often on the left (31.5%) or right foot (8.5%) than women (23.7% and 1.6%) [13]. Other findings of this study [13] are as follows: (i) men landed more often unilaterally than bilaterally after attacking in zones 4 (70.1%) and 6 (78.6%) but not in zones 2 (15.8%), 1 (17.6%), and 3 (24.2%); (ii) women landed predominantly with one foot when attacking in zone 6 (61.8%), less prominently when attacking in zones 1 (35.7%) and 4 (31.3%), and even less in zones 3 (17.1%) and 2 (13.3%). The authors explored the interaction between attack tempo and attack zone [13] and found that (i) men landed unilaterally in 78.7% of quick attacks in zone 4, and in 53.6% of slow attacks, suggesting that quicker attack tempos increase the rate of unilateral landing; (ii) women landed unilaterally in 44.5% of quick attacks in zone 4, and in 21.0% of slow attacks. This was the only study affording comparisons between men and women, showing that there are gender-based differences in exposure to unilateral landing.

3.5. Certainty of Evidence

Since only one multiarm study was found [9], GRADE was not applied. As a result of having a single study and its high risk of bias, the certainty of the evidence was deemed very low. For the observational studies [11,13,14,16,51–53], the STROBE checklist was applied (Table 3). Most studies did not explicitly address funding sources and competing interests, and 71.4% of studies did not address potential sources of bias or explain how the study size was arrived at. Across the board, characteristics of the participants were highly incompletely reported, and studies did not address whether there was missing data. There was no reporting of intra- or interobserver reliability in these studies and, where applicable, no reporting of standard errors of measurement or similar data. The certainty of evidence arising from these observational studies was very low.

Table 3. Checklist of items that should be included in reports of observational studies (STROBE).

	Item No	Recommendation	Percentage of Studies Reporting
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract.	100% (7/7)
		(b) Provide in the abstract an informative and balanced summary of what was performed and what was found.	100% (7/7)
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported.	100% (7/7)
Objectives	3	State-specific objectives, including any prespecified hypotheses.	100% (7/7)
Methods			
Study design	4	Present key elements of study design early in the paper.	57.1% (4/7)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection.	100% (7/7)
Participants	6	Give the eligibility criteria and the sources and methods of selection of participants.	100% (7/7)
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	100% (7/7)
Data sources/measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group.	100% (7/7)
Bias	9	Describe any efforts to address potential sources of bias.	28.6% (2/7)
Study size	10	Explain how the study size was arrived at.	28.6% (2/7)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why.	100% (7/7)
Statistical methods	12	(a) Describe all statistical methods.	100% (7/7)
		(b) Describe any methods used to examine subgroups and interactions.	42.9% (3/7)
		(c) Explain how missing data were addressed.	0% (0/7)
		(d) If applicable, describe analytical methods taking account of sampling strategy.	57.1% (4/7)
Results			
Participants	13	(a) Report numbers of individuals at each stage of study—e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed.	42.9% (3/7)
		(b) Give reasons for nonparticipation at each stage.	0% (0/7)
		(c) Consider use of a flow diagram.	0% (0/7)
Descriptive data	14	(a) Give characteristics of study participants (e.g., demographic, clinical, social) and information on exposures and potential confounders.	0% (0/7)
		(b) Indicate number of participants with missing data for each variable of interest.	28.6% (2/7)
Outcome data	15	Report numbers of outcome events or summary measures over time.	100% (7/7)
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included.	14.3% (1/7)
		(b) Report category boundaries when continuous variables were categorized.	14.3% (1/7)
Other analyses	17	Report other analyses conducted—e.g., analyses of subgroups and interactions, and sensitivity analyses.	57.1% (4/7)

Table 3. Cont.

	Item No	Recommendation	Percentage of Studies Reporting
Discussion			
Key results	18	Summarise key results with reference to study objectives.	100% (7/7)
Limitations	19	Discuss limitations of the study, considering sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	14.3% (1/7)
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	71.4% (5/7)
Generalisability	21	Discuss the generalisability (external validity) of the study results.	85.7% (6/7)
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based.	14.3% (1/7)

4. Discussion

4.1. Summary of Evidence

We reviewed the evidence concerning how volleyball players land after a spike jump, focusing on bilateral differences since the spike action in volleyball is highly asymmetric [54]. Eight studies were included in our review. Evidence from match analysis and laboratorial studies [9,11,13,16,51–53] suggests that landing after a spike jump is asymmetric in two forms: (i) landings where one foot contacts the ground first (usually, the left foot for right-handed players) and (ii) landings where the two feet contact the ground simultaneously, but one foot absorbs a greater percentage of the impact than the other (again, the left foot for right-handed players). Men landed unilaterally more often than women, and there were hints that attack zone and tempo may be associated with the rate of unilateral landings, but only one study provided solid data for that [13]. Further gender-based differences could not be assessed based on existing studies, given that (i) most only included men or women but not both, and (ii) they had very different study designs.

Micro-asymmetries exist, with unilateral landing being common [16]. These detailed analyses are unlikely to be feasible through match analysis studies unless the technology is developed, and pressure sensors can be incorporated in the tennis shoes of the athletes (this was not attempted in the analyzed studies). Although field-based tests with force platforms could probably help in this regard, the study design would likely demand tasks with highly reduced external validity, i.e., tasks that are extremely simplified in comparison with full, unrestrained gameplay. Even under laboratorial conditions and guaranteeing that male volleyball players landed on both feet into a force platform, Marquez, Masumura, and Ae [16] discovered that landing was asymmetric, with the left leg absorbing a greater percentage of the impact. Players also landed with one foot in front of the other, perhaps explaining at least part of this asymmetry, as each foot will have a different relationship with the inertial center of mass during landing [16]. Confidence in evidence is currently very low and there is no information establishing a relationship between asymmetrical/symmetrical landing from spike jumps and performance or injury risk.

It has been proposed that coaches teach different landings strategies or techniques to volleyball players [12,14], but it is doubtful that players will be able to consciously monitor how they land during real-game actions. Instead, Lobietti, Coleman, Pizzichillo, and Merni [13] suggest that, due to the predominance of single-leg landings in quicker attacks, especially on the left side of the court, coaches should start warming up on the right side of the court and using slower attack tempos so that players start by using techniques that will more likely result in landing with both feet simultaneously. As the authors state, this is at odds with what usually occurs, especially during the warm-up for official matches [13]. It is worth noting that the warm-up for official matches does not require the traditional spike warm-up, as teams can request a separate warm-up period and engage with alternative activities. This is seldom used due to tradition, not due to any inherent limitations of the rules.

Encouraging athletes to land with both feet to prevent knee injury [52,55] is aligned with ideas of reducing muscle imbalances [55]. However, asymmetry is an integral part of the volleyball spike, strengthening the hypothesis that asymmetry can be functional. Athletes adapt to the asymmetric requirements of spiking, including asymmetric landing, extending the physical and biological basis of asymmetry to a sports setting [56]. Asymmetries have shown benefits in running during states of fatigue [57]. Bilateral asymmetries of up to 15–20% are considered normal and are prevalent in sports, but there is likely an upper limit or threshold where asymmetries may become pathologic [58]. Furthermore, asymmetries (and their magnitude) are modulated by the type of test being used for assessment, chronological age, maturity, sex, type of sport, period of the season, modulators that may preclude the establishment of a particular threshold for increased injury risk [59].

Noncontact ACL injuries are the most prevalent noncontact injuries in volleyball, in both sexes, usually following a sudden deceleration while cutting or pivoting and landing from a jump [60,61]. Although our study lacks data to afford direct comparisons, it

seems that those injuries are more related to other landing characteristics than kinematic or kinetic bilateral asymmetries. Landing with reduced knee and hip flexion and increased knee valgus may increase the ACL's injury risk [9,62,63]. Moreover, the higher incidence of injury in women suggests they occur due to a greater knee joint valgus showed by women than men [64–67], which may result from neuromuscular and/or structural differences (e.g., augmented joint laxity in women and different pelvic anatomy [68]). Therefore, coaches should take care of limiting the knee dynamic valgus during a single-leg landing, becoming less taxing to the ACL and maybe reducing ACL noncontact injuries [64].

Disappointing results were found in the quality of the studies gathered in this review, and confidence in evidence was very low. More match analysis studies are required to assess the percentage of unilateral landings and whether they associate with attack zone and tempo, or other relevant variables. Analytical studies should provide two force platforms and avoid excluding asymmetric landings by design. If possible, these studies should create more realistic attacking conditions, with varied attack directions and levels of opposition. Experimental studies on whether these landing patterns can be modified should use randomized designs and assess if such modifications impair attack efficacy. Match analysis studies should provide inter- and/or intrarater reliability [1], while analytical studies should guarantee the blinding of the assessors [23]. Funding sources and competing interests should be openly acknowledged; if no funding and competing interests exist, authors should explicitly state that.

4.2. Limitations

The reduced number of studies available ($n = 8$), the heterogeneity in designs (match analysis, laboratorial spike landing tasks) and populations (i.e., from young players beginning to engage with the 6 vs. 6 games to top-level adult players), high risk of bias, lack of reporting of reliability measures, and/or standard errors of measurement and the overall very low confidence in cumulative evidence requires further studies to be performed to provide a clearer understanding of how volleyball players land after a spike jump. Furthermore, existing studies did not provide data concerning performance or injury risk, and therefore, the relationships between asymmetrical landings, performance, and injuries are currently unknown. Additionally, we did not analyze surface or shoe type, which could have implications for landing mechanics and its consequences for the joints.

4.3. Practical Implications and Suggestions for Future Studies

The practical implications of our findings are quite straightforward and include the following:

- (i) Unilateral landings are very common after a spike jump. This seems to be universal, i.e., regardless of playing level or sex (although it seems more prevalent in men). Therefore, coaches should acknowledge this reality and, instead of asking players to land on two feet, they should design conditioning programs improving unilateral landing, developing both the strength levels and the coordination required to properly cushion the asymmetric landings.
- (ii) Since the studies suggest that quicker attack tempos associate with an increased percentage of unilateral landing, players with hip, knee, or ankle pain or with previous injuries in these joints could benefit from practicing with slower attack tempos, at least temporarily, until symptoms resolve.
- (iii) Men seem to be more exposed to unilateral landing than women. If this is confirmed by further studies, perhaps conditioning programs for men should incorporate a greater percentage of single-leg strength training, with an emphasis on the eccentric component.

For future studies, we suggest the following:

- (i) Match analysis studies should use video cameras with high resolution and high sampling rates, as well as provide measures of interobserver reliability of the observations.

These studies should also provide context for the landing types (e.g., attack zone and tempo).

- (ii) Laboratorial or field studies should consider all landings and not just symmetric landings, to provide a more complete understanding of how players behave when landing after a spike jump. These studies should implement parallel randomized or cross-over randomized designs where task constraints (e.g., provenience of the ball, attack zone and tempo, type of opposition) are purposefully manipulated to better understand their effects on landing mechanics. These experiments could also test whether different shoe types and distinct indoor surfaces interfere with landing mechanics.
- (iii) Long-term injury-related implications of bilateral and unilateral landings on different surfaces could be assessed using cluster-randomized designs, as each team usually practices on the same surface during the week.
- (iv) The effects of fatigue on landing mechanics after a spike jump should also be assessed and, if a relationship is established, this may provide important information for coaches to manage the training sessions.
- (v) More studies are required comparing men and women under similar conditions, to better understand gender-based differences in terms of exposure to unilateral landing and the mechanical implications for each gender.

5. Conclusions

Studies analyzing spike landing showed a prevalence of unilateral landings (mostly the left leg first, for right-handed players) in men and women, with a suggestion that men may be more exposed than women. This asymmetry seems to be inherent to the spike action and may be unavoidable, despite proposals of strategies for circumventing it. Knee injuries are more prevalent in women, but the only study comparing men and women established that unilateral landing was more prevalent in men (40.0%) than in women (25.3%), raising doubts concerning the theoretical association between unilateral landing and knee injuries. It is also unclear how these landing asymmetries relate to neuromuscular or structural differences, such as an increased joint laxity in females and differences in pelvic structure and lower extremity alignment.

6. Other Information

Protocol and Registration

The protocol was published in INPLASY202140104, DOI: 10.37766/inplasy2021.4.0104. Initial searches in Scielo and in Cochrane Library retrieved zero results; therefore, we changed the protocol and eliminated the third code line (“land*”) specifically for these two databases.

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