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Landing Technique as a Determinant of Smash Success in Volleyball

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Abstract

Study purpose. This study was aimed at evaluating the effectiveness of a structured training program that was designed to improve volleyball landing techniques and their effect on smash performance. The program was focused on main elements such as single-leg and double-leg landings, together with correct body rotation during the landing phase.

Materials and methods. A randomized pretest–posttest control group design was used in this study, and 80 male and female U-18 volleyball athletes aged 16–18 years were involved. All eligible athletes who met the inclusion criteria were taken by a total sampling approach. The participants were then randomly placed into experimental and control groups (40 athletes each) after the pre-intervention test. A landing technique training program was given to the experimental group for 12 sessions (4 weeks × 3 sessions per week), while standard training was continued by the control group. After the intervention, a post-intervention test was given to both groups so that changes in performance could be measured.

Results. A greater improvement in landing technique performance from pre-test to post-test was shown by the experimental group (37.25 ± 2.62 to 63.30 ± 2.59) than by the control group (39.20 ± 2.76 to 47.55 ± 2.71). After the pre-test scores were controlled, a significant group effect on post-test scores was shown by ANCOVA, $F(1,77) = 4292.30$, $p < .001$, partial eta squared = .982. The adjusted mean difference between the groups was 17.49, 95% CI [16.96, 18.03]. A very large between-group difference was also shown by the supplementary post-test comparison, $t(78) = 26.57$, $p < .001$, Cohen's $d = 5.94$.

Conclusions. The structured landing training program was effective in improving landing technique performance among U-18 volleyball athletes. Safer landing mechanics were promoted through single-leg, double-leg, and rotational landing drills, so injury-prevention-oriented training may be supported by the

program. However, injury outcomes should be examined directly by future studies so that its preventive effects can be confirmed.

Keywords: landing technique, smash technique, volleyball, biomechanics

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Introduction

Volleyball is a physical activity that is placed in the category of games and sports. As a competitive sport, a high risk of injury is carried by volleyball (Leeuw et al., 2022). Special coordination of complex movements is required in this sport, such as jumping (Giustino et al., 2022), landing (Afonso et al., 2021), blocking (Wang et al., 2020), and spiking (Sarvestan et al., 2020), where roles are expected to be switched by players in a very short time. Mastery of basic techniques is not only needed for the execution of strategies (Sgrò et al., 2020) but is also needed so that self-confidence can be increased (Astuti et al., 2023) and optimism during competitions can be built (Umar et al., 2023).

The smash is a strong offensive strike that is directed toward the opponent's court, and it is seen as one of the most important techniques in volleyball (Putra et al., 2024; Suhairi et al., 2020). Complex movements are involved in this technique (Wicaksono et al., 2022), and sequential learning of coordinated motor skills is demanded (Permana et al., 2022). A high level of technical skill is required so that a successful smash can be performed (Suhairi et al., 2020), and a variety of smash variations can then be executed by athletes (Drikos et al., 2023). Therefore, the smash technique must be mastered correctly by players so that attacking opportunities can be maximized, points can be scored, and victory can be secured (Zhou et al., 2020).

The smash movement can be divided into separate stages of motor learning (Maki et al., 2022), which are 1) approach or run-up (Qadir et al., 2020), 2) take-off (Gjinovci et al., 2017), 3) hitting phase (De Alcaraz et al., 2017), and 4) landing (Farzami & Anbarian, 2020). Among these stages, landing is often performed imperfectly (Afonso et al., 2021), so team performance is not only reduced but severe injuries may also be caused (Takahashi et al., 2019). Early training is needed so that landing errors can be reduced, and one effective way is a training program that is designed specially for the characteristics of these movements (Putri et al., 2021). Such programs are aimed at improving performance while injury risks are reduced (Xu et al., 2021). Errors in the landing phase, which are often observed at rates of 23.82%–33.56%, usually happen when landing is performed by athletes with one foot, so imbalance is produced or body parts are even moved into the opponent's court (Anwar et al., 2020).

It is also indicated by previous studies that one-foot landing is often performed by volleyball players after spiking because of shifts in the center of gravity and loss of balance (Tillman et al., 2004). Although some injury risk is still carried by two-foot landings, one-foot landings are much more prone to injury (Xu et al., 2022). Moreover, athletes' recovery and return to training after injury are also influenced by psychological readiness (Aizawa et al., 2020). The effectiveness of training programs is also shaped by the competence of the coach (Chevrier et al., 2016), the use of varied training methods (Molla et al., 2023; Batez et al., 2021), and the availability of adequate facilities and infrastructure. Therefore, enough knowledge of proper landing techniques must be held by both coaches and athletes so that injury risks can be prevented (Tsai et al., 2020; Weldon et al., 2021).

Although landing mechanics are important in volleyball, general jump training or separate single-leg and double-leg landing techniques have mostly been focused on by previous studies, and little attention has been given to integrated training programs in which body rotation during the landing phase is included. Furthermore, structured training interventions

that are designed specially to improve landing mechanics in volleyball smash movements among adolescent athletes are still limited. Therefore, a structured landing training program in which single-leg, double-leg, and body rotation exercises are combined is proposed in this study. This study is aimed at evaluating the effectiveness of the proposed training program on the improvement of landing performance in U-18 volleyball athletes. It is hypothesized that significantly higher landing technique scores will be shown by athletes who are given the structured landing training program than by those who are given conventional training.

Materials and Methods

Study Participants

The study population was made up of 80 male and female U-18 volleyball athletes aged 16–18 years. All eligible athletes were taken by a total sampling technique. After the pre-test was completed, the participants were randomly placed into experimental and control groups, with 40 athletes in each group, by using a computer-generated random sequence. The allocation was performed by an independent researcher so that allocation concealment could be ensured and selection bias could be reduced. The experimental group was made up of 22 male and 18 female athletes, whereas the control group was made up of 21 male and 19 female athletes. Therefore, the sex distribution was relatively similar across the groups. Baseline differences in landing technique performance between the groups were examined by an independent samples t-test. Because the pre-test scores were significantly different between the experimental and control groups, the pre-test score was controlled statistically by ANCOVA in the main analysis.

This study was conducted based on ethical principles for research in which human participants are involved. Permission to conduct the study was obtained from the related schools, coaches, and institutional authorities before the data were collected. Written informed consent was obtained from participants aged 18 years, while written parental or guardian consent and participant assent were obtained for athletes under 18 years of age. The participants were informed about the study procedures, possible risks, voluntary participation, and their right to withdraw from the study at any time without penalty. All participant data were kept confidential and were used only for research purposes.

Study Organization

A randomized pretest–posttest control group design was used in this study. This design was chosen because two groups were involved in the study, namely an experimental group and a control group, so that the effectiveness of the landing technique training program could be assessed. The instrument that was used in this study was a volleyball landing technique test that was adapted from (Lobietti et al., 2010). Data collection was started with a pre-test for both groups so that baseline landing technique performance could be determined. A structured landing technique training program was then given to the experimental group for 12 sessions, while standard training was continued by the control group. Each training session was carried out for 60–75 minutes. After the intervention was completed, a post-test was given to both groups so that changes in landing technique performance could be evaluated, as is presented in Table 1.

Table 1. Landing Training Program

Single leg	Double leg	Rotation
Jumping on two feet and landing on one left foot	Jump with two feet and land with two feet	Jumping on two feet and landing on two feet with a reverse rotation body position
Jumping on two feet and landing on one right foot	Jump with two feet to the right and land with two feet	Jumping on one left foot and landing on one left foot with a reverse rotation body position

Jumping on one left foot and landing on one left foot	Jump with two feet to the left and land with two feet	Jumping on one right foot and landing on one right foot with a reverse rotation body position
Jumping on one right foot and landing on one right foot	Jump with two feet to the front and land with two feet	Jumping on one left foot and landing on one right foot with a reverse rotation body position
Jumping on one left foot and landing on one right foot	Jump with two feet to the back and land with two feet	Jumping on one right foot and landing on one left foot with a reverse rotation body position
Jumping on one right foot and landing on one left foot	Jump with two feet to the right, left, front, and back and land with two feet simultaneously with sustainability.	

The training program was designed based on the athletes' needs, movement characteristics, and exercise difficulty levels. Landing technique performance was measured by a standardized ordinal 1–4 technical rating scale. The content validity of the instrument was evaluated through expert judgment, in which three volleyball coaching and biomechanics experts were involved and the relevance and clarity of each assessment indicator were reviewed. So that scoring bias could be reduced, all participants were assessed independently by two trained raters with standardized scoring criteria after a calibration session.



Figure 1. Landing Single-leg



Figure 2. Landing Double-leg

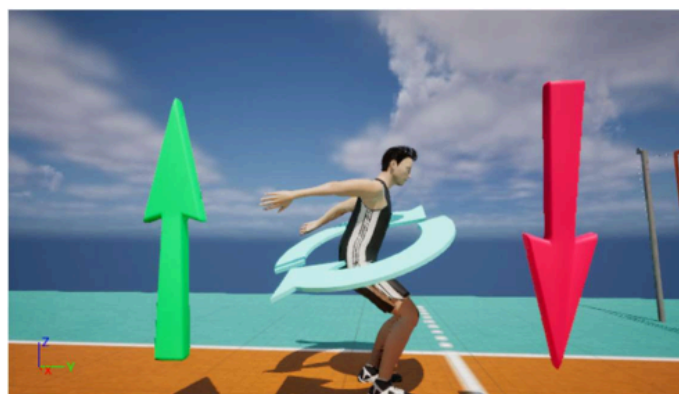


Figure 3. Landing Rotation

Research Procedure

Volleyball smash performance was evaluated based on the total score that was obtained by the athletes from tests in which specific movement elements were measured according to predetermined technical criteria. The assessment was arranged into four phases: (a) approach phase, (b) jump phase, (c) ball contact phase, and (d) landing phase. The landing phase was evaluated specially by a standardized 1–4-point ordinal scale that reflected the quality of movement execution. The scoring criteria were based on observable technical components, which included eye orientation, hand placement, toe alignment, hip position, knee flexion, and foot placement. These indicators were put together into the landing phase assessment rubric so that overall movement quality could be determined. The full scoring rubric is presented in [Table 2](#).

Table 2. Landing Technique Assessment

Phase	Components	Criteria Description	Score Interpretation
Approach Phase	Eye orientation, body alignment	Visual focus maintained toward target; body posture prepared for jump with controlled alignment	1 = poor focus/alignment, unstable preparation 2 = inconsistent focus and alignment 3 = good control with minor deviation 4 = excellent focus and optimal alignment
Jump Phase (Take-off)	Knee flexion, hip position, foot placement	Proper explosive take-off with correct knee and hip coordination and balanced foot push-off	1 = poor coordination, weak take-off 2 = limited knee/hip control 3 = good take-off with minor inefficiency 4 = explosive, well-coordinated take-off
Ball Contact Phase	Hand placement, upper body stability, eye orientation	Controlled upper limb positioning and stable trunk during ball contact	1 = poor control, unstable upper body 2 = inconsistent hand/body control 3 = good control with minor errors 4 = excellent stability and precise control
Landing Phase (Primary Evaluation)	Knee flexion, foot placement, toe alignment, hip position, trunk stability	Safe landing mechanics with proper shock absorption and balanced body posture upon ground contact	1 = unsafe landing, high instability 2 = partial control, noticeable imbalance 3 = good landing with minor instability 4 = excellent stable and safe landing mechanics

Each athlete was assessed independently by trained raters with standardized observation criteria. The final score is represented by the average rating across the trials.

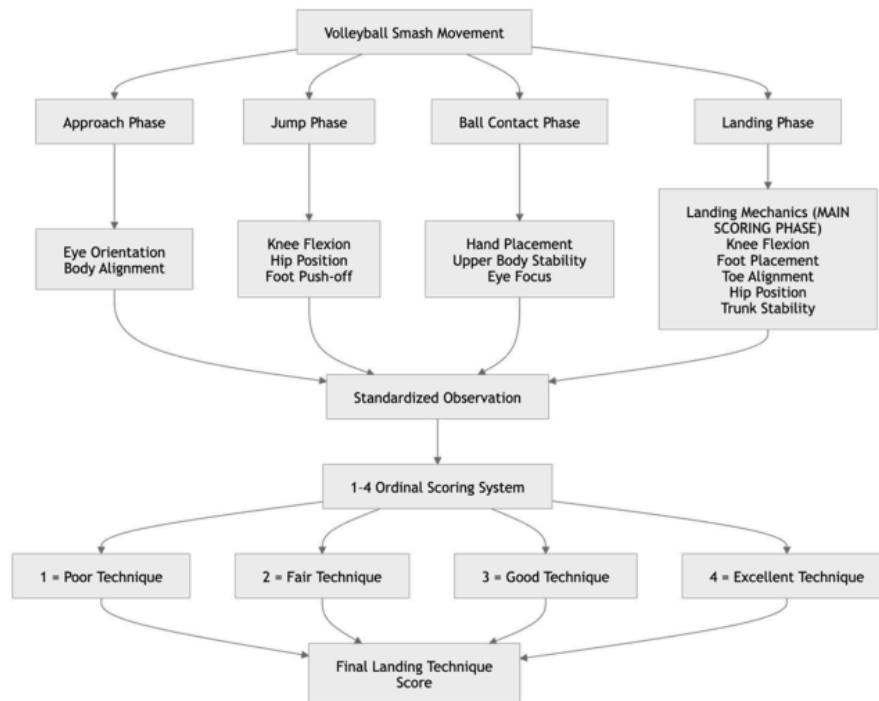


Figure 4. Conceptual Model of Volleyball Landing Technique Assessment

The training program was started with basic instruction on the importance of proper landing technique. The participants were introduced to the basic biomechanical principles of landing, and this was supported by video demonstrations of correct movements that were performed by professional athletes. In the practical part of the program, basic exercises were included, such as vertical jumps, bipedal and single-leg landings, and exercises that were designed to keep body balance when the ground was touched.

The intervention was carried out over four weeks with a frequency of three sessions per week, so a total of 12 training sessions was obtained. This training protocol was standardized for all participants so that the consistency of the intervention dose could be ensured. Each training session was carried out for 60–75 minutes and was made up of structured sets, and five repetitions of movement execution were included in each set. Six exercise variations were included in the training program, and these were arranged in a progressive sequence based on movement complexity and biomechanical demand. So that protocol fidelity could be kept, an identical structure in terms of volume, intensity, and exercise progression was followed in all sessions. Through this standardization, the training dosage was kept consistent across the whole intervention period, so the reproducibility of the study was improved.

Statistical Analysis

Because the pre-test scores were significantly different between the groups, analysis of covariance (ANCOVA) was used as the primary analysis. In the ANCOVA model, the post-test landing technique score was entered as the dependent variable, the group was entered as the fixed factor, and the pre-test landing technique score was entered as the covariate. The homogeneity of regression slopes assumption was examined by testing the interaction between the group and the pre-test score.

Paired samples t-tests were conducted as supplementary analyses so that within-group changes from pre-test to post-test could be examined. Independent samples t-tests were also used so that pre-test and post-test scores could be compared between the groups. Effect sizes

were reported by standardized mean change effect size for within-group comparisons, Cohen's d for between-group comparisons, and partial eta squared for ANCOVA. Ninety-five percent confidence intervals were calculated so that the precision of the mean differences could be estimated. Statistical significance was set at $p < .05$.

Although the normality assumption was violated by the control group pre-test data, parametric analyses were still used because 40 participants were included in each group and the main analysis was based on ANCOVA, which was used so that baseline differences between the groups could be adjusted. The paired samples t-test and the independent samples t-test were interpreted as supplementary analyses, while ANCOVA was taken as the primary test for the evaluation of the intervention effect.

Results

It was shown by the descriptive statistics that an improvement was obtained by the experimental group from 37.25 in the pre-test to 63.30 in the post-test. An improvement was also obtained by the control group from 39.20 to 47.55. It is indicated by these results that improvement was experienced by both groups; however, a greater increase was found in the experimental group. The descriptive results are presented in Table 3.

Table 3. Descriptive Statistics of Landing Technique Scores

Group	Pre-test Mean	SD	Post-test Mean	SD	N
Experimental	37.25	2.62	63.30	2.59	40
Control	39.20	2.76	47.55	2.71	40

The normality assumption was assessed by the Kolmogorov-Smirnov and Shapiro-Wilk tests at a significance level of $\alpha = .05$. In the experimental group, both the pre-test and the post-test data were normally distributed based on the Shapiro-Wilk test ($p = .392$ and $p = .406$, respectively). The normality assumption was violated by the control group pre-test data ($p = .011$), while the assumption was not violated by the control group post-test data ($p = .060$).

Table 4. Normality Test Results Based on Significance Values

Class		Kolmogorov-Smirnov Sig.	Shapiro-Wilk Sig.
Landing on Smash	Pretest Experiment	.027	.392
	Posttest Experiment	.036	.406
Volleyball	Pretest Control	.018	.011
	Posttest Control	.007	.060

It was shown by the baseline comparison that a statistically significant difference in pre-test scores was found between the experimental and control groups, $t(78) = -3.24$, $p = .002$, 95% CI [-3.15, -0.75], Cohen's $d = -0.73$. It is indicated by this result that the two groups were not fully equivalent before the intervention. Therefore, ANCOVA was used as the primary analysis so that initial differences in landing technique performance could be controlled.

Table 5. Baseline Comparison Between Experimental and Control Groups

Variable	Exp. Mean	SD	Control Mean	SD	Mean Diff.	t(df)	p	95% CI	Cohen'sd
Pre-test	37.25	2.62	39.20	2.76	-1.95	-3.24 (78)	.002	-3.15 to -0.75	-0.73

Supplementary paired samples t-tests were conducted so that within-group changes from pre-test to post-test could be described. It was shown by the results that both groups were improved from pre-test to post-test, and a larger mean change was found in the experimental group. However, because the groups were significantly different at baseline, these within-group results were interpreted only as supplementary descriptive evidence. The primary evaluation of the intervention effect was based on ANCOVA.

Table 6. Paired Samples t-test for Within-group Changes

Group	Pre	Post	Change	95% CI	t(df)	p	d_av
Experimental	37.25	63.30	26.05	25.98 to 26.12	746.42 (39)	< .001	9.99
Control	39.20	47.55	8.35	7.84 to 8.86	32.80 (39)	< .001	3.06

Note. Paired samples t-tests were interpreted as supplementary within-group analyses. The primary intervention effect was evaluated by ANCOVA because the baseline scores were significantly different between the groups.

It was indicated by Levene's test that the post-test variances between the experimental and control groups were homogeneous ($p = .868$), as is shown in Table 7.

Table 7. Test of Homogeneity of Variance

	Levene Statistic	df1	df2	Sig.
5 Based on Mean	.028	1	78	.868
Based on Median	.000	1	78	1.000
Based on Median and with adjusted df	.000	1	75.633	1.000
Based on trimmed mean	.018	1	78	.894

3 The homogeneity of regression slopes assumption was tested by examining the interaction between the group and the pre-test score. The interaction was not statistically significant, $F(1, 76) = 3.55$, $p = .063$, so it is indicated that the assumption was met.

Table 8. ANCOVA Results for Post-test Landing Technique Scores

Source	df	F	p	η^2
Pre-test score	1	359.31	< .001	.824
Group	1	4292.30	< .001	.982
Error	77	-	-	-

It was shown by the ANCOVA results that a significant effect of the group on post-test landing technique scores was found after the pre-test scores were controlled, $F(1, 77) = 4292.30$, $p < .001$, partial eta squared = .982. The adjusted mean score of the experimental group was 64.17, whereas the adjusted mean score of the control group was 46.68. The adjusted mean difference was 17.49, 95% CI (16.96, 18.03), $p < .001$. It is indicated by these findings that significantly greater improvement in landing technique performance was produced by the structured landing training program than by standard training after baseline performance was controlled.

Table 9. Adjusted Post-test Means Based on ANCOVA

Group	Adjusted Mean	SE	95% CI
Experimental	64.17	0.18	63.81 to 64.54

Control	46.68	0.18	46.31 to 47.04
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The independent samples t-test was used as a supplementary analysis. It was shown by the result that significantly higher post-test landing technique scores were obtained by the experimental group than by the control group, $t(78) = 26.57$, $p < .001$, mean difference = 15.75, 95% CI (14.57, 16.93), Cohen's $d = 5.94$. However, because the groups were significantly different at baseline, this comparison was interpreted as supplementary, while ANCOVA was used as the primary analysis.

Table 10. Supplementary Independent Samples t-test for Post-test Scores

Comparison	Mean Difference (95% CI)	t(df)	p	d
Experimental vs Control	15.75 (14.57, 16.93)	26.57 (78)	< .001	5.94

Overall, both groups were improved from pre-test to post-test, but substantially greater improvement was produced by the structured landing training program than by standard training. Because the groups were significantly different at baseline, the post-test independent samples t-test was interpreted only as supplementary. The primary conclusion was based on ANCOVA, and it was confirmed that the intervention effect was still significant after baseline differences in landing technique performance were controlled.

Discussion

Limited attention has been given to volleyball landing training programs in smash training research, although an important role is played by the landing phase in both performance outcomes and injury prevention. Therefore, structured training approaches that are combined with biomechanical analysis are needed so that landing mechanics in volleyball can be improved. This is supported by previous studies in which single-leg and double-leg landing mechanics were analyzed in injury prevention contexts (Taylor et al., 2016). The present training program was developed in a progressive way based on movement complexity, and single-leg, double-leg, and body-rotation landing exercises were included (Xu et al., 2021). The landing phase is an important part of the jumping movement, in which the mechanical energy that is produced during take-off must be controlled effectively by athletes so that a safe landing can be ensured and stability can be kept (Chorievna et al., 2022).

Proper landing mechanics are needed so that mechanical stress on the lower extremities can be reduced. An important role is played by knee flexion during landing in shock absorption and load distribution (Putra et al., 2023). Joint loading and injury risk during repetitive jump activities in volleyball may be increased when landing mechanics are not controlled enough. (Moran et al., 2019) reported that single-leg landing is related to an increased hip adduction moment, an increased knee abduction angle, and reduced knee flexion when it is compared with double-leg landing. It is indicated by these biomechanical differences that a higher mechanical demand is placed on the lower limb during single-leg landing. It is also suggested by previous literature that higher mechanical loading may be produced by single-leg landing than by double-leg landing, so potential injury risk is increased (Davis et al., 2019).

In the training program, biomechanical principles are combined with progressive movement difficulty so that structured skill development in landing mechanics can be supported. It has been shown by previous research that volleyball-specific landing performance is influenced by lower-limb kinematic and kinetic factors, which include joint angles, joint moments, ground reaction force, loading rate, and foot-strike patterns during block and spike jumps (Garcia et al., 2022). It has been shown that more effective landing strategies are used by experienced volleyball players than by novice players, especially during spike jump

landings, and this is reflected by greater ankle plantarflexion at initial contact and a greater ankle dorsiflexion range of motion. It is suggested by these findings that impact forces may be reduced and movement control may be improved when appropriate landing strategies are used during volleyball jump-landing tasks. Based on these biomechanical insights, single-leg landing, double-leg landing, and controlled body-rotation exercises are combined in the present program so that landing stability, movement control, and technical execution during volleyball smash performance can be improved.

It is suggested by the findings that improvements in movement control and landing stability may be supported by structured landing training. Through repeated exposure to movement tasks that become more complex, better awareness of body positioning during landing phases may be developed by athletes. Technical development in volleyball smash performance may be supported by this, especially in the control of landing mechanics under different movement conditions. However, the effectiveness of such training may be influenced by training duration, athlete characteristics, and coaching implementation.

Overall, a structured method for the analysis of movement patterns during landing tasks is provided by the body-rotation based landing training approach. When biomechanical principles are included in the training design, movement efficiency and control may be understood better by athletes. However, further research is needed so that long-term adaptations, retention effects, and the transferability of the training program to competitive match situations can be examined.

Several limitations are found in the present study. First, the intervention duration was relatively short (4 weeks), so long-term adaptation effects may not be observed. Second, no follow-up or retention test was conducted, so the durability of the training effects was not evaluated. Third, both male and female athletes were included without stratified analysis, so the interpretation of the results may be influenced. Fourth, the outcome assessment was based on an ordinal rater-based scoring system. Although expert judgment and rater calibration were conducted, quantitative evidence of content validity or inter-rater reliability was not reported in this study. Therefore, content validity index (CVI) and intraclass correlation coefficient (ICC) analyses should be included in future studies so that the psychometric evidence of the assessment instrument can be strengthened.

Conclusions

The structured volleyball landing training program was effective in improving landing technique performance among U-18 volleyball athletes. Significantly greater post-test performance than standard training was produced by the intervention after baseline differences were controlled. It is suggested by these findings that movement control can be improved and safer landing mechanics can be supported by structured exercises in which single-leg, double-leg, and rotational landing drills are included. However, because injury occurrence was not measured directly, the injury-prevention implications should be interpreted with caution. Long-term retention, sex-based differences, and actual injury outcomes should be examined in future studies so that the broader effectiveness of the program can be confirmed.

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Conflict of interest

It is declared by the authors that there are no conflicts of interest regarding the research, authorship, or publication of this article.

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