

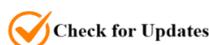
The Effect of Unilateral Plyometric Training on Dynamic Balance and Knee Proprioception in Elementary School Students

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Abstract: This study aimed to investigate the effects of an 8-week unilateral plyometric training protocol on dynamic balance and knee proprioception in middle school volleyball players. Sixteen female volleyball players aged 12-14 (13.00±1.00 years) participated in the study; the athletes were randomly assigned to an experimental (n = 8) and control (n = 8) groups. Dynamic balance performance was assessed using the Y-Balance Test, while knee proprioception was evaluated at three different angles (30°, 45°, 60°) using a digital goniometer. The analysis results revealed a statistically significant improvement in the experimental group's intra-group evaluation in 45° knee proprioception (p = 0.048) and Y-balance scores (Left: p = 0.002; Right: p = 0.006). The experimental group recorded an average increase of 10.88 cm (10.64%; d = 1.77) in the left leg reach distance and 7.88 cm (7.56%; d = 1.35) in the right leg. In the control group, a significant increase was observed in the left leg (p = 0.009), while no significant difference was found in the right leg and proprioception values (p > 0.05). In the between-group comparisons, no statistically significant difference was found in any of the measured parameters (p > 0.05). In conclusion, the unilateral plyometric training protocol led to significant improvements in dynamic balance and joint position sense in volleyball players. The findings, particularly with high effect sizes (d > 0.80), indicate that this training model is an effective method for achieving neuromuscular adaptation and should be included in athletes' performance enhancement and injury prevention strategies.

Keywords: Dynamic balance, plyometric training, proprioception, unilateral.

1. Introduction

Modern sports science is based on conducting high-intensity training sessions that can simulate situations that may occur during sports competitions. Creating specific variations in intensity during training is one of the fundamental elements. At the same time, it is necessary to prepare the athlete in advance to prevent possible injuries (Gabbett, 2016). Regarding this preparation process, scientist Boyle (2017) states in his book: "While athletes in many sports face unilateral situations, coaches' training exercises and tools consist of bilateral force models." At this point, the designed training program is of great importance; that is, the selection of movement patterns is as important as training parameters (frequency, intensity, number of sets, etc.) according to the nature of the sport (Zhang et al., 2024).

Although the positive effects of plyometric exercises on athletic performance are widely accepted in the literature, the question of whether unilateral or bilateral loading models are more effective according to the biomechanical requirements of the sport remains a topic of debate (Atıcı & Bayrakdar, 2025; Moran et al., 2021; Ramirez-Campillo et al., 2023). Particularly in sports such as volleyball, where asymmetric movement patterns and unilateral explosive force production are dominant, scientific evidence regarding the selection of training methods that maximize neuromuscular

adaptations is not yet as clear as desired (Dello Iacono et al., 2022). In this context, considering the unilateral nature of volleyball-specific movements and typical reaction situations, optimizing single-leg jumping mechanics is critical to minimizing injury risk and improving overall conditioning. Therefore, it is recommended that athletes be trained using unilateral movement patterns (Plesa, Kozinc, & Sarabon, 2022). Furthermore, several studies have found that motor skills are transferred to the contralateral side during unilateral movements (cross-training) (Hendy & Lamon, 2017; Bolton et al., 2019).

However, despite the known beneficial effects of plyometric training, the current literature indicates that the selection of unilateral or bilateral training to achieve more successful results in specific sports is lacking or limited (Maloney, 2019). The use of standard bilateral plyometric training for all sports increases interlimb asymmetry, reduces balance ability, and triggers performance decline and injury risk in sports that heavily utilize unilateral movement patterns (Fort-Vanmeerhaeghe et al., 2020; Helme et al., 2021; Fox et al., 2023). Indeed, the literature emphasizes that high asymmetry ratios negatively affect performance and that injury rates are four times higher when the difference exceeds 10% (Gustavsson et al., 2006; Madruga-Parera et al., 2020; Pardos-Mainer et al., 2020). Therefore, the use of measurements such as dynamic balance and proprioception is critical for the early detection of functional deficits and monitoring of neuromuscular adaptations that reduce injury risk (Krzysztofik et al., 2022; Stojiljkovic et al., 2025). Especially in sports like volleyball, these assessments form a fundamental link between protecting the athlete's health and improving performance (Sun et al., 2025).

All these data emphasize the critical importance of selecting training based on sport-specific movement patterns, especially in middle school athletes, where physical growth and neuromuscular development continue rapidly. In light of this information, the aim of this study is to determine the effect of an eight-week unilateral plyometric training program applied to middle school students involved in volleyball on dynamic balance and knee proprioception, as well as the magnitude of this effect. In line with the study's hypotheses, it is predicted that the eight-week unilateral plyometric training program will provide a statistically significant improvement in the dynamic balance performance of middle school students and will also lead to a significant improvement in the knee joint proprioceptive sensitivity of this group.

2. Materials and Methods

2.1. Research Model

This study employed an experimental design with a pretest–posttest control group model.

2.2. Research Group

The target population of the study consists of licensed female volleyball players who are actively involved in sports in the province of Şırnak. The study group, determined by purposive sampling, consists of 16 volunteer athletes aged 12–14 (Experimental group: $n = 8$; Control group: $n = 8$). The inclusion criteria for the study were defined as being female, aged between 12 and 14 years, having at least two years of regular sports history, and not having any vestibular or orthopedic disorders. The sample size was determined based on a priori power analysis using G*Power (v3.1.9.7) software ($\alpha = 0.05$; Power $[1-\beta] = 0.80$). Based on data obtained from similar populations in the literature, the expected effect size (Cohen's d) for the analysis was accepted as 1.45. The analyses performed at the end of the study showed effect sizes consistent with this estimate and even above the estimate ($d = 1.77$), particularly in the development of dynamic balance in the left leg of the experimental group. This is consistent with the existing literature reporting the strength of neuromuscular responses in young athletes with high neuroplasticity in response to short-term, intense plyometric training stimuli (Sun et al., 2025; Krzysztofik et al., 2022).

The sample for this study is limited to 16 licensed athletes aged 12–14 in Şırnak province. The main limitation of our study is that it was conducted on a specific population (female volleyball players aged 12–14) and that the sample size was kept small due to difficulties in adhering to the 8-week intensive training protocol and logistical constraints. However, the fact that the final effect size values achieved at the end of the study (Left leg $d = 1.77$; Right leg $d = 1.35$) exceeded the initial estimate of 1.45 proves that the current sample size has sufficient statistical power to detect training effects. Furthermore, the fact that the study was conducted only with female athletes in this age group may limit the

generalizability of the findings to different age groups or male athletes; this is considered an area for future research. Information on the anthropometric characteristics of the participants is presented in Table 2.

The study was approved by the Publication Ethics Committee of the Faculty of Social and Human Sciences at Van Yüzüncü Yıl University (Decision No: 2022/26-01, dated December 23, 2022). Prior to participation, written informed consent was obtained from the parents/guardians, and all participants were included in the study on a voluntary basis after being informed about the study procedures.

2.3. Data Collection Tools

2.3.1. Anthropometric measurements

Anthropometric measurements were performed according to standard procedures. Participants' body weight was determined using a digital scale with 0.1 kg accuracy; height was measured barefoot and in an anatomical stance (Lohman et al., 1988). To normalize dynamic balance data according to individual characteristics, leg length was measured and recorded as the distance between the Spina Iliaca Anterior Superior (SIAS) and the medial malleolus (Gribble et al., 2012). Participants' ages were verified using identification documents, and all descriptive statistics are presented in detail in Table 2.

2.3.2. Dynamic balance measurement

Participants' dynamic balance performance was determined using a standard Y Balance Test (YBT) setup consisting of a three-tiered tube connected to a central platform and measurement blocks moving on these tubes. Measurements were performed in a gym environment free of floor inclines and external stimuli; participants were barefoot and with their hands fixed at waist level. To minimize the effect of motor learning, all participants were given three trial attempts for each direction prior to the test. During the test, the free foot was pushed anteriorly, posteromedially, and posterolaterally.

In accordance with the standard application protocol defined in the literature (Plisky et al., 2009), measurements were invalidated and repeated if the support foot was lifted from the platform, weight was transferred to the block, balance was lost, or the foot touched the ground when returning to the starting position. The average of the three successful measurements obtained for each direction was recorded for analysis. To standardize individual leg length differences, the data were normalized, and the resulting left and right leg data are detailed in Table 3.

$$\text{Composite score} = \frac{\text{Anterior} + \text{Posterolateral} + \text{Posteromedial}}{3 \times \text{leg length}}$$

2.3.3. Knee proprioception measurement

Participants' knee joint proprioceptive sensitivity was assessed using the Passive Joint Position Sense (PJPS) test protocol. To eliminate visual perception and external stimuli, participants' eyes were kept closed throughout the test. Measurements were performed in a gym environment and in a quiet atmosphere at three different target angles: 30°, 45°, and 60° flexion. According to the protocol, the researcher passively brought the knee joint to the relevant target angle using a digital goniometer and waited 5 seconds in this position. The joint was then passively returned to its starting position (full extension).

To ensure standardization, three successful repetitions were performed for each target angle (Aslan, 2019). The participant was asked to actively repeat the perceived target angle; the deviation between the target angle and the achieved angle was recorded as an error score in degrees (°). To prevent loss of concentration and muscle fatigue during measurement, 30-second rest periods were provided between each repetition. In the analyses, the arithmetic mean of the three measurements obtained for each target angle was used, and the data obtained are detailed in Table 4.

The training programs implemented in the study were structured differently for the experimental group and the control group. The control group followed a standard volleyball training program five days a week. This program included 10 minutes of warm-up, strength, and conditioning exercises and 15 minutes of match training on two days a week; the other days included technical-tactical drills and 20 minutes of match training. In addition to the control group's routine volleyball training, the experimental group performed a unilateral plyometric training program twice a week for eight

weeks. Plyometric exercises were performed immediately after warm-up so that athletes would not be affected by training fatigue and could exert maximum effort.

Table 1. Unilateral exercise protocol.

Exercise	Week 1-3 sets	Week 4-8 sets	Repeat
1. Bilateral Static Jump	2	3	5
2. Unilateral Countermovement Jump	2	3	5
3. Unilateral Lateral Jump	2	3	5
4. Unilateral Box Jump	2	3	5
5. Unilateral Jump Over Obstacles	2	3	5

Note: 1. The exercise (Double-Leg Static Jump) was used as a bilateral preparatory movement to ensure safe neural adaptation and proper landing mechanics before progressing to unilateral loading.

This eight-week unilateral plyometric program consisted of a 10-minute warm-up, a 55-60-minute main session, and a 10-minute cool-down phase (Bogdanis et al., 2019). During training, a 1-minute rest protocol was applied between sets and a 3-minute rest protocol between exercises. The program volume was planned according to the principle of progressive overload; 2 sets were performed for each exercise during the first 3 weeks, and 3 sets were performed during the remaining 5 weeks. Wooden plyometric boxes 30 cm high and obstacles 15 cm high were used during the first 3-week period; intensity was increased during weeks 4-8, transitioning to boxes 45 cm high and obstacles 30 cm high. Training plates were used to track distance in lateral jumps, with targets set in the 50-70 cm range. Intensity control was based on the total number of foot-ground contacts per session; the contact number, which was approximately 60 in the first phase, was increased to the 90-100 range in the second phase.

The unilateral exercises implemented in the program included double-leg stationary jumps, single-leg counter jumps, single-leg lateral jumps, single-leg box jumps, single-leg jumps over obstacles, and single-leg drop jumps.

2.4. Data Analysis

The data obtained in this study were analyzed using the licensed SPSS 25.0 software package. The Shapiro-Wilk normality test was applied to investigate whether the variables showed a normal distribution, and it was determined that the data showed a normal distribution ($p > 0.05$). Additionally, skewness and kurtosis coefficients were used to verify the shape of the distribution. According to Tabachnik and Fidell (2013), if the skewness and kurtosis values are between -1.50 and +1.50, the data is considered to be normally distributed.

When examining the differences between groups, assuming that the variables were normally distributed, the Independent Samples T-test was used for two-variable comparisons, and the One-Way ANOVA test was used for comparisons involving more than two groups.

Cohen's d effect size was calculated to determine the practical significance of the analyses. In the experimental group, large effect sizes were found in the Y Balance Left ($d = 1.77$), Y Balance Right ($d = 1.35$), and Knee Proprioception 45° ($d = 0.84$) measurements ($d > 0.80$). The effect size was found to be insignificant in the Knee Proprioception 60° ($d = -0.05$) measurement. In the control group, a medium-large effect ($d = -0.75$) was detected at a 60° angle. The statistical significance level was accepted as ($p < 0.05$).

2.5. Ethical Approval

The study was conducted in accordance with the principles of the Helsinki Declaration and approved by the Publication Ethics Committee of the Faculty of Social and Human Sciences at Van Yüzüncü Yıl University (Decision No: 2022/26-01 December 23, 2022).

Informed consent was obtained from the parents of the individuals participating in the study in accordance with ethical principles. All participants volunteered to take part in the study. Before the study began, all participants and their parents were given detailed verbal information about the study. The authors declare that they acted in accordance with ethical rules at all stages of the study.

3. Results

The anthropometric characteristics of the participants in the study are shown in [Table 2](#).

Table 2. Anthropometric Measurements of Participants

Variables	Min-Max	m.±sd
Gender (Female: n=16)		
Age(year)	12-14	12.50±1.03
Height(cm)	135-172	157.4±9.42
Weight Before(kg)	28.80-63	47.13±10.93
Weight After(kg)	29-64	48.01±10.82
Leg Length(cm)	57-78	70.44±7.15

Min=Minimum; Max=Maximum; m = Mean; sd = Standard Deviation

Table 3. Comparison of Y-Balance Test Performance Between Experimental and Control Groups (Pre-Post Analysis)

Y-Balance test	Group	Pre-test (m±sd)	Post-test (m±sd)	Δ (cm)	Δ (%)	Within-group comparison		Cohen's d	Between-groups comparison		η ²
						t	p		F	p	
Left leg (cm)	Exp	102.25 ± 13.56	113.12 ± 13.48	10,88	10,64	5,00	0.002*	1,77	2215,00	0.159	0.137
	Con	105.62 ± 11.39	112.25 ± 13.63	6,62	6,27	3,57	0.009*	1,26			
Right leg (cm)	Exp	104.12 ± 14.63	112.00 ± 11.26	7,88	7,56	3,81	0.006*	1,35	1760,00	0.206	0.112
	Con	107.62 ± 14.01	111.12 ± 13.32	3,50	3,25	1,29	0.217	0,48			

*p<0.05

Upon examining the table, the pre-test average for the Y-Balance test results on the left side in the experimental group was 102.25 ± 13.56 cm, while the post-test average increased to 113.12 ± 13.48 cm. The experimental group showed an increase of 10.88 cm (10.64%), which is statistically significant (t = 5.00; p = 0.002). The effect size was calculated as Cohen's d = 1.77. The control group had a pre-test average of 105.62 ± 11.39 cm and a post-test average of 112.25 ± 13.63 cm. An increase of 6.62 cm (6.27%) was detected, and this change was statistically significant (t = 3.57; p = 0.009). The effect size in the control group was d = 1.26. No significant difference was found in the between-group comparison (F = 2215.00; p = 0.159; η² = 0.137). In the right-side results, the pre-test mean of the experimental group was 104.12 ± 14.63 cm, and the post-test mean was 112.00 ± 11.26 cm. An increase of 7.88 cm (7.56%) was detected, and this increase was statistically significant (t = 3.81; p = 0.006). The effect size was d = 1.35. In the control group, the pre-test mean was 107.62 ± 14.01 cm, and the post-test mean was 111.12 ± 13.32 cm. An increase of 3.50 cm (3.25%) was observed, but this change was not statistically significant (t = 1.29; p = 0.217). The effect size in the control group was d = 0.48. No significant difference was found in the between-group comparison (F = 1760.00; p = 0.206; η² = 0.112). In conclusion, within-group analyses revealed a statistically significant increase in the left direction in both groups and in the right direction only in the experimental group; however, no significant difference was found between groups for either the left or right direction.

Table 4. Comparison of Knee Proprioception Measurements at Different Angles Between Groups (Pre-Post Analysis)

Knee proprioception	Group	Pre-test (M±SD)	Post-test (M±SD)	Δ	Δ (%)	Within-group comparison		Cohen's d	Between-groups comparison		η ²
						t	p		F	p	
300	Exp	32.00±2.93	30.62±3.42	-1,38	-4,30	-1553,00	0.164	-0,55	0.019	0.893	0.001
	Con	30.25±3.54	28.62±3.42	-1,62	-5,37	-1021,00	0.341	-0,36			
450	Exp	43.75±3.62	47.12±3.87	3,38	7,71	2388,00	0.048*	0,84	0.158	0.697	0.011
	Con	40.75±6.16	42.88±3.14	2,12	5,21	0.757	0.474	0,27			
600	Exp	59.38±2.67	59.25±2.43	-0,12	-0,21	-0.150	0.885	-0,05	2339,00	0.148	0.143
	Con	57.62±3.81	55.50±5.01	-2,12	-3,69	-2109,00	0.073	-0,75			

*(p<0.05); M = Mean; SD= Standard Deviation

When examining the table, it is observed that at the 30-degree measurement, the final test values decreased compared to the pre-test in both the experimental group (Δ = -1.38; -4.30%) and the control group (Δ = -1.62; -5.37%). However, the within-group changes in both groups are not statistically significant (Experimental: p = 0.164; Control: p = 0.341). Effect sizes were calculated as d = -0.55 for the experimental group and d = -0.36 for the control group. No significant difference

was found in the between-group comparison ($F(1,14) = 0.019$; $p = 0.893$; $\eta^2 = 0.001$). At the 45-degree measurement, post-test values in the experimental group showed an increase compared to pre-test values ($\Delta = 3.38$; 7.71%), and this increase was statistically significant ($t(7) = 2.388$; $p = 0.048$). Although an increase was also observed in the control group ($\Delta = 2.12$; 5.21%), this change was not significant ($p = 0.474$). The effect size was determined as $d = 0.84$ in the experimental group and $d = 0.27$ in the control group. No significant difference was found in the between-groups analysis ($F(1,14) = 0.158$; $p = 0.697$; $\eta^2 = 0.011$). A very limited decrease was observed in the experimental group at the 60-degree measurement ($\Delta = -0.12$; -0.21%), and this change was not significant ($p = 0.885$; $d = -0.05$). The decrease was more pronounced in the control group ($\Delta = -2.12$; 3.699%), but this change was also not statistically significant ($p = 0.073$; $d = -0.75$). No significant difference was found in the between-group comparison ($F(1,14) = 2.339$; $p = 0.148$; $\eta^2 = 0.143$). Overall, a statistically significant increase was only detected in the experimental group at the 45-degree measurement; no statistically significant differences were found in any other degrees or groups in either the within-group or between-group analyses.

4. Discussion

The current study findings reveal that an eight-week unilateral plyometric training program statistically significantly improved dynamic balance performance and knee joint proprioceptive sensitivity in young volleyball players. Knee proprioception at the 45° final test levels was significantly higher. These significant increases recorded in the final test results, particularly in Y Balance Left ($d = 1.77$; $p = 0.002$) and Y Balance Right ($d = 1.35$; $p = 0.006$), demonstrate the development of stabilization capacity, which is critical for single-leg landing scenarios after blocks and spikes in volleyball. As a result of implementing the plyometric training protocol, a statistically significant ($p < 0.05$) increase was recorded in the Y Balance Test performance of the experimental group between the pre-test and post-test measurements. This finding demonstrates that specific dynamic balance interventions in the elementary school-aged population effectively improve body awareness and balance control ability by affecting both neural and muscular mechanisms. Furthermore, the results of our study on 45° knee proprioception and dynamic balance are in complete agreement with the findings of [Alikhani et al. \(2020\)](#), who reported that six weeks of plyometric training reduced joint position error at 45° flexion in female athletes. However, while [Alikhani et al. \(2020\)](#) examined a general group of female athletes, the main difference in our study is the rapid learning and development ability specific to adolescence in volleyball players aged 12-14. This situation clearly demonstrates the biological developmental advantage of this age group, as the nervous systems of young athletes in their developmental stage adapt much more quickly to single-leg jumping exercises than those of adults.

However, the unilateral structure of our study, which routinely incorporates different training elements, adds a new dimension to the literature in terms of its positive effects on factors such as injury and limb asymmetry. An individual's technical proficiency in a sport determines whether the desired skill should be trained unilaterally or bilaterally. Unilateral plyometric training shows faster effects on parameters such as power and jumping. Indeed, [Sun et al. \(2025\)](#) confirm that unilateral exercises provide higher efficiency in a short time. A review of the current literature reveals studies examining the effects of unilateral plyometric training on dynamic balance and knee proprioception. [Zhang et al. \(2024\)](#) found that unilateral training has a significant effect on jumping and strength quality. However, it is thought that the increased proprioceptive sensitivity of our volleyball players at critical angles such as 45° provides a more decisive functional gain than the pure strength increase mentioned by Zhang in order to balance the asymmetric loads encountered on the field.

[Bettariga et al. \(2023\)](#) determined in their study on soccer players that a 6-week unilateral complex training program significantly reduced vertical and horizontal jump asymmetry. Furthermore, these findings, which demonstrate the positive effect of unilateral training on asymmetry and the positive correlation between the reduction in asymmetry and balance ability, are supported by [Sun et al. \(2025\)](#). The lack of statistical significance in right-side balance development in the control group ($p = 0.217$) indicates that standard training is insufficient to correct the imbalances arising from the asymmetric nature of volleyball and highlights the necessity of unilateral plyometric exercises. This situation shows that technical work alone does not provide sufficient stabilization and that specific proprioceptive loading is essential for development. Furthermore, [Bandara and Thotawaththa \(2025\)](#) and [Cao et al. \(2024\)](#) found that unilateral training improved neuromuscular performance. In our study, focusing on volleyball players' position sense

at a 45° knee angle confirms the injury risk reduction advantage emphasized by Zhao et al. (2024) for basketball players through the volleyball-specific 'proprioceptive sensitivity' mechanism. In a similar study, Drozd et al. (2024) found that unilateral training on 16 soccer players had a greater effect on all variables and prevented injuries. According to the results of another study, Duan et al. (2024) determined that unilateral training is more effective in increasing explosive power and dynamic balance in the dominant leg. Sanchez-Sanchez et al. (2024) determined that unilateral exercises provide a significant improvement in jumping performance.

Furthermore, a study by Bogdanis et al. (2019) observed a large increase in the rate of strength development. The progressive loading provided by gradually increasing the box height from 30 cm to 45 cm in our training protocol ensured a systematic increase in training load. This progressive loading strategy is thought to be the fundamental mechanism behind the marked improvement in balance performance. Unlike previous studies, Hale et al. (2014) emphasized the contralateral effect of unilateral balance training, finding that it also improved the unloaded ankle.

The developments in this study reveal that combining unilateral training with plyometric training in volleyball leads to greater improvement in single-leg ability. Unilateral exercises are more beneficial in terms of achieving high efficiency in a shorter time during limited training periods. Unilateral plyometric training leads to greater neural adaptation, which is thought to affect knee proprioception and dynamic balance ability and to occur in conjunction with the presence of a contralateral effect. This study presents one of the first empirical findings showing that a unilateral plyometric training protocol specifically designed for unilateral movement patterns required in sports disciplines has significant and positive effects on the dynamic balance ability and, in particular, the 45° sensitivity of knee proprioception in young athletes in elementary school. This result highlights the potential of sport-specific unilateral exercises in training plans to reduce asymmetry and minimize injury risk, filling a methodological gap in the existing literature.

5. Conclusions

This study found that unilateral plyometric training produced more effective results on specific performance parameters compared to traditional methods. The choice between bilateral or unilateral exercise models in training planning should be based on the nature of the sport and the functional movement mechanics required in volleyball. Especially in motor skills where single-leg activity is dominant, unilateral plyometrics have been seen to be more functional in developing both single- and double-leg performance capacity by accelerating neural adaptation processes.

The success of unilateral loading in correcting bilateral imbalances and its ability to promote development even in the untrained limb through the effect of contralateral transfer (cross-training) confirms that this method offers a strategic advantage, especially during rehabilitation and injury periods.

In light of these findings, it is crucial for coaches to meticulously plan variables such as time, space, athlete age, training frequency, and load type in unilateral plyometric applications. Neglecting these factors in the planning process may lead to negative adaptations rather than the targeted neuromuscular gains.

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