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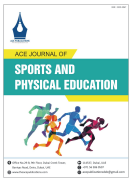

The Effectiveness of Unilateral Versus Bilateral Plyometric Training in Improving Kinematic Economy and Numerical Performance in Triple Jump Competitors

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KEY WORDS:
Unilateral, kinematic
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Economy
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Abstract: The aim of this study was to determine if unilateral plyometric training was superior to bilateral plyometric training to increase kinematic economy and performance in triple jumpers. The research design was an experimental design with 2 experimental groups that used pre- and post-test. Eight sportsmen aged 18 to 21 years from Al-Mahawil Sports Club of Babylon Governorate were selected as a research sample. They were randomly distributed to two equal experimental groups. From October 1, 2025, to April 3, 2026, the two groups underwent a unilateral plyometric training and bilateral plyometric training. The data collected were approach speed to and landing time on the platform, and performance in the triple jump (kinematic economy variables). Data were analysed statistically by statistically performing internal comparisons using the Wilcoxon signed rank test and comparisons between the two groups using the Mann Whitney U test with calculation of the effect size. Results indicated that after carrying out the two training programme, there was a positive change in both groups' performances. But the unilateral plyometric training group showed more gains in kinetic economy and performance relative to the bilateral training group. This study concluded unilateral plyometric training, was more effective to develop kinetic performance and enhance performance in triple jumpers. It suggested having such kind of training in the training programmes for such event.

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INTRODUCTION

The triple jump is one of the most technical events in track and field athletics and involves the athlete to sprint, jump, and coordinate their movements through three different movements: the hop, step, and jump. In this event, not only will the athlete need to be able to produce high amounts of power but also the ability to keep the velocity and efficiency of their movement throughout the entire sequence. For this reason, coaches and sport scientists are continually looking for methods in training that improve not only bio mechanical efficiency, but also competitive performance. Of these

techniques, plyometrics have proven to be one of the better methods for maximizing the potential of explosive power and athletic performance in jumping events.

The stretch-shortening cycle (SSC) is the basis for plyometric training, which involves a rapid eccentric contraction, followed immediately by a concentric contraction. This will enable athletes to make more force in less time, which will result in enhancements in power output, reactive strength and neuromuscular coordination. Plyometrics have been adopted as a key piece of training for athletes in sports that are of an explosive nature, specifically in sprint and jump sports, over the last few decades. Plyometric training has been shown in a multitude of studies to improve vertical jumping, horizontal jumping, sprint acceleration, and athletic abilities[1].

There are two main techniques that are used for plyometrics: unilateral and bilateral exercises. There are exercises that are performed with one leg at a time, known as unilateral plyometric exercises, including single-leg hops, bounds, and jumps. Bilateral plyometric exercises are performed using both legs at once, for example, squat jumps, counter movement jumps and box jumps. Both approaches have unique physiological and biomechanical advantages. While bilateral exercises may lead to higher overall force production with lower body power, unilateral exercises might increase balance, stability, exercise specific strength, and movement patterns that better simulate the demands of many sporting activities.

The triple jump features a series of unilateral ground contacts making unilateral plyometric exercises, in theory, more specific to the triple. In each of the three parts of the triple jump, the jumper has to take and produce a considerable amount of force with one foot, whilst keeping his/her body controlled and moving horizontally. Thus, methods that mimic these movements can be more effective in promoting adaptations for the event. But, the bilateral plyometrics exercise is also a key factor in developing the basic power and strength capacities required in a successful jump. Although these two training methods are widely used, controversy still exists about which is more effective for the triple jump athlete[2].

One of the factors that affect the performance of a triple jump is kinematic economy, which is the ability of athletes to carry out the movement patterns with efficiency and cost of the athlete using up the least amount of energy and the least amount of velocity. With more economical kinematics, athletes can maintain momentum throughout the hop, step, and jump phases and thereby increase the total jump distance. When considering efficiency of movement, factors include optimal joint angles, ground contact times, stride mechanics, and force application. Given the fact that plyometrics directly influence the function and mechanics of the neuromuscular system, they can be expected to impact kinematic economy in addition to traditional measures of performance[3].

Not only is movement efficiency important, but so are numerical performance indicators like jump distance, phase ratios, take-off velocity and competition results in the triple jump. The influence of various plyometric training modalities on these variables is of significant practical value for coaches, athletes and sports scientists who are looking for training strategies that are supported by scientific evidence.

Thus, this study will investigate the effect of unilateral and bilateral plyometric training on kinematic economy and numerical performance of triple jump athletes. The research will make it possible to compare the specific adaptation of each training approach and offer valuable insights for optimizing training programs and for the scientific understanding of performance enhancement in triple jump athletes.

Research Problem: Plyometric training is a modern training method that contributes to developing explosive power and improving technical and performance levels in jumping competitions, particularly the triple jump, which requires a high level of speed-strength, neuromuscular coordination, and motor economy during the hop, step, and jump phases. Despite the widespread use of unilateral and bilateral plyometric training in preparing triple jumpers, coaches still face difficulty in determining which type is more effective in improving motor economy and achieving better performance levels. Through the researcher's observation of athletes at Al-Mahawil Sports Club and the resulting variations in their technical and performance levels, coupled with the limited number of local studies comparing unilateral and bilateral plyometric training in triple jumpers, the need arose to conduct a scientific study to determine the effectiveness of each of these training methods in improving motor economy and performance levels for this group of athletes.

Research Objectives:

- To develop two training programs using unilateral and bilateral plyometric drills for triple jumpers.
- To identify the effect of unilateral plyometric drills on improving kinematic economy and performance in triple jumpers.
- To identify the effect of bilateral plyometric drills on

improving kinematic economy and performance in triple jumpers.
- To compare the effect of unilateral and bilateral plyometric drills on improving kinematic economy and performance in triple jumpers.
- To determine which of the two training methods is more effective in developing kinematic performance and performance.

Research Hypotheses:

- There are statistically significant differences between the pre-test and post-test results of the two experimental groups in the variables of kinematic economy and performance, favoring the post-tests.
- There are statistically significant differences between the group using unilateral plyometric drills and the group using bilateral plyometric drills in the post-tests.
- Unilateral plyometric training results in greater improvement in kinetic economy and performance compared to bilateral plyometric training in triple jumpers.

Research Areas:

- Human Scope: Eight (8) triple jumpers from Al-Mahawil Sports Club in Babylon Governorate, aged 18–21 years.
- Spatial Scope: Al-Mahawil Sports Club stadium and facilities in Babylon Governorate, Iraq.
- Temporal Scope: From October 1, 2025, to April 3, 2026.
- Subject Scope: A study of the effectiveness of unilateral plyometric training compared to bilateral plyometric training in improving kinetic economy and performance in triple jumpers.

MATERIALS AND METHODS

Research Methodology: The researcher adopted an experimental approach with two experimental groups using pre- and post-tests, as it was suitable for the nature of the research problem and its objectives, which aimed to compare the effect of unilateral and bilateral plyometric training on improving kinetic economy and performance in triple jump athletes

Research Population and Sample: The research population consisted of triple jump athletes from Al-Mahawil Sports Club in Babylon Governorate during the 2025–2026 sports season, totaling eight athletes aged 18–21 years.

All members of the population were selected purposively and then randomly assigned to two equal experimental groups:

- Experimental Group 1 (n = 4): Implemented the unilateral plyometric training program.
- Experimental Group 2 (n = 4): Implemented the bilateral plyometric training program.

Inclusion Criteria:

- The athlete must be officially registered with Al-Mahawil Sports Club.
- The athlete must have at least two years of coaching experience in jumping events.
- The athlete's musculoskeletal condition is to be cleared for the three months prior to the trial.

Exclusion Criteria:

- Failing to attend over 10% of training sessions.
- Being injured and unable to return to the training program. An injury that prevents continuation of the training program.

Experimental Design: Pre training tests were taken prior to the training program. The training programme was then applied for a period of some 24 weeks, from 1st October 2025 to 3rd April 2026. For the post tests, the same conditions as the pre tests were used[4].

Dependable Variables:

- First: Kinematic Economy Variables
- Final approach speed (m/s).
- Hooping time (seconds).
- Stepping time (seconds).
- Time of landing on the jump phase (seconds).
- How many percent of the horizontal velocity is retained between phases of the jump (%).
- Hoop-Step-Jump ratio.

Second: Digital Achievement Variable:

- The triple jump distance (m) is the overall distance jumped. The Triple jump distance (m) is the distance jumped in the triple jump.

Equipment and Tools Used:

- 240 frames/second or more 2 high speed digital cameras.
- Camera tripod.
- Metal measuring tape 50 m.

- Electronic timing device.
- Laptop to analyze data.
- Two dimensional motion analysis software (Kinovea).
- Data recording forms.

Test Description:

- Digital Achievement Measurement in the Triple Jump
- Objective: To measure the athlete's digital performance in the triple jump.
- Procedures:
- The athlete does a regular warm-up of 20 minutes.
- Three legal attempts are allowed.
- The best shot made is logged.
- The distance from the take-off board to the closest foot print made by the athlete in the landing pit is measured.

Unit of Measurement:

- Meter (m)

Validity and Reliability: This is an accredited test by the International Association of Athletics Federations (IAAF), and has strong validity and reliability.

Test II: Kinematic Economy Analysis Using Videography:

- The purpose of this study is to compare the efficiency of kinematic performance in the triple jump.

Camera Setup:

- The first camera is 15 meters away from hoop area.
- Second camera 15 metres set up away from step and jump area.
- The lens is h = 1.20 m off the ground.
- The axis of the camera is at right angles to the direction of camera movement.

Test Procedures:

- A set of calibration markers of known length are positioned in the field of view of the camera.
- The athlete will make 3 legal attempts.
- The best shot is used for the analysis.
- The analysis software is used to obtain kinematic data.

Extracted Variables:

- Final Approach Speed (m/s)
- Calculated as[5]:
- Speed = Distance ÷ Time

This is done in the final 5 meter approach to take-off.

- Landing Time

Recorded from the time the foot grounds until it is in the air during:

- Hoop
- Step
- Jump
- Unit of measurement: Second (s)

Horizontal Speed Conservation Index:

- Computed with the equation[6]:

The Speed Conservation Index (%) will be calculated as (Start Speed ÷ End Speed of Previous Phase) × 100

The percent is closer to 100%, the better the kinematic economy is.

Jump Phase Distribution Percentages

- Calculated as follows:
- Hop percentage is calculated as a percentage of hop distance over a total distance.
- Percent = Step distance / Total distance × 100

The percentage of the long jump is (the length of the long jump divided by the length of the entire jump) multiplied by 100.

Distribution should be about:

- Hop: 35–37%
- Step: 29–31%
- Long jump: 32–34%

Pilot Study: A pilot study is conducted on athletes outside the research sample to verify:

- Equipment functionality.
- Team efficiency.
- Test time.
- Clearness of registration forms.

Scientific Basis of Tests: The following are verified:

- Face validity by presenting the tests to experts in sports training and biomechanics.
- Reliability using the test-retest method. Objectivity through the agreement of the judges in analyzing motor performance.

Statistical Analysis: The SPSS statistical package (version 29) is used and includes:

- Mean.
- Standard deviation.
- Skewness coefficient.
- Shapiro-Wilk test to check for normality.
- Wilcoxon signed-rank test (within groups).
- Mann-Whitney U test (between groups).
- Effect size (r).
- Statistical significance level ($p \leq 0.05$).

RESULTS

The table shows that all statistical significance values were greater than (0.05), indicating the homogeneity of the data and the absence of severe deviations in the distribution.

The results indicate significant differences in favor of the post-tests and with a large effect size.

The results show an improvement in all variables, but some differences did not reach the level of statistical significance (0.05) due to the small sample size.

The results indicate the superiority of the group that used unilateral plyometric training compared to the group that used bilateral training.

The development ratios show that the unilateral group achieved greater improvement in all variables compared to the bilateral group, indicating a higher effectiveness of this type of training in developing motor economy and numerical achievement among triple jumpers.

Discussion of Results: The study results showed an improvement in the variables of kinematic economy and numerical performance among the participants in both experimental groups after the application of the two training programs. However, the degree of improvement was greater in the group that used unilateral plyometric training compared to the group that used bilateral plyometric training. These results can be explained in light of the mechanophysiological characteristics associated with the effectiveness of the triple jump and the nature of the training used.

Regarding the group that underwent unilateral plyometric training, the results showed significant differences between the pre- and post-tests in the variables of numerical performance, approach speed, and hopping landing time.[7]This will reflect the effectiveness of this type of training on developing specific physical abilities, which are relative to performance. This is due to the unilateral nature of training, which closely mimics the requirements of the triple jump, where the hopping, stepping and jumping

Table 1:Results of the Shapiro-Wilk test for normality of variables in pre-measurements

Variables	W	Sig.
Digital Achievement (M)	0.914	0.362
Final approach speed (m/s)	0.926	0.417
Hopscotch pivot time (s)	0.901	0.298
Step time (s)	0.933	0.451
The time of the jump (s)	0.918	0.377

requires take-off and landing with 1 foot with most of the performance phases. This is one of the factors that supports the law of specificity of training, an important concept in sports training science. Exercises that simulate competitive activity produce more neuromuscular adaptations to meet the requirements of athletic activity[8].

The increased approach speed and decreased landing time may also be attributed to the fact that unilateral training is well known to enhance explosive power, the reactive ability of functioning muscles, as well as efficient utilization of the stretch shortening mechanism. This boosts the athlete to attain higher velocities within shorter periods of time, decreasing ground reaction times and sustaining the ground speed between change of phases of the jump. This in turn has a positive effect on the kinetic economy and in final performance[9].

The results from the group that engaged in bilateral plyometric training demonstrated that there was an improvement in all variables studied, although it was not significant. This may because, bilateral training gives the overall strength or motor motor capacity building for the lower limbs, while unilateral training may be more motor specific to the lower limbs. Such training will help develop some aspects of physical fitness, but may not have such a significant effect on training the skill of triple jumping as training that will mimic the actual motor involvement of the sports itself[10].

Comparing the results of the two groups for the post tests showed that the unilateral training group was superior with respect to most variables and that the specificity of the training is a key determinant for enhancing sport performance. Apart from ensuring that horizontal speed is maintained, with minimal energy loss throughout the triple jump, the balance and stability when leaving and landing on one foot for the jumps is also essential. Unilateral training is more beneficial for these requirements than bilateral training.

The findings agree with current sports training principles that encourage the use of relevant exercises that simulate the movement system of the training skill. These exercises result in better neuromuscular control and greater efficiency in producing-force under actual performance conditions. Moreover, the substantial increase in the magnitude of effect in the unilateral

Table 2: Results of the Wilcoxon signed-rank test for the first experimental group (unilateral plyometry)

	Pretest		Posttest				
Variables	Mean	Std	Mean	Std	Z	Sig.	Impact size (r)
Digital achievement (m)	13.48	0.31	14.06	0.27	-2.03	0.042	0.72
Approach speed (m/s)	8.41	0.22	8.93	0.18	-2.00	0.046	0.71
Hoop landing time (s)	0.146	0.008	0.132	0.007	-2.02	0.043	0.71

Table 3: Results of the Wilcoxon test for the second experimental group (bilateral plyometry)

	Pretest	Posttest					
Variables	Mean	Std	Mean	Std	Z	Sig.	Impact size (r)
Digital achievement (m)	13.51	0.29	13.88	0.25	-1.84	0.066	0.65
Approach speed (m/s)	8.39	0.19	8.67	0.17	-1.83	0.067	0.64
Hoop landing time (s)	0.145	0.007	0.138	0.008	-1.79	0.073	0.63

Table 4: Results of the Mann-Whitney U test for comparing the two groups in post-test measurements

Variables	Average rank (single rank)	Average rank (binary)	U	Sig.
Digital achievement (m)	6.25	2.75	1.00	0.043
Approach speed (m/s)	6.00	3.00	2.00	0.048
Hoop landing time (s)	6.50	2.50	0.00	0.029

Table 5: Percentage development rates of the two groups in the main variables

Variables	Monogroup (%)	Binary group (%)
Digital achievement	4.30	2.74
Final approach speed	6.18	3.34
Hoop foothold time	9.59	4.83
Step foothold time	8.74	4.16
Jump foothold time	8.21	3.95

training group suggests that the global influence of the trainings program—beyond physical changes—concerns the mechanical changes related to kinetic economy[11].

According to the above, it can be concluded that the unilateral plyometric training is more suitable and preferable for the achievement of kinetic economy and the number of achievements in the execution of the triple jump because it has a great similarity in the learning content of the training taught with the content of the skills that are required in the execution of the triple jump; it can be seen that the level of functional and kinetic adaptations that are obtained from the unilateral plyometric training has a positive influence on the achievement level when viewed from the similarity of the learning content of the unilateral plyometric training taught with the learning content of triple jump skills so that it gives a functional and kinetic adaptation[12], so that when looked at from the learning content of the unilateral plyometric training taught and the learning content of the triple jump skills, namely unilateral movement learning with greater similarity with the actual requirements so that functional and kinetic adaptations can be achieved, reflected in the level of achievement.

CONCLUSIONS

- Unilateral plyometric training has proven sufficient to increase the kinetic economy and performance of triple jumpers, and is successful in developing physical and technical requirements of the event.
- Unilateral plyometric training has proven to be more effective than bilateral plyometric training for improvements in approach speed and landing time, thus enhancing motor performance efficiency.
- Bilateral plyometric training resulted in improvements in some physical and motor variables but smaller improvements than unilateral training.
- Bilateral plyometric training deserves more specific and effective neuromuscular adaptations due to its similarity with the actual requirements of the TRIPLE JUMP.
- A unilateral approach is more appropriate than a bilateral approach to enhance kinetic economy and consequently performance in triple jumpers at age 18–21 years.

Recommendations:

- Incorporate unilateral plyometric exercises in the training programme of triple jumpers as plyometrics have been shown to improve kinematic economy and performance.
- Use plyometric exercises based on the training specificity concept: choose exercises which resemble the different technical elements of the hop/step/jump.
- Test kinematic variables and performance periodically to track athlete's progress and assess

effectiveness of the training program(s) implemented.

- Carry out further research on bigger groups of athletes, different age groups, different training levels, with further biomechanical variables (take off angle, velocity of centre of mass and Reactive Power Index (RSI)) to provide more accurate results.

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