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Effects of Short-term Plyometric Training on Countermovement Vertical Jump Height and Kinematics of Take-Off

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Abstract

Background: Countermovement vertical jump is a crucial skill in many sports. Plyometric training is a prevalent method to improve athletes' jumping ability.

Objectives: The present study aimed to investigate the effect of a 6-week plyometric training on the kinematics of take-off and countermovement vertical jump height.

Methods: Fifteen young, healthy male subjects performed plyometric exercises in three sessions per week for six weeks. Digital videos of pre-training and post-training jumps were captured. The Kinovea software was used to measure the kinematic parameters of take-off in the sagittal plane. Pre and post-training values were compared by paired sample t-test with the statistical significance level of $P < 0.05$.

Results: Post-training results showed a higher jump height ($P < 0.05$), more flexed shoulder, and more extensive hip and knee at take-off ($P < 0.05$). Also, while hip extension velocity was decreased, shoulder flexion and knee extension velocities were significantly increased ($P < 0.05$).

Conclusions: The 6-week plyometric training, including 720 jumps, improved shoulder flexion, and hip and knee extensions at take-off, resulting in high CMJ height. We employed plyometric training to improve the shoulder flexion and hip and knee extension velocities and increase CMJ height.

Keywords: Countermovement Jump, Kinematics, Plyometric Exercise, Jump Height

1. Background

Countermovement vertical jump (CMJ) is a fundamental technique in some sports, such as volleyball, basketball, and gymnastics. Therefore, researchers and coaches need to improve their skills (1, 2). A good CMJ is the result of coordinated interactions between the neuromuscular process, muscle physiology, and skeletal system (3-5). Quantifying these interactions and evaluating their relations with the performance of CMJ can have many difficulties. Thus, the CMJ performance is indirectly evaluated by measuring the jump height and investigating the kinematic of the movement (2, 6-9). In this way, researchers tend to alter the kinematic parameters of the CMJ to improve the performance and also increase the vertical jump height (10-14).

We investigated the effects of plyometric training (PT) in the literature to achieve such improvement. Markovic conducted a meta-analysis showing that the number of PT sessions affect the CMJ performance (1). Arabatzi et al. indicated a significant increase in CMJ height and a decrease in maximum knee angle after 8-week PT, while the hip angle was not significantly altered (15). Moreover, Hammami et al. and Zubac et al. found a significant increase in CMJ height due to 8-week PT (16, 17). Adibpour et al. found a significant increase in CMJ height due to eight weeks of combined plyometric and weight training for young female basketball players (18). Oxfeldt et al. demonstrated that the results of the studies showed 3.4% to 26.3% improvement in CMJ height after four to twelve weeks of PT (19).

In contrast, some studies showed non-significant effects of PT on the CMJ height. For instance, Carlson et al. found no significant effect of 6-week PT on CMJ height in comparison to other training methods, including weight training or VertiMax training (20). Gül et al. showed a non-significant increase in vertical jump height after eight weeks of plyometric training for 13-years-old basketball players (21). The results of some other studies showed that PT can have significant effects on the CMJ only in specific conditions (22, 23). Rubley et al. found a significant increase in CMJ height after fourteen weeks of low-frequency, low-impact plyometric training. However, the increase was not significant after the seventh week (22). Verma et al. also found that the effect of PT on the CMJ height can vary in boys and girls non-basketball players. However, the gender-based effect of training in basketball players was not significant (23).

For optimum CMJ performance and maximum jump height, the kinematics of upper and lower extremity joints during the movement has to follow the pattern extracted from biomechanical fundamentals. The hierarchical model of vertical jump helps coaches and researchers design specific training and identify key events and parameters for movement analysis (24-26). Based on the biomechanical fundamentals of CMJ, ankle joints affect the jump height at take-off kinematics of the shoulder, hip, and knee. These parameters are studied in key events of CMJ, such as eccentric phase, concentric phase, and take-off but not related to a PT program (2, 8, 11, 14, 27). Flexion angle of the knee at the beginning of the concentric phase (7, 11, 27) and arm swing in the concentric phase (6, 28) affect CMJ performance. Also, shoulder flexion angle (2, 28) and hip and knee angular velocities (29) are important parameters of CMJ take-off. These parameters have a direct effect on the jump height, which means shoulder flexion angle, hip angular velocity, or knee angular velocity increase at take-off.

2. Objectives

Accordingly, there seems to be a gap in the literature between the studies investigating the effects of PTs on the jump height and the ones related to the kinematics of the jump. To our knowledge, the effect of plyometric training on the kinematics of CMJ take-off has not yet been studied. The purpose of this study is to investigate the effect of 6-week plyometric training on the kinematics of take-off and CMJ height.

3. Methods

3.1. Participants

We randomly selected fifteen young and healthy male participants (age = 27.6 ± 3.7 years, height = 178.9 ± 6.8 cm, weight = 74.4 ± 10.2 kg) with no history of musculoskeletal pathology or injury. That the participants have no backgrounds in volleyball, basketball, and gymnastics was a condition for entering the research. The eligible volunteers were invited for data collection. Having explained the aims and procedures of the study to the subjects, we obtained their written consents.

3.2. Data Collection

After getting written consent from participants, A set of spherical reflective markers with two cm diameter were attached to their joint center in the lateral part of the right lower and upper limbs. The Markers were attached on the second metatarsal of the right foot, right lateral calcaneus (ankle), right lateral condyle of the femur (knee), right great trochanter (hip), styloid process of the radius (wrist), lateral epicondyle of the humerus (elbow), and greater tubercle (shoulder) according to the protocol used in the study by Leporace et al. (30). The movements of markers were recorded with a high-speed (240 f/s) video camera. The data were collected in two pre-training and post-training sessions. In each session, after ten minutes warm-up, the videos were captured for six countermovement jumps with a one-minute interval in between. The post-training session was recorded after three days of the final training session.

3.3. Training Procedure

Over the course of six weeks, this included three training sessions per week, each of which began with 10 minutes warm-up, including jogging and dynamic stretching exercises, and finished with 20 maximum efforts CMJ and 20 box jumps of 60 cm height. The order of the jumps was selected randomly.

3.4. Data Analyses

The videos were imported in Kinovea software (V 0.8.24). The markers were manually tracked into the Kinovea software for the whole period of each jump. Joint angles were measured in a local reference system which full extension is considered as 180 degrees (degs). The position of each marker relative to the reference system was also determined. Jump height was defined as the difference of hip marker vertical position between standing and its highest value. The three highest jumps were selected for kinematic analyses to calculate the average of joint angles and angular velocities at take-off in the sagittal plane (31, 32).

3.5. Statistical Analyses

We employed the paired-sample t-test to compare the jump height and the kinematic parameters between pre and post-training sessions using SPSS software.

4. Results

Table 1 depicts the results of the paired sample t-test before and after training for jump height and kinematic parameters at CMJ take-off. As it is clear, the CMJ height increased significantly after plyometric training ($P < 0.01$).

Also, the shoulder angle, shoulder angular velocity, hip angle, knee angle, and knee angular velocity showed a significant rise after training ($P < 0.01$). However, hip angular velocity decreased significantly after training ($P < 0.05$).

5. Discussion

The purpose of this study was to investigate the effect of six weeks of plyometric training on the CMJ height and kinematic of lower limb and shoulder at take-off in male athletes. The results showed a significant increase in the jump height due to the training program. Despite critical changes in other studied kinematic parameters via the training method, the hip angular velocity did not show any improvement after training.

The significantly increased CMJ height due to the plyometric training in this study is in agreement with studies about the effect of short-term plyometric training (1, 15-19). In the current study, the CMJ height was increased from 43.80 cm to 53.13 cm (21.3%) after 6-week plyometric training. Zubac et al., Hammami et al., Arabtazi et al., and Adibpour et al. also showed an increased jump height of 11.4%, 14.0 %, 14.6%, and 18.8%, respectively after 8-week training. Therefore, the training program used in this study showed a better effect on the CMJ height in a shorter training period, which could be due to designed plyometric exercises, training intensity, demographics of participants, and sports background of the subjects. However, the increased jump height in this study was in contrast with the outcome of the review conducted by Oxfeldt et al., who showed improvement in the CMJ height after increasing the training sessions (19). Rubley et al. showed an increase of the CMJ height of about 13% after seven weeks of low-impact plyometric training, but their results were not significantly different from pre-training (22). Comparing all the results, we could conclude that the high-intensity short-term PT might be the most efficient, but this needs to be investigated further in future studies with consideration of other conditions, including the type of exercise used in the training method.

In this study, the training program improved the knee extension, which, according to the hierarchical model, is effective on jump height (26). Similar results are noted by Moreau, who studied the kinematics of take-off of loaded CMJ (14). They showed more extent knee at take-off increases jump height in female gymnasts and soccer athletes (14). They also demonstrated that the increase of shoulder flexion velocity after training, which can be one of the effective parameters on CMJ height, improved by PT. Lees et al. indicated the effects of arm swing on CMJ height because the increased shoulder ROM and flexion velocity might improve the work and power generated by the shoulder to increase jump height (28). Hip and knee extension velocities at take-off are also crucial parameters of CMJ that are significantly increased after PT. Balster et al. indicated that an increase in hip and knee angular velocities at take-off would improve the jump height (29).

The results of the present study revealed that the standard deviation of jump height and all other studied parameters would decrease after training. Also, the standard deviation of jump height, hip angle, shoulder angle, and knee angle would decrease to %50, %84, %78, and %76, respectively. It shows the effect of the training program on the ability of the jumper for performing the similar technique in different trials, which could justify the results for the positive effects of the training program on the jump height improvement.

The main limitation of this study was that only the biomechanical parameters were measured in the sagittal plane, although, based on the literature, the 2D analysis of CMJ is reliable.

5.1. Conclusions

The 6-week plyometric training improved CMJ performance, resulting in a significant increase in jump height. The PT significantly improved not only the shoulder flexion and hip and knee extensions at take-off but also the angular velocities of the shoulder, hip, and knee.

5.2. Practical Applications

Countermovement vertical jump is an important factor in volleyball, basketball, and gymnastics. Thus, improving CMJ improvement via training methods such as plyometric training is of great importance for coaches. A deep understanding of kinematic parameters of CMJ at take-off can help coaches design individualized training programs. The present study examined the effect of 6-week PT on CMJ height, angle of the shoulder, hip, and knee, and angular velocities of mentioned joints in males. The angle of the shoulder, hip, and knee at take-off and also angular velocities of these joints seem to be effective on CMJ height. Thus, coaches might use PT to improve these kinematic parameters and improve CMJ. Coaches should consider different strategies such as PT to improve shoulder flexion and increase hip and knee extension velocities at take-off. Improvement of kinematic parameters of movement can improve athletic performance. Therefore, for an optimal training design, it is necessary to consider kinematic parameters in addition to the ultimate goal of motor skill.

Footnotes

Authors' Contribution: Study concept and design: R. A., A. H., and S. E.; analysis and interpretation of data: R. A., S. E.,

Table 1. The Results of the Paired Sample T-Test Before and After Training for Jump Height and Kinematic Parameters at CMJ Take-Off [a]

	Pre-Training	Post-Training	P Value
CMJ height (m) [b]	43.80 ± 7.79	53.13 ± 3.9	< 0.01
Shoulder angle (degs) [b]	112.83 ± 7.31	128.36 ± 3.59	< 0.01
Shoulder angular velocity (degs/s) [b]	576.94 ± 85.32	618.04 ± 47.93	< 0.01
Hip angle (degs) [b]	160.37 ± 5.11	172.56 ± 0.81	< 0.01
Hip angular velocity (degs/s) [b]	239.97 ± 28.78	225.68 ± 10.23	0.03
Knee angle (degs) [b]	165.70 ± 5.18	172.71 ± 1.24	< 0.01
Knee angular velocity (degs/s) [b]	193.59 ± 32.99	234.73 ± 10.95	< 0.01

[a] Values are expressed as mean ± SD.
[b] Significant difference between pre and post-training.

and A. H.; drafting of the manuscript: S. E.; critical revision of the manuscript for important intellectual content: R. A., A. H., and S. E.; statistical analysis: R. A.

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Informed Consent: The eligible volunteers were invited for data collecting. After oral and experimental demonstration of the study, including its aims and procedure, their written consents were obtained.

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